Design and Implementation of Test Stand Upgrades for Investigating Gearset Churning Losses with Baffles

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Design and Implementation of Test Stand Upgrades for Investigating Gearset Churning Losses with Baffles

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ME4800 Senior Design Project

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CAViDS Consortium, Caster Concepts, and Conceptual Innovations
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Disclaimer

This project was written by students at Western Michigan University to fulfill an engineering curriculum requirement. Western Michigan University makes no representation that the material contained in this report is error-free or complete in all respects. Persons or organizations who choose to use this material do so at their own risk.
Abstract

The automotive industry is continually researching ways to decrease energy losses in drivetrain applications. Rotating gear sets in an oil bath suffer frictional losses due to oil churning. The Center for Advanced Vehicle Design and Simulation (CAViDS) consortium has proposed studies to understand and reduce these churning losses. The primary means to reduce these churning losses are to redirect the oil flow using baffles and/or alter the oil viscosity. To perform churning loss optimization under controlled conditions, an existing test stand was upgraded to improve safety, introduce oil temperature control, and allow for the interchange of baffle designs. For safety, an enclosure was designed and manufactured to prevent injury from rotating and high-power electrical components. To manage oil temperature, a feedback control system was developed based upon results from heat transfer analysis. To create interchangeable baffle designs, comprehensive computer-aided design work was done to create a three-dimensional (3D) printable system with geometric retention for the baffle geometries. Use of the improved test stand produced data and validated relationships on the effects that oil temperature and rotational speed have on churning losses.
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Section 1: Introduction

1.1: Background

Automotive gearboxes and gear transmissions are plagued with numerous inefficiencies resulting in reduced service life, performance, and range. A point of interest in the industry is the power/energy loss due to churning. Churning is defined as the displacement and agitation of a given fluid [1]. In the case of gear transmissions and gearboxes, churning losses are due to gear submersion in a lubricant which is called dip lubrication [1]. Dip lubrication is a method that involves only the partial submersion of a gear or gear set in lubricant. The resultant opposing forces associated with the gear having to displace and move through the lubricant as it rotates, cause the churning losses.

The consequences of churning are numerous and have negative impacts on performance. Churning losses are primarily manifested in elevated fluid temperatures, leading to accelerated lubricant breakdown, lower efficiency, and reduction of gearbox life. Diminishing the churning loss and its effects is vital to increase product reliability and overall performance.

The industry has proposed a few solutions to minimize these losses including optimization of lubricant level, flow control, and certain gear geometries. One that may lead to a significant reduction in churning losses is the implementation of baffles. Baffles are devices intended to direct and control the fluid flow around a gear or gearset whilst also maintaining an optimal amount of fluid to prevent excessive frictional losses. These baffles would be a geometrically integrated component capable of increasing efficiency and overall performance.
1.2: Problem Statement

The Center for Advanced Vehicle Design and Simulation (CAViDS) automotive industry partners are interested in researching and quantifying churning losses. The existing CAViDS test machine required modification, as it was not able to be safely operated, reach the target lubricant temperature, or have a repeatable automated test procedure to generate experimental data in order investigate churning losses and validate computational fluid dynamics (CFD) simulations.

1.3: Objective

The aim of this project was to modify the existing test machine into a safer and more robust system for the quantification and subsequent research on the optimization of baffles for churning loss reduction. Specifically, the following project objectives were set:

Objective 1: Reduce shaft misalignment and vibration.

Objective 2: Increase safety during machine operation.

Objective 3: Add a method of heating the operating fluid.

Objective 4: Modify and refine gearbox inserts.

Objective 5: Develop and document an automated and repeatable test procedure.
1.4: Benchmarking

Benchmarking is an important tool used in the evaluation of a given design against a known standard, previous design, or competitor design. In the case of the CAViDS test machine, there is no standard or competitor design available for comparison. To benchmark the machine upgrades, comparisons will be made versus the pre-existing design (shown in Figure 1) and the following machine operating criteria.

![Pre-Existing Test Machine](image)

*Figure 1: Pre-Existing Test Machine*

To benchmark the revised machine, as chosen by the project objectives and issues with the pre-existing machine, the following operating criteria will be evaluated:

- Shaft misalignment
- Ability to adjust fluid viscosity
- Machine operator considerations

To further benchmark the revised machine, we set the following operating criteria:

- Heat to a maximum operating temperature of 100°C
- Complete data acquisition in less than 30 seconds
- Maintain fluid temperature at the desired for the entire test duration
1.5: Specifications and Requirements

Reduce rotating component shaft misalignment and vibration

- Modification of existing machine base/cart
- New structure and mounts for machine components

Design and implementation of operator safety cover

- Protection against the following high-speed rotating component failure
  - Shaft couplers
  - Motor
  - Torque meter
- Removable for machine maintenance or modification

Design and implementation of baffle system

- Interchangeable baffle types/geometries
- Baffle designs based on documentation from Arduin, [1]
- Seal test volume to prevent lubricant leakage, causing lubricant volume present in the test volume to change
- Fluid heating system passages and seals

Design and implementation of lubricant temperature control system

- Adjustable temperature set-point
- Capable of an operating temperature of 100°C
- Automated heating procedure
- Non-disruptive to fluid flow during testing
- Non-oxidative fluid heating method
- Ability to drain and fill lubricant

Testing of the machine and baffle performance quantification

- Validation of all machine functions
• Design-of-experiment (DOE) and test matrix
• Data acquisition
• Data analysis
  o Quantification of churning losses
  o Comparison to CFD results
• Determination of baffle design performance
• Determination of fluid viscosity effects

The final deliverables for this project include: an upgraded test stand structure (3D printed mounts and a flat machine steel base plate), machine safety cover, fluid temperature control system (pump, in-line heater, and plumbing), an interchangeable baffle system designed for 3D printing, a complete system for automated machine control and data acquisition, and data for quantifying churning losses.

1.6: Limitations

Achievable shaft rotational speeds, available volume, and gearset have been determined to be the main limitations of this project, based on components from the existing machine and CAViDS partner requirements. Achievable rotational speeds are restricted by the existing motor and the available volume by the existing gearbox. Testing will be conducted at rotational speed set points of 600 RPM, 1000 RPM, 2000 RPM, and 3000 RPM.
Section 2: Project Design

2.1: Test Machine

One of the important objectives of this project was to re-design and construct a safer and more robust structure for the test machine. Safety was an important consideration for this test machine, as it operates at rotational speeds up to 3000 RPM. Component failure at these high speeds could potentially harm the machine operator and environment. Improving machine robustness was another important consideration to ensure consistent and repeatable test results later in the project. The primary solutions to address these considerations were a new component mounting method and safety cover, respectively. To determine the optimal design for each solution, a decision matrix was created for each design alternative and analyzed based on characteristics such as cost, manufacturability, and effectiveness.

2.1.1: Design Alternatives

**Machine Structure**

Several designs were evaluated for the machine structure improvements. The first design consisted of a steel machine base, steel uprights, and steel mounting plates for the motor and torque sensor, which can be seen in Figure 2.

*Figure 2: Mount Design 1*
The second design consisted of a steel machine base and simple 3D printed mounts for the motor and torque sensor, shown in Figure 3.

![Figure 3: Mount Design 2](image)

The last design is a hybrid of these two solutions consisting of a steel machine base, steel upright, and 3D printed mounts which slot over and clamp on to the upright. This design can be seen in Figure 4.

![Figure 4: Mount Design 3](image)
Safety Cover

Two main designs were evaluated for the safety cover implementation. Both designs share similar methods of construction, consisting of a primary skeleton structure based on t-slot aluminum extrusion with polycarbonate panels attached. Where these designs differ is in the ease of access for service. The first design, shown in Figure 5, uses a rigid structure where in the case of machine services the operator must unbolt the panels. The second design in Figure 6 simplifies service by introducing a hinged cover and handle, which exposes the front and top of the machine for service.

Figure 5: Safety Shield Design 1: Fixed

Figure 6: Safety Shield Design 2: Hinged
2.1.2: Decision Matrices

The matrix shown in Table 1 was used to decide on the design of the machine structure. The options considered were steel mounts welded to a steel base plate, 3D printed mounts bolted to a steel base plate, and a hybrid that included the 3D printed mounts bolted to a vertical reinforcement that is welded to a base plate. The criteria to help decide were cost, durability, vibration resistance, and ease of installation. Our team decided to move forward with the hybrid option, given that it offers the precision of laser cutting to maintain shaft alignment and the flexibility to re-print the mounts if there are design errors.

Table 1: Machine Structure Matrix

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Steel Mounts and Base Plate Welded</th>
<th>3D Printed Mounts Bolted to Steel Plate</th>
<th>Hybrid 3D Printed Mounts Bolted to Vertical Reinforcement Welded to Base Plate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>3</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Durability</td>
<td>5</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Vibration Resistance</td>
<td>5</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Ease of Install</td>
<td>2</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>15</td>
<td>15</td>
<td>16</td>
</tr>
<tr>
<td>Weighted Total</td>
<td>3.9</td>
<td>3.9</td>
<td>4</td>
</tr>
</tbody>
</table>

The safety shield decision matrix in Table 2 was determined using four criteria: cost, safety, accessibility, and ease of installation. The hinged safety cover with a handle is ultimately the best option for the project. Both are comparable solutions in cost and ability to protect the machine operator in case of component failure. Although, being able to easily open the cover with a handle compared to having to unfasten and pull a panel off is the determining factor.

Table 2: Safety Shield Cover Matrix

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Fixed Safety Cover</th>
<th>Hinged Safety Cover with Locking Mechanism</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>0.4</td>
<td>5</td>
</tr>
<tr>
<td>Safety</td>
<td>0.3</td>
<td>5</td>
</tr>
<tr>
<td>Accessibility</td>
<td>0.2</td>
<td>1</td>
</tr>
<tr>
<td>Ease of Install</td>
<td>0.1</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>1</td>
<td>15</td>
</tr>
<tr>
<td>Weighted Total</td>
<td></td>
<td>4.1</td>
</tr>
</tbody>
</table>
2.1.3: Design Implementation

*Machine Structure Manufacturing and Assembly*

The first step in the manufacturing process was to laser cut the steel sheet metal components. This laser cutting service and material was provided by project sponsors. Two-dimensional (2D) drawings and DXF files were generated for manufacturing. After laser cutting, additional post processing was required. For example, some of the base plate and electrical panel holes required tapping, which the group accomplished using a tapping arm, as shown in Figure 7.

![Figure 7: Cutout Holes using Tapping Arm](image1.jpg)

After the base plate was drilled and tapped, the center upright and supports were TIG welded on, as shown in Figure 8.

![Figure 8: Welded Base Plate](image2.jpg)
After welding, the base plate was then powder-coated wrinkle black. Lastly, the motor and sensor mounts were 3D printed out of PLA 3D and bolted to the center upright. The 3D printed mounts are shown in Figure 9.

![Figure 9: Torque Sensor and Motor Mounts](image)

The final assembly of the machine structure is shown in Figure 10. Adding the steel base plate ensured that the working surface provided a flat surface to build upon. The steel upright ensured that the lateral alignment of the torque sensor and motor are rigid. The 3D mounts were adjusted to improve the vertical alignment of the torque sensor and motor. The safety cover was thoughtfully designed with a hinged enclosure of T-slot extrusion framing and polycarbonate panels. Notably, it was equipped with a handle to facilitate easy lifting of the cover during maintenance, and a locking mechanism to maximize safety measures. An electrical panel was also installed on the side of the machine structure to access all electrical components and consolidate them in a single location.

![Figure 10: Final Machine Structure Design](image)
2.2: Temperature Control System

The development of a system to accurately control the lubricant temperature within the test machine is another important feature implementation for this project. Not only does the system need to heat the fluid, but it must also be non-disruptive to the fluid flow during tests and non-oxidative during heating.

2.2.1: Design Alternatives

Three different external temperature control system designs were proposed. The first proposed system, shown in Figure 11, would use a remote reservoir to heat the fluid. When the fluid at the piping outlet and the reservoir match, the valve would close and the subsequent lubricant volume into the gearbox would be determined based on a known pump flow rate. This flow rate is known because the pump is specified to be a “constant flow rate” device, and thus the data are available through the manufacturer’s product datasheet. This process would be controlled through the Controllino PLC.

![Figure 11: Temperature Control System w/ Constant Flow Rate Pump](image)

The following lubricant temperature control system, in Figure 12, is the simplest both mechanically and electrically, due to the heating element being directly located in the volume of the gearbox enclosure. This system would operate based on the principle that the heating element is located behind the baffles and as such, would not disrupt the oil flow around the gears. This system would be filled manually by an operator using an alternate method to determine fluid
volume, such as a graduated container. In this case, only the heating element would be controlled through the Controllino PLC taking feedback only from a single thermocouple within the gearbox.

![Controllino PLC diagram](image)

*Figure 12: Temperature Control System in Gearbox Heater*

The last design option for the temperature control system is displayed in Figure 13. This design features a constant flow rate pump with an external in-line heater. The fluid would be circulated through the gearbox and system until the desired temperature is reached. The heating would take place prior to testing in order to ensure no disruption in the fluid flow during gearbox operation. Similar to the other systems, a Controllino PLC is or would be used for controlling the pump and the heating elements.

![Temperature control system w/ In-line Heater](image)

*Figure 13: Temperature control system w/ In-line Heater*
2.2.2: Decision Matrices

The decision matrix shown in Table 3 supports the heating method selected to reach the desired temperature within the gearbox. The following options were (1) the external heating reservoir – resistive heater, (2) external in-line heater – resistive heater, and (3) submerged heating element inside reservoir – resistive heater. The criteria considered are cost, effective heating method, time to heat, and ease of installation. The team decided to develop the concept of an in-line heater and create our own design. By doing so, it allows this heating method to be inexpensive, in comparison to commercial off-the-shelf in-line heaters. Effectiveness is being considered as a heating method's ability to prevent excessive thermal losses during the heating process. The in-line heater will heat the fluid as it travels through a small diameter pipe, enabling rapid heating and the ability to insulate the heated section. The chosen heating method is also easy to install. With the addition of flexible tubing, the fluid will cycle through the tubing into the external in-line heater and back into the gearbox. The test fluid will cycle until the operating temperature is reached and at which point the test can begin.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>External Heating Reservoir - Resistive Heater</th>
<th>External In-line Heater - Resistive Heater</th>
<th>Submerged Heating Element Inside Reservoir - Resistive Heater</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>0.3</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Effectiveness</td>
<td>0.3</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Time To Heat</td>
<td>0.25</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Ease Of Install</td>
<td>0.15</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>1</td>
<td>13</td>
<td>16</td>
</tr>
<tr>
<td>Weighted Total</td>
<td>3.25</td>
<td>4</td>
<td>3.8</td>
</tr>
</tbody>
</table>

*Table 3: Heating Method Matrix*
2.2.3: Design Implementation

Due to the cost of commercial in-line process heaters ($600-$900) being nearly or over half of the overall $1500 budget set aside for the project, the decision was made to design our own in-line heater assembly. The following sections will document the in-line heater calculations, component selection, design, and assembly necessary. Design was driven with final temperature goals of 40°C and 100°C, assuming an initial fluid temperature of 25°C, no heat losses, and neglecting hot/cold fluid mixing within the gearbox. Target temperatures of 40°C and 100°C were selected based on the ASTM standards for testing lubricants.

Calculations

Before beginning the design of the fluid heating system, it was important to understand the basic power required for heating the fluid volume contained within the gearbox. Using the volume, fluid properties, and the assumption that the entire fluid volume is to be uniformly heated, the following calculations were completed.

Gearbox total volume,

\[ V_{\text{total}} = L \times W \times H \]  \hspace{1cm} (1)

Where:

\[ V_{\text{total}} \] = total volume, \( L \) = length, \( W \) = width, and \( H \) = height, of the gearbox testing volume

Minimum optimal heating power requirement,

\[ Q_{\text{optimal}} = \rho \times V \times C_p \times (T_i - T_f) \] \[ \frac{\Delta t}{\Delta t} \] \hspace{1cm} (2)

Where:

\( m \) = mass of the fluid, \( C_p \) = specific heat of the fluid, \( \Delta t \) = designated heating time

\( T_i \) = initial fluid temperature, and \( T_f \) = final fluid temperature
The designated heating time is 2-minutes, initial fluid temperature is 25°C, and final fluid temperature is 40°C. The specific heat is 2018 J/(kg-K) and density is 839 kg/m³, which is the average for our temperature range. After calculations, the heating power requirement under optimal conditions of conduction was determined to be 289 W.

The short heating time for the fluid from 25°C to a maximum of 40°C was determined to be fair justification for the further implementation of the in-line heater system. The goal was to achieve the maximum temperature as quickly as possible; the target time was anywhere between 2-5 minutes.

To get a more accurate understanding of the necessary heating requirements, further calculations were performed. These calculations try and account for only a small portion of the fluid being heated within the fluid heater at any given time. These calculations were also used for future application goals of reaching 100°C under similar heating times.

To calculate the heating times, various preliminary equations needed to be computed and are shown in this following section. These calculations assume no heat loss through fluid mixing and assume a rounded-up heating element power of 300 W.

The pipe velocities can be determined using the following equation:

\[ U = \frac{Q}{A} \]  \hspace{1cm} (3)

Where:

\[ U = \text{pipe velocity}, \; Q = \text{volumetric flow rate}, \; \text{and} \; A = \text{Pipe cross – sectional area} \]
The residence time,

\[ t_{res} = \frac{S}{U} \]  \hspace{1cm} (4)

Where:

\( t_{res} = \text{residence time}, \) \( S = \text{heated length}, \) \( \) \( U = \text{fluid velocity} \)

Heater Volume,

\[ V_{heater} = \frac{\pi}{4} \times D^2 \times L \]  \hspace{1cm} (5)

Where:

\( V_{heater} = \text{heater volume}, \) \( D = \text{heater inside diameter}, \) \( L = \text{heater length} \)

Fluid passes,

\[ f_p = \frac{V_{total}}{V_{heater}} \]  \hspace{1cm} (6)

Heat flux rate,

\[ q'' = \frac{q}{A} = \frac{q}{\pi \times D \times L} \]  \hspace{1cm} (7)

Where:

\( q'' = \text{heat flux rate and } q = \text{input power} \)

Temperature rise,

\[ \Delta T_{rise} = \frac{q'' \times \pi \times D \times L}{\dot{m} \times C_p \times 39.4} = \frac{q'' \times \pi \times D \times L}{Q \times \rho \times C_p \times 39.4} \]  \hspace{1cm} (8)
Where:

\[ \Delta T_{\text{rise}} = \text{temperature change through one passage, } \rho = \text{fluid density, and} \]

39.4 is the unit conversion from inches to meters

Heating time calculation,

\[
t_{\text{heating}} = \frac{f_p \times \Delta T_{\text{target}} \times t_{\text{res}}}{60 \times \Delta T_{\text{rise}}}
\]

(9)

Where:

\[ t_{\text{heating}} = \text{heating time and } \Delta T_{\text{target}} = \text{target temperature change} \]

From these calculations, the heating time for the 40°C target temperature was 1.9 minutes with a 300W heating element (Q_{\text{Heater}}), the results are shown in Table 4.

<table>
<thead>
<tr>
<th>Calculation Results (40°C Goal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( Q_{\text{Heater}} )</td>
</tr>
<tr>
<td>( t_{\text{res}} )</td>
</tr>
<tr>
<td>( \text{fluid passes} )</td>
</tr>
<tr>
<td>( q'' )</td>
</tr>
<tr>
<td>( \Delta T_{\text{rise}} )</td>
</tr>
<tr>
<td>( t_{\text{heating}} )</td>
</tr>
</tbody>
</table>

Table 4: Calculation Results at 40°C

For future testing applications it was required that the system be able to reach a fluid temperature of 100°C. Later design decisions proposed that the in-line heater assembly power
could be simply increased from 300W to 900W to allow for this to be possible. Through iterative calculations it was found that by increasing the heating power to 900W, a comparable heating time to the 40°C case can be reached. The calculation results are shown in Table 5.

<table>
<thead>
<tr>
<th>Calculation Results (100°C Goal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q_{Heater}$</td>
</tr>
<tr>
<td>$t_{res}$</td>
</tr>
<tr>
<td>fluid passes</td>
</tr>
<tr>
<td>$q''$</td>
</tr>
<tr>
<td>$\Delta T_{rise}$</td>
</tr>
<tr>
<td>$t_{heating}$</td>
</tr>
</tbody>
</table>

(Table 5: Calculation Results at 100°C)

For both 40°C and 100°C heating cases, to circulate the total fluid volume through the inline heater, 1019 passes are required. It was found that each of these passes took approximately 35ms. Within each passage of the heater, the fluid rises 4.65°C and 14°C for each case respectively. With the assumption of no heat loss through mixing of the warm and cold fluid, the heating time was found to be 1.9 and 3.2 minutes for each case, respectively. Although these values are underestimated because heat losses through the gearbox enclosure and transient mixing of hot and cold fluid elements are neglected, it provides a first-order estimate of the expected heating times to guide the design.
**Design Layout**

The component diagram in Figure 14 was used to illustrate the control system's functionality and show the necessary components. These include the temperature sensors, piping, fluid pump, and in-line heater assembly. The fluid heating system operates by using a rotary gear pump to circulate the fluid through the in-line heater and into and out of the gearbox and back into the heater, completing the loop. The heating process is continuously monitored by thermistors placed at the inlet and outlet of the gearbox, enabling the machine to regulate temperatures and achieve the desired temperature setpoint.

![Figure 14: Plumbing Component Diagram](image-url)
**Component Selection**

The first component to be selected before CAD design is the heating element for the in-line heater assembly; the heating element selection (McMaster-Carr part number 35025K134) was based on the design specifications (Section 2.2.3) and the flexibility in the power options available for the size. Shown below in Table 6 is a comparison of the calculated values versus the selected heating element specifications. The dimensional properties of this heating element can be seen in Figure 15. Due to the size and power of the heating element, this also proved to be a perfect option for scaling into our in-line heater assembly for future goals. One heating element would suffice for the 40°C lubricant temperature setpoint goal and three or more can fit into an assembly for the 100°C goal.

<table>
<thead>
<tr>
<th>Calculated Specifications</th>
<th>McMaster-Carr 35025K134 Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heater Power</td>
<td>289 W</td>
</tr>
<tr>
<td>Heater Length</td>
<td>3.00 in</td>
</tr>
<tr>
<td>Heater Power</td>
<td>300 W</td>
</tr>
<tr>
<td>Heater Length</td>
<td>3.00 in</td>
</tr>
</tbody>
</table>

*Table 6: Heater Cartridge Specifications*

*Figure 15: Cartridge Heater Schematic [2]*
The primary considerations for selecting the pump were that it should circulate the fluid volume of the entire gearbox around twice a minute and be able to operate at the maximum system temperature of 100⁰C. To meet these specifications, the McMaster-Carr part number 8220K43 pump was chosen. The important operating specifications and dimensional drawing for this pump can be seen in Table 7 and Figure 16, respectively.

<table>
<thead>
<tr>
<th>McMaster-Carr 8220K43 Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pump Type</strong></td>
</tr>
<tr>
<td><strong>Flow Rate</strong></td>
</tr>
<tr>
<td><strong>Voltage</strong></td>
</tr>
</tbody>
</table>

*Table 7: Pump Specifications*

![Figure 16: Constant Flow Rate Pump Schematic [2]](image)

The primary factors in the selection of a temperature sensor were that it would be robust, easily interchangeable, be rated for at least 100⁰C and simple to implement both electrically, and
in software. The selected temperature sensor is the 104NT thermistor cartridge from E3D as shown in Figure 17. This sensor shares a common form factor with other sensor types, such as thermocouples and resistance temperature detectors, which may be useful if a different type of sensor is needed in the future.

![Figure 17: 104 NT Thermistor Cartridge](image)

**CAD Modeling**

Integrating the thermistors and cartridge style heating elements into an in-line heater was accomplished through creating a series of slip fit holes in a cylindrical body that surround a central fluid passage. The heating cartridges slide into the largest of the holes and are retained via an endplate that is fastened on with four small bolts. The thermistor cartridge can slip into any of the holes located between any of the four available heater cartridge locations closest to the center fluid passage. Figure 18 and Figure 19 show the empty heater body and heater body with tube fittings pressed into place and the end plates attached. Figure 20 and Figure 21 then show the complete in-line heater assembly with heating elements and thermistor installed.
Figure 18: In-Line Heater Body

Figure 19: In-Line Heater w/ Retaining Collar
Figure 20: Sectional View of In-Line Heater

Figure 21: Full Assembly of In-Line Heater
Incorporating this in-line heater assembly into the overall fluid heating system was accomplished by using a modular sub-plate system. This sub-plate contains the pump, in-line heater assembly, and DIN rail mounted terminal blocks. The sub-plate also has mounting accommodations for an additional set of in-line heater assemblies should the application necessitate these in the future. The populated sub-plate design is pictured in Figure 22. The entire test machine can also accommodate two of these subplates, should there be a need for any additional components in the temperature control system.

*Figure 22: Modular Subplate System*
**System Manufacturing/Assembly**

The in-line heater body was machined using a mill. Once the body was complete, the tube fitting was press fit into the body. The cartridge heaters were then inserted into the specified locations, which were then contained using a unique machined collar that was fastened in place. To ensure the safety of the operator and surrounding components, the entire assembly was then encapsulated in a 3-inch long, ¼-inch thick, layer of silicone insulation, which was intended to prevent high temperature burns. The insulation also helps minimize the heat lost through convective heat transfer. The in-line heater and pump are shown in Figure 23.

![Figure 23: Inline Heater and Pump](image-url)
The modular sub-plate is displayed in Figure 24. The sub-plate is fastened to the machine base plate, which can be easily removed for maintenance. The pump and in-line heater are also fastened to the sub-plate.

Figure 24: Modular Subplate Assembly
The fluid heating system plumbing is depicted in Figure 25. At the top of the figure is the gearbox outlet which connects to the pump inlet. The outlet of the pump is then connected to the inlet of the heater, which is guided to the gearbox inlet. The heated fluid will then be recirculated until the desired temperature is reached.

Figure 25: Plumbing Routing

A ¼-inch NPT brass plug, shown in Figure 26, houses the thermistors using high-temperature epoxy. One of these NPT plugs is located at the inlet and outlet of the gearbox, respectively, to monitor the temperatures of the working fluid throughout the heating cycle.

Figure 26: Custom Removable Thermistors
2.3: Machine Control System

2.3.1: Design

Before purchasing any components for our machine control system, an electrical design layout was created to ensure that all necessary components were accounted for. In doing so, several design criteria were established: the machine control system must control all machine components' functions, perform all data acquisition, and offer a safe way for the operator to interface with the machine. This ultimately led to the selection of the Controllino PLC, as well as several other components, such as the emergency stop, power button, and test enable button. The final diagram used for machine component purchasing and manufacturing is shown in Figure 27. The diagram does not account for the final components incorporated into the design, such as the torque sensors, variable frequency drive (VFD), and 24VDC power supply for the Controllino PLC which are incorporated in the final assembly pictures shown later.
Figure 27: Wiring Diagram
The unpopulated control panel is shown in Figure 28. The control panel is located on the back of the safety shield, allowing easy access for modification or maintenance. The complete electronic assembly will be housed on this panel and the DIN rail allows for components to be easily mounted or removed.

Figure 28: Unpopulated Control Panel
The final and assembled control system panel is shown in Figure 29, with labels according to the primary components. Here the VFD, Controllino, power supplies, fuses, and terminals are all housed and mounted on the DIN rail.

Figure 29: Control System Panel
2.3.2: Controller Selection

The matrix in Table 8 represents the controllers that were considered for the temperature control system. These controllers were the Arduino, Controllino, and RoboRio. The main criteria considered were cost, terminal connections, input/output (I/O) types, and I/O capacity. Based on the design criteria, the Controllino is the best given the relatively low cost, terminal connection, and available I/O. The screw terminals instead of pin connectors, allow for wires to be secured, unlike the other controllers that use pin headers. The Controllino also has 0-10V analog I/O, which would make performing torque meter data acquisition and VFD control simple to implement. The I/O capacity is less significant for our project, given that we only have three temperature sensors, heaters, pump, VFD, and torque meter to connect back to the controller. If necessary, the Controllino allows for the flexibility to add additional I/O in the future.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Weight (Wt)</th>
<th>Arduino</th>
<th>Controllino</th>
<th>RoboRio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>0.5</td>
<td>5</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Terminal Connections</td>
<td>0.25</td>
<td>1</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Industrial I/O</td>
<td>0.125</td>
<td>2</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>I/O Capacity</td>
<td>0.125</td>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>1</td>
<td>11</td>
<td>16</td>
<td>10</td>
</tr>
<tr>
<td>Weighted Total</td>
<td></td>
<td>3.375</td>
<td>3.75</td>
<td>1.875</td>
</tr>
</tbody>
</table>

*Table 8: Controller Matrix*
2.4: Baffle System

To control fluid flow and minimize churning losses, various baffles/volume inserts would need to be designed, implemented, and tested. Further revisions to the volume inserts would be required to minimize the lubricant volume loss due to seepage. To resolve this problem, several proposed solutions consisted of friction fit inserts, implementation of O-ring material at the insert-gearbox wall interface, or likewise RTV sealant along the insert-gearbox wall interface. There were also multiple methods of installing the volume inserts that were evaluated. These included loading from the top of the gearbox in multiple pieces, front loading once piece, and finally front loading in multiple pieces. Decision matrices were used to drive design for which method and solution worked the best for this application.

2.4.1: Design Alternatives

In a prior project, “Gearbox Baffle Optimization” [1]. The impact of different baffle shapes (axial and radial) on churning losses was investigated. Figure 30 presents four fundamental types of radial baffle designs: a) boards, b) semicircle, c) oval, and d) snowman. It is desired to compare churning loss results corresponding to the four different radial designs.

![Figure 30: Baffle Designs [1]]
The baffles in the gearbox are supported by volume inserts, which are an additional baffle configuration. These inserts form part of the supporting structure for each baffle design and have a standardized internal geometry to fit into. Figure 31 shows the models for the side blocks and bottom blocks, as well as the existing volume inserts assembled.

![Figure 31: Existing Volume Inserts](image-url)
2.4.2: Decision Matrices

The decision matrix shown in Table 9 was created for the baffle construction and three choices that include top-loaded multiple pieces, front-loaded multiple pieces, and front-loaded one piece. The criteria that received focus were ease of installation, cost, time to manufacture/3D print, and durability. Comparing the totals for all three, the final decision for baffle construction was found to be the top-loaded multiple piece design. Starting with the ease of installation, the top-loaded baffle was tedious to install, given that the operator has to insert the baffles from the top of the gearbox while maneuvering around the fixed gearset. The cost and time to manufacture the top loaded pieces was significantly cheaper and time efficient than the front-loaded designs. In order to load the baffles from the front, the gearbox would have to be heavily modified and require the removal of additional fasteners to change inserts. Finally, the material that was used for the printing of the baffles was PLA and would have similar durability specifications for all the choices. Overall, installing the top-loaded baffle design is difficult, but the benefits of avoiding gearbox modifications outweighed the drawbacks in terms of cost and time.

![Table 9: Baffle Construction Matrix](image)

Table 10 shows the next decision matrix that pertains to sealing of the volume inserts to prevent seepage. The options consist of friction fit, O-ring material, and RTV sealant. The criteria follow the cost, effectiveness, ease of installation, and durability. Our team decided on the friction fit. As seen in Table 10, the friction fit design is an inexpensive, easy to install, and durable option. The only drawback is that the friction fit is the least effective at preventing seepage, due to relying on a strict tolerance rather than an O-ring or RTV sealant to block fluid from seeping through.
Table 10: Volume Sealing Matrix

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Wt</th>
<th>Friction Fit</th>
<th>O-Ring Material</th>
<th>RTV Sealant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>0.4</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Effectiveness</td>
<td>0.3</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Ease of Installation</td>
<td>0.2</td>
<td>4</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Durability</td>
<td>0.1</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>1</td>
<td>16</td>
<td>15</td>
<td>17</td>
</tr>
<tr>
<td>Weighted Total</td>
<td></td>
<td>4.1</td>
<td>3.8</td>
<td>4.1</td>
</tr>
</tbody>
</table>

2.4.3: Design Implementation

With the temperature control system added to the machine, the original volume inserts had no fluid passages, buoyancy issues, and fit too loose. Therefore, modifications needed to be made to improve the pre-existing volume inserts’ functionality. The first design, shown in Figure 32, shows a sectional view of the assembly consisting of two side blocks and two bottom blocks. The side blocks had piping starting from the back, going halfway into the side of the insert and then turning right out into a triangular opening slit. The diameter of the piping was 0.1875 inches, and the slit width was 0.03 inches. The bottom blocks were also modified to improve their fit, while retaining an opening for fluid drainage, shown in Figure 33.
The first design of the volume inserts was 3D printed and underwent testing. However, multiple issues surfaced and required modifications. Initially, there was no sealing between the gearbox's openings and the inserts where the fluid traveled through, leading to the fluid traveling behind the volume inserts. Consequently, as the temperature of the fluid increased, the back of the insert warped, shown in Figure 34. It was later discovered that the warping had resulted from an incorrect sensor calibration of the machine code. Another issue was the slow fluid flow caused from a narrow width slit and vertical piping. More pressure was necessary to direct the fluid straight up the piping and out through the slit opening. Lastly, the seepage surrounding the volume inserts required attention.
A second design was created; the front, back view, and the sectional view of the volume inserts assembled are shown in Figure 35. To minimize printing time and improve the efficiency of the process, the volume inserts were divided into six distinct parts. This approach also allows for greater flexibility, as any faulty or incorrect parts can be easily identified and reprinted without having to redo the entire assembly. Next, adjusting the slit to an angle would allow the fluid to flow efficiently. The 0.03 inch slit width was then changed to 0.06 inches to allow more fluid to exit the inlet side block into the test volume available. After testing one of the side blocks, it was discovered that the width of the gearbox decreased from top to bottom. To fix this problem, a taper was incorporated into the 3D printed side blocks. Finally, O-ring grooves were added to the side block openings to make sure the fluid entered and exited the piping directly to the gearbox inlet and outlet. The O-ring and taper implementations can be seen in Figure 36.
Further modifications to the outlet side block were required due to the oil level being insufficient to exit at a consistent rate. This resulted in significant aeration problems when the fluid level dropped too low. To address this, changing the orientation of the outlet insert slit from vertical to horizontal was proposed, as this would help prevent the formation of air bubbles. This design change is shown on the left in Figure 37, where the outlet side block has the horizontal slit instead of the vertical slit. Similarly, in Figure 37 on the right, the horizontal slit was moved down, and a ledge was created to ensure the proper outflow of the fluid.
The new changes to the blocks were implemented and 3D printed. After conducting tests with all the inserts in place, the temperature reached 40°C, and an issue of warping on the top of the bottom blocks was encountered. This problem was addressed by adjusting the infill and wall thickness during the 3D printing process to ¼-inch and 35%, respectively. The warping on the bottom blocks is shown in Figure 38.

Figure 39 shows the last modification made to the volume inserts: a way to interlock the pieces instead of using glue. The bottom component of the side blocks now features a chamfered extruded square, while the top components of the side blocks have the extruded square removed. With this design, inserts can be quickly and easily removed and replaced as necessary.
The final design of the volume inserts is shown in Figure 40. The design showcases the fluid passages, drain passage located at the bottom, and all the components that are friction-fit together.
Figure 41 displays the 3D printed components housed within the gearbox. This represents the first baffle configuration that was implemented for testing purposes. The 3D printed parts have been specifically designed and tested to ensure their compatibility and effectiveness within the gearbox.
Section 3: Validation and Testing

3.1: Software Development

A suite of different software is used for data acquisition, transfer, and analysis in the machine control system for testing. The software flow is as follows: (1) Data acquisition and machine control is accomplished through the Controllino. The code has been created through the Arduino IDE; (2) Data is then sent over USB from the Controllino to a local PC and read from the serial line with a Python program running in any Python IDE. (3) This Python program then takes the data and organizes it into a .CSV file according to the corresponding columns of rotational speed (in RPM), temperature (in degrees Celsius), and torque (in lbf-in). From here, the data are taken into Excel to be later manipulated and analyzed. A flow graphic of this process can be seen in Figure 42. All the Arduino IDE and Python code can be found in Appendix C. As mentioned prior, any Python IDE is acceptable, but machine instructions do specifically mention the PyCharm IDE being used.

![Flow Graphic](image-url)
3.2: Temperature Control System Validation

During the testing of all machine functions, the primary concern was the accuracy of temperature measurements for the fluid temperature control system. To validate these measurements, a contact thermometer with a K-type thermocouple was used to monitor the temperature in the gearbox and compare it to the calculated fluid temperature within the gearbox. The placement of this thermocouple can be seen in Figure 43.

When performing these initial validation tests, it was found that sensor reading differed significantly from the actual temperature displayed on the thermometer. To correct this issue, a set of data was gathered comparing the actual temperature from the thermometers against the values produced by the test machine. After gathering data, a plot was created to gauge what type
of model fit would be best to use for our calibration. Upon plotting the data, it was quite clear the relationship between our data was linear, as seen in Figure 44.

![Figure 44: Machine VS Meter Temperature Readings](image)

Using the data analytics tool within Excel, a linear model was generated from the data. The result of this is the following calibration “curve”:

\[ Y(x) = -16.21X + 1.95 \]

Where \( Y \) is the newly found temperature after calibration, and \( X \) is the old temperature perceived by the controller. After incorporating this calibration into our machine’s code, the heating test up to 40°C was re-ran with the machine reading a temperature of only approximately 0.4 degrees higher than that of the thermometer. The test setup with the machine temperature readings and thermometer is in Figure 45.
Figure 45: Test Setup with Machine Temperature Readings
3.3: Test Setup, Procedure, and Data Acquisition

To keep track of the required tests and trials, a test matrix was developed that was driven by two main parameters: temperature and rotational speed. The system was tested with DEXRON VI transmission fluid at two temperatures: 25°C and 40°C. The 15°C increases in temperature should decrease the oil viscosity, allowing for studies on the relationship between fluid temperature and churning losses. Torque data was collected at 600 RPM, 1000 RPM, and 2000 RPM, which were selected by the CAViDS Consortium to provide a wide range of applicable speeds for investigating churning losses. To ensure the validity of the testing, we conducted three trials for every iteration of rotational speed and temperature.

3.3.1: Test Procedure Summary

As previously mentioned, a series of scripts written in Arduino IDE and Python is used to automate the testing and data acquisition process. To ensure safety, there is a strict procedure that the operator must follow in summary below:

1. Operator must check that the emergency stop button is turned on, the machine is completely disconnected from the 208VAC wall outlet, the safety shield is down, and the locking mechanism is engaged.
2. Insert the volume inserts and baffles into the gearbox.
3. Pour the room temperature DEXRON VI into the gearbox until the fluid level reaches approximately the centerline of the pinion gear (bottom gear).
4. Connect with a PC to the PLC and enters the testing parameters. Rotational speed: 600 RPM, 1000 RPM, or 2000 RPM. Testing temperature: 25°C or 40°C.
5. Upload machine code to the PLC, and the python program is launched simultaneously.
6. Press enable button for the heating cycle and the automated test to start (During testing, the python program allocates the data received from the serial monitor into a CSV file).
7. Once the test is complete; the operator turns off the enable button and saves the CSV file into a remote folder for data analysis.
8. At this point, the operator can perform another trial or disconnect the machine by turning off the power, switching the emergency stop button to the depressed position, and finally unplugging the machine from the outlet.

9. When operator is done testing, using the drain valve to drain the oil into a remote reservoir and remove all volume inserts and baffles.

**Disclaimer:**

This is not a complete set of instructions and is meant for reference only. To ensure the operator knows how to safely operate the machine and collect data, an instruction manual is available, describing every step in great detail with photographs.
3.4: Data and Analysis

The Python program was used to collect temperature, rotational speed, torque, and time data from the serial line during testing. For each temperature and rotational speed value, three trials were conducted to evaluate consistency of the machine's performance. The DEXRON VI was filled to the centerline of the pinion gear or 1.4 liters. The data collected was then processed to determine the appropriate steady-state torque value from each trial. After processing the data acquired by the machine, the resulting steady-state torque can be acquired for each trial and is shown in Table 11.

<table>
<thead>
<tr>
<th>Test Set Points</th>
<th>Derived Data</th>
<th>Test Set Points</th>
<th>Derived Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial</td>
<td>Speed (rpm)</td>
<td>Temperature (*C)</td>
<td>AVG Torque (N-m)</td>
</tr>
<tr>
<td>1</td>
<td>600</td>
<td>25</td>
<td>0.2437</td>
</tr>
<tr>
<td>2</td>
<td>0.2813</td>
<td>0.2794</td>
<td>3</td>
</tr>
<tr>
<td>1</td>
<td>1000</td>
<td>25</td>
<td>0.3437</td>
</tr>
<tr>
<td>2</td>
<td>0.3264</td>
<td>3</td>
<td>0.3264</td>
</tr>
<tr>
<td>1</td>
<td>2000</td>
<td>25</td>
<td>0.6693</td>
</tr>
<tr>
<td>2</td>
<td>0.5768</td>
<td>3</td>
<td>0.4799</td>
</tr>
<tr>
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<td>2</td>
<td>2000</td>
<td>600</td>
</tr>
<tr>
<td>2</td>
<td>0.2071</td>
<td>1</td>
<td>0.1753</td>
</tr>
<tr>
<td>3</td>
<td>0.1599</td>
<td>3</td>
<td>0.1599</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>600</td>
<td>1000</td>
</tr>
<tr>
<td>2</td>
<td>0.2766</td>
<td>1</td>
<td>0.2873</td>
</tr>
<tr>
<td>3</td>
<td>0.2686</td>
<td>3</td>
<td>0.2686</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>2000</td>
<td>0.4885</td>
</tr>
<tr>
<td>2</td>
<td>0.4297</td>
<td>3</td>
<td>0.3994</td>
</tr>
</tbody>
</table>

Table 11: Average Steady State Torque Results

Figure 46 shows a plot of torque versus time, which provides a visual representation of the torque readings collected during the test. Within the first 2000 milliseconds there is a transient spike, but this was negated for the purpose of this project. This occurs in all of the trials
that were collected. The steady state value, which indicates the load in the system over time, is of particular interest. Once the steady state was reached, the steady state data was tabulated, and an average value was calculated, as shown later. Figure 46 compares a single trial for a rotational speed of 600 RPM at temperature values of 25°C (yellow line) and 40°C (blue line). It should be noted that at the lower temperature (yellow line), the torque loss is higher compared to the higher temperature (blue line). This can be attributed to the decrease in viscosity at higher temperatures. The steady state value for 600 RPM was reached at 2200 milliseconds, and the resulting steady state torque was calculated to be 0.261 N·m (2.37 lbf-in) and 0.181 N·m (1.6 lbf-in) for 600 RPM at 25 °C and 40 °C, respectively.

![Figure 46: Torque vs Time at 600 RPM](image)

The torque versus time plots for the 1000 RPM and 2000 RPM trials are shown in Figure 47 and Figure 48, respectively. On these plots the 25°C and 40°C trials are denoted by the yellow and blue lines respectively. The settling time for these rotational speeds are about 200 and 2000 milliseconds longer than that of the 600 RPM trials, as expected, since the fluid experiences higher turbulence at higher rotational speeds. Additionally, there is a trend of decrease churning losses with an increase in temperature for both the 1000 RPM and 2000 RPM cases. This trend aligns with the results of the lower 600 RPM test and provides further evidence towards the validity of our experimental outcomes. This suggests that the increased temperatures decrease the viscosity of the fluids therefore decreasing the churning losses.
The plot in Figure 49 displays the average steady-state torque load in the system for each rotational speed case, as well as the temperature at which that value was obtained. The standard deviation was also calculated for the average torque value at each rotational speed. Using these standard deviations from each trial, an overall standard deviation was calculated across the entire 3-trial dataset and applied to the overall average steady-state torque for each 3-trial set. These averages and standard deviations are shown in Figure 49 and Table 12, illustrating the dispersion of the data related to the average of each data set.
Similar to Figure 49, Figure 50 shows the power loss at 600, 1000, and 2000 RPM for both the 25°C and 40°C cases. This power loss is derived from the previous average torque value and should be taken as the actual churning loss in the system for each case. The final churning loss data for each case is tabulated in Table 13. Churning loss in terms of power (Watts) is calculated using Equation 10.

Churning loss is determined using the following equation:

\[ C_{Loss} = \tau \times N \times \frac{2\pi}{60} \]  

(10)

Where:

\[ C_{Loss} = \text{Churning Losses}, \quad \tau = \text{Average torque}, \quad N = \text{Rotational speed in RPM} \]
Figure 50: Power vs Speed

<table>
<thead>
<tr>
<th>RPM</th>
<th>Temperature (°C)</th>
<th>Churning Loss (Watts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>600</td>
<td>25</td>
<td>17</td>
</tr>
<tr>
<td>1000</td>
<td></td>
<td>35</td>
</tr>
<tr>
<td>2000</td>
<td></td>
<td>121</td>
</tr>
<tr>
<td>600</td>
<td>40</td>
<td>11</td>
</tr>
<tr>
<td>1000</td>
<td></td>
<td>29</td>
</tr>
<tr>
<td>2000</td>
<td></td>
<td>92</td>
</tr>
</tbody>
</table>

Table 13: Churning Loss Results

Based on consistent data acquisition, machine reliability, and data analysis, we can confidently identify trends in churning losses. Specifically, we have observed that higher temperatures are associated with lower power losses due to churning, and that increasing the gearset speed (RPM) results in higher power losses due to churning. The findings are logical as we expect that with higher temperatures the fluid viscosity will decrease resulting in less drag on the gear/gearset. Furthermore, it is expected that churning losses would increase with an increase in rotational speed, due to the increase in turbulence and solid/fluid friction within the gearbox.
Section 4: Bill of Materials

Table 14 and Table 15 show the bill of materials containing a detailed breakdown of each component purchased for the project, including the name of the supplier, quantity, and total cost of each part. The project required components from various suppliers, including PHIDGETS INC, McMaster-Carr, Amazon, ALRO Plastics, Digi-Key, and Automation Direct. The team was awarded two scholarships- one for machine improvement worth $750 and another for the temperature control system worth $728. The total cost of the project was $1,458.45, which is well within the budget of $1,478 awarded to the team. Note that this list excludes any components sponsored by Caster Concepts/Conceptual Innovations.

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Supplier</th>
<th>Part</th>
<th>Quantity</th>
<th>Cost Per Unit</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>PHIDGETS Inc.</td>
<td>PG30 Profile 30x30 (L=432MM)</td>
<td>4</td>
<td>$4.63</td>
<td>$18.52</td>
</tr>
<tr>
<td>2</td>
<td>PHIDGETS Inc.</td>
<td>PG30 Profile 30x30 (L=540MM)</td>
<td>4</td>
<td>$5.54</td>
<td>$22.16</td>
</tr>
<tr>
<td>3</td>
<td>PHIDGETS Inc.</td>
<td>PG30 Profile 30x30 (L=330MM)</td>
<td>4</td>
<td>$3.77</td>
<td>$15.08</td>
</tr>
<tr>
<td>4</td>
<td>PHIDGETS Inc.</td>
<td>PG30 Profile 30x30 (L=305MM)</td>
<td>2</td>
<td>$3.56</td>
<td>$7.12</td>
</tr>
<tr>
<td>5</td>
<td>PHIDGETS Inc.</td>
<td>PG30 Profile 30x30 (L=1000MM)</td>
<td>2</td>
<td>$9.40</td>
<td>$18.80</td>
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<tr>
<td>6</td>
<td>McMaster-Carr</td>
<td>Button Head Hex Drive Screw 91239A316</td>
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<td>$27.64</td>
</tr>
<tr>
<td>7</td>
<td>McMaster-Carr</td>
<td>Black-Oxide Alloy Steel Hex Drive Flat Head Screw 91294A236</td>
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<td>$14.45</td>
</tr>
<tr>
<td>8</td>
<td>McMaster-Carr</td>
<td>Button Head Hex Drive Screw 91255A716</td>
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<td>$9.22</td>
<td>$9.22</td>
</tr>
<tr>
<td>Part Number</td>
<td>Part Number</td>
<td>Part Number</td>
<td>Part Number</td>
<td>Part Number</td>
<td>Part Number</td>
</tr>
<tr>
<td>-------------</td>
<td>-------------</td>
<td>-------------</td>
<td>-------------</td>
<td>-------------</td>
<td>-------------</td>
</tr>
<tr>
<td>9</td>
<td>McMaster-Carr</td>
<td>Black-Oxide Alloy Steel Socket Head Screw 91251A580</td>
<td>1</td>
<td>$11.37</td>
<td>$11.37</td>
</tr>
<tr>
<td>10</td>
<td>McMaster-Carr</td>
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<tr>
<td>11</td>
<td>McMaster-Carr</td>
<td>T-Slotted Framing 5537T847</td>
<td>2</td>
<td>$15.83</td>
<td>$31.66</td>
</tr>
<tr>
<td>12</td>
<td>McMaster-Carr</td>
<td>Unthreaded-Hole Pull Handle 1950A61</td>
<td>1</td>
<td>$11.64</td>
<td>$11.64</td>
</tr>
<tr>
<td>13</td>
<td>McMaster-Carr</td>
<td>Alloy Steel Socket Head Screw 91290A328</td>
<td>1</td>
<td>$13.22</td>
<td>$13.22</td>
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<td>14</td>
<td>McMaster-Carr</td>
<td>T-Slotted Framing 5537T418</td>
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<td>$24.11</td>
<td>$24.11</td>
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<tr>
<td>15</td>
<td>McMaster-Carr</td>
<td>Single Clip Mounting Adapter for DIN 3 Rail 8961K28</td>
<td>4</td>
<td>$2.40</td>
<td>$9.60</td>
</tr>
<tr>
<td>16</td>
<td>Alro Plastics</td>
<td>BRONZE K09 FILM MASK POLYCARB (48 X 48 IN) P0809448</td>
<td>1</td>
<td>$140.41</td>
<td>$140.41</td>
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<tr>
<td>17</td>
<td>Amazon</td>
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<td>1</td>
<td>$24.99</td>
<td>$24.99</td>
</tr>
<tr>
<td>18</td>
<td>Automation Direct</td>
<td>WEG VFD (CFW300A07P3S2NB20) 230V 1P INPUT, 230V 3P OUTPUT</td>
<td>1</td>
<td>$277.00</td>
<td>$277.00</td>
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<tr>
<td>19</td>
<td>Amazon</td>
<td>Elegoo 1.75mm Filament</td>
<td>4</td>
<td>$13.85</td>
<td>$55.40</td>
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</tbody>
</table>

**TOTAL** | **$745.86**

*Table 14: Machine Improvement BOM*
<table>
<thead>
<tr>
<th>Part Number</th>
<th>Supplier</th>
<th>Part</th>
<th>Quantity</th>
<th>Cost Per Unit</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>McMaster-Carr</td>
<td>1 Compact Constant-Flow-Rate Pump for Water and Oil 8220K43</td>
<td>1</td>
<td>$79.92</td>
<td>$79.92</td>
</tr>
<tr>
<td>2</td>
<td>McMaster-Carr</td>
<td>Insertion Heater with Standard Wire Lead Covering 35025K134</td>
<td>3</td>
<td>$39.94</td>
<td>$119.82</td>
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<tr>
<td>3</td>
<td>Digi-Key</td>
<td>AC/DC CONVERTER 12V 150W 1866-3324-ND</td>
<td>1</td>
<td>$27.75</td>
<td>$27.75</td>
</tr>
<tr>
<td>4</td>
<td>Amazon</td>
<td>CONTROLLINO MAXI Power Automation</td>
<td>1</td>
<td>$280.28</td>
<td>$280.28</td>
</tr>
<tr>
<td>5</td>
<td>McMaster-Carr</td>
<td>Barbed Hose Fitting 2838N13</td>
<td>2</td>
<td>$2.58</td>
<td>$5.16</td>
</tr>
<tr>
<td>6</td>
<td>McMaster-Carr</td>
<td>Stainless Steel Tubing 5560K1</td>
<td>1</td>
<td>$8.65</td>
<td>$8.65</td>
</tr>
<tr>
<td>7</td>
<td>McMaster-Carr</td>
<td>Straight Pipe Fitting 5485K22</td>
<td>2</td>
<td>$2.67</td>
<td>$5.34</td>
</tr>
<tr>
<td>8</td>
<td>McMaster-Carr</td>
<td>Hollow Plug Fitting 50785K22</td>
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<tr>
<td>9</td>
<td>McMaster-Carr</td>
<td>In-line Tee Fitting 50785K72</td>
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<tr>
<td>10</td>
<td>McMaster-Carr</td>
<td>Silicone For Insulation 5236K105</td>
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<td>$15.49</td>
</tr>
<tr>
<td>11</td>
<td>McMaster-Carr</td>
<td>Mounting Clamp 3006T312</td>
<td>1</td>
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<td>$14.67</td>
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<tr>
<td>12</td>
<td>Amazon</td>
<td>Thermistor Cartridge</td>
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<td>13</td>
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<td>Epoxy</td>
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<td>$8.68</td>
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<td>14</td>
<td>Digi-Key</td>
<td>Relay Contactor</td>
<td>1</td>
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<td>15</td>
<td>Amazon</td>
<td>24V Power Supply</td>
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<td>$26.68</td>
<td>$26.68</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>$712.59</strong></td>
</tr>
</tbody>
</table>

*Table 15: Temperature Control System BOM*
Section 5: Conclusions

The project objectives focused on improving the overall safety, rigidity, and functionality of the test machine. Meeting the objectives was done through equipping the machine with a temperature control system, steel machine base, safety cover, and automated testing procedure.

The revised test machine no longer has significant shaft misalignment or vibration. In case of an emergency or component failure, the machine now includes safety devices in the form of an emergency stop button and safety cover. To study the effects that temperature may have on churning losses, the lubricant can now be heated to the required temperature of 40°C. Modifications were made to the existing insert designs to accommodate the new fluid heating system and have tighter tolerances to reduce excessive fluid seepage. To control the new test machine, a control system was also developed, which includes a test procedure that is both automated and repeatable. Each of these solutions has proven to be effective on the machine’s capacity to perform tests and acquire data.

The data acquired from the machine have proven to be repeatable between tests. This is reflected through the data collected across each of the three trials ran for each set of test parameters showing little variance. The largest variance being ±11.6%, from the 25°C and 1000 RPM tests and the lowest variance being ±1.71%, from the 25°C and 2000 RPM tests. Through experimental testing, it was found that increasing rotational speed results in an increase in churning losses and increasing temperature results in a decrease in churning losses. This is shown in the data, with the lowest churning loss being 11W from the 40°C and 600 RPM test, and the highest churning loss being 121W from the 25°C and 2000 RPM test. These results are consistent with expectation because higher rotational speeds result in an increase in fluid turbulence and consequently a higher churning loss. Furthermore, it is expected that churning loss would decrease with an increase in temperature, due to the fluid viscosity decreasing and the resulting force required for the gear to move through the fluid being lower.
Section 6: Future Work

The key focus for future efforts will be developing and manufacturing interchangeable baffles, followed by testing to optimize performance due to churning losses. With the new baffle designs, higher temperatures of 100°C will be explored, which will require higher grade 3D printing materials capable of withstanding higher temperatures. Furthermore, various fluids with different viscosity values will be tested as an alternative option for investigating the effect of viscosity on churning losses. Lastly, the experimental data obtained will be compared to Computational Fluid Dynamics (CFD) results produced as part of a separate CAViDS project. Findings from the future work will be used to build upon the conclusions of this project and will help drive further advancements in the field.
Section 7: References


Section 8: Appendices

Appendix A - Gantt Chart:
Appendix B - Engineering Standards:

- ANSI: American National Standards Institute (ANSI)
- API: American Petroleum Institute (API)
- ASME: American Society of Mechanical Engineers (ASME)
- ASTM: American Society for Testing and Materials (ASTM)
- ISO: International Organization for Standardization (ISO)
- SAE International: Society of Automotive Engineers International (SAE)
Appendix C - Coding:

Arduino IDE Code:

```c
#include <Controllino.h>

//---USER DEFINE TESTING PARAMETERS---/
#define T_HEATER 250 // IN-LINE HEATER BODY MAINTENANCE TEMPERATURE ---- (MAXIMUM VALUE OF ??*C)
#define T_TARGET 25 // TARGET TEMPERATURE FOR TESTING
#define RPM 600 // CONTROL VARIABLE FOR VDF FREQUENCY
#define T_MIN 100 // MAXIMUM VALUE OF 60HZ
#define T_MAX 2000 // MAXIMUM VALUE OF 60HZ

// FREQUENCY-SPEED SETTINGS //
// ------- Hz ------- RPM -------/
//------- 10.00 ---- 600 ------/
//------- 16.67 ---- 1000 ------/
//------- 33.33 ---- 2000 ------/

//--CONTROLINO CONNECTIONS-----------------------------------------------
GEARBOX OUTLET THERMISTOR @ A10
GEARBOX INLET THERMISTOR @ A11
IN-LINE HEATER @0 THERMISTOR @ A12
IN-LINE HEATER @1 THERMISTOR @ A13
PUMP CONTROL @ R0
IN-LINE HEATER CONTROL @ R2
VFD ENABLE CONTROL @ D00
VFD SPEED CONTROL @ A00

-----------------------------------------------/

//-----THERMISTOR CALC CONSTANTS---/
#define RTH 100000 // THERMISTOR NOMINAL RESISTANCE, (R)
#define B 4200 // THERMISTOR BETA VALUE, (k)
#define VCC 5 // PIN HEADER SUPPLY VOLTAGE, (V)
#define R 100000 // FULL-UP RESISTOR RESISTANCE, (R)
#define T0 298.15 // NOMINAL ATMOSPHERIC TEMPERATURE, 29C TO K CONVERSION

//-----THERMISTOR CALC VARIABLES-----/
float RTH, VRH, lns, THO, VRTH; 
float R2, VR2, ls, TH2, VR2H; 

//-----HEATER AND PUMP CONTROL VARIAELES---/
float T_FLUID; // AVERAGE FLUID TEMPERATURE CALCULATION
float T_H APPROX1, T_H APPROX2; // ACCEPTABLE IN-LINE HEATER TEMPERATURES
float T_F APPROX1, T_F APPROX2; // ACCEPTABLE FLUID TEMPERATURES

//--START TEST BUTTON VARIABLE------/
int ENABLE = 0; // BEGIN TESTING AKA ENABLE BUTTON, HI(ENABLED), LO(DISABLED)

//---------TORQUE SENSOR VARIABLES------/
#define TORQUE_SENSOR_RANGE 50.0 // MAX TORQUE SENSOR READING (LBF-IN)
float VOLTAGE; // TORQUE SENSOR VOLTAGE READING (V)
float TORQUE; // CALCULATED TORQUE VALUE (LBF-IN)

//----------DATA PRINTING TO CSV------/
bool DATA_LABELS = true; // DEFAULT PRINTING DATA LABELS TO TRUE

//---------MOTOR SPEED CALC-------/
```
float VFD Hz = (RPM / 60);                           // CALCULATED FREQUENCY SETTING FOR MOTOR

void setup() {
    Serial.begin(9600);                          // SET SERIAL COMM BAUDRATE
    pinMode(CONTROLLING_A0, INPUT);             // INITIALIZE A0 A3 INPUT (GEARBOX OUTLET THERMISTOR)
    pinMode(CONTROLLING_A1, INPUT);             // INITIALIZE A1 A3 INPUT (GEARBOX INLET THERMISTOR)
    pinMode(CONTROLLING_A2, INPUT);             // INITIALIZE A2 A3 INPUT (IN-LINE HEATER #0 THERMISTOR)
    pinMode(CONTROLLING_A3, INPUT);             // INITIALIZE A3 A3 INPUT (START TEST BUTTON)
    pinMode(CONTROLLING_R0, OUTPUT);            // INITIALIZE R0 A3 RELAY OUTPUT (PUMP ON-OFF CONTROL)
    pinMode(CONTROLLING_R2, OUTPUT);            // INITIALIZE R2 A3 RELAY OUTPUT (IN-LINE HEATER ON-OFF CONTROL)
digitalWrite(CONTROLLING_R0, LOW);           // INITIALIZE R0 LOW BY DEFAULT (PUMP OFF)
digitalWrite(CONTROLLING_R2, LOW);           // INITIALIZE R2 LOW BY DEFAULT (IN-LINE HEATER OFF)
    pinMode(CONTROLLING_A00, OUTPUT);           // INITIALIZE A00 A3 OUTPUT (VFD SPEED CONTROL 0-10V)
    pinMode(CONTROLLING_A01, OUTPUT);           // INITIALIZE A01 A3 OUTPUT (VFD ENABLE CONTROL)
analogWrite(CONTROLLING_A00, 0);             // INITIALIZE A00 A3 ZERO (ZERO Hz VFD COMMAND)
digitalWrite(CONTROLLING_A01, LOW);          // INITIALIZE A01 LOW BY DEFAULT (VFD DISABLED)
    pinMode(CONTROLLING_A12, INPUT);            // INITIALIZE A12 A3 INPUT (TORQUE SENSOR READING)
}

float STEINHART (float VRT) {
    float TX = 0;                                  // INITIALIZE CALCULATED TEMPERATURE TO ZERO
    VRT = (VCC / 1024.0) * VRT;                   // ANALOG TO VOLTAGE CONVERSION
    VR0 = VCC - VRT;                              // VOLTAGE ACROSS FULL-UP RESISTOR
    RTO = VRT / (VR0 / R);                       // THERMISTOR RESISTANCE
    In0 = log((RTO / RTX));                      // STEINHART CALCULATION SETUP
    TX = 1 / (1 / (ln(In0) / B) + (1 / T0));     // STEINHART CALCULATION FOR HEATER TEMP
    TX = TX - 273.15 - 56.3;                     // CONVERSION TO CELSIUS AND SUBTRACTION OF ERROR OFFSET
    TX = TX * (1.85076) - 14.206;                 // LINEAR REGRESSION FOR TEMPERATURE ERROR
    return TX;
}

void loop() {
    digitalWrite(CONTROLLING_A00, 0);            // SET VFD SPEED TO ZERO
digitalWrite(CONTROLLING_A01, HIGH);          // DISABLE VFD

    if (digitalRead(CONTROLLING_A3) == HIGH) {   // IF ENABLE IS HIGH
        // READ TEMPERATURE SENSORS //
        VRT0 = analogRead(CONTROLLING_A0);       // READING OF GEARBOX OUTLET ANALOG THERMISTOR VOLTAGE, VRT
        TX0 = STEINHART (VRT0);                  // READING OF GEARBOX INLET ANALOG THERMISTOR VOLTAGE, VRT
        VRT1 = analogRead(CONTROLLING_A1);       // READING OF IN-LINE HEATER ANALOG THERMISTOR VOLTAGE, VRT
        TX1 = STEINHART (VRT1);                  // READING OF IN-LINE HEATER ANALOG THERMISTOR VOLTAGE, VRT
        VRT2 = analogRead(CONTROLLING_A2);       // READING OF IN-LINE HEATER ANALOG THERMISTOR VOLTAGE, VRT
TX1 = STEINHART (VRT2);

/* Serial.print("\n"); Serial.print("TEMPERATURES:"); // PRINT TEMPERATURE DATA LABEL
Serial.print("\n"); Serial.print(TX0); // PRINT GEARBOX OUTLET TEMPERATURE
Serial.print("\n"); Serial.print("C"); Serial.print(" "); Serial.print(TX2); // PRINT GEARBOX INLET TEMPERATURE
Serial.print("C"); Serial.print(" "); Serial.print(TX1); // PRINT IN-LINE HEATER TEMPERATURE
Serial.print("C"); Serial.print(" "); Serial.print(T_FLUID); // PRINT IN-LINE HEATER TEMPERATURE
Serial.print("C"); */

T_FLUID = (TX0 + TX1) / 2; // AVERAGE FLUID TEMPERATURE CALCULATION
T_H_APPROX1 = T_HEATER + 1; // ACCEPTABLE UPPER IN-LINE HEATER TEMPERATURE TARGET
T_H_APPROX2 = T_HEATER - 1; // ACCEPTABLE LOWER IN-LINE HEATER TEMPERATURE TARGET
T_F_APPROX1 = T_TARGET + 1; // ACCEPTABLE UPPER FLUID TEMPERATURE TARGET
T_F_APPROX2 = T_TARGET - 1; // ACCEPTABLE LOWER FLUID TEMPERATURE TARGET

while (T_FLUID <= T_TARGET) {

  // READ TEMPERATURE SENSORS AGAIN //
  VRT0 = analogRead(CONTROLLING_A0); // READING OF GEARBOX OUTLET ANALOG THERMISTOR VOLTAGE, VRT
  VRT1 = analogRead(CONTROLLING_A1); // READING OF GEARBOX INLET ANALOG THERMISTOR VOLTAGE, VRT
  VRT2 = analogRead(CONTROLLING_A2); // READING OF IN-LINE HEATER ANALOG THERMISTOR VOLTAGE, VRT

  /* Serial.print("\n"); Serial.print("TEMPERATURES:"); // PRINT TEMPERATURE DATA LABEL
Serial.print("\n"); Serial.print(TX0); // PRINT GEARBOX OUTLET TEMPERATURE
Serial.print("\n"); Serial.print("C"); Serial.print(" "); Serial.print(TX2); // PRINT GEARBOX INLET TEMPERATURE
Serial.print("C"); Serial.print(" "); Serial.print(TX1); // PRINT IN-LINE HEATER TEMPERATURE
Serial.print("C"); Serial.print(" "); Serial.print(T_FLUID); // PRINT IN-LINE HEATER TEMPERATURE
Serial.print("C"); */

  T_FLUID = (TX0 + TX1) / 2; // AVERAGE FLUID TEMPERATURE CALCULATION
  T_H_APPROX1 = T_HEATER + 1; // ACCEPTABLE UPPER IN-LINE HEATER TEMPERATURE TARGET
  T_H_APPROX2 = T_HEATER - 1; // ACCEPTABLE LOWER IN-LINE HEATER TEMPERATURE TARGET
  T_F_APPROX1 = T_TARGET + 1; // ACCEPTABLE UPPER FLUID TEMPERATURE TARGET
  T_F_APPROX2 = T_TARGET - 1; // ACCEPTABLE LOWER FLUID TEMPERATURE TARGET
TARGET

if (TX2 < T_TARGET) {
  digitalWrite(CONTROLLING_R2, HIGH); // TURN ON IN-LINE HEATER
  digitalWrite(CONTROLLING_R2, HIGH); // TURN ON PUMP
} else if (TX2 > T_TARGET) {
  digitalWrite(CONTROLLING_R2, LOW); // TURN OFF IN-LINE HEATER
  digitalWrite(CONTROLLING_R2, HIGH); // TURN ON PUMP
}

if (T_FLUID >= T_TARGET) {
  digitalWrite(CONTROLLING_R0, LOW); // TURN OFF HEATER
  digitalWrite(CONTROLLING_R0, LOW); // TURN OFF PUMP
  unsigned long TIME = millis(); // INITIALIZE AND GET CURRENT TIME IN MS
  while (1) { // TRAP IN TERMINAL WHILE LOOP
    while (millis() - TIME < T_DUR+1) { // LOOP AND AQUIRE DATA FOR 6 SECONDS
      digitalWrite(CONTROLLING_A01, LOW); // ENABLE VFD
      float VFOut = map(VFD_Hz, 0, 50.0, 0, 255); // FREQUENCY MAPPED TO ANALOG OUT 0-10V
      analogWrite(CONTROLLING_A00, VFOut); // WRITE MOTOR SPEED SIGNAL TO VFD
      VOLTAGE = (analogRead(CONTROLLING_A112) / 1024.0) * 10; // READ VOLTAGE FROM ANALOG INPUT A112
      TORQUE = (VOLTAGE / 10.0) * TORQUE_SENSOR_RANGE; // CONVERT VOLTAGE TO TORQUE SENSOR USING SENSOR RANGE
      while (DATA LABELS) { // BEGIN PRINTING DATA LABELS FOR CSV
        Serial.print("MOTORS SPEED (RPM) "); // PRINT MOTOR SPEED LABEL FOR CSV
        Serial.print(" "); // COMMA
        Serial.print("FLUID TEMPERATURE (C) "); // PRINT TEMPERATURE LABEL FOR CSV
        Serial.print(" "); // COMMA
        Serial.print("TORQUE (LBF-IN) "); // PRINT TORQUE DATA LABEL FOR CSV
        Serial.print(" "); // COMMA
        DATA_LABELS = false; // STOP PRINTING DATA LABELS
      }
      Serial.print(RPM); // PRINT RPM SETTING
      Serial.print(" "); // COMMA
      Serial.print(T_FLUID); // PRINT FLUID TEMPERATURE SETTING
      Serial.print(" "); // COMMA
      DATA_LABELS = true; // START PRINTING DATA LABELS
    }
  }
}
Serial.print(TORQUE);           // PRINT TORQUE
DATA
Serial.print("\n");

delay(100);                     // LIMIT
     // SAMPLING RATE FOR DATA ACQUISITION
}

analogWrite(CONTROLLING_R00, 0); // SET VFD SIGNAL TO 0 HI
digitalWrite(CONTROLLING_R01, HIGH); // DISABLE VFD

}

if (digitalRead(CONTROLLING_A3) == LOW) { // IF ENABLE IS LOW
digitalWrite(CONTROLLING_R2, LOW);       // TURN OFF HEATER
digitalWrite(CONTROLLING_R2, LOW);       // TURN OFF PUMP
}

//delay(300); // DELAY FOR PRINTING

}
import serial

arduino_port="/dev/usbmodem101"
baud = 9600
fileName="data.csv"
samples = 10
print_labels = False

ser = serial.Serial(arduino_port, baud)
print("Connected to Arduino port:" + arduino_port)
file = open(fileName,"w")
print("created file")
line = 0
while line <= samples:
    if print_labels:
        if line==0:
            print("printing column headers")
        else:
            print("line" + str(line)+ ": writing..")
    getData=str(ser.readline())
    data=getData[2:][:-5] #possibly change this for number of variables
    print(data)
    file = open(fileName, "a")
    file.write(data + "\n")
    line = line + 1
print("data collection complete!")
Appendix D- Resumes:

Tyler Bretes

tylerbretes@gmail.com  |  (517) 474-2522  |  https://www.linkedin.com/in/tyler-bretes-298877252

OBJECTIVE
Dedicated mechanical engineering student, with over 5-years of industry experience in robotics and materials handling, seeking full-time employment opportunities after graduation in April of 2023.

EDUCATION
Western Michigan University  |  Kalamazoo, Michigan  |  Sep 2020 - Present  |  GPA: 3.51
  • Pursuing a bachelor's degree in mechanical engineering
  • Dean's List (2 Semesters)
Jackson College  |  Jackson, Michigan  |  Sep 2017 - May 2020  |  GPA: 3.8

WORK EXPERIENCE
Conceptual Innovations  |  Albion, Michigan  |  2017 - Present  |  Engineering
  • Product fabrication, assembly, and testing.
  • Control systems wiring, involving both low to high AC/DC voltages and both closed/open loop controls.
  • Holistic research and development experience. Designed, manufactured, and tested a small scale "omni-directional drive pod" leading to six-figure, teleoperated robot purchases from customers such as Boeing, NASA, BAE Systems, Northrop Grumman, and Argonne National Laboratory.
  • Engineering project management for a team of up to 8 younger interns, including training, project/task division, design reviews, materials purchasing, and general project assistance.
Print3D Manufacturing LLC  |  Parma, Michigan  |  2019 - Present  |  Owner
  • Owned and operated by myself, I manufacture 3D printed components and assemblies for customers in the automotive and material handling industries. Generating annual revenues from 15 to 20,000 dollars.

VOLUNTEER EXPERIENCE
Concord High School  |  Concord, Michigan  |  2018 - Present  |  Robotics Mentor
  • SOLIDWORKS and electrical wiring instruction for students in grades 9 through 12.

SOFTWARE SKILLS AND EXPERIENCE
  • SOLIDWORKS
  • DipTrace PCB
  • AutoCAD

MANUFACTURING/FABRICATION SKILLS AND EXPERIENCE
  • General industrial manufacturing shop & power tools (drill press, bandsaw, grinders, Sanders, etc.)
  • TIG & MIG Welding
  • Manual Mill and Lathe
  • CNC Mill/Router

HOBBIES
• FIRST Robotics Competition
• I have a strong passion for maintaining, repairing, and building cars. Over the years I have replaced clutches, brakes, entire suspensions, and transmissions. I have also installed custom car audio, refinished headlights, and rebuilt the automatic transmission for my own vehicle.

PROJECT REPOSITORY - Feel free to visit my project repository below to see a few images of my projects!
https://sites.google.com/view/tylerbretes/home
Reno Bunce
Senior Mechanical Engineering Student - LinkedIn: linkedin.com/in/reno-bunce-7a8671218
Phone: 248-760-7251 Email: reno.v.bunce@wmich.edu

OBJECTIVE
Dedicated and hardworking mechanical engineering student with significant testing, design, and manufacturing experience from internships/co-ops. Seeking full-time employment in April 2023 in a challenging and fast-paced environment.

EDUCATION
Western Michigan University – Kalamazoo, MI
Academic Status - Senior
Expected Graduation - April 2023
Major - Bachelor of Science in Mechanical Engineering
Minor - Mathematics
Cumulative GPA - 3.71

EXPERIENCE
Lambda Chi Alpha — Career Development Leadership
Eaton Corporation, Battle Creek, MI — Mechanical Design/Testing Engineering Co-op
- CMM Capability Study: Organized and led a team for a capability study that measures gear teeth from different die-stage tools. After processes such as forging, machining, heat treatment, and hardening is set to a global tolerance for bevel gear teeth.
- 12” E-Loader 4 Pinion Design/Simulation: Designed bevel gear micro geometry using KSSwift and PTI Creo Parametric 3.0. FE software: Transmission 3D was used to conduct simulations including bending stress, contact pressure, and contact pressure patterns. Micro geometry modifications were driven by simulation results to reach the goal of an acceptable stress analysis.

American Axle & Manufacturing, Three Rivers, MI — Tooling Engineer/Indirect Materials Co-op
- Reverse Engineering Design: Reverse engineered an existing tool to establish an understanding of the product’s purpose and functionality. Designed a professional AutoCAD 3D model to replace outsourced tooling.
- Rebuild/Qualifying Tooling: Trained and performed daily rebuilds for gear/pinion arbors (tooling that holds gears/pinions while being machined) and gear/pinion cutter heads while using CNC machines.
- Pneumatic Blow Off System: Increased product quality by implementing a pneumatic blow off system for ring gear process that eliminates shot peen from the threads.

Tenneco, Lansing, MI — Continuous Improvement/Manufacturing Engineering Internship
- Designed/Fabricated Prototype Cardboard Tugger Cart: Increased line efficiency by assigning the operator’s responsibility of dispensing of used cardboard to material handlers. Stationary cardboard holders were installed at the end of each line and designed a tugger cart prototype. The cart was designed with fencing and a retractable tow hitch that would be attached to a material tugger for safety.
- Cycle Time Analysis/Validation/Standardized Work: Documented and designed job aid and SOP. Documents included information about how to perform tasks, sequencing of assemblies, and time, while considering quality, safety, and technique.
- Weld Quality Station: Designed and welded a stand and leverage tool to perform destructive tests or brackets to examine weld quality.
- Process Layout: Designed new floor layout using AutoCad to improve efficiency and material flow.

DENSO Manufacturing Michigan, Inc., Battle Creek, MI — Process Engineering Internship
- Pneumatic Schematic: Designed a pneumatic schematic by reverse engineering a puck elevator for Auto-Pack project. The Auto-Pack project increased efficiency, implemented a vision system for quality assurance, and added an automated transfer cart for storing final assemblies. Project cost was $301,088 and the payback was 2.5 years. The cost savings was $127,000 a year and over 7 years would save $538,576.
- Condenser and Shroud Quality: Organized cross-functional team to develop improvements for increased yield for condensers and shrouds.
# Matthew Jose Martín

(734) 756-2307 | mjmartin117@gmail.com

## Education

Western Michigan University — Kalamazoo, MI  
Mechanical Engineering major with a minor in Mathematics  
GPA: 3.88  

## Relevant Course Work:

- Control Systems  
- Instrumentation  
- Machine Design  
- Circuit Analysis  
- Mechanics of Materials  
- Thermodynamics I & II  
- Engineering Graphics  
- Mechanism Analysis  
- Programming in C

## Work Experience

**Product Engineer Intern (Lighting) — Magna International**  
Plymouth, MI  
2022  
- Aided PEs on various task related to validation and verification, benchmarking, and product development.  
- Tested preproduction lamps for legal light intensity measurements.  
- Determine the root cause for the failures in testing of lamps.

**Warehouse Team Member — Amazon**  
Livonia, MI  
2020-2021

**Clerk — Kroger**  
Plymouth, MI  
2018-2019

## Professional Service and Organizations

**Formula SAE**  
2021 - Present

**Driver Controls Design Engineer**  
- Design all driver control components for the WMU FSAE team using SolidWorks.

**American Institute of Aeronautics and Astronautics**  
2019 - Present

**Launch Vehicle Lead Engineer and Secretary**  
- Participated in advanced collegiate level rocketry competitions.  
- Design, simulate, and implement a high-powered aerospace vehicle.

**Engineers Without Borders**  
2020 - Present

**President**  
- Facilitate and organize communication and meetings with faculty, members, and mentors.

**Lee’s Honors College and Alpha Lambda Delta**  
2019 - Present

**Member**  
- Community of academic scholars with like-minded ideals and goals for future successes.

## Skills

- SolidWorks  
- AutoCAD  
- LabVIEW  
- MATLAB  
- Microsoft Office Programs  
- LTSpice  
- Ansys Simulation  
- Teamwork & Collaboration  
- Time Management  
- Research

## Projects

**Carbon Monocoque Chassis — Formula SAE**  
- Contributed to the full manufacturing process of a carbon composite monocoque chassis.  
- Used Ansys simulation software to validate the point stresses and loading experienced on the chassis.

**Design of a Theoretical Transmission**  
- Calculated and optimized all components for gear and shaft selection of a theoretical transmission.
ABET Evaluation Questionnaires:

**ABET Program Evaluation Questionnaire**
**Mechanical and Aerospace Engineering Project (ME/AE 4800) Program Outcomes’ Indicators Assessment Worksheet**

Semester: **Spring 2023**  
Project Group Number: 04-23-14

Project Title: **Design and Implementation of Test Stand Upgrades for Investigating Gearset Churning Losses with Baffles**

Student Members: Tyler Bretes, Reno Bunce, Julissa Torres, Matthew Martin

Faculty Team Members: Dr. Richard Meyer and Dr. Claudia Hansford-Fajardo

Please respond to all of the following questionnaires as best you can.

**Student Name:** Tyler Bretes

Outcomes (2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.

Performance Indicators:

1. Generates a detailed statement of all the specified engineering needs for the design project.
2. Identifies and lists potential public health, safety and welfare concerns for consideration in the design process.
3. Identifies and lists global, cultural, social, environmental and economic factors that are relevant to the development of the project product.
4. Produces solutions that satisfy the engineering needs, address the public concerns and consider the effects of the relevant design factors.

**Performance Indicator 1**

Describe the engineering needs for this project.

Develop a system to quantify the churning losses for a specific light duty transmission gearset. This system must be able to study the effects that baffle design and viscosity may have on churning losses. Interchangeable baffle geometries and oil heating system are the primary design implementations for these studies.

List the project goals along with performance criteria.

Design and implementation fluid heating system

- Operating temperature of 100°C
- Non-disruptive to fluid flow during tests
- Non-oxidative heating of fluid
• Heating time of less than 5-minutes
• Ability to drain and swap fluid

Design and implementation of machine structure improvements
• Reduce rotating shaft misalignment
• Safety shield to protect operator from rotating component failure
• Accommodations for robust component mounting

Design and implementation of interchangeable baffles
• Ability to swap various geometries per previous master thesis literature review
• Reduce oil leakage past baffles
• Withstand oil temperatures up to 100°C

Testing and creation of DOE Matrix

List the project constraints.
• Existing gearbox
  o Gearbox and geartrain design restricted to those already implemented
  o Gearset testing rotational speeds to be 600, 1000, 2000, and 3000 rpm.

List the methods/procedures that were implemented to ensure that the customer expectations were addressed.
To ensure the method and procedures meet expectation regular weekly meetings were held with faculty advisors. Additional presentation(s) of project progress were shared with CAViDS Consortium members.

Performance Indicator 2
Describe potential public health, safety, and welfare concerns regarding this project and describe how they were addressed in the final design.

Public health:
To protect operator health, contact with the oil/fluid used during testing will be done so with proper personal protective equipment. Operator contact with oil/fluid is eliminated entirely during draining process due to remote box drain.

Public safety:
There were concerns of rotating machine component failure causing harm to the operator. To address these concerns a polycarbonate shield and structure was designed and implemented.

Public welfare: N/A
**Performance Indicator 3**

List and explain all possible global, cultural, social, environmental, and economic factors relevant to the product of this project.

Global factors: N/A

Cultural factors: N/A

Social factors: N/A

Environmental factors:

Any used oil/fluid from testing will be drained into a container and disposed of or recycled in an appropriate manner.

Economic factors: N/A

**Performance Indicator 4**  
(To be addressed by the faculty adviser)

Outcome (4) An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental and societal contexts.

**Performance Indicator 2:**

Student is able to make informed judgments based on the impact of engineering solutions in global, economic, environmental and societal context.

Did you adapt your project to make it useful in many countries? Y / N / NA If yes, explain:

Did you consider standards and regulations, either U.S. or international? Y / N / NA If yes, explain how they affected your project:
Yes. In order to ensure our initial engineering calculations were accurate, all DEXRON VI ATF material properties were retrieved from SAE (Society of Automotive Engineers) documentation. System design was also complete with meeting the ASTM standards of testing lubricants at operational temperatures of 40 and 100 degrees Celsius.

Did you consider the effects of manufacturing in various locations? Y / N / NA If yes, where in the report did you address this issue?

Did you have to balance effects of costs and performance? Y / N / NA If yes, explain and refer to the report as appropriate.

Yes. We based our budget off a finite amount awarded to our group from an undergraduate research scholarship. This budget meant that we had to sacrifice using high-end industrial grade in-line heaters for a custom manufactured, cheaper alternative. Additionally, the decision was made use the Controllino PLC as our primary over the controller due to the lower cost versus the NI RoboRIO, which would be a superior option based on our experience with LabVIEW programming.

Did you consider effects of maintenance, failure and repair on cost, safety, etc.? Y / N / NA If yes, where in the report did you address them?

Yes. Overall system design kept maintenance in mind with most subsystems being modular and easily removable for maintenance and replacement. Maintenance and repair features are most noticeable in the sub-plate for the in-line heating system, removable 3D-printed baffles, and oil drain valve for the gearbox. Safety was a high priority and the implementation of a safety cover was one of the primary highlights of the project. Through implementing this safety cover the machine operator will be protected in the case of a high-speed rotating component failure.

What were your considerations (e.g., cost, weight, manufacturing, availability, safety, recycling, etc.) in the selection of materials? List, explain and refer to the text of the report as appropriate.

When selecting specific componentry for our machine, cost, ease of use, and solution effectiveness were the common criterion. For example, in our report we should multiple decision matrices, which detail the selection though process for major components or design decisions such as our controller, temperature sensor, fluid heating method, and safety cover implementation.

Does your project impact air quality, water quality, noise levels, and other environmental aspects? Y / N / NA If yes, explain how and show what were your actions.

Does your project impact human health during manufacturing or normal use? Y / N / NA If yes, explain what you did to alleviate the risks.
Are there any other safety issues typical to your project? **Y / N / NA** If yes, explain your decisions and actions. Refer to the report as appropriate.

For this project and others like it, there is always a great risk involved with using high speed electric motors. On top of potential motor failure, there is the risk of any componentry attached to the shaft also becoming projectile due to a possible failure in materials or mechanical system itself. The specific actions taken during this project to address this issue consisted of implementing a safety cover consisting of an aluminum frame and polycarbonate panel shielding.
Outcome (5) An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks and meet objectives

Performance Indicators:

1. Student’s ability to function effectively
2. Student provides task specific leadership.
3. Student creates a collaborative and inclusive environment.
4. Group establishes goals.
5. Group plans tasks

Performance Indicators 2 & 5

List all tasks required to accomplish the goals of this project and name the group member responsible for the completion of each task.

<table>
<thead>
<tr>
<th>Task</th>
<th>Tyler Brete</th>
<th>Reno Bunce</th>
<th>Julissa Torres</th>
<th>Matthew Martin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural and Safety Improvements</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Design</td>
<td>X</td>
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<tr>
<td>Manufacturing</td>
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<tr>
<td>Assembly</td>
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<tr>
<td>Temperature Control System</td>
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<tr>
<td>Research</td>
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<tr>
<td>Design</td>
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<tr>
<td>Manufacturing</td>
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<tr>
<td>Assembly</td>
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<tr>
<td>Control Panel</td>
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<tr>
<td>Design</td>
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<tr>
<td>Manufacturing</td>
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<tr>
<td>Assembly</td>
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<td>Baffles</td>
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<tr>
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<tr>
<td>Design</td>
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<tr>
<td>Manufacturing</td>
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<tr>
<td>Assembly</td>
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<tr>
<td>Coding</td>
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<td>Arduino IDE (Machine)</td>
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<td>Python (Data Processing)</td>
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<td>Instruction Manuals</td>
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<td>Machine Operation</td>
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<td>Software Setup</td>
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<tr>
<td>Testing</td>
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<td>X</td>
</tr>
</tbody>
</table>
Performance Indicator 1 (Project’s adviser will determine whether the listed tasks were completed).

Answer the following questions:

For project tasks in which I was not the leader, I provided the following inputs towards their completion:

- **Task: Baffles**
  - I offered guidance to Julissa during the design phase. This included big picture design decisions for fluid routing and technical guidance when using SolidWorks. I assisted in the assembly and testing of the baffle designs as well as contributing to discussion regarding design modifications. I also provided two 3D-printers to be used for the printing of any baffle/volume insert components.

Performance Indicator 3

For project tasks in which you were the leader, describe the input other group members provided towards the successful completion of these tasks.

- **Task: Temperature Control System**
  - **Name of Student 1:** Julissa Torres – Performed preliminary calculations which helped guide the designs heating element power selection process.
  - **Name of Student 2:** Matthew Martin – Performed preliminary calculations which helped guide the designs heating element power selection process. Assisted in the mechanical assembly and necessary modifications for retrofit to the existing gearbox.
  - **Name of Student 3:** Reno Bunce – Assisted in the mechanical assembly and necessary modifications for retrofit to the existing gearbox.

- **Task: Control Panel**
  - **Name of Student 1:** Julissa Torres – Assisted in the assembly of all panel components.
  - **Name of Student 2:** Matthew Martin – Assisted in the assembly of all panel components.
  - **Name of Student 3:** Reno Bunce – Assisted in the initial layout and wiring of the control system components.

- **Task: Structural and Safety Improvements**
  - **Name of Student 1:** Julissa Torres – Assisted in the manufacturing of all sheet metal components and the assembly of all structural machine components.
  - **Name of Student 2:** Matthew Martin – Assisted in the assembly of all structural machine components.
  - **Name of Student 3:** Reno Bunce – Assisted in the manufacturing of all sheet metal components and the assembly of all structural machine components.

- **Task: Coding**
Performance Indicator 4

List all goals this project had to satisfy to be considered successfully completed.

1. Resolve machine rotating shaft misalignment
2. Add safety accommodations for machine operators
3. Add fluid heating system capable of reaching at least 40 degrees Celsius
4. Add a refined volume insert and interchangeable baffle system
5. Validate all machine functions
6. Perform data acquisition and analysis for the quantification of churning losses

Performance Indicator 6  
(To be addressed by the faculty adviser)

Outcome (7) An ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

Performance Indicators:

1. Student’s ability to find information relevant to problem solution without guidance.
2. Student’s ability to identify the additional knowledge needed to complete project.
3. Student’s ability to acquire and apply the additional knowledge needed to complete project.

Performance Indicator 1

Describe what information you found in order to successfully complete the tasks you were assigned in the project.

Before beginning design for the temperature control system, I did a lot of preliminary research work looking at various ways we could determine the best method for heating. I also looked at what the necessary calculations might be needed for this project and tried to provide insight to both Matthew and Julissa during their research. I also performed a lot of research to find valid material properties for the fluid being used in our test machine.

What sources did you use to find this information?

The majority of the information I found was from industry supplies for various process heaters such as Watlow, Wattco, and Omega Engineering. I retrieved technical documentation for the fluid in our test machine from the Society of Automotive Engineers J311 documentation and ExxonMobil’s online documentation.

Performance Indicator 2

Describe what additional knowledge/skills you needed to acquire or improve in order to successfully complete the tasks you were assigned in the project.

For this project I relied heavily on my previous experiences with my internship through one of our sponsors, Conceptual Innovations. This internship gave me all the necessary CAD, manufacturing, software, and electrical knowledge to construct this test machine. I heavily relied on the design projects in which I used SolidWorks to
design sheet metal components and then the manufacturing capabilities that open up from this. I also implemented a lot of the skills I learned from industrial control systems that we design and manufacture as well.

**Performance Indicator 3**

Describe what approach/process you followed in order to acquire or improve the additional knowledge/skills you needed.

During this project one of the largest hurdles, I had to overcome was developing the actual Arduino IDE code that ran on our machine controller. I have experience using the Arduino coding language in the past, but my skills are far from fully developed. To solve this problem, I spent a lot of time reading through online forms and tutorials to learn how to connect the various instrumentation and devices used during this project. I also referenced the controller's documentation and tutorials from the manufacturer Controllino to learn the specific controller syntax.
Outcome (2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.

Performance Indicators:
1. Generates a detailed statement of all the specified engineering needs for the design project.
2. Identifies and lists potential public health, safety and welfare concerns for consideration in the design process.
3. Identifies and lists global, cultural, social, environmental and economic factors that are relevant to the development of the project product.
4. Produces solutions that satisfy the engineering needs, address the public concerns and consider the effects of the relevant design factors.

Performance Indicator 1

Describe the engineering needs for this project.

The scope for this project is to replicate a transmission gear set and test for churning losses using varies baffle types and oils with different viscosities. The engineering needs include design and implementation of interchangeable baffle geometries and temperature control system, selecting and intergrading instrumentation and sensors, developing software to support our test machine and temperature control system components, while considering the safety of the operator. It was also required to collaborate with experts including faculty mentors and CAViDS Consortium, and other interested parties. Finally, this project required a multidisciplinary approach including mechanical, software, and electrical engineering.

List the project goals along with performance criteria.

Design and implement test machine and structural improvements

- Hinged safety cover with locking mechanism to create a physical barrier between high-speed rotating components and the operator to ensure safe testing environment.
- Steel base and vertical plate combined with 3D printed mounts to decrease shaft alignment and vibration.

Design and implement temperature control system for test fluid

- Variable testing temperature of 40C-100C
- Heating time that is reasonable between 5-15 minutes
- Circulate and heat fluid without disrupting the flow of the fluid
- Heating the fluid without oxidizing it
- Capability of draining and testing varies fluids without contamination

Design and implement multiple baffle types for the gearbox

- Capability of installing varies baffle geometries and volume inserts
- Material of baffles/volume inserts must be capable of withstanding temperatures of 100C
- Develop a tight tolerance range for baffles/volume inserts to reduce fluid seepage

DOE and testing matrix
• Create DOE and testing matrix that includes detailed instructions to perform churning loss test

List the project constraints.

Gearbox

• Testing parameters: Rotational velocities of gearset are 600, 1000, 2000, 3000 rpm
• Gearbox or gearset cannot be modified

List the methods/procedures that were implemented to ensure that the customer expectations were addressed.

• Weekly meetings with faculty mentors to share progress updates, troubleshooting, and discussed overall scope of the project to ensure our team stays focused.
• Monthly meetings with representatives from CAViDS Consortium members and other interested parties. Meetings included presentations led by the students to provide updates and listen to customer input.

Performance Indicator 2

Describe potential public health, safety, and welfare concerns regarding this project and describe how they were addressed in the final design.

Public health:
The main concern is the operator's health and exposure to test fluid. Latches were installed on the gearbox’s lid to prevent oil splashing. The gearbox is also equipped with a drain valve to eliminate physical contact with the fluid. Lastly, the operator must wear proper PPE (Personal Protective Equipment) when handling and filling gearbox with test fluid.

Public safety:
The initial test machine had possible safety risks with exposed rotating components that could cause harm to the operator if failures were to occur. To prevent the possibility of injuries, a safety shield with a locking mechanism was designed and implemented.

Public welfare: N/A

Performance Indicator 3

List and explain all possible global, cultural, social, environmental, and economic factors relevant to the product of this project.

Global factors: N/A
Cultural factors: N/A

Social factors: N/A

Environmental factors:
The testing fluids are varying types of oil. All test fluid must be drained from the gearbox into a proper container and recycled appropriately.

Economic factors: N/A

**Performance Indicator 4** *(To be addressed by the faculty adviser)*

Outcome (4) An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental and societal contexts.

**Performance Indicator 2:**

Student is able to make informed judgments based on the impact of engineering solutions in global, economic, environmental and societal context.

Did you adapt your project to make it useful in many countries? Y / N / NA If yes, explain:

Did you consider standards and regulations, either U.S. or international? Y / N / NA If yes, explain how they affected your project:

Our team collected material properties of DEXRON VI ATF from Society of Automotive Engineers. Following the standard material properties ensures that our calculations reflect our results.

Did you consider the effects of manufacturing in various locations? Y / N / NA If yes, where in the report did you address this issue?

Did you have to balance effects of costs and performance? Y / N / NA If yes, explain and refer to the report as appropriate.

Our team was limited to the undergraduate research award that was received. Given the restricted budget, our team had to carefully evaluate cost vs performance. In order to stay within the budget, the team manufactured and built the majority of the expensive components. The team has access to Caster Concepts equipment to manufacture reinforced steel base plate, safety shield corner brackets and polycarbonate covers, and in-line heater. Lastly, our team decided to buy the cheaper PLC Controllino instead of a high-grade industrial controller. This controller that was selected was the minimum required controller to operate our temperature control system and test stand.

Did you consider effects of maintenance, failure and repair on cost, safety, etc.? Y / N / NA If yes, where in the report did you address them?

Yes, all of these things were considered in our team’s project. We have multiple sub-assemblies, one including the sub-plate for the in-line heater, pump, and terminals. If components needed maintenance they would be easily removed and repaired. We also have removable baffles/volume inserts. If they were to fail then they would be able to be removed and reprinted. Lastly, the group considered safety as
one of our main priorities. In order to keep the operator safe, we implemented a safety shield over high-speed rotating components to prevent possible injuries.

What were your considerations (e.g., cost, weight, manufacturing, availability, safety, recycling, etc.) in the selection of materials? List, explain and refer to the text of the report as appropriate.

Our group's main considerations included cost, ease of use, and how effective the selection is. In our report we heavily relied on decision matrices to guide selection of materials. Some examples of decision matrices that we used include safety cover, controller, pump, heating method, temperature sensor, etc.

Does your project impact air quality, water quality, noise levels, and other environmental aspects? **Y / N / NA** If yes, explain how and show what were your actions.

Does your project impact human health during manufacturing or normal use? **Y / N / NA** If yes, explain what you did to alleviate the risks.

Are there any other safety issues typical to your project? **Y / N / NA** If yes, explain your decisions and actions. Refer to the report as appropriate.

As mentioned before, there is risk associated with failure of rotation components like the motor or shafts. If one of these were to fail, they could potentially cause flying objects towards the operator and cause major harm. Our group considered this possibility of failure immediately. We decided to implement a safety cover with a locking mechanism over all rotating components to eliminate this risk. We also wired an E-Stop to the control panel of the machine, in case of an emergency, the operator would be able to immediately cut all power to the system.

Outcome (5) An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks and meet objectives

Performance Indicators:
1. Student’s ability to function effectively
2. Student provides task specific leadership.
3. Student creates a collaborative and inclusive environment.
4. Group establishes goals.
5. Group plans tasks

**Performance Indicators 2 & 5**
List all tasks required to accomplish the goals of this project and name the group member responsible for the completion of each task.

<table>
<thead>
<tr>
<th>Task</th>
<th>Tyler Bretes</th>
<th>Reno Bunce</th>
<th>Julissa Torres</th>
<th>Matthew Martin</th>
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</thead>
<tbody>
<tr>
<td>Structural and Safety Improvements</td>
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<td>Design</td>
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<td>Performance Indicator 1</td>
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Answer the following questions:

For project tasks in which I was **not** the leader, I provided the following inputs towards their completion:

- **Task:** Structural and Safety Improvements
  - Assisted with manufacturing all the sheet metal, brackets, and plates for the test stand.
  - Assisted in assembly of base plate, mounts, and safety cover.

- **Task:** Control Panel
  - Assisted with electrical wiring and layout for control panel components. Also helped troubleshoot issues.
• **Task: Temperature Control System**
  - Assembled the sub assembly that included the pump, in-line heater with insulation, and terminals.
  - Assisted in modifying the gearbox to add inlets and outlets for the test fluid. Also assisted in routing the piping.

• **Task: Baffles**
  - Sanded down and modifications to baffles so they would fit properly in the gearbox.

**Performance Indicator 3**
For project tasks in which you were the leader, describe the input other group members provided towards the successful completion of these tasks.

• **Task: Project Administration and Planning (Project Manager for Timeline, Tasks, and Goals)**
  - **Name of Student 1:** Julissa Torres – Provided detailed updates and realistic timelines on baffles design.
  - **Name of Student 2:** Tyler Bretes – Provided detailed updates on the majority of design and manufacturing. Also helped with the idea of breaking the project into subtopics for organization and tracking time.
  - **Name of Student 3:** Matt Martin – Provided detailed updates on quality of baffle prints and printing times.

• **Task: Testing Matrix (DOE Excel Data Output)**
  - **Name of Student 1:** Julissa Torres – Assisted with insight on testing parameters and response.
  - **Name of Student 2:** Tyler Bretes – Assisted with insight on testing parameters and response.
  - **Name of Student 3:** Matt Martin – Assisted with insight on testing parameters and response.

**Performance Indicator 4**
List all goals this project had to satisfy to be considered successfully completed.

1. Resolve machine rotating shaft misalignment
2. Add safety accommodations for machine operators
3. Add fluid heating system capable of reaching at least 40 degrees Celsius
4. Add a refined volume insert and interchangeable baffle system
5. Validate all machine functions
6. Perform data acquisition and analysis for the quantification of churning losses

**Performance Indicator 6 (To be addressed by the faculty adviser)**

Outcome (7) An ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

Performance Indicators:
1. Student’s ability to find information relevant to problem solution without guidance.
2. Student’s ability to identify the additional knowledge needed to complete project.
3. Student’s ability to acquire and apply the additional knowledge needed to complete project.

**Performance Indicator 1**

Describe what information you found in order to successfully complete the tasks you were assigned in the project.

One of the tasks I was assigned was to create the instructions for the churning loss test. I have experience in a manufacturing/industrial engineering role. That being said, I used prior knowledge and documentation examples including SOP (Standard Operating Procedure) and Lean Six Sigma Control Plans. These examples and methods helped with the success of creating a professional test sequence that included technique, quality, and safety.

What sources did you use to find this information?

The majority of the information was found through OSHA, American Society for Quality, and past experience. I also discussed with team members, faculty mentors, and industrial mentors about the approach and method of the test instructions.

**Performance Indicator 2**

Describe what additional knowledge/skills you needed to acquire or improve in order to successfully complete the tasks you were assigned in the project.

During the project I was able to strengthen my skills as well as learn new skills. My past manufacturing experience helped identify the risk of exposed rotating objects that could cause the operator. My experience also helped me think about safety features such as a physically barrier protecting the operator. Lastly, my experience helped me construct the instructions for our test machine. The instructions used a similar approach as lean six sigma control plans and standard operating procedure documentation, while keeping in mind of technique, quality, and safety.

I also learned new skills while working on this project. I took advantage of learning and asking questions from my experienced teammates. Specifically, I had minimum experience when it comes to software and electrical wiring. Tyler is very experienced and comfortable with this kind of work. Tyler educated me on different electrical components and I improved my skills of wiring schematics and wiring the control panel for the temperature control system. I also learned a lot about PLC controllers and the coding behind them. I asked tons of questions and enjoyed helping with the electrical side of the project.
Performance Indicator 3

Describe what approach/process you followed in order to acquire or improve the additional knowledge/skills you needed.

During the project I was responsible for multiple parts, some including project planning/schedule, test instructions, control panel/wiring temperature control system, etc. I improved skills from my engineering experience. I used my current Test Engineering role to improve my project planning/management for our project. I currently have work projects with detail and dependent tasks, this helped improve my project planning timeline and management of the project. I also acquired skills from my experience to help layout and create the instructions for the test procedure. I referred to previous test instructions that I have from work to ensure that our instructions align with the standard in the real world. Lastly, I had limited skills with the electrical side of the project. To improve my skills, I asked Tyler many questions and concepts to further my knowledge so that I could help with wiring the test machine.
Outcome (2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.

Performance Indicators:
1. Generates a detailed statement of all the specified engineering needs for the design project.
2. Identifies and lists potential public health, safety and welfare concerns for consideration in the design process.
3. Identifies and lists global, cultural, social, environmental and economic factors that are relevant to the development of the project product.
4. Produces solutions that satisfy engineering needs, address the public concerns and consider the effects of the relevant design factors.

(If you copy and paste from the report, mention Section number or page numbers. If any question or item is not relevant to your project, write N/A)

**Performance Indicator 1**
Describe the engineering needs for this project.
This project will study the effects of oil temperatures and baffle geometries effects on churning losses in a gearset. The design and development of a testing apparatus will be required to quantify the losses experienced.

List the project goals along with performance criteria.
**Design implementation of machine structure**
- Reduce misalignment of the torque sensor and the motor
- Create a safety cover to protect the operator during testing

**Design implementation of temperature control system**
- Achieve a temperature of 100°C
- Heating time in the range of 6-10 minutes, preferred
- Ability to drain fluid
- Non-disruptive and non-oxidating to flow during testing

**Design implementation of Baffles**
- Interchangeable for different geometries
- Withstand temperatures up to 100°C
- Minimize the buoyancy forces and oil seepage

**Design of experiment**
- Make an interface that is intuitive and easy to run.
- The data displayed in an excel matrix

List the project constraints.
The gearbox was restricted from design changes.
Rotational speeds of 600, 1000, 2000, and 3000 RPM

List the methods/procedures that were implemented to ensure that the customer expectations were addressed.
In order to ensure the customers' satisfaction, we held periodic presentations to the CAViDS advisory board. This was additional to the weekly update meetings we held with our faculty mentors.

**Performance Indicator 2**
Describe potential public health, safety, and welfare concerns regarding this project and describe how they were addressed in the final design.

Public health:
The operator's health will be protected by ensuring proper PPE usage when handling the working fluids. At the end of testing, the working fluid will be drained into a remote reservoir hence eliminating the operator's contact with the fluid. Once the fluid is ready to be disposed of, the team will do so in an ethical manner.

Public safety:
Our project addressed the concerns of machine failure. In order to protect the safety of the operator, the safety shield was added to enclose all rotating components.

Public welfare:
N/A

**Performance Indicator 3**
List and explain all possible global, cultural, social, environmental, and economic factors relevant to the product of this project.

Global factors:
N/A

Cultural factors:
N/A

Social factors:
N/A

Environmental factors:
The working fluid can be toxic if not properly disposed of. The group has devised a method for safely disposing of the working fluid after testing has been completed.

Economic factors:
N/A

**Performance Indicator 4**
Outcome (4) An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental and societal contexts.

Performance Indicator 2:
Student is able to make informed judgments based on the impact of engineering solutions in global, economic, environmental and societal context.

Did you adapt your project to make it useful in many countries? Y / N / NA If yes, explain: N/A

Did you consider standards and regulations, either U.S. or international? Y / N / NA If yes, explain how they affected your project:
Yes, Dextron IV automatic transmission fluids properties were used for calculations. These values were obtained from SAE guidelines. Similarly, the ATSM standards were withheld for the temperature of the working fluid testing.

Did you consider the effects of manufacturing in various locations? Y / N / NA If yes, where in the report did you address this issue?
N/A

Did you have to balance effects of costs and performance? Y / N / NA If yes, explain and refer to the report as appropriate.
Yes, the budget for this project was acquired through the ORI Undergrad Research Scholarship. Since this was our working budget, the team stayed under the limitations of funding.

Did you consider effects of maintenance, failure and repair on cost, safety, etc.? Y / N / NA If yes, where in the report did you address them?
Yes, the safety machine cover was designed with the safety of the operator, ease of maintenance, and possible failure in mind. The machine cover will contain any flying debris in the unfortunate scenario that machine failure occurs.

What were your considerations (e.g., cost, weight, manufacturing, availability, safety, recycling, etc.) in the selection of materials? List, explain and refer to the text of the report as appropriate.
The considerations of cost, availability, temperature resistance, and oil resistance were kept in mind when selecting materials.

Does your project impact air quality, water quality, noise levels, and other environmental aspects? Y / N / NA If yes, explain how and show what were your actions.
N/A

Does your project impact human health during manufacturing or normal use? Y / N / NA If yes, explain what you did to alleviate the risks.
N/A
Are there any other safety issues typical to your project? Y / N / NA If yes, explain your decisions and actions. Refer to the report as appropriate.

For this project the main safety issue comes from the high-speed motor and all the components attached to it. Any mechanical failures would be contained by the safety shield cover as stated in section two of our report.

Outcome (5) An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks and meet objectives

Performance Indicators:

1. Student’s ability to function effectively
2. Student provides task specific leadership.
3. Student creates a collaborative and inclusive environment.
4. Group establishes goals.
5. Group plans tasks

(If you copy and paste from the report, mention Section number or page numbers.)

**Performance Indicators 2 & 5**

List all tasks required to accomplish the goals of this project, and name the group member responsible for the completion of each task.

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<tr>
<td>Design</td>
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<td>Assembly</td>
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<td>Research</td>
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<td>Assembly</td>
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<tr>
<td>Coding</td>
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<tr>
<td>Arduino IDE (Machine)</td>
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</table>
Performance Indicator 1
(Project’s adviser will determine whether the listed tasks were completed).

Answer the following questions:

For project tasks in which I was not the leader, I provided the following inputs towards their completion:

- **Task: Structural and Safety Improvements**
  - Assisted in assembly of all structural machine components
- **Task: Temperature Control System**
  - Performed preliminary calculations which helped guide the design heating element power selection process
- **Task: Baffles**
  - Assisted in assembly and manufacturing of all baffles and iterations
- **Task: Coding**
  - I developed python code to read the Arduino serial monitor and display the readings into a CSV file.

Performance Indicator 3
For project tasks in which you were the leader, describe the input other group members provided towards the successful completion of these tasks.

- **Task: Instruction Manuals**
  - **Name of Student 1:** Reno Bunce-Assisted in the creation of the Machine Operation Manual.
  - **Name of Student 2:** Julissa Torres-Assisted in reviewing both manuals to ensure operator could follow the provided instructions.
  - **Name of Student 3:** Tyler Brete-Assisted in reviewing both manuals to ensure operator could follow the provided instructions.

Performance Indicator 4
List all goals this project had to satisfy to be considered successfully completed.

1. Resolve machine rotating shaft misalignment
2. Add safety accommodations for machine operators
3. Add fluid heating system capable of reaching at least 40 degrees Celsius
4. Add a refined volume insert and interchangeable baffle system
5. Validate all machine functions
6. Perform data acquisition and analysis for the quantification of churning losses

**Performance Indicator 6**
(To be addressed by the faculty adviser).
Outcome (7) An ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

Performance Indicators:

1. Student’s ability to find information relevant to problem solution without guidance.
2. Student’s ability to identify the additional knowledge needed to complete project.
3. Student’s ability to acquire and apply the additional knowledge needed to complete project.

**Performance Indicator 1**

Describe what information you found in order to successfully complete the tasks you were assigned in the project.
For the temperature calculations, I used fluid property documentations and looked up additional equations to successfully complete the calculations. As for interfacing between Python and Arduino to export data into a CSV format, I located a relevant example and adapted it to suit the requirements of our project. In the case of the instruction manuals, I used multiple iterations of running the test to help further develop an instruction manual.

What sources did you use to find this information?
For the tasks I primarily used the internet to find any documentation or information helpful for the tasks. For example, we were able to locate a document on the DEXRON VI’s fluid specifications including values for density and viscosity. Assistance by our mentor Dr. Fajardo was also especially helpful. As mentioned previously, I was able to find a similar project allocating data from python into an excel. In addition, I found resources such as the Arduino forum and YouTube to be particularly useful in completing the project.

**Performance Indicator 2**

Describe what additional knowledge/skills you needed to acquire or improve in order to successfully complete the tasks you were assigned in the project.
By using my internship skills, I was able to construct Testing manuals ensuring that the test was going to be repeatable by others who may pick up the project upon our completion. CAD experience in the past had helped me assist on select design questions. Other skills and knowledge from classes were used to help with tasks such as temperature calculations and prototyping.

Through this project I acquired a lot of new skills and knowledge. Specifically, gaining more experience with coding projects and prototyping through testing and the manufacturing of baffles. Most of the projects done in other courses are theoretical designs and never come to life in a prototype, so this was
some of my first exposure to prototypes. Additionally, while manufacturing the baffles, I gained extensive knowledge on 3d printing.

Performance Indicator 3

Describe what approach/process you followed in order to acquire or improve the additional knowledge/skills you needed.

My prototyping knowledge was my largest hurdle for this project. As stated before, prototyping isn’t really built into the education curriculum, so a lot of the process was new to me. By obtaining knowledge from my experienced teammates and faculty mentors, I was able to increase my knowledge of prototyping. Some knowledge was also gained through physical experience during the manufacturing processes of the components. Finally, I maintained a mindset that treated every setback as a valuable lesson that taught me what worked and what did not work. This approach proved to be critical to the successful completion of the project.
Outcome (2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.

Performance Indicators:

5. Generates a detailed statement of all the specified engineering needs for the design project.
6. Identifies and lists potential public health, safety and welfare concerns for consideration in the design process.
7. Identifies and lists global, cultural, social, environmental and economic factors that are relevant to the development of the project product.
8. Produces solutions that satisfy the engineering needs, address the public concerns and consider the effects of the relevant design factors.

(If you copy and paste from the report, mention Section number or page numbers. If any question or item is not relevant to your project, write N/A)

Performance Indicator 1

Describe the engineering needs for this project.

The implementation of an external temperature control system and different baffles will be used to investigate frictional losses due to oil churning for drivetrain applications.

List the project goals along with performance criteria.

The project goals consist of designing and implementing machine improvements, fluid heating system, interchangeable baffles, and testing to quantify the churning losses. The machine improvements will include a safety shield to protect the operator, steel base structure and 3D mounts that will help with misalignment and a better structure. The fluid heating system will be capable of an operating temperature of 100°C, adjustable temperature setting, fluid flow to heat up before entering the gearbox, and a system that will not oxidize. The different baffles will be designed to allow a fluent fluid flow in the gearbox, they will be based off Megan Arduin’s documentation (see references), and O-rings placed to prevent seepage in the baffles. The testing will make sure all the components are working and, in the end, quantify the churning losses.

List the project constraints.

There are two main constraints for the project due to the already existing test machine. The motor and gearbox being used constrain the speed and volume being used for testing.
List the methods/procedures that were implemented to ensure that the customer expectations were addressed.

To ensure that the customer expectations were addressed, the team had weekly meetings with the advisors and gave a presentation with the up-to-date progress on the project to the CAViDS board. The communication between the customer and the team allowed us to not lose sight of our goals for the project.

**Performance Indicator 2**

Describe potential public health, safety, and welfare concerns regarding this project and describe how they were addressed in the final design.

Public health:

The oil will be drained from the bottom to reduce the public’s exposure, where long term exposure can be harmful.

Public safety:

For the public’s safety when running the machine, any mechanical failures will be contained with the enclosure created. An emergency stop was also added as a safety mechanism to shut the whole machine off.

Public welfare:

N/A

**Performance Indicator 3**

List and explain all possible global, cultural, social, environmental, and economic factors relevant to the product of this project.

Global factors:

N/A

Cultural factors:

N/A

Social factors:

N/A
Environmental factors:

For this project the fluid (Oil) will need to be disposed of properly.

Economic factors:

N/A

**Performance Indicator 4**

(To be addressed by the faculty adviser).

Outcome (4) An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental and societal contexts.

**Performance Indicator 2:**

Student is able to make informed judgments based on the impact of engineering solutions in global, economic, environmental and societal context.

Did you adapt your project to make it useful in many countries? Y / N / NA If yes, explain:

N/A

Did you consider standards and regulations, either U.S. or international? Y / N / NA If yes, explain how they affected your project:

Yes, the DEXRON-VI Automatic Transmission Fluid properties were used for initial calculations for the project. Likewise, we looked at the ASTM for the standard testing temperatures of oil.

Did you consider the effects of manufacturing in various locations? Y / N / NA If yes, where in the report did you address this issue?

N/A

Did you have to balance effects of costs and performance? Y / N / NA If yes, explain and refer to the report as appropriate.

Yes, the team had a budget from two undergraduate research scholarships awarded. Some components for the project were based on the cost, such as the in-line heaters and the Controllino. The in-line heaters would be customed instead of buying from a supplier. The Controllino would be a better route with all its open-source software and cheaper than a RoboRIO.
Did you consider effects of maintenance, failure and repair on cost, safety, etc.? Y / N / NA If yes, where in the report did you address them?

Yes, the test machine enclosure allows for easy access of the machine for any maintenance. The enclosure was also created to keep any mechanical failures contained. The consideration of maintenance was in the sub-plate of the in-line heater assembly, the removable 3D printed mounts, and a control panel with all the electrical components that could easily be accessed.

What were your considerations (e.g., cost, weight, manufacturing, availability, safety, recycling, etc.) in the selection of materials? List, explain and refer to the text of the report as appropriate.

The team considered cost, availability, compact, oil-resistant, and high-temperature in the selection of materials. In the report, there are multiple decision matrices to show the considerations for the selection of materials.

Does your project impact air quality, water quality, noise levels, and other environmental aspects? Y / N / NA If yes, explain how and show what were your actions.

N/A

Does your project impact human health during manufacturing or normal use? Y / N / NA If yes, explain what you did to alleviate the risks.

N/A

Are there any other safety issues typical to your project? Y / N / NA If yes, explain your decisions and actions. Refer to the report as appropriate.

For this project the main safety issue comes from the high-speed motor and all the components attached to it. Any mechanical failures would be contained by the safety shield cover as stated in section two of our report.
Outcome (5) An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks and meet objectives

Performance Indicators:

7. Student’s ability to function effectively
8. Student provides task specific leadership.
9. Student creates a collaborative and inclusive environment.
10. Group establishes goals.
11. Group plans tasks

(If you copy and paste from the report, mention Section number or page numbers.)

**Performance Indicators 2 & 5**

List all tasks required to accomplish the goals of this project, and name the group member responsible for the completion of each task.

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**Performance Indicator 1**

*(Project’s adviser will determine whether the listed tasks were completed).*

Answer the following questions:

For project tasks in which I was **not** the leader, I provided the following inputs towards their completion:

- **Task: Temperature Control System**
  - Performed preliminary calculations which helped guide the designs heating element power selection process.

- **Task: Control Panel**
  - Assisted in the assembly of all panel components.
  - Designed and 3D printed the mount for the Power, Enable, and E-stop buttons.

- **Task: Structural and Safety Improvements**
  - Assisted in the manufacturing of all sheet metal components and the assembly of all structural machine components.

- **Task: Coding**
  - Assisted in creating a circuit and using Arduino to work with Python in outputting values into a CSV file.

- **Instruction Manual**
  - I helped review both manuals to ensure that the operator could easily follow the instructions provided.
Performance Indicator 3

For project tasks in which you were the leader, describe the input other group members provided towards the successful completion of these tasks.

- **Task: Baffles**
  - Tyler provided guidance with the baffle design decisions and SolidWorks technical guidance. He also provided two 3D-printers to be used for printing.
  - Matthew helped with sanding down parts, starting prints, and assembling the baffles in the gearbox.
  - Reno helped to assemble the baffles into the gearbox before running the machine for testing.
- **Budgeting**
  - Created an excel sheet with both scholarship budgets with the parts, suppliers, quantities, cost per each unit, total cost to keep track of the money available for the project and for the final cost of our project.

Performance Indicator 4

List all goals this project had to satisfy to be considered successfully completed.

1. Resolve machine rotating shaft misalignment
2. Add safety accommodations for machine operators
3. Add fluid heating system capable of reaching at least 40 degrees Celsius
4. Add a refined volume insert and interchangeable baffle system
5. Validate all machine functions
6. Perform data acquisition and analysis for the quantification of churning losses

Performance Indicator 6

(To be addressed by the faculty adviser)

Outcome (7) An ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

Performance Indicators:

4. Student’s ability to find information relevant to problem solution without guidance.
5. Student’s ability to identify the additional knowledge needed to complete project.
6. Student’s ability to acquire and apply the additional knowledge needed to complete project.
**Performance Indicator 1**

Describe what information you found in order to successfully complete the tasks you were assigned in the project.

To successfully complete the tasks I was assigned, I used Megan Arduin’s master's thesis for the baffles as well as using her references for more information. For the calculations, I used fluid property documentation and looked up other equations as needed.

What sources did you use to find this information?

I used documentation for the fluid in our test machine from the Society of Automotive Engineers J311 documentation and ExxonMobil’s online documentation and used Megan Arduin’s “Gearbox Baffle Optimization” documentation. I also reached out to our advisor Dr. Fajardo-Hansford with Matthew to help guide us with the heating calculations.

**Performance Indicator 2**

Describe what additional knowledge/skills you needed to acquire or improve in order to successfully complete the tasks you were assigned in the project.

For the tasks I was assigned in this project I relied on my internship skills for CAD modeling, as well as understanding how the design would need to be created for the least amount of support to be removed. For the calculations, I relied on heat transfer and other classes I have taken to get the correct equations needed for the project. I also had many purchase orders to do at my internship which allowed me to make an organized sheet with our budget and the purchases we made for the project.

**Performance Indicator 3**

Describe what approach/process you followed in order to acquire or improve the additional knowledge/skills you needed.

In order to enhance my abilities and knowledge required for the tasks at hand, I sought the guidance of my teammates to acquire fresh insights and skills in areas where I lacked proficiency. This involved collaborating with them on using Python in conjunction with the Arduino IDE to generate the results onto a CSV file. During this project, I faced a significant challenge in comprehending the various electrical components necessary for the system. To overcome this, I examined the wiring diagram and closely observed the operations of the control panel to grasp how all the components collaborated in the final product.