Statement of Confidentiality

The complete senior project report was submitted to the project advisor and sponsor. The results of this project are of a confidential nature and will not be published at this time.
Statement of Disclaimer

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ERG Aerospace

Metal Foam Drying Process

by

Ethan Serpa
eserpa@calpoly.edu

Daniel Moore
dmoore06@calpoly.edu

Bryce Zander
bzander@calpoly.edu

Michael Mullen
mpmullen@calpoly.edu

Mechanical Engineering Department
California Polytechnic State University
San Luis Obispo
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Abstract:

ERG Aerospace’s current production has a bottleneck because of their aluminum foam drying process. The current benchmark of three logs per hour is unsatisfactory; the goal is to improve the process by developing a device that dries eight logs in thirty minutes, or a scalable prototype. Some important requirements are that the device is reliable, robust, safe, and compact. A detailed analysis of how ideas were brainstormed and solutions were developed is explained. The explanations for how the solutions were narrowed down and a plan for testing performance of the selected design is also described. The chosen design is a centrifuge with a capacity of eight foam blocks. Plans for manufacturing and testing are included. The team will be tracking the project timeline using a Gantt chart, and specific upcoming steps are detailed along with key project deliverables dates.

Section 1: Introduction

ERG Aerospace produces metal foams for various specialized applications such as heat sinks and filters. They are currently expanding and need to increase their production throughput to keep up with their customer’s demands. ERG Aerospace recognized that the time it took to dry their metal foam after quenching was the main bottleneck of their production process. As a four-person senior project team, the group is confident that the necessary skills and dedication are present to develop a solution to this problem.

Section 2: Background

The task that has been assigned is to develop a process that reduces the time it takes to dry metal foam blocks so that the bottleneck is eliminated. Through meetings it was learned that ERG wants the device to be reliable, cost under $4000 for a scalable prototype, and take up minimal floor space. It is highly desired that the machine can dry the foam blocks with minimal human interaction. They have also requested that the foam not be exposed to temperatures over 180°F as they have found that this compromises the heat treatment and causes the aluminum to stain. Deionized water was not found to be necessary because a later cleaning procedure reduces the impact of staining.
The information for preliminary benchmarking was limited considering the narrow focus of the project. The current method, a small centrifuge device, dries 3 logs in one hour. The centrifuge runs at 350 rpm and has a rotor radius of 9 inches. This is currently supplemented by box fans while the machine is unavailable, which take 10 hours to dry the individual logs.

Currently, there is a relative scarcity of literature on different drying processes for metal foam, so general drying processes were examined. In one report, "Ultralight Metal Foam" by Jiang et al. [1], the primary method discussed is rinsing samples in deionized water and then placing the samples in a drier at 120°C for 30 minutes. Notably, the temperature at which these samples were dried far exceeds the acceptable temperature of the aluminum foam blocks. Also, these samples were only 8mm x 8mm x 30mm and were for experimental use, so maximizing throughput in an industrial context was not a priority. Centrifugal dryers exist for many materials and processes, but none are designed or capable for this specific application [2]. As far as general literary references, the focus is often on different drying methods and water transfer, but does not relate to the specific materials being dried in this application [3]. One effect that will need to be accounted for is viscous fingering; this may present a problem with forced air as a water removal method [4]. It is possible that the addition of surfactants may help to reduce the surface tension of the water in the blocks; this could help in water removal and will merit further testing [5]. The heat transfer properties of some types of metal foam have been studied, but this is not specific to the foam made by ERG and is not applied to drying [6]. No current patents exist regarding metal foam drying processes and there are only very broad, non-specialized industrial driers that are unfit for the client.

Madou et al. investigated general water movement across a centrifuge as modeled by a compact disc [7]. In this paper it is reported that a model developed by Duffy et al. can be used while assuming the exit geometry is round, the water droplets exit as spherical, and that there is no pressure required to wet the chamber outside of the block. To apply this model to a wet log the additional assumption that the radial length of the water samples are roughly the width of the log must be made. Using this model the critical centripetal velocity required to force the water out of the log can be calculated. As can be seen in Appendix D, the calculated centripetal velocity is quite small. This is likely due to the fluid being modeled as a droplet of water exiting a round channel with an air water interface instead of an aluminum water interface. The estimation of the required centripetal velocity...
will be much lower than in realistic application and should be treated as the absolute lowest value to be considered.

**Section 3: Objectives**

ERG Aerospace needs to remove a manufacturing bottleneck. Currently, the cause of this bottleneck is the slow drying time and low capacity of their current water removal system. Water must be quickly removed without temperatures exceeding 180 °F from aluminum foam blocks that are heat-treated and then quenched. ERG needs a working solution that involves minimal human interaction during the drying process while offering high reliability and low maintenance. Figure 1 shows a boundary diagram modeling the limits of the project relative to the current process at ERG. The circled portion is the process that will be designed by the team.

![Figure 1: Boundary diagram showing current basic drying process and operator](image)

A list of needs and wants was generated based on the initial presentation and subsequent meetings with ERG Aerospace. It was found that the needs of this project are as follows: the logs are completely dry, temperatures do not exceed 180°F, loads on the logs do not exceed 200 psi, the machine is safe and reliable, and at minimum, a scalable prototype is delivered by June. Some of the important wants are that 8 logs can be dried in 30 minutes, additional logs can be introduced to the drying process at any time, and that different shapes of logs can be dried using the same machine. The full needs and wants have been condensed into an engineering specifications table in Table 1.
A QFD (Quality Function Deployment) House of Quality, seen in Appendix A, was generated using weighted customer needs and wants to reach measurable engineering specifications. The benchmarks currently in place at ERG were compared and given data corresponding to the engineering requirements for the project. The specifications that were found to be most important were total capacity, run time, noise, and ergonomics.

Table 1. Engineering Specifications Table.

<table>
<thead>
<tr>
<th>Spec. #</th>
<th>Parameter Description</th>
<th>Requirement or Target (units)</th>
<th>Tolerance</th>
<th>Risk</th>
<th>Compliance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Production Cost</td>
<td>$4,000</td>
<td>Max.</td>
<td>M</td>
<td>A</td>
</tr>
<tr>
<td>2</td>
<td>Noise</td>
<td>85 dB</td>
<td>Max.</td>
<td>M</td>
<td>T, I</td>
</tr>
<tr>
<td>3</td>
<td>Capacity</td>
<td>8 logs</td>
<td>Min.</td>
<td>H</td>
<td>A, I, S</td>
</tr>
<tr>
<td>4</td>
<td>Floor Space</td>
<td>8 ft x 10 ft</td>
<td>Max.</td>
<td>L</td>
<td>A, I</td>
</tr>
<tr>
<td>5</td>
<td>Pressure on logs</td>
<td>200 psi</td>
<td>Max.</td>
<td>M</td>
<td>T, A</td>
</tr>
<tr>
<td>6</td>
<td>Power Usage</td>
<td>100 kW*hr</td>
<td>Max.</td>
<td>L</td>
<td>A</td>
</tr>
<tr>
<td>7</td>
<td>Drying Time</td>
<td>30 min</td>
<td>Max.</td>
<td>H</td>
<td>T</td>
</tr>
<tr>
<td>8</td>
<td>Log temperature</td>
<td>180 °F</td>
<td>Max.</td>
<td>M</td>
<td>T, I</td>
</tr>
</tbody>
</table>

1. Production cost will be tracked by documenting the cost of individual components and assembly costs.

2. Noise levels will be tested using a sound level meter.

3. Capacity will be measured by comparing the given dimensions of the logs with the capacity of the designed storage space.

4. Floor space will be kept within the requirements by designing it to fit target size and measure final machine dimensions. This will likely include access area.
5. The maximum expected pressure on the logs will be calculated by modeling their sides as a solid surface and performing rigid body dynamics analysis on the system. Additional data will be collected after the logs are tested on a prototype to ensure that no deformities occur.

6. Power usage will be tracked by documenting the given power usage of the components.

7. Drying time will be tested on scalable prototypes.

8. The temperature of the log will be restricted to not exceed 180°F by measuring the temperature within the drying apparatus.

The specifications listed as high risk are capacity and drying time. It possible but undesirable that a design significantly improving on the current benchmarks could still fail to dry 8 logs in 30 minutes.

**Section 4: Concept Design Development**

The team had three major ideation sessions where possible solutions to the problem were explored. The first meeting was focused on brainstorming water removal methods in general. The second session of ideation had an emphasis on methods of testing water removal methods. The third and final session was specific to possible variations on the centrifuge or forced air ideas; various methods of combining these with other drying modes were discussed. After the ideation meetings the team discussed the feasibility of the different solutions to hone in on the best ideas. The standout ideas from the ideation sessions were spinning the blocks, vibrating the blocks, heating the blocks, exposing the blocks to high pressure airflow, combining multiple solutions into one conveyor belt system, and using an alternative quenching method. An image of the solutions generated from the first large ideation session can be found in Figure 2.
The six main solutions were then further expanded so that they could be realistically benchmarked and compared to the current solution utilized by ERG Aerospace. During this phase it was found that ERG Aerospace does not currently wish to change their quenching process, so alternative quenching was removed from the solutions list. Using a Pugh matrix, the solutions were compared with the current operation used as the datum point. After the first Pugh matrix the conveyor system and vibration mechanism were eliminated as realistic solutions. Further analysis of the results of the first Pugh matrix led to the creation of an additional idea, combining a traditional centrifuge with forced air. This second Pugh matrix was developed to further cross-reference ideas and compare the remaining solutions. This matrix showed that a heated vacuum was the best solution followed by the centrifuge and forced air. After discussing the feasibility of implementing a heated vacuum with a Cal Poly professor in the chemistry department; it was determined that the vacuum would not have reliable throughput to be implemented for such a critical component of business. As a result of the cross-referenced matrices, the group decided to focus on centripetal and forced air solutions. Due to new information about the pressure drop across the blocks, the centrifuge model became the preferred option.
Preliminary analysis with forced air on the coupon samples has proved it is an efficient method for removing water, however after testing the method on full-size blocks it was found that the pressure drop was not reliable and setting up a system based on this method was deemed to be impractical. The concept prototype shown in Figure 3 was assembled to demonstrate the spinning capabilities of a centrifuge, the idea of closing the chamber (left open so that the inside can be seen) and the possibility of adding forced air to the system. The only material used for this prototype was wood, simply to give ERG an idea of the solution being proposed.

![Figure 3. Concept prototype w/ a cut view to demonstrate spinning center.](image)

For the concepts at the PDR stage, a labeled solid model that conveys the centrifuge chamber design was developed, along with a solid model of the possible forced air solution. These annotated models can be seen in Figures 4 and 5. The blocks would be loaded through an access door and the machine will only be able to run when the door is sealed for safety. The capacity of the current chamber for
both methods fits eight blocks, and the door has different positions depending on the method of drying.

Figure 4. Preliminary centrifuge solid model, with main components labeled

The goal of the proposed solution is to dry at least eight blocks in thirty minutes. The centrifuge will remove the water by spinning the wet logs and forcing the water out with centripetal forces. ERG Aerospace is currently utilizing a centrifuge, so it is a known working solution but not currently meet throughput standards.

One risk associated with a spinning device is potential damage to the blocks. This will ideally be resolved by proper fixturing of the blocks and analysis of the dynamic stresses due to rotation, along with dynamic impact calculations for a safe chamber strength.
The forced air modifications would blow compressed air on the wet logs to force the water out. ERG Aerospace has confirmed this method works, but that there is a potential issue with pressure drop through the porous, large logs. A centrifuge combined with forced air would remove the water through a combination of centripetal forces and compressed air. This would have certainly resulted in a more complicated apparatus but could have led to greater throughput than each of the processes could individually accomplish.

Due to the variety of concerns with compressed air related to viscous fingering, the large pressure drop, and concerns about the noise level, the compressed air method was rejected in favor of a pure centrifugal water removal model. Since the centrifugal model was already proven to work, an improved centrifuge is guaranteed to improve throughput by improving on the speed, size, and capacity of the existing process at ERG.

Due to ease of manufacturing, the octagonal housing shown in the preliminary CAD models was replaced by a square housing constructed from welded tubing and sheet metal. The centrifuge skeleton from early CAD models was replaced by 2 hoops with 4 spokes each, connected vertically.
by block fixtures. Additionally, an inclined drainage plate was added to direct the water out of the housing.

Section 5: Final Design

Design at CDR

The group decided to use the large centrifuge as the final design for this project. The centrifuge mechanism will spin with a central shaft that receives power from a motor. The motor will be connected to the shaft by a belt and pulley system, and the motor will spin at approximately 1200 rpm, controlled by a variable frequency drive with speed control which will be stepped down to approximately 580-600 rpm by the pulley ratio. The motor specifications were determined using rotational inertia calculations on SolidWorks and by hand to determine the torque required to move the large centrifuge chamber at the desired speed of 600 RPM and a time-to-speed of 90 seconds. With a required torque of approximately 60 lb.-in, the current selected motor provides startup torque with a factor of safety of 4 with the pulley ratio, along with 86% efficiency. Therefore, the centrifuge will get up to 600 RPM much faster than 90 seconds. This 1 HP, 3-phase, inverter rated motor is also sized appropriately with the selected VFD’s specifications. The centrifuge mechanism will be housed in a square structure built out of 1”x1” square steel tubing with internal aluminum plating to prevent water from causing the outer steel plating to rust. The motor assembly will be secured to the top of the housing.
The designed centrifuge will have a larger radius of 17.5” and much greater rotational speed than the current centrifuge utilized by ERG Aerospace, and this increase in the force exerted on the blocks will result in a faster drying time. A large safety concern that the group addressed early is the possibility of mass ejecting from the centrifuge during operation. To prevent injury in the case of an unanticipated kinetic event, steel plating hereafter declared as a missile shield was added to the outside of the centrifuge housing. The missile shield was sized by comparing the minimum yield strength of the material with three times the anticipated maximum force that a wet block could exert over an impact area of .02 inches. Currently the material thickness results in a factor of safety of approximately 2 under these conditions.
Since the missile shield will be made of steel and the purpose of this centrifuge is to remove water, rusting is a concern. To address this, aluminum splash plates will be fixed to the inner walls of the steel tubing in order to prevent water from reaching the missile shield during the spinning process. While the missile shield will be welded into place, the splash plates will be secured in place with sheet metal screws.

The most challenging concern to safety is damping the vibrations that will occur from potential imbalances in the centrifuge. To address this the group is securing the shaft to the frame with customized rubber dampers. The specific dampers have not been purchased, but drawings have been created in Appendix G to illuminate the intended design prior to the testing on the group’s rotor kit. The rotor testing and corresponding calculations will identify what type of rubber dampers are required to properly damp the system and prevent failure due to vibrations. This testing will provide required spring constants for the bushings to size and specify them for future use.

Large noise levels will likely occur during machine operation. To minimize operator exposure to this noise the group will be placing acoustic damping material in the inch of space between the
missile shield and splash plates. While this will not completely eliminate the noise, it will reduce it and increase operator and shop comfort as a result.

As this is a relatively large piece of rotating machinery it is of great importance to the group that measures are taken to prevent incidental user injury. The first stage of protection in place will be a reed switch connected to the access door. While the door is open, the VFD will sever the current to the motor which will prevent premature centrifuge start up during loading or unloading. There will also be a large LED attached to the VFD housing, and when it is running it will be flashing red. From a mechanical perspective, there will also be a toggle clamp attached to the lid preventing the access door from opening unless manually unlocked. The operator and shop floor will be responsible for making sound judgement choices and not purposely opening the clamp while it is running. ERG has approved the current safety measures.

Maintenance will be needed whether it be repairing a block holder, replacing a bearing, or general cleaning. To allow for this the top cross-member support and top plate will be secured in place using fasteners. This will allow the centrifuge mechanism to be completely removed from the housing so that the entire centrifuge assembly can be maintained. The frame, missile shield, and lower cross-member support are not included in the previous list because they are welded to one another. This allows them to be cleaned when the centrifuge is disassembled, but it does not allow for individual pieces to be replaced.

For details on the in-depth cost analysis of the current centrifuge design see the Indented Bill of Materials in Appendix I. This bill of materials includes assembly features and a breakdown of manufacturing, along with part vendors, quantity, and cost. As of now, the current budget with minor over-estimations and a “slush fund,” (amounted at 10% of the total expected cost) is $4238.69.
Changes for Final Design

After CDR, the machine was 90 degrees as shown in the figure below. This design change was made so that the imbalance forces would be exerted in a vertical direction and damping could be achieved through the use of ground damping mounts.

![Figure 8. New orientation of machine following design change.](image)

The most distinct change is the vibration isolation; the whole system is now allowed to vibrate but damped at the feet instead of isolating the vibration at the shaft. Ideally there would be the funds and time to cost, prototype, and test multiple durometers of custom rubber for the bearing housings. With the timeline and budget, it was determined to be impractical to design reliable damped bearing housings. Instead, pre-designed vibration mounts at the feet will be used and bolted to the floor, eliminating the risk of the machine “walking,” away under large imbalances. The vibration isolators shown in figure 9, are integrated spring dampers with a natural frequency of between 3.5 Hz and 4.9 Hz depending on the loading. Since our system operates at 10 Hz we should be well into the vibration isolation range which occurs at above the natural frequency times the square root of two. In our case we achieve vibration isolation above 6.9 Hz. Since vibration isolators with the desired spring stiffness weren’t available, we chose vibration isolators with a lighter spring
then nested springs in parallel underneath the vibration isolators to raise the effective spring stiffness.

Figure 9. Vibration isolation feet.

Since the machine was rotated this means that the door to access the inside of the machine and load/unload the blocks was moved to the side of the machine from the top where it was previously located. The motor mounting scheme was also changed since it was decided to remove the auto tensioner from the design. To make up for the lack of an auto-tensioner slots were cut into the frame where the motor mounts so that the tensions can be manually applied to the belt. Finally we found that 1-1/4” square steel tubing provided better support for the centrifuge and changed all the frame tubing to this size. This change resulted in slightly larger outer dimensions of the frame but visually looks the same as the previous material.

Section 6: Manufacturing Plan

Outsourced Parts

The centrifuge hoops were outsourced to a specialty machine shop in Paso Robles called Waterjet Central, and made to the specifications in the drawing of the part. Compression hubs were ordered from Fenner Drives as described below. All of the hardware including motor, motor pulley, shaft pulley, v-belt, bearings, seals, and bolts will be ordered from McMaster-Carr, while their part numbers are called out in their respective drawings.
Frame Tube Cutting and Base Square

The frame will be made of 1-1/4”x1-1/4” square steel tubing along with a small amount of 1”x2” square tubing. The purchased tubing will be cut to length and left square at the ends. There are a total of eight pieces of tubing that should be cut to 38 inches, four pieces of tubing cut to 30 inches, and four pieces of tubing cut to 21.7 inches.

The 38 inch and 30 inch lengths of tubing will now be welded together to form the basic structure of the centrifuge. Begin by welding the end face of one of the 38 inch tubes to the base of one of the side faces of a 30 inch tube. The resulting shape will look like an “L” with a 30 inch side and a 38 inch side that meet at the base. Ensure that the flat sides of both tubes are aligned with one another. Repeat this welding process on the other end of the 38 inch tube. The tube will now be shaped like a “U” with two 30 inch sides and one 38 inch base. Ensure that the flats of the tubes are aligned. Line up a 38 inch tube at the top of the U shape so that it mirrors the other 38 inch tube. After verifying that the flats of all the tubes are aligned, weld this 38 inch tube into place. The resulting shape will be a flat rectangle with two 38 inch sides and two 30 inch sides. Repeat the above steps to produce one more rectangle for a total of two rectangles.

Stand both rectangles up and secure them in place so that one of the 38 inch sides is at the base and the 30 inch sides make up the height. They should both be 30 inches tall at this point. Line up one 38 inch tube so that its end faces are perpendicular to the bottom side faces of two opposing 30 inch tubes. Verify that the flats of the tubes are aligned and weld the 38 inch tube in place. Repeat this step for the other edge of the base. The two rectangles should not be fixed in place 38 inches away from one another by the two 38 inch tubes. Carefully rotate the assembly so that the newly welded 38 inch tubes are facing upwards. As before, locate a 38 inch tube between the two base faces of the 30 inch tubes. Ensure that the flats of the tubes are aligned and then weld the 38 inch tube in place. Repeat this for the other edge of the base.
Cross Member Supports

Once the frame is in place 6”x6” 10 gauge steel sheet need to welded inside the front and back faces to support the cross member support that will be added in the following construction steps. Make the eight steel supports by cutting 6”x6” squares out of 10 gauge sheet metal, then in one corner of each piece cut out a 1-1/4”x1-1/4” square section. This cut out allows the support to sit flush with one of the pieces of tubing used in the frame. Locate one 6”x6” cut out on the inside of one of the 36” steel tubes such that the top of the cut out sits flush with the bottom of the tube. Line up the 1-1/4” notch in the cutout such that it fits onto the edge of one of the 30” pieces of tubing. Before welding the cutout in to place refer to the picture below to ensure that it is properly located. When satisfied with its location weld it into place. Repeat this process for the 7 remaining cut outs, when done the frame will now look like the model in the figure below.
Figure 11: Frame with the cross member supporting squares in place.

Cross Member Construction

The 1”x2” tubing should be cut into eight pieces that are 8 inches long each. These small sections of tubing will need to be cut to form into two separate squares. Begin forming the square by cutting the ends at a 45 degree angle so that the length of the angled edge is 2.83 inches. Repeat these cuts on each of the 1”x2” tubes. Once all the cuts are done, weld the 1”x2” tubes together by their 2.3 inch faces so that a square is formed. See the figure below to ensure that the alignment is correct.

Figure 12: Tubing arranged into square, forming center of cross member.
The square will have four flat edges that the 22.87 inch tube will be welded to. Before welding the 22.87 inch tubing, make two 45 degree cuts of 0.71 inches each so that one end of the tube terminates in a point. The 22.87 inch tube must have one of its end faces welded to the 1 inch angled flat edges of the square. This will result in an “x” shape with a square in the middle. The top and bottom surfaces of this “x” must be flat relative to the top and bottom surfaces of the inner square. This whole process will result in the creation of two “x-members”. When finished with this step the x-member will look as it does in the figure below.

![Figure 13. Single x-member with tubing connected to the center square.](image)

Take one of the base squares and fit the x-member inside of it such that the angled cuts of the x-member fit into the inner corners of the base square. Once the cross members are in place, drill a hole through the end of each leg of the x-member such that it goes through the entirety of the x-member and all the way through the cross member support in the corner. A top down view of this step is shown in the figure below.
Figure 14. Hole cut through the cross member and support.

Vibration Isolation Feet

While the vibration isolation feet themselves are purchased, manufacturing is required to integrate the damping onto the frame. …..

Splash Plates

Now that the skeleton is formed, begin constructing the splash plates. They will be made from 24 gauge galvanized steel and placed on the inner walls of the machine. Begin by cutting each sheet into 38”x30” rectangles. Then in each corner of the rectangle make a cut that goes 4.75 inches in from the 38 inch side and 1.38 inches in from the 30 inch side. These cutouts are made in order to facilitate the corner plates. See the below figure for clarification on these cuts.
Once the cuts are made position one of the splash plates on the inside face of the machine, secure it in place so that it can be drilled into. Select an appropriately sized corrosion resistant machine screw to secure the splash shields in place. Drill an appropriately sized hole so that the machine screw can be screwed into place and hold the splash shield in place. Secure each splash shield with three screws on each of the 30 inch sides. When this process is completed it will look like the figure below.
Bearing Housing Blocks

Both of the Bearing housing blocks on each side are identical. The original stock size for each housing is a 6-1/4”x 6-1/4” block of A36 steel, 2 inches thick. The final shape of the bearing housing will be CNC machined. Each bearing inner race and two lip seals press fit into the housing, so tolerances and concentricity of these features are important. The first operation machines the top shown in figure 17 includes facing and squaring the stock, then clearing out the pockets on each corner for the bolt holes.
Each bolt hole is a $\frac{1}{2}''$ through hole to provide a tight fit clearance. A center hole is drilled through the whole block. This hole will be used as the origin point for the operation on the other side of the block to maintain concentricity between the two blocks. After drilling all holes the surface for the outer lip seal will be bored to a diameter of 1.499 inches. Flipping the block over, the second operation will be performed on the bottom as shown in Figure 18.
First the surface will be faced then each step will be bored out. The first step down with a diameter of 2.623 inches, locates the inner lip seal. The next step provides clearance for the shaft so that if shimming is necessary the shaft surface still seals on the inner lip seal. The chamfer down to the next step helps locate the bearing outer race for the press fit. This diameter is 1.9785 inches which provides a .0015 interference fit with the inner race. The step after, is a small clearance space to ensure the tapered rollers will not clash with the bearing housing once the bearing is fully seated in the housing. These bearing housings are bolted on to the x-frames after the entire machine is assembled and connect the shaft and rotating assembly to the frame.

Main Shaft

The shaft stock is 4ft long and 2 inches diameter, made of 1045 steel which has been turned, ground, and polished. The stock size is first cut on a horizontal band saw to 41 inches in length. Then a large lathe is used to secure one side with 3 inches of stick-out. Extra care must be taken to ensure the shaft is centered on the lathe and axially aligned. On the shaft drawing in the drawing

Figure 19. Manufacturing of drive shaft in BRAE shop.
package, the left side was turned first. The first operation was to face off the end and shorten the overall length by .200 inches. Then the diameter was turned down using successive passes of .1 inches off the diameter with an rpm of 700 and feed of .0092 inches per rev. After turning down the first side, the shaft is flipped in the chuck and the pulley side of the shaft can be machined. Since the required stick-out is large ~8 inches a live end should be used. This requires the end of the shaft to be faced off and then center drilled. With a tail stock and live end, the shaft tolerances will be much tighter. Similar speeds and feeds to the previous operation should be used; however, once the diameter decreases to <1 inch, the speed should be increased to 1200 rpm for a better surface finish. After turning down the diameter on each side a chamfer is added to the 1.0012 inch step to help center the bearing when press-fitting it on. After turning, the end with a diameter of .75 is placed in the vice on a mill and a 5/16 end mill cuts a slot approximately 5 inches long at a depth of 5/32 inches. After polishing and deburring the shaft machining is finished.

Block Fixture and Hoops

For the block fixture assembly, it is first necessary to use a waterjet cutter on two 3’x3’ 1/2” thick steel plate to create the hoop geometry, shown in Figure 20.

Figure 20. Waterjet geometry for the fixture hoops.
Next, cut the 1”x1”x1/8” angle iron into 16 20” lengths. Use a #30 drill bit to drill holes at 10” and 10.25” on 8 of the angle iron pieces, then drill holes at 9.75” and 10” on the remaining 8 pieces. Deburr the cut ends and holes. Next, set up a TIG welder for 1/8” steel. Using 2 squares, align the inside of the angle irons vertically along the square edges on the waterjet hoops so that the holes are along the radial edge and 10” and 10.25” respectively from the hoop surface. Tack weld all 16 pieces in place. Next, use the compression hubs (Figure 21) to connect the second hoop on top of the angle irons.

Figure 21. B-LOC 2” M5x40 compression hubs.

If necessary, bend the welds so that the inside of the angle iron pieces again aligns with the squared edges of the hoops as shown in Appendix G. Tack weld the angle irons into position on the second plate. Once the angle irons are tacked on both ends, verify that they are aligned correctly. Once this is done, fillet weld both outside faces of each angle iron to each plate. Then loosen and remove the compression hubs and shaft carefully. Next, cut 9” lengths of 1/8” x 1.5” steel bar stock. Fillet weld the ends of this stock to the outside of the top hoop so that it extends 1” across the squared area. When this is done, the assembly should look similar to Figure 22.
Next, cut 8 1” lengths of 1/4”-20 threaded steel stock. Deburr the edges and tack weld these to the center of each center ring bar on the outside of the bottom hoop. After this, it is possible to paint the assembly. Using rust and abrasion resistant paint, paint all surface of the assembly, taking extra care to coat the inside edges of the angle iron. Once the assembly is painted, use a sheet metal shear to cut 8 2” by 18.5” pieces of 16 gauge galvanized sheet. Drill 2 holes 0.7” on each end of the sheet metal parts using a #30 drill bit, one at 1” from the edge and one at 1.25” from the edge. Use a sheet metal break to bend each piece up at a distance of 5.5” from each end. Next, use #43 blind rivets to fasten the sheet metal parts to the holes in the angle iron as shown in Appendix G. Make sure that the flat rivet head is on the inside of the angle iron to prevent excessive interference with the blocks. Now cut 8 2”x 6” rectangles out of 1/2” thick polypropylene sheet using a band saw or table saw. Carefully deburr the edges. Drill a 1/4” hole at a distance of 1/2” from the end of the plastic parts as shown. Use a 1/2” chamfer tool on one side of this hole. Next, slide the plastic parts over the welded studs on the front hoop with the chamfer side towards the hoop. Use 1/4”-20 wing nuts to tighten down the polypropylene parts against the hoop surface. The resulting assembly should look like Figure 23.
Figure 23. Hoop fixture subassembly.
Centrifuge Shaft Assembly

To assemble the rotating assembly begin by pressing the tapered roller bearings onto the main shaft. Position the shaft in a secure manner under a press and carefully line up the bearing so that it will be pressed onto the shaft in the proper orientation. Ensure that the skinnier side of the bearing is facing outwards. Apply pressure only to the bearing using the press to begin to press the bearing into place. Continue to press the bearing into place until it is just above the base of the shaft step it is being pressed onto. Repeat this for the bearing on the other side of the shaft.

Once the bearings are both in place attach the compression hubs to the block and hoop fixture assembly. Keep both compression hubs loose and slide the shaft through them, tighten the hubs. You will now have the shaft connected to the block and hoop fixture assembly, now referred to as the shaft assembly. The configuration should now look like the figure below.

![Figure 24. Shaft with bearings secured to the block and hoop fixture assembly.](image)

You must now attach the bearing housing blocks to the frame. Begin by centering one of the blocks over the x-member center square as best as possible. Mark where to drill holes for ½-13 bolts and then drill the holes. Secure the bearing block to the frame. Insert the laser alignment plug inside the first bearing block and place the laser bore light inside the tube. Then insert the laser aligning target plug in the second bearing housing. Line up the second bearing housing on the outside of the x-member center square on the opposite side of the frame. Carefully line up the second bearing housing so that it is as in line as possible with the first bearing housing with the laser dot right in the
center of the target dot on the second bearing housing. Mark where to drill holes for \(\frac{1}{2}-13\) bolts and then drill the holes. Do not secure the bearing block to the x-member at this point in time. Remove one of the x-members and carefully slide the shaft assembly into place such that the tapered roller bearing is fully engaged in the bearing housing block that is still in place. Keep the shaft assembly support and secure the other x-member to the frame. Line up the final bearing housing block with the holes that were drilled for it. Slide the bearing block over the tapered roller bearing and secure it in place. It might be necessary to shim the bearing housing block in order for it to be secured in place. After completing this step the machine will look similar to the figure below. Note that the below figure has all its shielding removed to better illustrate what the assembly looks like.

![Image of shaft assembly in the machine with the shielding hidden from view.](image)

**Figure 25.** Shaft assembly in the machine with the shielding hidden from view.

**Sound Damping Material**

Add the 5/8 inch thick sound damping material to the outside of the splash plates. Cut the material into four separate 27.5”x38” rectangular sections. Place one section on the outside of a splash plate such that it sits within the 1 inch gap between the splash plate and the outer edge of the frame. Secure the sound damping material with adhesive that does not damage the sound damping material or the aluminum. Repeat this for the other three rectangular sections. Ensure that each of the four splash plates has sound damping material on the outside of it. To create the sound damping for the front and rear panels cut the sound damping material as shown in the figure below. Cut out eight of
these. When placing the sound shielding in the access door cut the sound shield as necessary to allow for the access door to open and close. Ensure that you do no throw out this cut shielding as it is used to dampen sound for the access door.

Figure 26. Layout of sound shielding for the front and rear panels.

Missile Shield

For this step the shield will be made and attached to the frame. Purchase enough 10 gauge steel to create four separate 30”x40” rectangular sections. These rectangular sections are the missile shields. With the frame resting right side up, set one of the plates against the side wall of the frame. Line up the top and bottom of the missile shield with the top and bottom edges of the frame. Then line up the right and left edges of the missile shield with the left and right edge of the frame. If properly sized then the missile shield will perfectly cover one side of the frame and completely enclose the splash plate and sound damping material. Secure the missile shield in place once it is lined up, be careful as the missile shields are heavy. After securing the missile shield it must be welded in place.
Repeat these steps for the other three missile shields. Once done only the front and rear faces of the machine will be uncovered. Refer to the figure below if unsure on the orientation of the missile shielding material.

![Figure 27](image.png)

Figure 27. Missile shield attached to the frame in the proper position.

**Vibration Isolating Feet**

The feet will all be located on the outer edge of one of the missile shields. It is not important which missile shield is chosen as long as all the feet are attached to the same face of the shield. The selected side will become the bottom of the entire assembly and hereafter referred to as the bottom base square while the opposite base square will referred to as the top base square.

After selecting a side to attach the feet to, begin fabricating the feet from 1-1/4”x1-1/4” steel tubing. Cut four 1 inch long section of the tubing to make four separate feet. It is not critical that they are all exactly the same length as an adjustable foot mount will be fitted to them for final leveling, but the closer they are in length the better. Locate one of the feet at the corner of the bottom base square so that it lines up with the 38 inch tubing. Once the foot is correctly located, weld it in place. Repeat this for the other three feet at the other three corners of the bottom base plate. The end result will be a foot tube at each of the four corners of the bottom base plate. In the below figure the feet are properly located.
Now the foot block must be made. Beginning by cutting four 1.5 inch sections from a 1”x1” steel billet. Face each of the billet sections down so that it is .83”x.83”. Do not reduce the billet length to less than 1.5 inches in this step. Drill a 1 inch deep hole using a 27/64” drill bit at the center of the billets 1”x1” face. Tap ½-13 threads into the hole. Repeat this process for all four of the foot blocks.

Four heavy duty vibration damping mounts will be purchased from novibes.com. Thread these mounts into each of the four foot blocks. Then place the blocks inside of the foot tubes that are attached to the bottom base square. Adjust the height of the damping mounts until the frame rests as level as possible. While the final assembly can also be leveled through these same means it is recommended that the leveling be done as best as possible at this phase since the frame is as light as it can be.
Figure 29. Image of foot assembly properly attached to bottom of frame.

Drain Hole

Now that the missile shields have been welded into place it is time to cut the drain hole. On the bottom face of the machine, the face that has the feet placed on it, drill a small hole in the middle of the splash plate that goes all the way through both the sound damping material and the missile shield. Select an appropriately sized bolt so that it can be placed through this hole and fixed to a nut on the other side. Place a washer under the head of the screw and under the nut. Tighten down the bolt and nut so that the splash plate is pulled down to a low point in that location. Drill a second hole close to the bolt and make it large enough to fit the selected tubing. This hole is what the water will actually drain through. Place the tubing in the tubing hole and caulk around its edge so water does not seep into the sound damping material. Add caulkking around the bolt so that water cannot seep into the sound damping material through its hole. The below figure is a picture of what the bolt looks like while in the proper location. Note that the machine is upside down in this figure.
Motor Drive System

Now that the missile shield is attached, the motor will fastened to the mounting plate on the missile shield. There will be a requirement to have a means of marking the missile shield to locate drill locations for this step. Begin by locating the 1/8” mounting plate that is manufactured from its respective drawing to the outer frame. Once the top of the plate is extruding over the top of the frame and parallel to the surface, mark the locations. This plate will need to be stitch welded into place to support the dampers and mounting for the motor. Locate the main shaft of the motor so that it is aligned with the main shaft of the centrifuge, which should look similar to below:
Figure 31. Motor mounted on machine with mounting plate.

Make sure that the motor pulley is at the same height as the shaft pulley, which will be approximately 4 inches from the top lid and be located with a setscrew and key onto the main shaft, with its location fixed. Once both conditions have been met, mark the missile shield through the motor mounting plate. After the motor mounting plate is welded to the frame and slotted to provide the required tension for the belt, secure each damper on the inside of the frame with a nylock nut. The motor mounting plate model is shown below.

Once the vibration isolation dampers are secured to the frame put the motor on the threads of the damper that are outside of the missile shield. Secure the motor in place with nylock nuts, and then proceed to wire the motor leads to the VFD controller, and the VFD to an appropriate 240V 3PH outlet.
Front and Rear Lids

Begin shaping the lid from a piece of 16-gauge sheet metal that is 40.75”x40.75”. If the sheet metal is larger than this, cut it down to size. In only one of the sheets cut an access door, a recommended shape is shown in the figure below but as long as an operator can reach place and retrieve block the shape is not paramount. Do not discard the cut out piece of sheet metal since it will be used as the access door for the centrifuge. One more cut must be made to the sheets before they can be attached to the frame. A 6.5” x 6.5” square cut with its center 20 inches away from the 40-inch long sides will be made in the sheet metal. This cut allows the bearing blocks to fit through the panel, it is important that the cuts are not too large as water could get through them. Line up the cut out access door piece with the sheet it was cut from, secure the two pieces together with surface mount hinges that allow the door to open. Be sure that the access door can actually rotate on the hinges. If the door does not open check to make sure that the edges of the access door don’t overlap with the lid. If there is no overlap and the access door still does not swing check to make sure that the hinges both open in the same direction and are mounted on the same side of both the lid and the access door. Once it has been verified that the access door can open it is time to install the lid onto the frame. Line up the lid so that it covers the entire front of the frame and the access door opens downwards, additionally ensure that the internal splash plate and sound shielding is in place. Use sheet metal screws to secure the edges of the lid into the frame. Do not screw the access door into the frame as it will not be able to open if screwed in place. Once the access door opens properly, attach the toggle clamp on either side of the lid, in line with one of the access door’s edges. Secure this toggle clamp with four sheet metal screws, and this will act as a mechanical safety and indication the machine is running. The other 40.75”x40.75” sheet will be secured to the back. Cut out a 6.5”x6.5” square hole in the middle to accommodate the bearing block. Line up the sheet so that it completely covers the rear of the machine, ensure that the internal splash plate and sound shielding are in place, and use machine screws to secure it in place. The figure below shows how the front and rear lids should look after being installed.
V-Belt and Cover

Once the main shaft pulley and motor pulley are in place the v-belt can then be attached to provide the required power transmission. Simply place this belt around the main pulley and motor pulley. According to Bando V-Belt tensioning guidelines, the belt does not start with a tension force of at least 3.6 lbs. it will not run ideally, so verify with a tensioning gauge that the motor is mounted in a properly tensioned location. Once the entire motor drive assembly is in place and running smoothly, a sheet metal cover will need to be developed. From the large stock of sheet metal, reference the appropriate drawing and note that it is 32” long, and approximately 12” wide, with 5.5” of height clearance. The cover can be bent with the bend instructions into proper shape and secured with sheet metal screws.
The location of these sheet metal screws is not important, the only requirement is that they prevent the cover from moving drastically enough to hit any of the motor drive components. The cover has been sized appropriately to provide clearance on every side and with enough height for the main shaft and will block any hands from interacting with the motor, pulleys, or belt while in operation.
Section 7: Design Verification Plan

The first parameter to be established is the range of weights for the aluminum blocks before and after drying. With current data from ERG Aerospace, the logs weigh 15-19 pounds immediately after quenching. After initial draining, the blocks are approximately 8-9 pounds, and then fed into the “water extractor.” When the blocks are fully dry, depending on porosity, they weigh between 6.5 and 7.5 pounds. These weights are critical for determining the amount of rotor imbalance possible and for determining dynamic and static loads on the centrifuge. The current data is based on a smaller sample size, and the team is expecting a larger distribution of masses to appropriately model the system. The procedure should involve weighing blocks on a floor (or higher precision if possible) scale after immersing them in water for several minutes. This weight can be compared to the dry weight, which will help establish further variations of weight. ERG is expecting to deliver more data after their next few quenching processes.
To ensure proper bearing life, a bearing temperature of less than 210 °F must be maintained. Since the bearings are relatively inexpensive and temperature is a function of load, airflow and many other variables, the bearing temperature will be measured on the final assembly. The final centrifuge will run several cycles under a heavy imbalance. Then the retaining ring in the lower bearing housing will be removed, the lower bearing will slide out, and the bearing temperature will be measured with an IR thermometer to ensure it is under 210°F.

A specification that the team needs to know before final delivery is the noise output. By using a sound level reader and measuring the dB output from the machine running at full speed and operation capacity once the final prototype is built, it can be determined whether or not additional insulation/noise cancelling additions are required. If the sound levels appear to be over 85 dB average during an eight-hour shift, appropriate sound-proofing will be considered. This test will be performed before the blast shield plates are welded in place on the frame. This allows the sound damping material to be tested and changed if necessary.

Drying rate testing is helpful to establish a better model for how changes in rotational speed and radius of rotation effect water removal rate. A spare motor will be used to spin a foam sample at a rotational speed different from the 350 RPM currently in place at ERG. By comparing the resulting drying rate with the current drying performance at ERG, it should be possible to better model the effects of varied parameters on drying rate. Once the final prototype is assembled, the VFD control on the motor can very accurately set the rotational speed of the motor and testing can begin based on the preliminary testing mentioned above. By finding an optimal drying rate and not running the machine too quickly, the life of bearings and structural components will be maintained.

Another possible variation to drying procedure is the introduction of a surfactant to the water in the quenching basin. To test the effects of surfactants on water removal rate, a second trial for each speed can be performed during drying rate testing, allowing a comparison between drying with or without surfactants. Surfactants would simply be added to the tap water that quench blocks, and if enough time is available, different concentrations or different surfactants could be introduced for further runs.
It is also important to test the housing material to verify that it is strong enough to safely enclose the centrifuge. Pressurized air will be used to propel one of the small foam samples at a piece of plate steel to verify that the housing will be strong enough to contain an unanticipated kinetic event. This test was completed, and the blast shields are extremely strong and capable of handling any sudden transience.

To verify and maintain optimal operating conditions and power transmission for the final prototype, the overall running belt tension will need to be determined. Once the motor and pulleys are assembled and located correctly, acquire the appropriate tension values with the gauge and fix the motor securely into the location that provides optimal running performance.

The slowdown speed of the motor will need to be tested extensively at operating conditions to determine if it is enough of a braking system for ERG, or if there will be a desire for a friction braking system at the main centrifuge shaft. Ideally, the door will not be opened during operation, and therefore the E-stop with dynamic braking will be enough to meet ERG’s demands. A timer will be set to determine the time it takes the main centrifuge shaft to go from full speed, approximately 600 RPM as of now, to 0 RPM with only dynamic motor braking. This test will be repeated up to ten times to ensure reliability and verify the VFD can handle the abrupt slowdown without damage. If the heat dissipated becomes an issue, the VFD box could potentially be equipped with a small fan running on its own power.

A final test that will need to be run in the final prototype stage is visually inspecting the pressure on the blocks once a goal RPM is determined. Once the machine is installed and implemented, there will need to be a full payload of blocks run at the specified speed to determine if there is damage inflicted on the blocks from the fixtures due to the pressure as a result of high angular velocity and resulting force. If the desired speed causes damage to the blocks, the angular velocity will simply need to be reduced enough with the VFD to dry the blocks as fast as possible without damage.
Section 8: Project Management

The overall design process included defining the problem and proceeding to brainstorm multiple possible methods of removing water from the aluminum foam blocks. The steps of this process are research, ideation, scale testing, and evaluation of the different methods; after this a method of water removal was selected that will govern the machine design process. During the machine design process, the project will follow the same path of research, ideation, scale testing, and evaluation. For full scale manufacturing and assembly, it is desirable to begin the process early and outsource work for reliable, high-quality products. In terms of manufacturing, tripling the time estimates will ideally keep the team on schedule.

To further maintain a reasonable timeline, a Gantt chart was used as shown in Appendix F. In addition, regular feedback from ERG during weekly calls will help verify any design decisions with the customer needs. Meeting twice weekly during lab sections will also allow regular progress and verification of ideas with the project advisor. Many weekend meetings and communication with vendors will allow manufacturing and assembly move smoothly.

The next steps in the project were to order materials, begin assembly, and attempt to test as many components as possible before the final design review was submitted. Before any materials are ordered, detailed parts and suppliers were sent to ERG Aerospace for review. Once they were approved, ERG Aerospace ordered the necessary materials to complete the development and delivered them to the Mustang 60 machine shop on Cal Poly’s campus. Once the building materials arrived, the group began to assemble the centrifuge as outlined in the Gantt chart in Appendix F. Section 7 has already discussed the upcoming testing that will be performed. It is preferred to test the full-scale machine by senior expo, but as long as it runs by Finals Week, the client and team are satisfied. In Table 3, the key deliverables and timeline for senior project are shown.
Table 3. Key Deliverables and Timeline of Senior Project.

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**Deviations**

Initially, the complete process including testing and implementation was to be done before June 1, 2018. Due to manufacturing delays, unexpected lead times, and some incorrect sizing, the implementation date was set back to June 12, 2018 which worked for ERG due to large renovations occurring in their facility. Manufacturing and assembly will be completed by June 9, 2018, and the machine will be delivered on June 12. The testing and conclusions will have to be completed on-site at ERG Aerospace due to the VFD control box being set up in Oakland. Once the machine is completely installed, a full CAD folder, operating manual, and important results will be given to ERG Aerospace and the project will be completed.
Section 9: Conclusions and Recommendations

The purpose of the Final Design Review is to notify the sponsor of all components, planning, and ideation that went into the development of the project. This report informs the sponsor of the selected design concepts along with a final design, manufacturing plans, and drawings for complete assembly and verification of key parameters. It also comes with important testing parameters that need to be verified for safe, reliable operation. It was understood that a scalable prototype developed by June, 2018 was the minimum expectation from the project team. However, the team was motivated to manufacture and develop a full-scale prototype that can be integrated directly onto the shop floor and improve ERG’s manufacturing productivity. The final design of a centrifugal drying machine was chosen because the team believed it could be finished and delivered to ERG to immediately increase product output.

Unfortunately, testing was not able to be performed before submittal of the final document, and important operating parameters and results are yet to be determined. As mentioned previously, these will occur on June 12, 2018 when the machine is delivered. The testing plans are relatively simple and do not require complex testing equipment or extended periods of operation and will be completed in one day on ERG’s campus. Details of the testing and an operating manual will be provided to allow ERG to operate the machine reliably and safely.

Future Development Suggestions

Ideally, this project would have a longer timeline due to the large scope of building a capable, functioning, industrial machine while taking classes and fulfilling obligations. An initial suggestion for future projects is to prototype more of the initial designs. By scaling a vacuum chamber or discovering a method to avoid the large pressure drop within the block with forced air, the total amount of manufacturing/assembly could be reduced and the design could be simplified. Further designs could be developed to perform quietly, further optimize shop space, or rapidly dry the blocks using a completely new method. With the scope of the project being open-ended, there are many engineering solutions that could be comprised.
References:


Appendices:

Appendix A: QFD House of Quality
Appendix B: Decision Matrix
Appendix C: Preliminary Figures of Selected Concepts
Appendix D: Analysis and Calculations
Appendix E: Safety Hazard Checklist
Appendix F: Gantt chart
Appendix G: Complete Drawing Package
Appendix H: Purchased Parts Details, Links
Appendix I: Budget and Procurement List Embedded in Complete Bill of Materials
Appendix J: Operating/User Manual
# Appendix A. QFD House of Quality

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**Importance Scoring** | **61** | **73** | **24** | **84** | **28** | **30** | **56** | **14** | **60** | **35** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** |

| **Importance Rating (%)** | **39** | **41** | **32** | **38** | **30** | **72** | **18** | **78** | **45** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** |

- ● = 9 Strong Correlation
- ○ = 3 Medium Correlation
- △ = 1 Small Correlation
- Blank No Correlation
# Appendix B: Decision Matrix

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<th>Forced Air Weighted</th>
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<td>127</td>
<td>27</td>
<td>89</td>
<td>30</td>
<td>98</td>
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</tbody>
</table>
Appendix C: Annotated Figures of Top 5 Solutions
Appendix D: Motor Analysis

Motor Requirements:

Ladd Requirements:

Blocks, fixtures, hoops, shaft are all contributors.

Block = 11 lb (approx., max starting weight).

Shaft = 12 lb (material properties for shaft steel on SolidWorks).

Block fixtures = 75-80 lb TOTAL. (Initial estimate)

Hoops, spoke = 10 lb each.

\[ \sum M_{sys} = (1116 \times 8) + 1216 + 7516 + (1016)(2) \]

\[ \sum M_{sys} = 195 \text{ lb} \]

Inertia Calculations:

Blocks: Modeled as point masses due to relatively constant mass distribution.

\[ I_b = \frac{1}{2} m R^2 \]

\[ I_b = (11 \text{ lb})(1 \text{ ft})^2 \]

\[ I_b = 11 \text{ lb-ft}^2 \]

\[ \sum I_b = 88 \text{ lb-ft}^2 \]

Shaft: Modeled as solid cylinder even w/ steps. (Conservative).

\[ I_{SHAFT} = \frac{1}{4} m R^2 \]

\[ = \frac{1}{4}(12 \text{ lb})(0.75 \text{ in})(1.5 \text{ in})^2 \]

\[ I_{SHAFT} = 0.034 \text{ lb-ft}^2 \]

(E.S. 2/15/18)

(Thickest shaft diameter at D=1.5 in.)

(Pretty much negligible to spin shaft w/ good bearings).
MAGNET REQUIREMENTS (CONT.)

**FIXTURES:** WITH EVEN DISTRIBUTION BUT A LITTLE MORE MASS LIKELY AT A CIRCULAR \( I \) WILL MODEL AS POINT Masses.

\[
\text{I}_{\text{FIXT}} = \frac{\text{MR}^2}{2} = (10 \text{ lb})(13 \text{ inc.} (\text{ft/12})^2
\]

\[\text{I}_{\text{FIXT}} = 11.94 \text{ lb-ft}^2\]

\[9 \text{I}_{\text{FIXT}} = 99.92 \text{ lb-ft}^2\]

**HOOPS:** MOVED AS HOLLOW CYLINDERS.

\[\text{I}_{\text{HOOP}} = \frac{\text{MR}^2}{2}\]

\[= (5 \text{ lbs})(15" \cdot 15"/12")^2\]

\[\text{I}_{\text{HOOP}} = 7.814 \text{ lb-ft}^2\]

\[9 \text{I}_{\text{HOOP}} = 70.32 \text{ lb-ft}^2\]

\[\text{Total:}\]

\[\text{INET} = 98 \text{ lb-ft}^2 + 0.03 \text{ lb-ft}^2 + 93.73 \text{ lb-ft}^2 + 15.62 \text{ lb-ft}^2\]

\[\text{INET} = 197.6 \text{ lb-ft}^2\]

**DETERMINATION TORQUE:**

**ELECTRIC INDUSTRIAL MOTOR DESIGN GUIDELINES:**

\[\text{T}_{\text{REQ}} = \frac{\text{INET} \cdot (\Delta N)}{308 \cdot t}\]

\[\text{T}_{\text{REQ}} = \frac{(97.6 \text{ lb-ft}^2) \cdot (600 \text{ rpm} - 0 \text{ rpm})}{308 \cdot (905)}\]

\[\text{T}_{\text{REQ}} = 4.27 \text{ ft-lb}\]

\[\text{T}_{\text{REQ}} = 4.27 \text{ ft-lb} \times \frac{12 \text{ in}}{1 \text{ ft}}\]

\[\text{T}_{\text{REQ}} = 51.24 \text{ in-lb}\]
3 PH, 208-230v/960v AC motor w/ UDO application, 1760 RPM.

Key specs:
- 85.5% efficient.
- 103.2 lb.in starting torque.
- 96.8 lb.in accelerating torque.
- 150 lb.in peak torque.
- 35.6 lb.in continuous operating torque.

- As you can see, these specs (with a 2:1 pulley ratio) will provide more than enough factors of safety for 200% operations.
- Machine will run well to set speeds to satisfy drying requirements.

Inc. / E.S. 2/13/18
Appendix E: Safety Hazard Checklist

Y  N

☑ Y ☐ 1. Will the system include hazardous revolving, running, rolling, or mixing actions?
☐ ☑ ☐ 2. Will the system include hazardous reciprocating, shearing, punching, pressing, squeezing, drawing, or cutting actions?
☑ Y ☐ 3. Will any part of the design undergo high accelerations/decelerations?
☑ Y ☐ 4. Will the system have any large (>5 kg) moving masses or large (>250 N) forces?
☐ ☑ ☐ 5. Could the system produce a projectile?
☐ ☑ ☐ 6. Could the system fall (due to gravity), creating injury?
☑ Y ☐ 7. Will a user be exposed to overhanging weights as part of the design?
☐ ☑ ☐ 8. Will the system have any burrs, sharp edges, shear points, or pinch points?
☐ ☑ ☐ 9. Will any part of the electrical systems not be grounded?
☐ ☑ ☐ 10. Will there be any large batteries (over 30 V)?
☐ ☑ ☐ 11. Will there be any exposed electrical connections in the system (over 40 V)?
☑ Y ☐ 12. Will there be any stored energy in the system such as flywheels, hanging weights or pressurized fluids/gases?
☑ Y ☐ 13. Will there be any explosive or flammable liquids, gases, or small particle fuel as part of the system?
☑ Y ☐ 14. Will the user be required to exert any abnormal effort or experience any abnormal physical posture during the use of the design?
☐ ☑ ☐ 15. Will there be any materials known to be hazardous to humans involved in either the design or its manufacturing?
☑ Y ☐ 16. Could the system generate high levels (>90 dB) of noise?
☐ ☑ ☐ 17. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, or cold/high temperatures, during normal use?
☑ Y ☐ 18. Is it possible for the system to be used in an unsafe manner?
☑ Y ☐ 19. For powered systems, is there an emergency stop button?
☐ ☑ ☐ 20. Will there be any other potential hazards not listed above? If yes, please explain on reverse.
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<th>Description of Hazard</th>
<th>Planned Corrective Action</th>
<th>Planned Date</th>
<th>Actual Date</th>
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<tr>
<td>Large spinning aluminum foam blocks</td>
<td>The logs will be spun in a reinforced, enclosed centrifuge</td>
<td>April 15</td>
<td>April 26</td>
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<tr>
<td>Blocks accelerating quickly up to speed</td>
<td>Machine is secured to ground, placed in reinforced housing</td>
<td>June 12</td>
<td>June 12</td>
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<tr>
<td>Large moving masses</td>
<td>The logs are stored and secured in place to the fixed centrifuge</td>
<td>April 15</td>
<td>April 26</td>
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<tr>
<td>Possibility of pinching at edge of centrifuge</td>
<td>The spinning surface will be enclosed in a housing to reduce operator exposure</td>
<td>April 15</td>
<td>April 26</td>
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<tr>
<td>Forced air ventilation using shop air</td>
<td>Air will not be pointed at operator and will have an emergency stop switch</td>
<td>No longer relevant</td>
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<td>Forced air blowing on foam could be loud</td>
<td>Include sounds reduction in the housing design</td>
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<tr>
<td>System could be improperly used</td>
<td>Provide safety training, a user manual, and detailed operating procedures along with safety mechanisms in place</td>
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<td>End Date</td>
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**NOTES:**

UNLESS OTHERWISE SPECIFIED:

1. DIM ARE IN INCHES
2. TOLERANCES:
   .XX=±.01  .XXX=±.005
3. MATERIAL: ALUMINUM 6061-T6
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<td>single crossmember</td>
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<td>1&quot;X2&quot; STEEL TUBING</td>
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<td>BEARING HOUSING BLOCK</td>
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</tr>
<tr>
<td>13</td>
<td>5154T307</td>
<td>INNER LIP SEAL</td>
<td>2</td>
</tr>
<tr>
<td>ITEM NO.</td>
<td>PART NUMBER</td>
<td>DESCRIPTION</td>
<td>QTY.</td>
</tr>
<tr>
<td>----------</td>
<td>-------------</td>
<td>------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>1</td>
<td>100411</td>
<td>1-1/4&quot; SQUARE STEEL TUBING</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>100408</td>
<td>1&quot;X2&quot; STEEL TUBING</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>100402</td>
<td>MAIN SHAFT</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>100311</td>
<td>LID</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>100314</td>
<td>DOOR</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>100112</td>
<td>EXTERNAL LID</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>100314B</td>
<td>EXTERNAL DOOR</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>1798A210</td>
<td>SURFACE MOUNT HINGE</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>100106</td>
<td>LID SOUND SHIELDING</td>
<td>7</td>
</tr>
<tr>
<td>10</td>
<td>100306</td>
<td>FULL HOOP ASSEMBLY</td>
<td>1</td>
</tr>
<tr>
<td>11</td>
<td>80275A33</td>
<td>DOOR HANDLE</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>92196A712</td>
<td>STAINLESS STEEL SOCKET HEAD BOLT</td>
<td>8</td>
</tr>
<tr>
<td>13</td>
<td>91831A137</td>
<td>STAINLESS STEEL LOCKNUT</td>
<td>16</td>
</tr>
<tr>
<td>14</td>
<td>92198A724</td>
<td>STAINLESS STEEL HEX BOLT</td>
<td>8</td>
</tr>
<tr>
<td>15</td>
<td>90190A291</td>
<td>MACHINE SCREWS</td>
<td>56</td>
</tr>
<tr>
<td>ITEM NO.</td>
<td>PART NUMBER</td>
<td>DESCRIPTION</td>
<td>QTY.</td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
<td>----------------------</td>
<td>------</td>
</tr>
<tr>
<td>1</td>
<td>100301</td>
<td>MISSILE SHIELD</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>100302</td>
<td>SPLASH PLATE</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>100106</td>
<td>SOUND SHIELDING</td>
<td>8</td>
</tr>
<tr>
<td>ITEM NO.</td>
<td>PART NUMBER</td>
<td>DESCRIPTION</td>
<td>QTY.</td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
<td>----------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>1</td>
<td>5990K306</td>
<td>MOTOR</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>97135A230</td>
<td>MOTOR MOUNTING NUT</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>9213K330</td>
<td>MOTOR ISOLATION DAMPERS</td>
<td>8</td>
</tr>
</tbody>
</table>
NOTES:
UNLESS OTHERWISE SPECIFIED:
1. DIM ARE IN INCHES
2. TOLERANCES: .XX=±.01 .XXX=±.005
3. MATERIAL: MINERAL FIBER
NOTES:
UNLESS OTHERWISE SPECIFIED:
1. DIM ARE IN INCHES
2. TOLERANCES: .XX=±.01 .XXX=±.005
3. MATERIAL: MINERAL FIBER
Fits 0.625" Shaft Dia.

For 1.25" Hole Dia.

0.285" Wire Wd.

0.115" Wire Thick.

2" Length

9573K67

Color-Coded Die Spring
Nylon-Insert Locknut

1/2"-13 Thread

Dimensions:
- 3/4" width
- 19/32" height
NOTES:
UNLESS OTHERWISE SPECIFIED:
1. DIM ARE IN INCHES
2. TOLERANCES:
   .XX=±.01
   .XXX=±.005
3. MATERIAL: 16 GA STEEL
NOTES:
UNLESS OTHERWISE SPECIFIED:
1. DIM ARE IN INCHES
2. TOLERANCES:
   .XX=±.01       .XXX=±.005
3. MATERIAL: 16 GA STEEL
NOTES:
1. ALL DIMENSIONS IN INCHES
2. MATERIAL IS SHEET METAL
3. SEE SHEET 2 FOR BEND DIMENSIONS
4. TOLERANCES:
   
   X.XX = ±.10
   ANGLES = ±5°
NOTES:
1. REFERENCE SHEET 1
2. ALL DIMENSIONS IN INCHES
3. MATERIAL IS SHEET METAL
4. TOLERANCES:
   X.XX = + .50
5. THICKNESS OF STEEL IS CALLED AS REFERENCE.
Understanding the installation requirements for your GS2 drive will help to ensure that it operates within its environmental and electrical limits.

Note: Never use only this catalog for installation instructions or operation of equipment; refer to the user manual, GS2-M.

### Environmental Specifications

<table>
<thead>
<tr>
<th>Protective Structure 1</th>
<th>IP20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient Operating Temperature 2</td>
<td>-10 to 50°C (14°F to 122°F) -10 to 40°C (14°F to 104°F) for models 7.5HP and higher</td>
</tr>
<tr>
<td>Storage Temperature 3</td>
<td>-20 to 60°C (-4°F to 140°F)</td>
</tr>
<tr>
<td>Humidity</td>
<td>To 90% (no condensation)</td>
</tr>
<tr>
<td>Vibration 4</td>
<td>5.9 m/s² (0.6g), 10 to 55 Hz</td>
</tr>
<tr>
<td>Location</td>
<td>Altitude 1,000 m or less, indoors (no corrosive gases or dust)</td>
</tr>
</tbody>
</table>

1: Protective structure is based upon EN60529
2: The ambient temperature must be in the range of -10° to 40° C. If the range will be up to 50° C, you will need to set the carrier frequency to 2.1 kHz or less and derate the output current to 80% or less. See our Web site for derating curves.
3: The storage temperature refers to the short-term temperature during transport.
4: Conforms to the test method specified in JIS C0911 (1984)

### Watt-loss Chart

<table>
<thead>
<tr>
<th>GS2 Drive Model</th>
<th>At full load</th>
</tr>
</thead>
<tbody>
<tr>
<td>GS2-10P2</td>
<td>24</td>
</tr>
<tr>
<td>GS2-10P5</td>
<td>34</td>
</tr>
<tr>
<td>GS2-11P0</td>
<td>46</td>
</tr>
<tr>
<td>GS2-20P5</td>
<td>34</td>
</tr>
<tr>
<td>GS2-21P0</td>
<td>57</td>
</tr>
<tr>
<td>GS2-22P0</td>
<td>77</td>
</tr>
<tr>
<td>GS2-23P0</td>
<td>111</td>
</tr>
<tr>
<td>GS2-25P0</td>
<td>185</td>
</tr>
<tr>
<td>GS2-27P5</td>
<td>255</td>
</tr>
<tr>
<td>GS2-41P0</td>
<td>73</td>
</tr>
<tr>
<td>GS2-42P0</td>
<td>86</td>
</tr>
<tr>
<td>GS2-43P0</td>
<td>102</td>
</tr>
<tr>
<td>GS2-45P0</td>
<td>170</td>
</tr>
<tr>
<td>GS2-47P5</td>
<td>240</td>
</tr>
<tr>
<td>GS2-40T10</td>
<td>255</td>
</tr>
<tr>
<td>GS2-51P0</td>
<td>30</td>
</tr>
<tr>
<td>GS2-52P0</td>
<td>58</td>
</tr>
<tr>
<td>GS2-53P0</td>
<td>88</td>
</tr>
<tr>
<td>GS2-55P0</td>
<td>132</td>
</tr>
<tr>
<td>GS2-57P5</td>
<td>191</td>
</tr>
<tr>
<td>GS2-5010</td>
<td>211</td>
</tr>
</tbody>
</table>

Warning: AC drives generate a large amount of heat which may damage the AC drive. Auxiliary cooling methods are typically required in order not to exceed maximum ambient temperatures.
GS2 Specifications – Terminals

**Main Circuit Wiring**

<table>
<thead>
<tr>
<th>Terminal</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1, L2, L3</td>
<td>Input power</td>
</tr>
<tr>
<td>T1, T2, T3</td>
<td>AC drive output</td>
</tr>
<tr>
<td>B1, B2</td>
<td>DC resistor input</td>
</tr>
<tr>
<td>⊥</td>
<td>Ground</td>
</tr>
</tbody>
</table>

**Control Circuit Terminals**

<table>
<thead>
<tr>
<th>Terminal Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1O</td>
<td>Relay output 1 normally open</td>
</tr>
<tr>
<td>R1C</td>
<td>Relay output 1 normally closed</td>
</tr>
<tr>
<td>R1</td>
<td>Relay output 1 common</td>
</tr>
<tr>
<td>R2O</td>
<td>Relay output 2 normally open</td>
</tr>
<tr>
<td>R2C</td>
<td>Relay output 2 normally closed</td>
</tr>
<tr>
<td>R2</td>
<td>Relay output 2 common</td>
</tr>
<tr>
<td>DI1</td>
<td>Digital input 1</td>
</tr>
<tr>
<td>DI2</td>
<td>Digital input 2</td>
</tr>
<tr>
<td>DI3</td>
<td>Digital input 3</td>
</tr>
<tr>
<td>DI4</td>
<td>Digital input 4</td>
</tr>
<tr>
<td>DI5</td>
<td>Digital input 5</td>
</tr>
<tr>
<td>DI6</td>
<td>Digital input 6</td>
</tr>
<tr>
<td>DCM</td>
<td>Digital common</td>
</tr>
<tr>
<td>AI</td>
<td>Analog input</td>
</tr>
<tr>
<td>+10V</td>
<td>Internal power supply (DC 10V) @ 10 mA</td>
</tr>
<tr>
<td>AO</td>
<td>Analog output</td>
</tr>
<tr>
<td>ACM</td>
<td>Analog common</td>
</tr>
</tbody>
</table>

Note: Use twisted-shielded, twisted-pair or shielded-lead wires for the control signal wiring. It is recommended to run all signal wiring in a separate steel conduit. The shield wire should only be connected at the drive. Do not connect shield wire on both ends.
Note: Users MUST connect wiring according to the circuit diagram shown below. (Refer to user manual GS2-M for additional specific wiring information.)

Warning: Do not plug a modem or telephone into the GS2 RJ-12 Serial Comm Port, or permanent damage may result. Terminals 2 and 5 should not be used as a power source for your communication connection.

Power Source*
- 100-120V ±10%
- 200-240V ±10%
- 380-480V ±10%
- 500-600V -15%;+10%

* Use terminals L1, L2 for 115V 1-phase models; use any two of L1, L2, L3 for 230V 1-phase models.

Grounding resistance less than 0.1Ω

Factory default setting

Factory default source of frequency command is via the keypad potentiometer

Main circuit (power) terminals
Control circuit terminal
Shielded leads

For the latest prices, please check AutomationDirect.com.

For the latest prices, please check AutomationDirect.com.

Note: Please refer to the following pages for explanations and information regarding line reactors (71), braking resistors (90), EMI filters (102), RF filters (111), and fuses (112).

Warning: Do not plug a modem or telephone into the GS2 RJ-12 Serial Comm Port, or permanent damage may result. Terminals 2 and 5 should not be used as a power source for your communication connection.
GS2 Specifications – Dimensions

GS2-10P2, GS2-10P5, GS2-11P0; GS2-20P5, GS2-21P0, GS2-22P0; GS2-41P0, GS2-42P0, GS2-43P0; GS2-51P0, GS2-52P0, GS2-53P0

GS2-23P0, GS2-25P0, GS2-27P5; GS2-45P0, GS2-47P5, GS2-4010; GS2-55P0, GS2-57P5, GS2-5010

For the latest prices, please check AutomationDirect.com.
NOTES:
UNLESS OTHERWISE SPECIFIED:
1. DIM ARE IN INCHES
2. TOLERANCES: .XX=±.01 .XXX=±.005
3. MATERIAL: 10 Ga Steel

Cal Poly Mechanical Engineering
ME 430 - SPRING 2018
Lab Section: 06
Title: MISSILE SHIELD
Dwg. #: 100301
Date: 6/6/2018
Scale: 1:5
Chkd. By: BRYCE ZANDER
NOTES:
UNLESS OTHERWISE SPECIFIED:
1. DIM ARE IN INCHES
2. TOLERANCES:
   .XX=±.01   .XXX=±.005
3. MATERIAL: 26 Ga Galvanized Steel
<table>
<thead>
<tr>
<th>ITEM NO.</th>
<th>PART NUMBER</th>
<th>DESCRIPTION</th>
<th>QTY.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100423</td>
<td>Waterjet spoked hoop</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>100425</td>
<td>Angle iron (aligned left)</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>100425</td>
<td>Angle iron (aligned right)</td>
<td>8</td>
</tr>
<tr>
<td>4</td>
<td>100429</td>
<td>Fixture bars</td>
<td>8</td>
</tr>
<tr>
<td>5</td>
<td>100424</td>
<td>B-LOC Compression Hubs</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>100428</td>
<td>1/4”-20 Threaded studs</td>
<td>8</td>
</tr>
<tr>
<td>7</td>
<td>100426</td>
<td>Sheet metal block holders</td>
<td>8</td>
</tr>
<tr>
<td>8</td>
<td>100427</td>
<td>Plastic block stops</td>
<td>8</td>
</tr>
<tr>
<td>9</td>
<td>100430</td>
<td>Wing nuts</td>
<td>8</td>
</tr>
</tbody>
</table>

**NOTES:**

1. NO. 43 ALUMINUM BLIND RIVETS WERE USED TO SECURE SHEET METAL TO THE ANGLE IRONS
2. FOR MORE ASSEMBLY DETAILS SEE WELD DIAGRAMS
For V-Belt:
A-Section (4L, A, and AX)
B-Section (5L, B, and BX)

1.7" Pitch Diameter for A-Section V-Belts
2.1" Pitch Diameter for B-Section V-Belts

5/16"-18 x 3/8" Long Set Screw

1.7" Pitch Diameter for A-Section V-Belts
0.625" Pitch Diameter for B-Section V-Belts

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Information in this drawing is provided for reference only.

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>5990K306</td>
<td>Base-Mount AC Motor</td>
</tr>
</tbody>
</table>
Clamp is supplied with both a metal and nonmarring holding screw.
NOTES:
UNLESS OTHERWISE SPECIFIED:
1. DIM ARE IN INCHES
2. TOLERANCES:
   .XX=±.01  .XXX=±.005
3. MATERIAL: 26 GA GALVANIZED STEEL
Hinge uses #8 screws.
Dimensions are in inches, unless noted.

- Leaf Height: 3.00
- Pin Dia.: 0.25
- Knuckle Dia.: 2.50
- Open Width: 3.00
- Leaf Height: 1.94
- Pin Dia.: 0.22
- Knuckle Dia.: 0.41
- Thickness: 0.080
- Width: 2.50

Surface-Mount Hinge

1798A21

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http://www.mcmaster.com
Information in this drawing is provided for reference only.
NOTES:
UNLESS OTHERWISE SPECIFIED:
1. DIM ARE IN INCHES
2. TOLERANCES: .XX±.01 .XXX±.005
3. MATERIAL: 26 GA GALVANIZED STEEL
NOTES:
UNLESS OTHERWISE SPECIFIED:
1. DIM ARE IN INCHES
2. TOLERANCES:
   .XX=±.01       .XXX=±.005
3. MATERIAL: 16 GA STEEL
For V-Belt:
A-Section (4L, A, and AX)
B-Section (5L, B, and BX)
Information in this drawing is provided for reference only.

For Min. Bore Wd.
0.329"

For Shaft Dia.
2" +0.003/-0.003"

For Bore Dia.
2.623" +0.001/-0.001"

SECTION A-A

PART NUMBER 5154T307

Spring-Loaded Rotary Shaft Seal
Thread Length may vary from 1 1/4" to 1 5/8" in length.

1/2"-13 Thread

Thread Length may vary from 1 1/4" to 1 5/8" in length.
Information in this drawing is provided for reference only.

http://www.mcmaster.com

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5154T23

Spring-Loaded
Rotary Shaft Seal
NOTES:
UNLESS OTHERWISE SPECIFIED:
1. DIM ARE IN INCHES
2. TOLERANCES: .XX=±.01 .XXX=±.005
3. MATERIAL: CARBON STEEL
NOTES:
UNLESS OTHERWISE SPECIFIED:
1. DIM ARE IN INCHES
2. TOLERANCES: .XX=±.01 .XXX=±.005
3. MATERIAL: 10 GA STEEL
Stainless Steel Socket Head Cap Screw

Information in this drawing is provided for reference only.

http://www.mcmaster.com
NOTES:
UNLESS OTHERWISE SPECIFIED:
1. DIM ARE IN INCHES
2. TOLERANCES: .XX=±.01  .XXX=±.005
3. MATERIAL: CARBON STEEL
NOTES:
UNLESS OTHERWISE SPECIFIED:
1. DIM ARE IN INCHES
2. TOLERANCES:
   .XX=±.01
   .XXX=±.005
3. MATERIAL: CARBON STEEL
NOTES:
UNLESS OTHERWISE SPECIFIED:
1. DIM ARE IN INCHES
2. TOLERANCES: .XX=±.01 .XXX=±.005
3. MATERIAL: CARBON STEEL
NOTES:
1. VERTICAL ANGLE IRON IS 1/8" THICK A36 STEEL UNCOATED
2. PLATES ARE 1/2" MILD STEEL PLATE UNCOATED
3. WELD PATTERN TO BE REPEATED FOR TOP PLATE
4. SEE ENCLOSED PART DRAWINGS FOR PART DIMENSIONS
5. TACK FIRST FOR ALIGNMENT, THEN COMPLETE FILLETS
NOTES:
1. BARS ARE 1/8" THICK PLAIN STEEL UNCOATED
2. PLATES ARE 1/2" MILD STEEL PLATE UNCOATED
3. WELD TO BE REPEATED AT EACH END OF ALL 8 BARS
4. SEE ATTACHED PART DRAWINGS FOR DIMENSIONS
5. TOLERANCE ON BAR ALIGNMENT IS ±0.01"
NOTES:
1. PLATE MATERIAL IS 1/2" MILD STEEL
2. STUD MATERIAL IS 1/4"-20 PLAIN STEEL ROD
3. PATTERN INCLUDES 8 WELDS
NOTES:
UNLESS OTHERWISE SPECIFIED:
1. DIM ARE IN INCHES
2. TOLERANCES:
   .XX=±.01   .XXX=±.005
3. MATERIAL: 1/2" MILD STEEL PLATE
4. WATERJET TO DESIRED GEOMETRY
5. DESIRED VOLUME: 2
6. BREAK ALL SHARP EDGES
B-LOC 2" COMPRESSION HUB
BCH20
MATERIAL: STEEL
TORQUE TRANSMISSION: 683 FT-LB
THRUST LOADING: 9060 LB
BORE DIAMETER: 3.071 IN
OUTER DIAMETER: 3.542 IN
SHAFT DIAMETER: 2 IN
THICKNESS RANGE: 0.394-0.512 IN
SCREW SIZE: M5 x 40

SCALE: 1:1.000
NOTES:
UNLESS OTHERWISE SPECIFIED:
1. DIM. ARE IN INCHES
2. TOLERANCES:
   .XX=±.01   .XXX=±.005
3. MATERIAL: STEEL ANGLE IRON STOCK
4. DEBURR SHARP EDGES

Cal Poly Mechanical Engineering  Lab Section: 06  Title: FIXTURE ANGLE IRONS  Drwn. By: DANIEL MOORE
ME 430 - SPRING 2018  Dwg. #: 100425  Date: 6/8/2018  Scale:1:4  Chkd. By:
NOTES:
1. FOR DESIRED FINAL DIMENSIONS SEE PART DRAWING
2. TOLERANCES:
   .XX = ±.01  .XXX = ±.005
3. MATERIAL: 16GA GALVANIZED STEEL SHEET
NOTES:
UNLESS OTHERWISE SPECIFIED:
1. DIM ARE IN INCHES
2. TOLERANCES: .XX=±.01 .XXX=±.005
3. MATERIAL: 16GA GALVANIZED STEEL SHEET
4. 8 PARTS TOTAL
NOTES:
UNLESS OTHERWISE SPECIFIED:
1. DIM ARE IN INCHES
2. TOLERANCES:
   XX=±.01, XXX=±.005
3. MATERIAL: POLYPROPYLENE
4. CLEAN EDGES AFTER CUTTING
5. 8 PIECES TOTAL
NOTES:
UNLESS OTHERWISE SPECIFIED:
1. DIM ARE IN INCHES
2. TOLERANCES:
   XXX=±.005
3. MATERIAL: PLAIN STEEL 1/4"-20 THREADED ROD
4. DEBURR SHARP EDGES
5. 8 PIECES TOTAL
NOTES:
UNLESS OTHERWISE SPECIFIED:
1. DIM ARE IN INCHES
2. TOLERANCES:
   .XX=±.01    .XXX=±.005
3. MATERIAL IS PLAIN STEEL BAR
4. DEBURR SHARP EDGES
NOTES:
UNLESS OTHERWISE SPECIFIED:
1. DIM ARE IN INCHES
2. TOLERANCES: .XX=±.01 .XXX=±.005
3. MATERIAL: CARBON STEEL
NOTES:
ISOMETRIC VIEW 1:12 SCALE
UNLESS OTHERWISE SPECIFIED:
1. DIM ARE IN INCHES
2. TOLERANCES:
   .XX=±.01       .XXX=±.005
3. MATERIAL: CARBON STEEL
Blue Die-Springs
https://www.mcmaster.com/#9573k67j=1cvfk7j
$7.72 each Quantity:4

Threaded studs ½-13 6” long
https://www.mcmaster.com/#90322a153=1cvfzep
$5.25 each Quantity:4

Hex head bolt ½-13, 3” long, partially threaded
https://www.mcmaster.com/#92198a724=1cvesgo
$5.91 for 5, Quantity:2

Socket head bolt 1/2-13, 1” long, fully threaded
https://www.mcmaster.com/#92196a712=1cvf2s3
$6.99 for 5, Quantity:2

Lock nuts ½-13
https://www.mcmaster.com/#91831A137
$5.28 for 10 Quantity:2

Finish Masters (D’Angelos Coating)
227 Tank Farm Road San Luis Obispo, CA 93401
805-546-0494
DTM Aerosol Primer Black
$11.73 per can, Part No: 3931 Quantity:2
415 Rust Preventative Coating 1 part Epoxy (1 Pint)
~$30 per pint, Part No:3931 Quantity:1

Motor Pulley, 2.5 OD, ⅞” Shaft diameter, V.
https://www.mcmaster.com/#6204k137=1cuwgc8

Shaft Pulley, 7.45 OD, ¾” shaft diameter, V.
https://www.mcmaster.com/#6204k521=1cuwku5

V Belt - 61” circumference. A Trade size. ½” wd x 5/16” thick.
https://www.mcmaster.com/#6186k161=1cvepcxr

2 x Toggle Clamps
https://www.mcmaster.com/#5126a24=1d20dom

2x Door Hinge
https://www.mcmaster.com/#1603a24=1ca99u6
2X Compression hubs
Product #BCH202200-040
http://www.fennerdrives.com/b-loc-compression-hubs/_/BCH20-2-M5x40/?s=cHwz

1X Lock-style solenoid - 12V
Product 1512
https://www.adafruit.com/product/1512?gclid=Cj0KCQjwkpfWBRDZARIsAAfeXaqkgTtZ5j5J6DWTcCoSO4GELZBoQaG1jicV9QLAgZb-hhYFkrs3MaApq3EALw_wcB

1X Momentary switch activation for electronic lock
https://www.mouser.com/ProductDetail/E_Switch/PV6F240SS-341?qs=S%2FCBhQS5rGqn1hpFigwow%3D%3D&gclid=Cj0KCQjwkpfWBRDZARIsAAfeXaqeSebtdETfyEaU62VzuMAwqx-SGOGXjNc7qoWm0bAWww32FHMcFQaAmfVEALw_wcB

1X Emergency stop button - AutomationDirect - for VFD input, hard, rapid, stop.
https://www.automationdirect.com/adc/Shopping/Catalog/Pushbuttons-_z-_Switches-_z-_Indicators/IDEM_Emergency_Stop_Control_ Stations/ES-P-230002?utm_source=google&utm_medium=product-search&gclid=Cj0KCQjwkpfWBRDZARIsAAfeXap40gTAbw1l0KRr10gF7czxuhnpC IpDqqi-SqJHxNAMXc8lOfomEkaAiwYEA Lw_wcB

1X Shaft Steel 1045 TG&P 2in diameter 4ft length

4 x Vibration damping mounts
https://www.mcmaster.com/#9213k33/=1butrj5

1 pack Vibration mount nuts
https://www.mcmaster.com/#97135a230/=1butr70

1 x Motor
https://www.mcmaster.com/#5990k306/=1butrqlz

1 x Vfd
https://www.automationdirect.com/adc/Shopping/Catalog/Drives/GS2_(115_-z-_230_-z-460_-z-_575_VAC_V-z-Hz_Control)/GS2_Drive_Units_(115_-z-_230_-z-460_-z-_575_VAC)/GS2-21P0
1 x Braking resistor
https://www.automationdirect.com/adc/Shopping/Catalog/Drives/AC_Drive_(VFD)_Spare_Parts_-_a-__Accessories/GS_Braking_Options_(Braking_Units_-_a-__Resistors)/Braking_Options_(All_GS_Drives)/GS-21P0-BR

1 pack Sheet metal screws
https://www.mcmaster.com/#90190a291/=1but62

4 x Vibration mounting feet
https://www.mcmaster.com/#63965k47/=1butsga

1 x Acrylic sheet .08” x 24” x 48” clear
https://www.acmeplastics.com/hot-deals/080-x-24-x-48-nominal-clear-extruded-acrylic

1 piece, 12in x 12in, Polystyrene sheet .5” thick 12”x12”

Tensioning Screws etc
1 pack washers: https://www.mcmaster.com/#93852A103
1 pack screws: https://www.mcmaster.com/#90087a243/=1butte6
2 x bolts: https://www.mcmaster.com/#92620a583/=1buttmx

Tensioner and idler shaft
1 x tensioner: https://www.mcmaster.com/#1816k2/=1buttsr
1 x idler shaft: https://www.mcmaster.com/#1816k4/=1butv7u

1 x Tensioner Mounting block
https://www.discountsteel.com/items/6061_Aluminum_Flat_Bar.cfm?item_id=133&size_no=114&pieceLength=cut&len_ft=0&len_in=9&len_fraction=0&pieceCutType=45%7C3&itemComments=&qty=1#skus
  - 9 inch length, 1.5” x 2.5” stock bar ASTM B221-08 6061-T6 Aluminum Flat Bar

1 x Fiberglass bar grating, 3ft length
https://www.mcmaster.com/#6228t44/=1butwm9

10 x 7ft long 1-1/4”x1-1/4” steel tubes
https://www.discountsteel.com/items/Structural_Mechanical_Steel_Square_Tube.cfm?item_id=206&size_no=24#skus
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Note: The GS2 Series Drive User Manual provided will govern the electrical implementation of the system, and provide all wiring diagrams and information necessary to run the variable frequency drive with the AC motor. The electrical warnings and guidelines must be obeyed at all times, and will only be referenced in this manual. Please refer to the GS2 manual for any VFD/Motor questions or concerns.
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Before Use

1. Verify that all installation and wiring instructions are followed per Sections 2-2 through 2-12 in the GS2 Series User Manual before attempting to run the machine.
2. Familiarize yourself with the following VFD keypad and operating interface:

   ![VFD Keypad Interface](image)

   Figure 1. VFD keypad interface.

3. If this is the first operation of the machine, verify that the correct programming is applied to the VFD, by checking the various settings using the Program Key. Follow the GS2 Manual for any initial programming or changes to the settings.
4. Once the VFD is wired, programmed, and installed, reference “Operating the Machine,” for further steps and processes.
Operating the Machine

Opening the Access Door

⚠️ Verify that the machine is not running prior to opening the door; do NOT open the door if it is running.

1. Once the machine is at rest, press in the E-Stop button so that the machine can not run while hands/arms are inside the machine.
2. Verify that the door handle is supported with one hand before opening the door and releasing the toggle clamps.
3. Release the toggle clamps and carefully allow the door to lower and set on the bearing block.
4. Once the door is open, proceed with the following section, “Loading the Blocks.”

Loading the Blocks

⚠️ As the blocks are still wet at this stage it is important to be careful of wet spots on the floor, even on rubber mats wet spots provide a slipping hazard that warrants caution.

1. Securely hold each block with both hands.
2. Slide the block into the fixture housing as shown in Figure 2, being careful to avoid pinching hands or fingers.
3. Once the block is placed in the housing, close the securing latch to lock the block in, and rotate the centrifuge so the next fixture housing is easily accessible (Figure 3).

4. Repeat this process until the machine is fully loaded. After, proceed to “Securing the Access Door.”
Securing the Access Door

1. After ensuring the machine is either empty or fully loaded, begin the process of closing the door.
2. Lift the door that has been resting on the bearing block up to the surface of the machine.
3. With the door flush to the surface, re-clamp the toggle clamps to the door to secure it in place.
4. If the machine needs to be run, proceed to “Starting the Centrifuge.”

Starting the Centrifuge

⚠️ Before starting the centrifuge, ensure that the access door is properly secured as outlined in the “Securing the Access Door” section.

1. Disengage the emergency stop switch so that the VFD will be able to send the RUN signal to the motor and start the drying process.
2. Proceed to the VFD box located on the wall near the machine and press the RUN button.

3. Pressing RUN will start the machine. The VFD will have a predetermined ramp time and acceleration, and will reach the desired speed at a safe rate.
4. If the machine needs to be stopped in an emergency situation for any reason, engage the emergency stop switch. Otherwise, please see “Stopping the Centrifuge” once the machine has run for the desired drying time.
Stopping the Centrifuge

⚠️ Under normal circumstances, do NOT use the emergency stop button to turn off the device. The VFD will be programmed to perform highly aggressive braking to stop under an emergency, and can cause damage to the materials or machine.

1. Once the blocks have run for the desired drying time, proceed to the VFD box mounted on the wall and press the STOP key.

![Stop/Reset Key](image)

Figure. Reset Key on VFD.

2. Reference “Unloading the Blocks,” to unload and start a new cycle.
Unloading the Blocks

1. Once the machine has come to a complete stop using the standard stop method, ensure that the emergency stop button is engaged so that the motor can not accidentally start.

2. Once the door is open, carefully remove one block at a time using both hands. Grip blocks from the sides as shown. Between each block removal slowly rotate the centrifuge by turning the chamber using both hands.

![Safe grip location for block removal](image)

3. Once the blocks are unloaded proceed to “Loading the Blocks” or “Securing the Access Door” sections as necessary.
**Maintenance**

This machine is made of a large quantity of steel, which is inherently not waterproof. Splash shields have been installed to minimize the interaction of water with the frame, while the main centrifuge chamber has been coated in POR-15, an abrasion-resistant primer coating. This primer can be seen in the Bill of Materials, and should be reapplied if noticeable patches or areas of steel are exposed directly to water. There is also a large majority of the steel that is not inside the water containment zone and this is coated with a standard water-proof primer, also available in the Bill of Materials.

For general maintenance and disassembly, the exploded assembly drawings will be the ideal location to view how the machine is put together and how to access/remove inner components. The machine is designed to be disassembled in an orderly method, and comes apart exactly as displayed in the exploded views. For further reading on assembly and manufacturing of parts refer to the Manufacturing Plan section of the final design review.