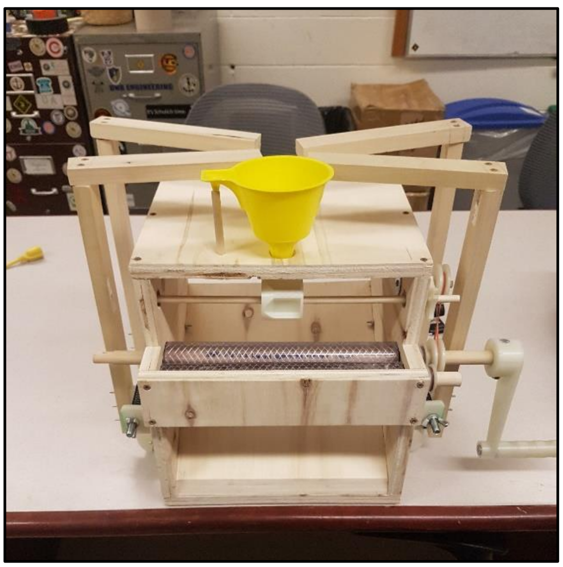
Lakehead University

Engineering 2939-WA
Technology Project

Wild Rice Processor
Final Project Report

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Abstract

Wild rice is an abundant natural resource in Northern Ontario and has the potential to provide aspiring entrepreneurs with a source of income. A food staple in indigenous culture, wild rice is also of significant cultural importance. The traditional process of harvesting wild rice is a community-oriented effort, collected via canoe like the process indicated in *Figure 1*. The wild rice kernels are separated from the plant by hitting it with a stick and are collected in the canoe [1]. The kernels are then dried, roasted, dehusked, and winnowed to before they are ready to cook. This traditional process is not an optimized procedure and has the potential to be enhanced by the design process [16].

Figure 1: Wild rice harvesting

Efficiently processing large quantities of raw wild rice is a tedious process; typically requiring the utilization of expensive material processing machines. Without the use of these machines, it’s difficult to maintain a competitive sales presence in the agricultural market [2]. The purpose of this project is to utilize previously established designs to

construct a rice processing machine to assist in this effort. Through a combination of easily obtainable materials and specially designed 3D printed parts a kit can be developed to achieve this goal in a manner that falls in-line with the original scope of the project. The result is a machine that can be utilized by entrepreneurs to assist in the processing of green wild rice into wild rice that is ready for sale [16].

By utilizing design tools knowledge of science and mathematics can be applied to solving real-world problems [3]. For example, a revised client statement was utilized the refine the deliverables necessary for project completion. In addition, a weighted objective tree was created to organize and prioritize specific aspects of the project. To optimize the design further, a pairwise comparison chart (PCC) was utilized to rank the generated objected in order of importance. The means for the proposed functions, and their associated relationships were further investigated using a function-means tree, and the progress of each projects specific task was tracked using a Gantt chart [16].

The most prevalent focus of the project was to transfer knowledge from Lakehead University back to the community. This was accomplished by designing a machine that satisfied the following constraints: cost under 500 dollars, easy to use and maintain, and able to process raw material. The greatest benefit of the conceived design lies in the proposed manner of its operation. The primary source of power for dehulling wild rice kernels depends on the physical motion of an operator and has been specifically designed to allow operation by a right-handed or left-handed operator. Besides the ease of access to most of the basic components, this opens the opportunity for a much larger network of expertise and experience to support the First Nation communities and families in Northern Ontario [16].

Figure 2: Completed prototype

The general final design consists of a single machine that accomplish two separate functions: dehusking and winnowing. Dehusking is accomplished by taking the dried and scorched kernels and passing them through two dowels (rollers) coated with food-safe polyvinyl tubing. The rollers dehusk the kernels, and the remaining product is winnowed through a series of screens that are laid on top of the collecting bucket. The resulting processed product is collected in a bucket on the bottom of the machine and is emptied as required, or it is reintroduced into the machine after adjusting the width of the rollers to accommodate different raw material sizes.

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I. Introduction and Problem Statement

a. Motivation

Our team continues to purpose our interest in supporting First Nation communities and in the next design iteration of a wild rice processing machine. First described during a tutorial in AT-2001 on September 20th, 2016, our team quickly identified it as an excellent opportunity to channel our collective knowledge of science and mathematics into a fundamental engineering problem. We possess the talent and the ambition to deliver an exceptional solution that will greatly benefit local First Nation communities.

This is a challenging task highlighted by tight monetary restrictions. However, our experience and motivation has allowed us to comfortably align ourselves so that we have reliable access to the resources required. We have reliable transportation, access to a network of individuals experienced with the mechanical aspect of our design, and the ability to fundamentally apply the basics of engineering concepts with engineering design tools.

Our team is grateful for the opportunity to continue to develop a wild rice processing machine. We're confident that we have developed a dynamic and effective solution to the accessibly of wild rice processing in indigenous communities in northern Ontario.

b. Initial Client Statement

The revised client statement from the previous design iteration was established as the following: "design a human-powered wild rice processing machine." In this project, a revised statement with a more precise scope was explored. That was done by clarifying client objectives, establishing user requirements, identifying constraints, and establishing principle functions.

Clarification of client's objectives:

- Assistive device to process wild rice
- Assembled from accessible materials, specialized parts
- Operated by a human-powered means

Established user requirements:

- Withstands forces from typical workload (24 hours)
- Easy to assemble kit
- Moved to worksite with minimal effort

Identified constraints:

- Assembled for no more than $500
- Easy to maintain and operate

Established principal functions

- Dehusk kernels from wild rice
- Winnow kernels from food waste

II. Revised Problem Statement

The revised client statement is as follows: "design a human-powered wild rice processing machine kit." This was established after doing further research on the wild rice industry and operations. In further design iterations, it will be necessary to analyze the shipping cost of the associated kit and investigate the most efficient way of packing it properly.

III. Design Attributes

The following table (*Table 1)* is used to distinguish constraints, objectives, functions and means from characteristics necessary to a function machine. These traits were identified and discussed by the team during team meetings [16].

Characteristics	O	C	F	M
Durable	✔			
Safe		✔		
Assembled for no more than $500		✔		
Easy to transport	✔			
Easy to repair		✔		
Easy to use		✔		
Dehusks rice			✔	
Winnows rice			✔	
Supplies rice			✔	
Filters rice from other particles				✔
Crushed between rollers				✔
Incremented with Geneva drive				✔

Table 1: Design attributes

Utilizing *Table 1,* an objective tree was created to rank the objectives by order of importance, the most important is the further left as seen in *Figure 3.*

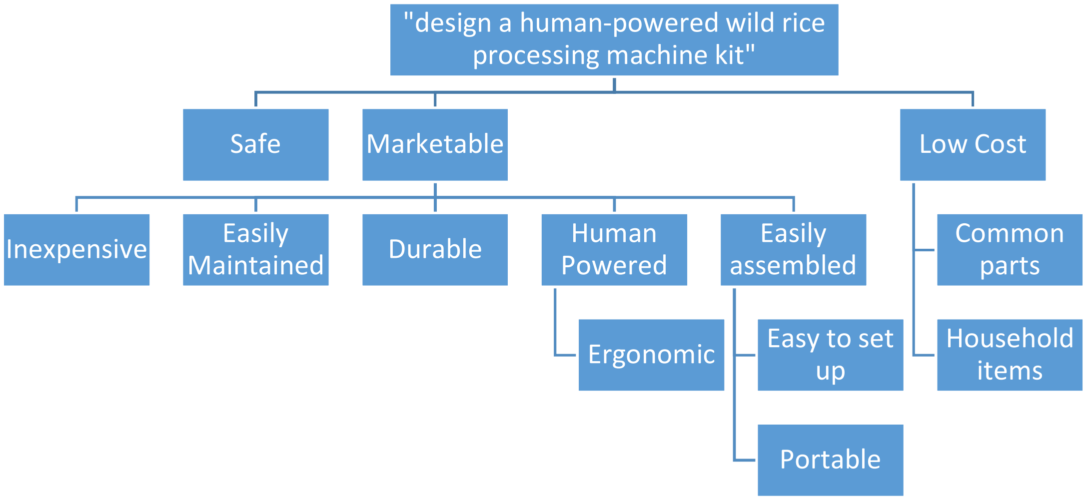


Figure 3: Objective tree

Finally, the use a function-means tree (*Figure 4*) is essential in identifying the desired functions of the final design. This allows the specific methodology in which it performs the functions to be discussed, and for alternatives to be designed [16].

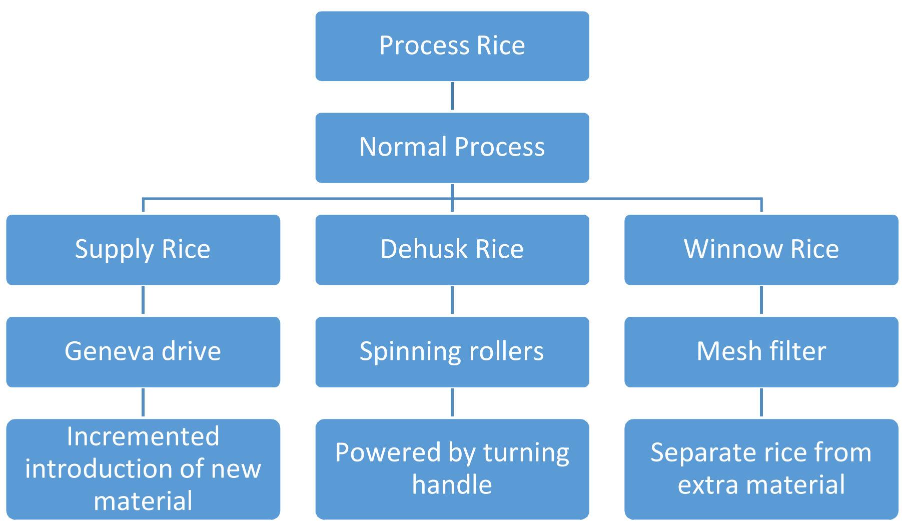


Figure 4: Function means tree

IV. Generation of Design Alternatives

The team analysed the ENGI-1112 designs with the purpose of finding desirable traits that can be implemented in our design. Each one of the 7 designs was analysed and the results were displayed below in *Table 2*. This allowed us to determine attributes that would coincide with the spirit of our project in addition to attributes that could be deemed unnecessary, or those don't align with the goals of the scope of the project.

It was concluded that most of the designs didn't have any desirable traits, which is likely attributable to the fact that they were completed by first-year engineering students with limited design experience. A notable exception is the utilization of rollers, which the current design agreed are an efficient method to accomplish rice dehusking. In addition, the use of adjustable legs would greatly affect the portability of the finished machine.

Design	Desirable Traits	Unessential Traits
Rice 2 [17]	• Use of rollers to dehusk rice • Removable legs in *Prototype 1*	• A 12 V battery was used in *Prototype 3* to drive the system
Rice 3 [18]	• No noteworthy traits	• Use of loose rubber; possible safety concerns
Rice 4 [19]	• No noteworthy traits	• Processes a small amount of rice per batch
Rice 5 [20]	• No noteworthy traits	• No noteworthy traits
Rice 6 [21]	• No noteworthy traits	• No noteworthy traits
Rice 7 [22]	• Use of rollers to dehusk rice	• No noteworthy traits
Rice 8 [23]	• No noteworthy traits	• No noteworthy traits

Table 2: Identified traits in other final designs

V. Design Selection

a. Description of Metrics

Most of the established metrics are carried over from a previous design iteration with a notable exception of *Kit Assembly* [16].

Objective: Safe Machine Operation

Units: Rating safety on a scale of 1 (worst) to 5 (best).

Metric: Identify potential safety hazards or concerns. Starting at 5, the total score is calculated with the following equation, with n representing the number of identified safety concerns: $Score = 5 - n$

Objective: Minimize the cost

Units: Rating cost on a scale of 1 (worst) to 5 (best).

Metric: Estimate a bill of materials for each design and calculate a total cost. Assign ratings to the calculated cost as follows:

Estimated Cost ($)	Points
400-500	**1**
300-400	**2**
200-300	**3**
100-200	**4**
1-100	**5**

Table 3: Metric for cost

Objective: Efficient design

Units: Rating efficiency on a scale of 1 (worst) to 5 (best).

Metric: Using a prototype to benchmark, the process can be attempted and graded as follows:

Produced Product in 72 Hours (tonne)	Points
0.2	**1**
0.4	**2**
0.6	**3**
0.8	**4**
1	**5**

Table 4: Metric for efficiency

Objective: Effective inclusion of human-power

Units: Rating human-power on a scale of 1 (worst) to 5 (best).

Metric: Judged as a group, on a subjective scale, that rates the effectiveness of the integration of a human powered design. In this instance, each design incorporated human powered design in a similar manner; a metric is not essential since each design will likely have the same score.

Objective: Portability potential

Units: Rating portability on a scale of 1 (worst) to 5 (best).

Metric: Estimate a bill of materials for each design and estimate a total overall weight of the design. The portability of the final design is most heavily influenced by the overall weight of the design.

Weight (kg)	Points
> 14	**1**
11-14	**2**
8-11	**3**
5-8	**4**
< 5	**5**

Table 5: Metric for portability

Objective: Resist working forces from daily operation

Units: Rating durability on a scale of 1 (worst) to 5 (best).

Metric: Judged as a group, on a subjective scale, that rates the designs ability to resist daily working forces based on the materials the design is composed of.

Objective: Easy to operate and maintain

Units: Rating ease of use on a scale of 1 (worst) to 5 (best).

Metric: Judged as a group, on a subjective scale that rates the ease of use of the design based its overall complexity.

Objective: Assembly of machine or kit

Units: Rating ease of use on a scale of 1 (worst) to 5 (best).

Metric: Judged as a group, on a subjective scale that rates the ease of use of the design based on the complexity and difficultly involved in its assembly.

b. Selection of a Final Design

The design selection process was started by analyzing the 2016 ENGI-1112-FA group designs to see if there were any desirable traits that could be implemented in our design. However, the final designs were not excellent since they were done by first year engineering students. While it's difficult to ascertain explicitly, some designs likely weren't feasible, or their method of operation wasn't clearly explained. This is explained in more detail in *Generation of Design Alternatives*.

The final design was selected via a pairwise comparison chart (PCC). Each team member, and two mechanical engineering students where asked to rank the objectives against one another to find the most important to the successful operation of the machine (*Table 7-9*). The scores from the previous four PCC's were accumulated in an Aggregate PCC as seen in *Table 10*. From the aggregate PCC, the objectives were ranked by importance from 1 to 7 in *Table 11*, with 1 is highest priority and 7 is lowest priority.

Objective	Safe	Cost	Efficiency	Portability	Durability	Ease of Use	Assembly	Score
Safe	-	1	1	1	1	1	1	6
Cost	0	-	0	1	0.5	1	0.5	3
Efficiency	0	1	-	1	1	0	0.5	3.5
Portability	0	0	0	-	0	0	1	1
Durability	0	0.5	0	1	-	1	1	3.5
Ease of Use	0	0	1	1	0	-	1	3
Assembly	0	0.5	0.5	0	0	0	-	1

Table 6: PCC (Adam Genno)

Objective	Safe	Cost	Efficiency	Portability	Durability	Ease of Use	Assembly	Score
Safe	-	1	1	1	1	1	1	7
Cost	0	-	0	0.5	0.5	1	1	3.5
Efficiency	0	1	-	1	1	0	1	4.5
Portability	0	0.5	0	-	0	0	0.5	1
Durability	0	0.5	0	1	-	0	1	3.5
Ease of Use	0	0	1	1	1	-	1	4
Assembly	0	0	0	0.5	0	0	-	0.5

Table 7: PCC (Mohammad Darzaid)

Objective	Safe	Cost	Efficiency	Portability	Durability	Ease of Use	Assembly	Score
Safe	-	1	1	1	1	1	1	6
Cost	0	-	0	1	0	0	0	1
Efficiency	0	1	-	1	1	0.5	0.5	4
Portability	0	0	0	-	0	0	0	0
Durability	0	1	0	1	-	0.5	0	2.5
Ease of Use	0	1	0.5	1	0.5	-	0.5	3.5
Assembly	0	1	0.5	1	1	0.5	-	4

Table 8: PCC (Engineering Student 1)

Objectives	Safe	Cost	Efficiency	Portability	Durability	Ease of Use	Assembly	Score
Safe	-	1	1	1	1	1	1	6
Cost	0	-	0	1	1	0	0	2
Efficiency	0	1	-	1	1	1	1	5
Portability	0	0	0	-	1	0	1	2
Durability	0	0	0	0	-	0.5	1	1.5
Ease of Use	0	1	0	1	0.5	-	0.5	3
Assembly	0	1	0	0	0	0.5	-	1.5

Table 9: PCC (Engineering Student 2)

Objective	Members				Score
	Adam	Moe	Student 1	Student 2	
Safe	6	6	6	6	24
Cost	3	3.5	1	2	9.5
Efficiency	3.5	4.5	4	5	17
Portability	1	1	0	2	4
Durability	3.5	3.5	2.5	1.5	11
Ease of Use	3	4	3.5	3	13.5
Assembly	1	0.5	4	1.5	7

Table 10: Aggregate PCC

Priority	Objective
1	Safe
2	Efficiency
3	Ease of Use
4	Durability
5	Cost
6	Kit Assembly
7	Portability

Table 11: Objective rank

Using *Table 10*, a final design was drafted and compared with the ENGI-1112 design to determine if an improvement to the initial design had been created. This was accomplished by appropriately weighting the objectives and their associated scores, as seen in *Table* 12. The newly developed final design was found to satisfy the design requirements more appropriately and was used as the basis for the project.

Design Constraints	ENGI-1112 Design (Appendix A)	Developed Design (Appendix B)
Cost under $500	✔	✔
Efficient	-	-
Easy to use	✔	✔
Easy to maintain	✔	✔
Human Powered	✔	✔

Table 12: Comparison matrix A

Design Objectives	Score	Score
Safe	5	4
Cost	3	2
Efficiency	-	-
Portability	1	3
Durability	3	4
Ease of Use	3	5
Kit design	0	5
Total Score:	15	23

Table 13: Comparison matrix B

c. Break-even Analysis

A break-even analysis was conducted to see how many machines would need to be created and sold to start a profitable operation. The analysis was done for a small one-person operation with a volunteer available 8 hour a day.

First, it was determined what types of equipment would be needed, as seen in *Appendix F*. A reasonable revenue per machine of $200 was established, which bring the cost closer to the original scope of the project of $500. The total cost of the equipment was then added to the total material cost to obtain a fixed cost. Fixed cost was then divided by the revenue, minus the variable cost which was assumed to be $20 to account for price changes in purchased materials.

The following calculation was used to determine the number of machines needed to break even:

$$Q_{BEP} = \frac{FC}{r - v}$$

Where:

$FC = \$1{,}536.99$ (cost of fabrication equipment, *Table 16)*

$+ \$340.41$ (cost of materials for one machine, *Table 15)*

$FC = \$1{,}877.40$

$r =$ revenue per unit $= \$200$

$v =$variable cost per unit $= \$20$

$$Q_{BEP} = \frac{1877.4}{200 - 20} = 10.43 \approx 11\ machines$$

Therefore, 11 machines would have to be sold to start creating profit.

The major contributor to construction time is due to 3D printing time, which takes around 60 hours to print all the parts necessary for one machine. If an operator is responsible for successfully printing parts for 8 hours a day, the following calculation was made to calculate the number of days required to complete a single machine:

$$\frac{60\ hr}{8\ hr/day} = 7.5\ days \approx 8\ days$$

Therefore, 8 days are required to print the parts necessary for one machine. Knowing that 11 machines would have to be sold to start creating profit, the following calculation can be used to calculate the number of days until the break-even point is reached:

$$\left(\frac{8\ days}{1\ machine}\right) \cdot 11\ machines = 88\ days$$

Therefore, by using the equipment in *Appendix F* and by selling the machines at $540.41 (a revenue of $200), it was found that 11 machines will need to be sold to start breaking even. This can be accomplished by within approximately 88 working days.

VI. Final Design

a. Feasibility of the final design

Raw, unprocessed wild rice was not immediately available for testing with the completed prototype, and a substitute was utilized instead. Preliminary morphometric analysis reveals a similar geometry; a husk that surrounds a seed.

Figure 5: Processed material through prototype with one pass

Running sunflower seeds through the device is successful in separating some of the seeds from the shells, which can then be effectively filtered out with the use of a gradient. It is also noteworthy, however, that the wide range of sizes of the material utilized resulted in some husks not opening, and some being completely pulverized by the separation process. The initial mode of operation involved multiple product passes, and therefore remains feasible, perhaps beginning with a wider roller stand-off.

b. Strengths of the final design

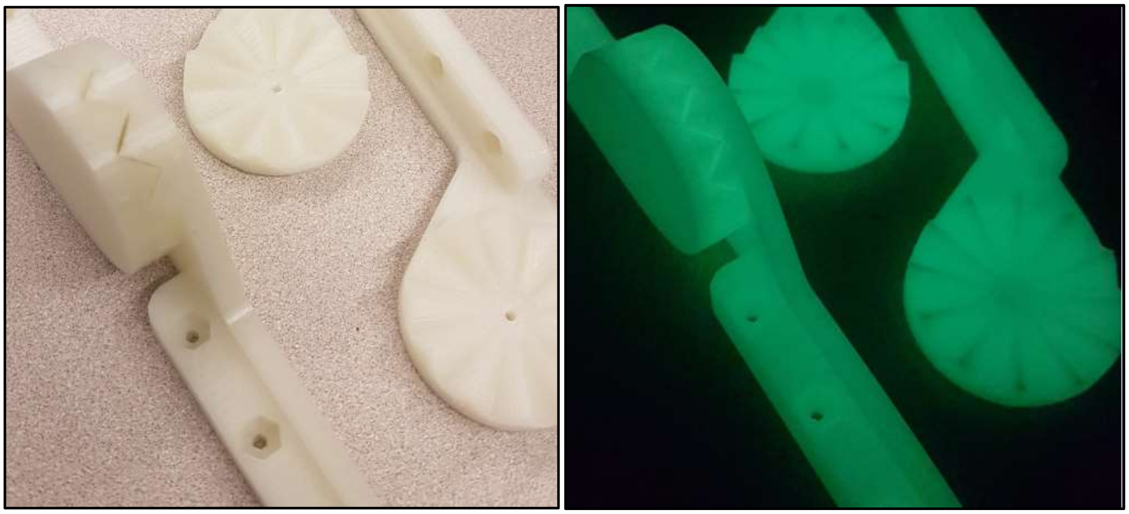


Figure 6: Visibility of 3D printed parts in daylight (left) and darkness (right)

Glow-in-the-dark 3D filament was selected for use to amplify the effectiveness of the printed parts. In addition to having identical tensile strength to other PLA filaments, it also has the added benefit of luminescence in darker environments, which falls in line with the spirit of the project.

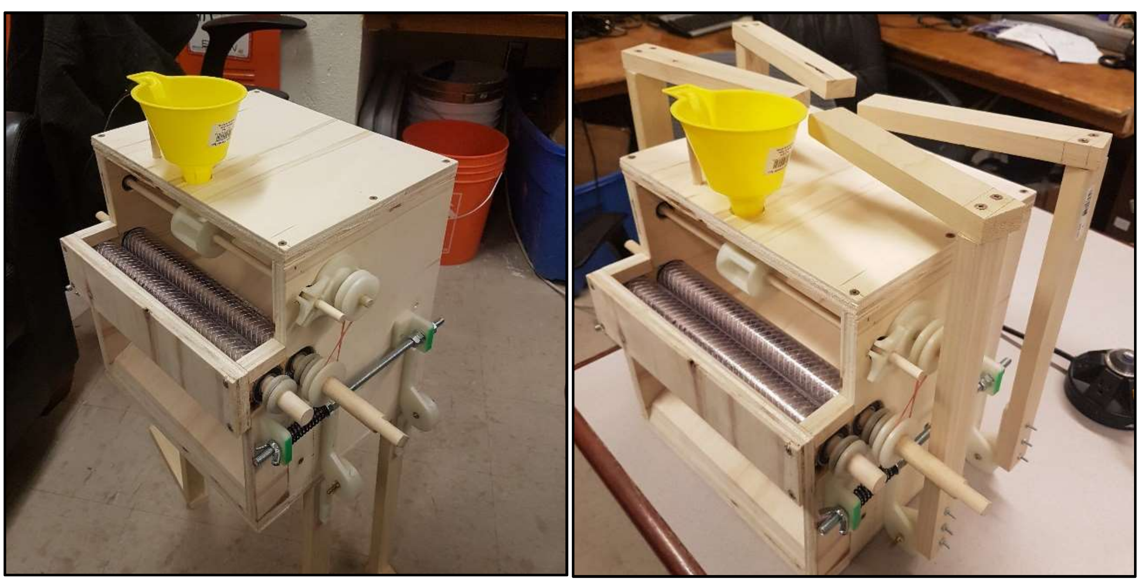


Figure 7: Rice processor with legs unfolded (left) and folded (right)

One of the preliminary design concepts that was carried through to design completion is the inclusion of legs that can be folded into an upright position. This allows the prototype to occupy a smaller footprint for storage, or for it to be utilized as a table-tap device.

Figure 8: Handle connection points

Specially shaped handle attachment points allow the device to be operated by either a left-handed or right-handed individual when the legs are unfolded, and by a right-handed individual when the device is folded. Left-handed operation when the legs are folded is possible, provided excess machine screw threads have been removed from the backside of *Leg A*.

c. Weaknesses of the final design

Figure 9: Damaged hinge

When attempting to store the folded machine, a protruded object perpendicularly collided with the folded hinge assembly, breaking it in the location above. It is strongly recommended further reinforcement is investigated in future design iterations.

Figure 10: Hinge alignment

Interference was encountered between the drive system dowel and *Leg A* when attempting to convert the legs into the folded position. As a result, two pairs of hinges had to be moved inwards by 1”. In addition, the hinges were moved downwards due to the protrusion of the hinge assembly connecting *Box D* and *Box E*, as discussed in *Suggestions and recommendations*.

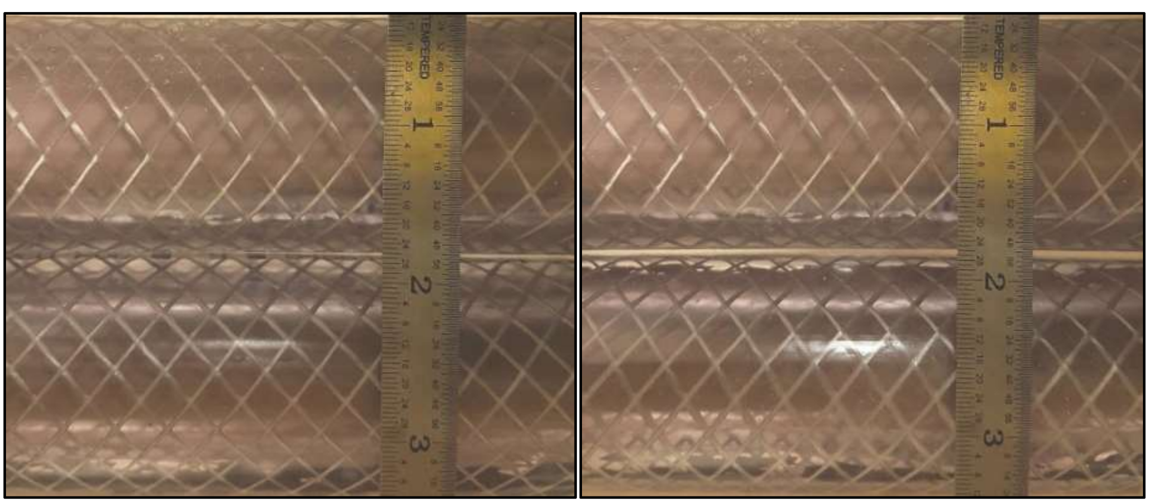


Figure 11: Smallest roller deviation (top) and largest roller deviation (bottom)

The layers of PVC tubing were assembled well in advance of the rest of the materials utilized. As a result, they were stored lengthwise on a shelf, and took on an ovular shape. Holding one roller stationary and rotating the other reveals a deviation ranging between 1/32” and 1/16”. In the future, more safeguards need to be in place to prevent the warping of the rollers, or to investigate a functional alternative to layers of PVC tubing.

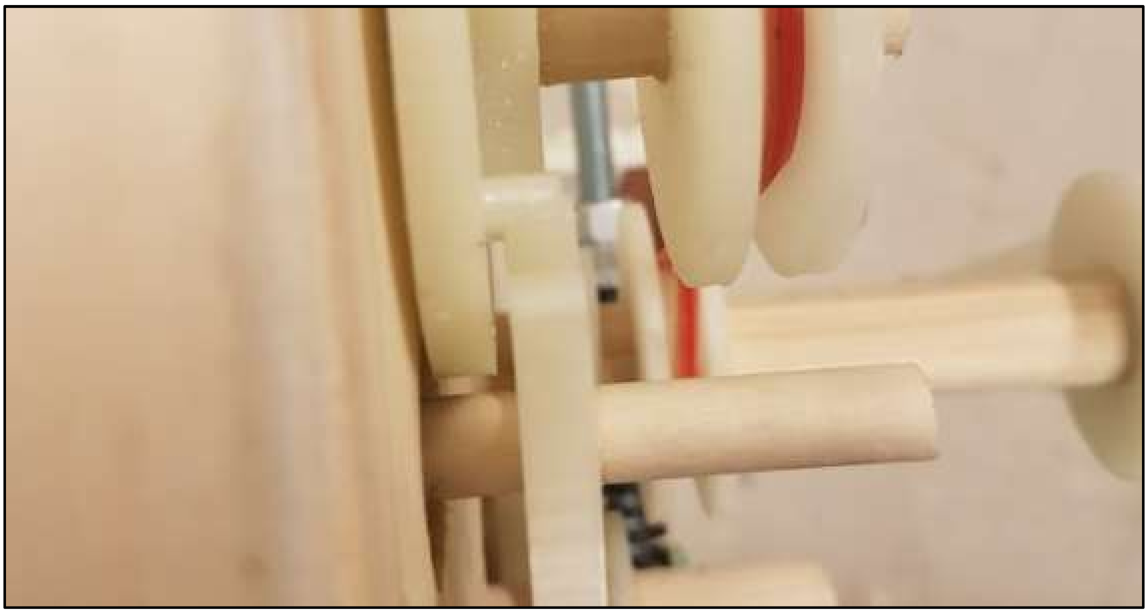


Figure 12: Geneva B Spacer clearance

The radius of the *Geneva Drive B Spacer* was found to be too large to fit on the dowel and allow for the gears to mate properly. As a result, it was omitted from the final assembly of the prototype. However, it’s function has proven to be unnecessary, as securely fastening the drive appears to be sufficient enough to allow the device to operate.

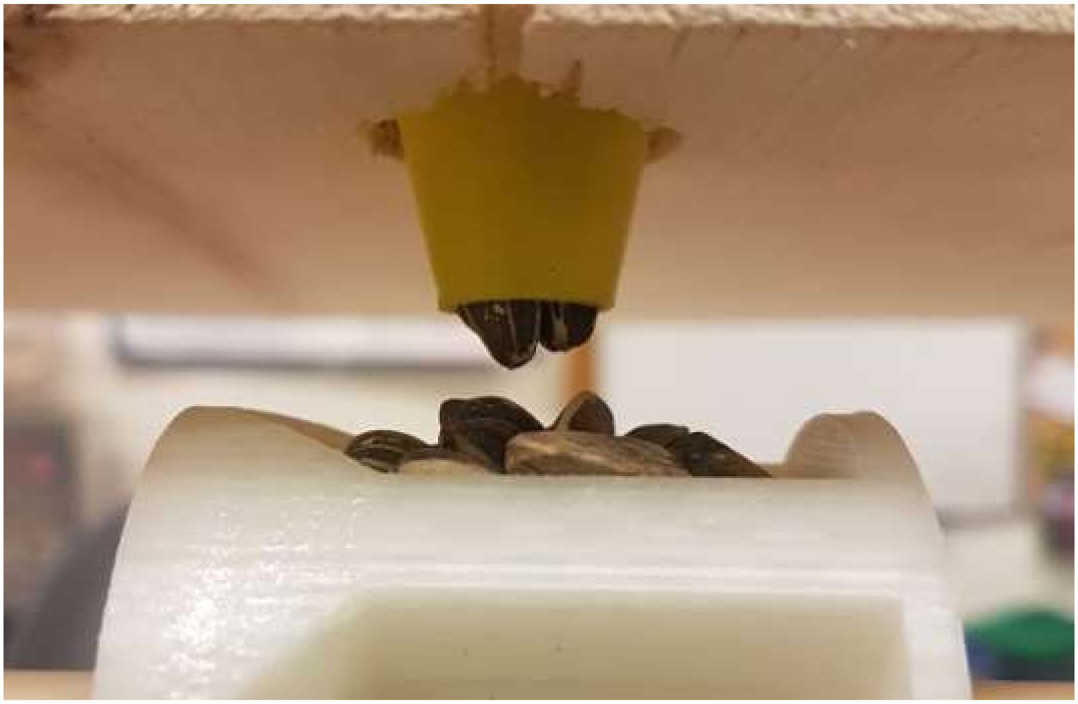


Figure 13: Jammed feeder

The sample material utilized in the prototype was frequently subject to jamming. Preliminary research indicates wild rice is generally smaller than the sunflowers seeds utilized in the experiment, but precautions should be taken in future design iterations regardless, either by widening the input mechanism or investigating a similar alternative.

d. Suggestions and recommendations

Figure 14: Reduced length dowel from outside (left) and inside (right)

As a last-minute effort to reduce cost, the dowel was shortened to reduce the number of bearings required. Instead, a washed was attached directly to the interior surface of the dowel as support. Preliminary testing indicates that the device still operates as planned.

Figure 15: Plugged hole in Box A

For aesthetic purposes the unused hole was plugged with a dowel since the bearing and thus its required hole is no longer necessary. Removing this feature from future designs would also reduce the time required to cut the hole, as noted in *Appendix G.*

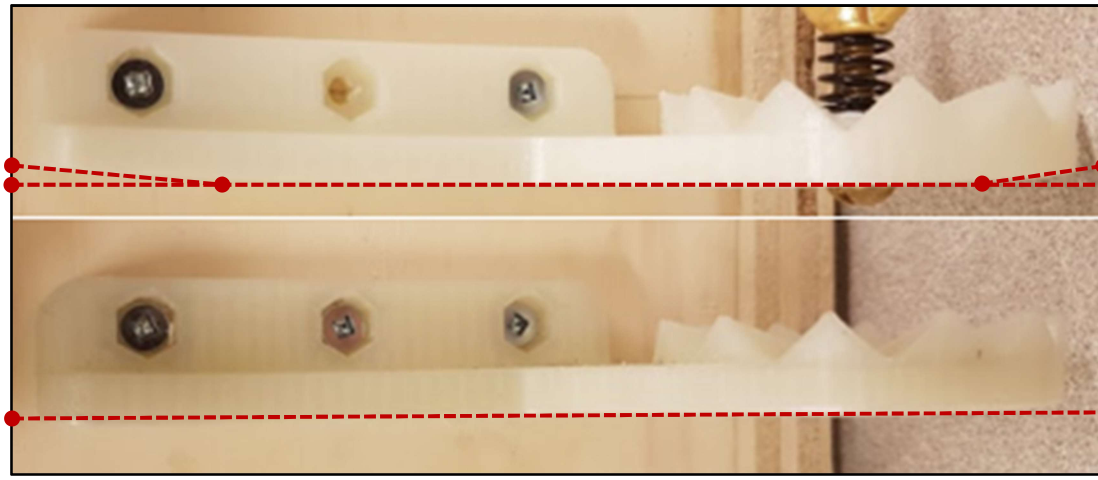


Figure 16: 25% infill (top) and 50% infill (bottom)

A replacement hinge had to be printed for a broken part and was printed with a much higher infill to strengthen the part and avoid similar instances. The resulting print was subject to much less warping, as indicated in red. It is recommended that print density, and subsequently the associated print times is revaluated for a higher print infill.

Figure 17: Hinge connection offset

The initial design did not accommodate the extra height that would be added from the addition of the hinge between *Box D* and *Box E*. As a result, this would cause the machine to sit on an angle on a flat surface. To accommodate this, the original hinge spacing was offset vertically by approximately 1/8”. It is strongly recommended that this offset is integrated in future design iterations.

Figure 18: Potential storage area

The area under box G would make an ideal storage location for the handle when the machine is not in use. This could be accomplished by bracing a door across the open face. This area could also be used to store extra drive belts, or other spare fasteners.

Figure 19: Leg adjustment

Since the hinges were moved more inward, the legs were curled inwards as well to provide a more stable base. A heavy object like a rock, or even the operators foot, can be placed so that it spans the ends of both legs to provide greater stability. This also accommodates the curvature of the funnel, eliminating the need for it to be removed when the legs are upright.

VII. Teamwork and Project Management

a. Team Charter

LAKEHEAD UNIVERSITY RICE MACHINE

TEAM CHARTER

This charter documents key information regarding a project to be conducted by students at Lakehead University (LU) on behalf of a private client. The class instructor will be Dr. M. Liu, and the team leader will be Adam Genno.

The team agrees to place the safety of the machine operator as its highest priority, and to work in accord with LU's honour code.

Goals

The project is selected to align with the Technology Project criteria (ENGI-2939), and the students understand that they are expected to work to accomplish LU's goals for the course, the goals of the design team, and the needs of the client.

The goals of ENGI-2939 are to:

1. Develop a 'kit' of parts that can be assembled into a functional rice machine
2. Establish the next iteration of design for the Rice Machine

The goals of the design team are to:

1. satisfy the client's needs
2. write a formal report outlining the design process
3. develop a functional rice machine prototype

Deliverables

The following deliverables will be completed by April 13th, 2018:

1. a final report is completed outlining the selected final design, and the design process that allowed to team to select an appropriate design;
2. a functional prototype of the Rice Machine; and
3. a short presentation of the machines' method of operations and its features.

Resource limits

The team is expected to work an average of 10 hours per week per team member. The total cost of the individual components of the final design is not to exceed a value of $500.

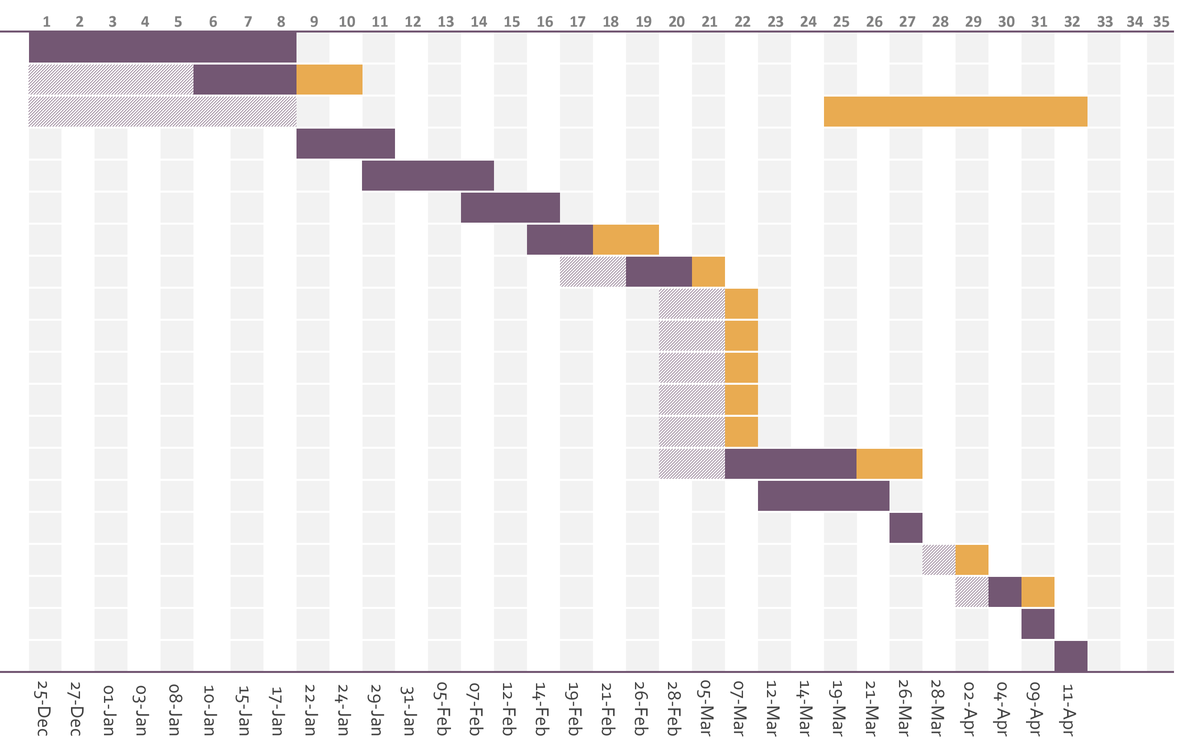
Other Restrictions or Information

The team will place the safety of the user above all other aspects in their design activity. The above format has been adapted from a previous design iteration [16].

Wild Rice Processor

Plan | Actual | % Complete | Actual (beyond plan) | % Complete (beyond plan)

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Individual Research	1	8	1	8	100%
Proposal Development	1	8	6	5	100%
Request Funding	1	8	25	8	100%
Objectives and Functions	9	3	9	3	100%
Generation of Design Alternatives	11	4	11	4	100%
Selection of Design	14	3	14	3	100%
Individual Report Work	16	2	16	4	100%
Introduction and Problem Statement	17	4	19	3	100%
Existing and Revised Problem Statement	20	2	22	1	100%
Design Attributes	20	2	22	1	100%
Generation of Design Alternatives	20	2	22	1	100%
Design Selection	20	2	22	1	100%
Design Individual Parts	20	2	22	1	100%
3D Print Parts	20	6	22	6	100%
Construct Prototype	23	4	23	4	100%
Conclusions and Recommendations	27	1	27	1	100%
Edit Report	28	1	29	1	100%
Review Report	29	2	30	2	100%
Print Report	31	1	31	1	100%
Deliver Report	32	1	32	1	100%



VIII. Conclusions and Recommendations

The rice processing machine was successfully designed using the various design tools illustrated above in *Section II-V*. Specifically, by utilizing a list of the characteristics, a function means tree and an objective were utilized to identify the functions, means, and objectives. In addition, previous designs were analysed to see if they contain any desirable traits. Finally, multiple PCC's were used to rank the objective, and a final design was created based on the rankings. The generated final design (ENGI-2939) was compared with the previous design (ENGI-1112) to ensure a satisfactory improvement on the initial design concept was developed.

The design meets all the clients' requirements and objectives. It is comprised of a body that's made of wood which helps with durability. The attached legs can be folded 180^{o} to make the design more portable. Two rollers are used to dehusk the rice, driven by means of a rotating handle. The input is regulated by means of a feeder wheel that is controlled by a Geneva drive to increment the input.

The design can be improved by increasing the size of the feeder wheel to allow for more rice to be dehusked. A bigger funnel can also be used to hold more rice which will in turn decrease the amount of time before the funnel will have to be refilled. To increase durability and weather resistance, wood can be supplemented with metal. Further design recommendation for the next iteration of the design are discussed in *Suggestions and Recommendations.*

IX. References

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X. Appendix A: Final Design (ENGI-1112)

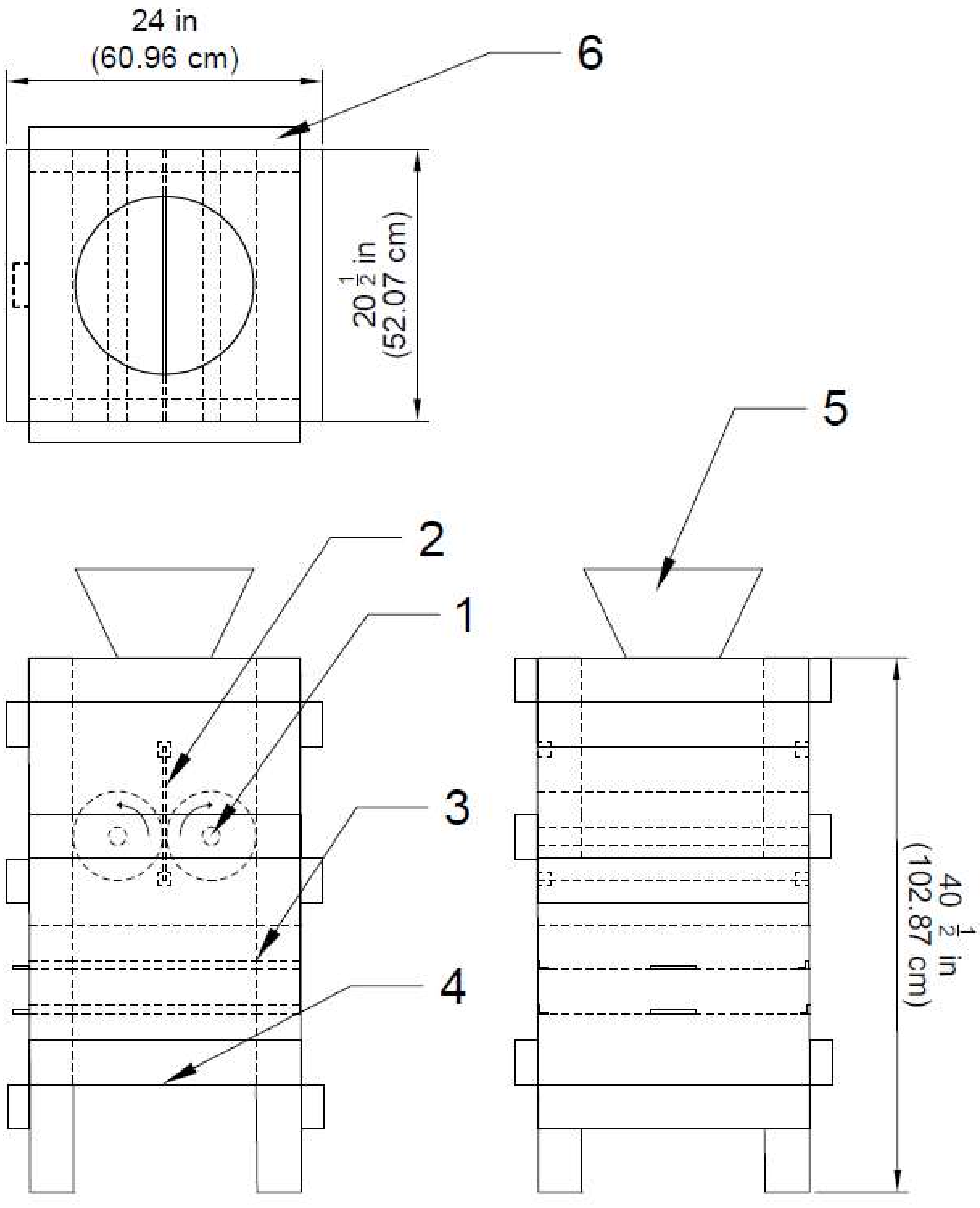


Figure 20: Dehusking concept: Group 1 (ENGI-1112)

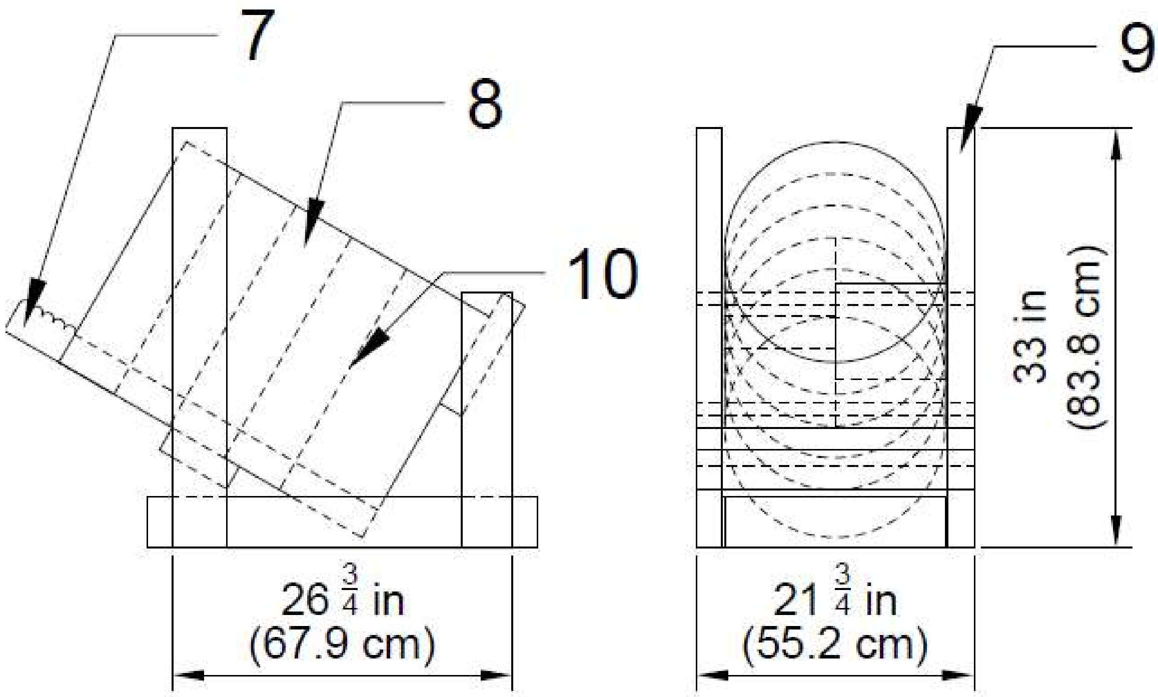


Figure 21: Roasting concept: Group 1 (ENGI-1112)

XI. Appendix B: Bill of Materials (ENGI-1112)

Callout	Description	Approximate Cost ($)	Ref.
1	Rolling pin / wooden dowels	14.41	[6]
2	Steel mesh	55.19	[7]
3	Filter medium	23.09	[8]
4	Collection bucket	3.97	[9]
5	Funnel	3.98	[10]
6	Lumber	5.24 (x6) = 31.44	[11]
7	Handle	14.99	[12]
8	Galvanized steel trash can	32.99	[13]
9	Lumber - 2 x 4 x 8’ (as required)	5.24 (x6) = 31.44	[11]
10	Separation plate	13.28 (x3) = 53.12	[14]
	Total Cost:	264.62	

Table 14: Bill of materials (ENGI-1112)

XII. Appendix C: Design Concept (ENGI-2939)

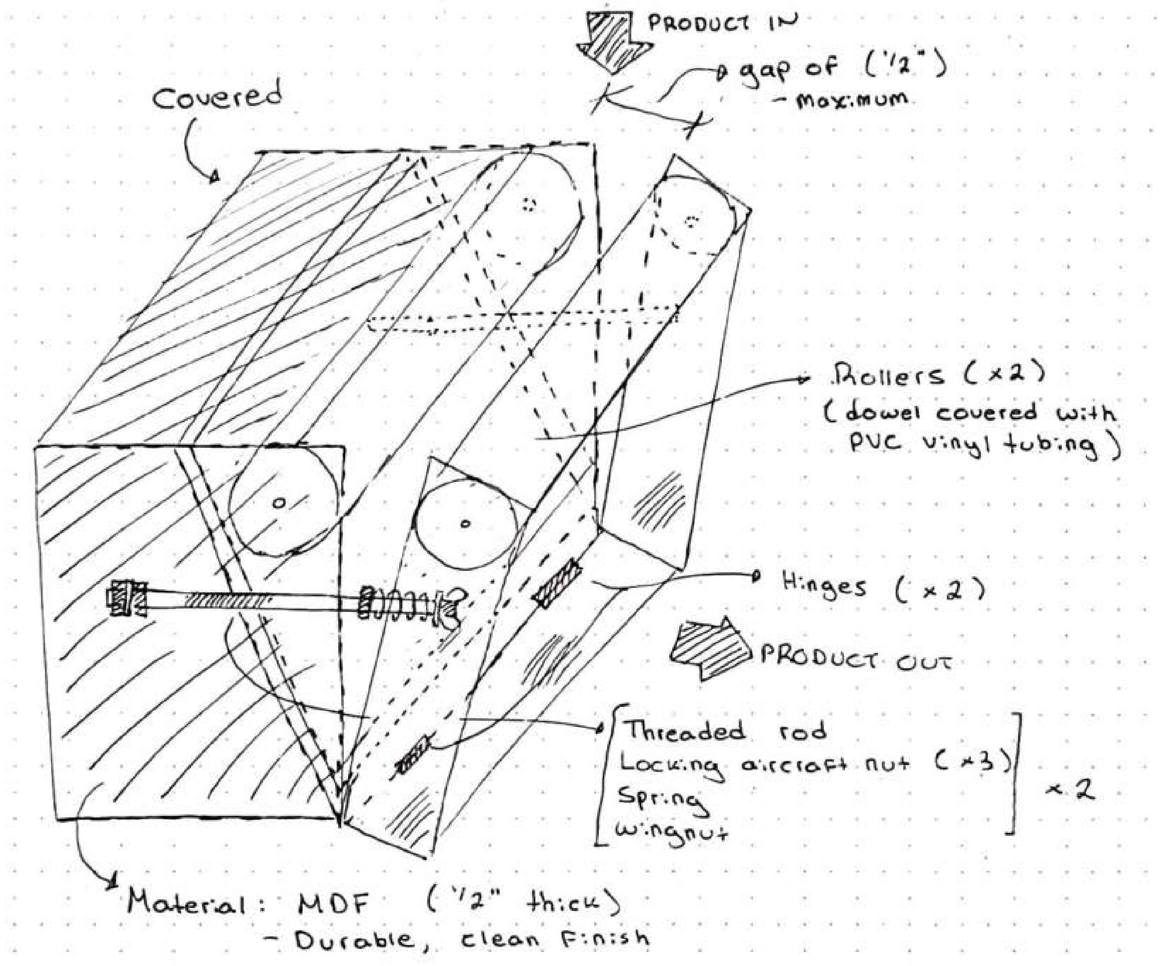


Figure 22: Design concept: Rollers (ENGI-2939)

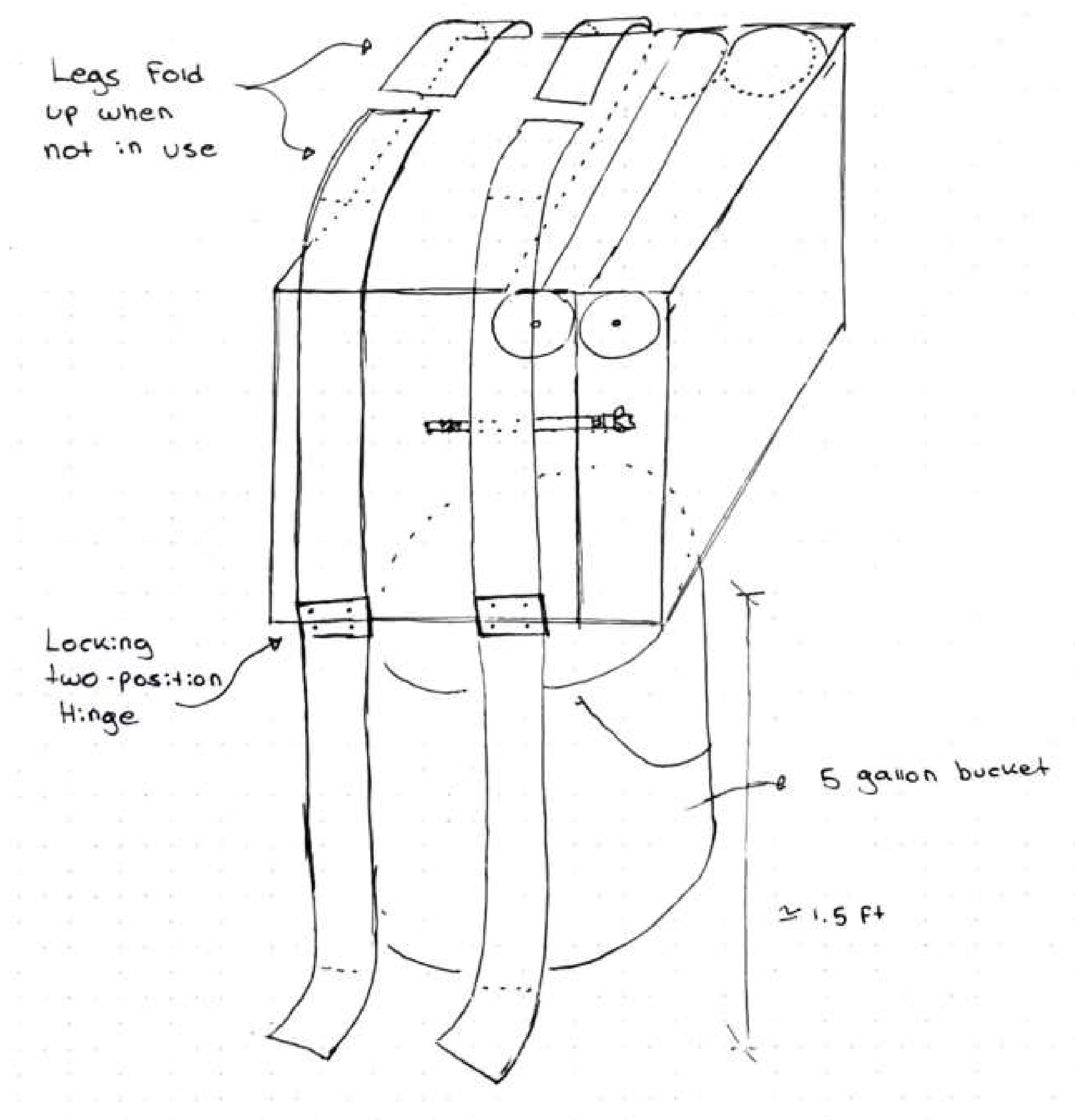


Figure 23: Design concept: Legs (ENGI-2939)

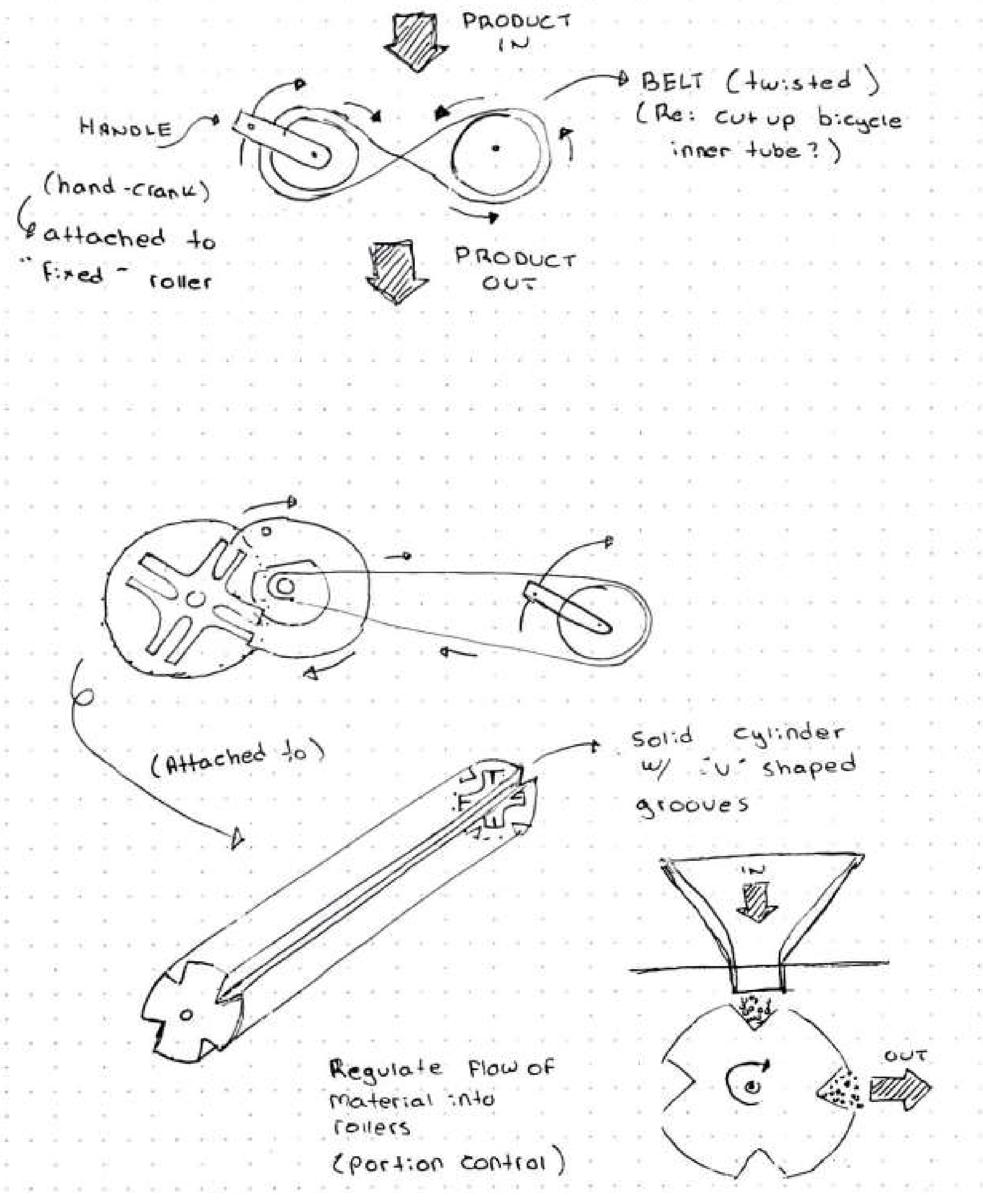
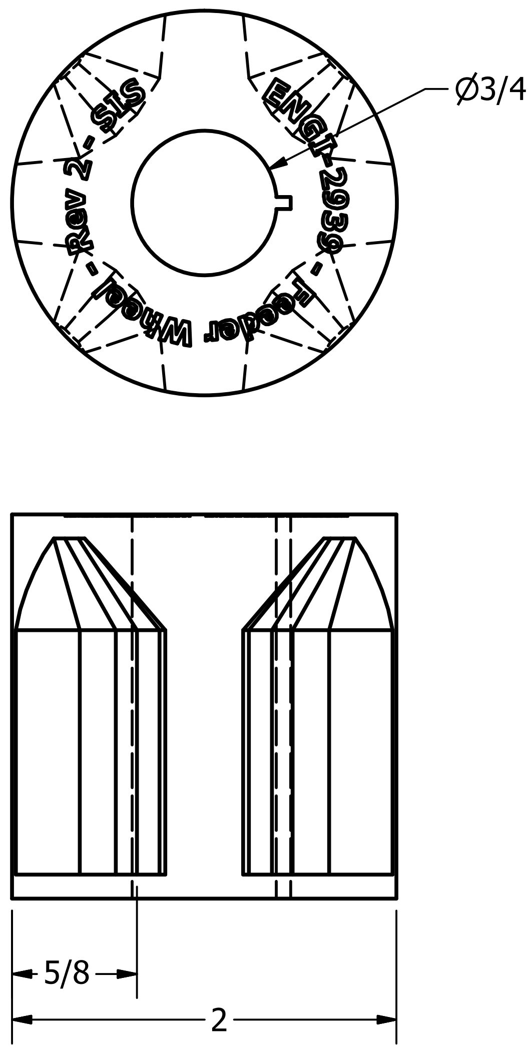
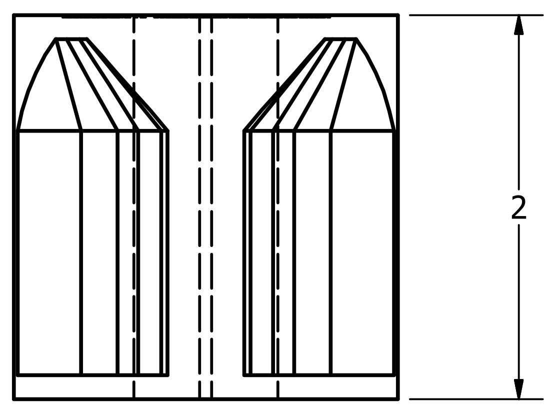
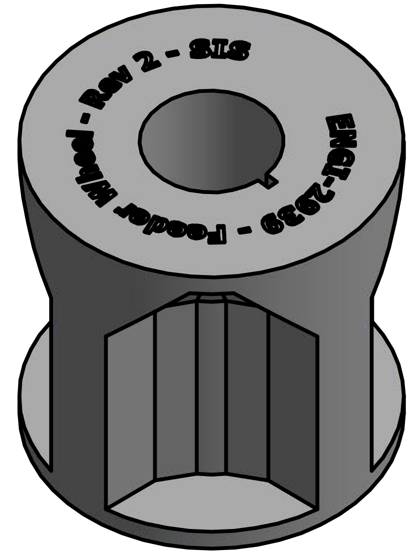


Figure 24: Design concept: Drive System (ENGI-2939)







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CHECKED				
QA		TITLE		
MFG		Feeder Wheel		
APPROVED				
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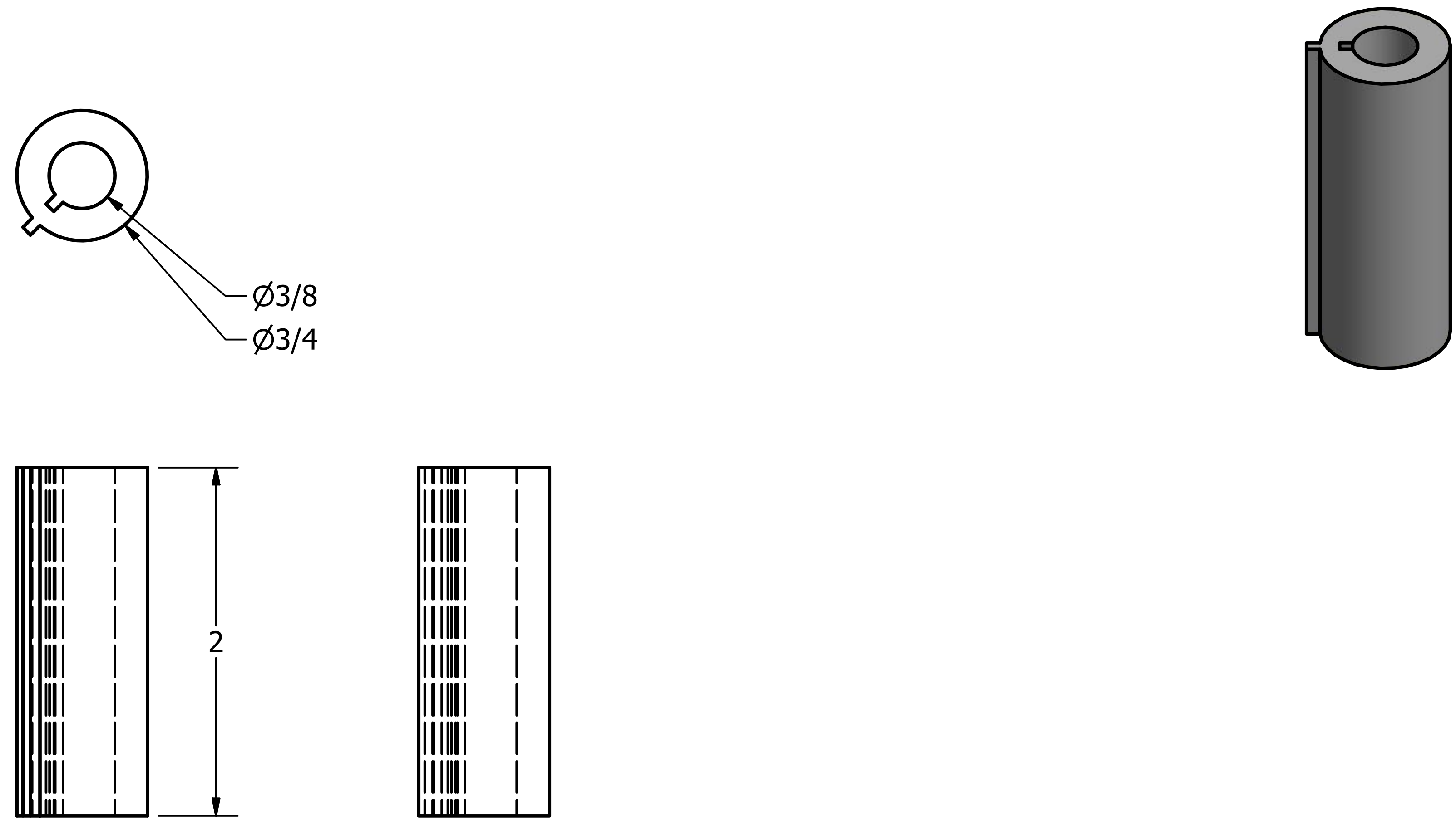

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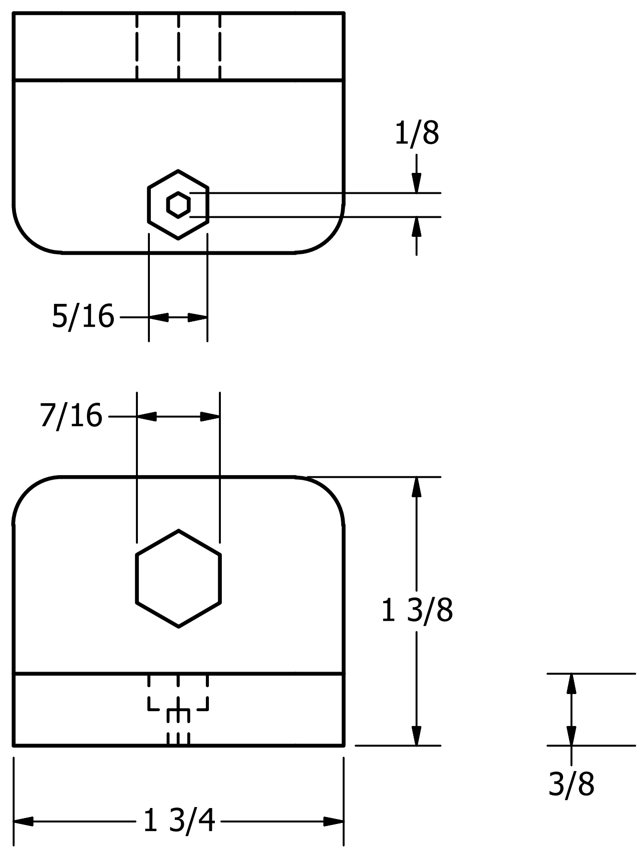

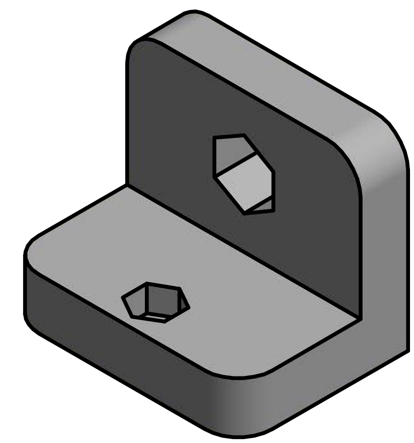

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MFG		
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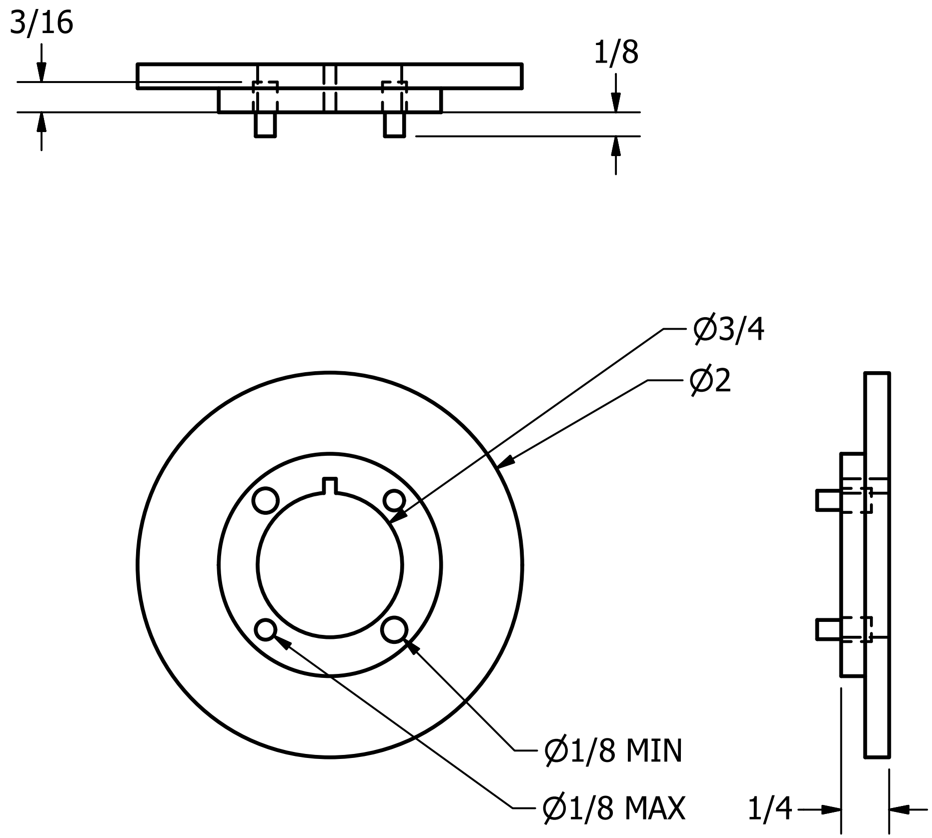

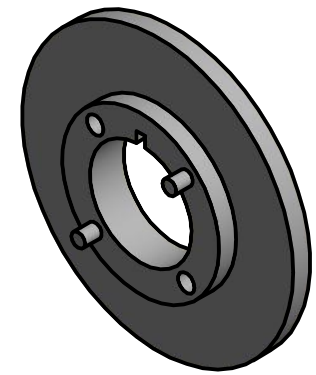

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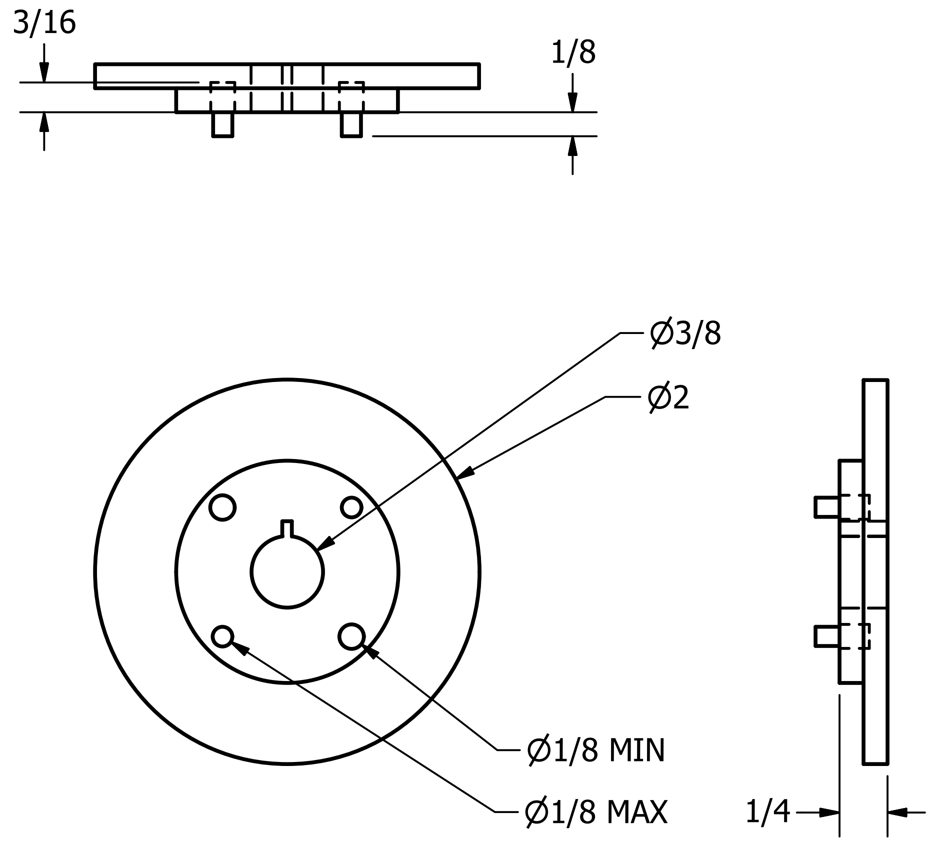

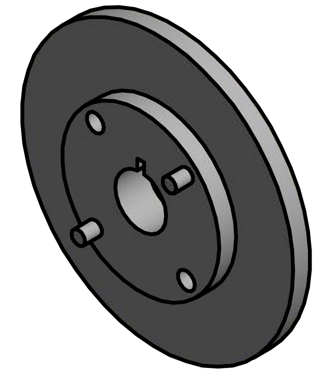

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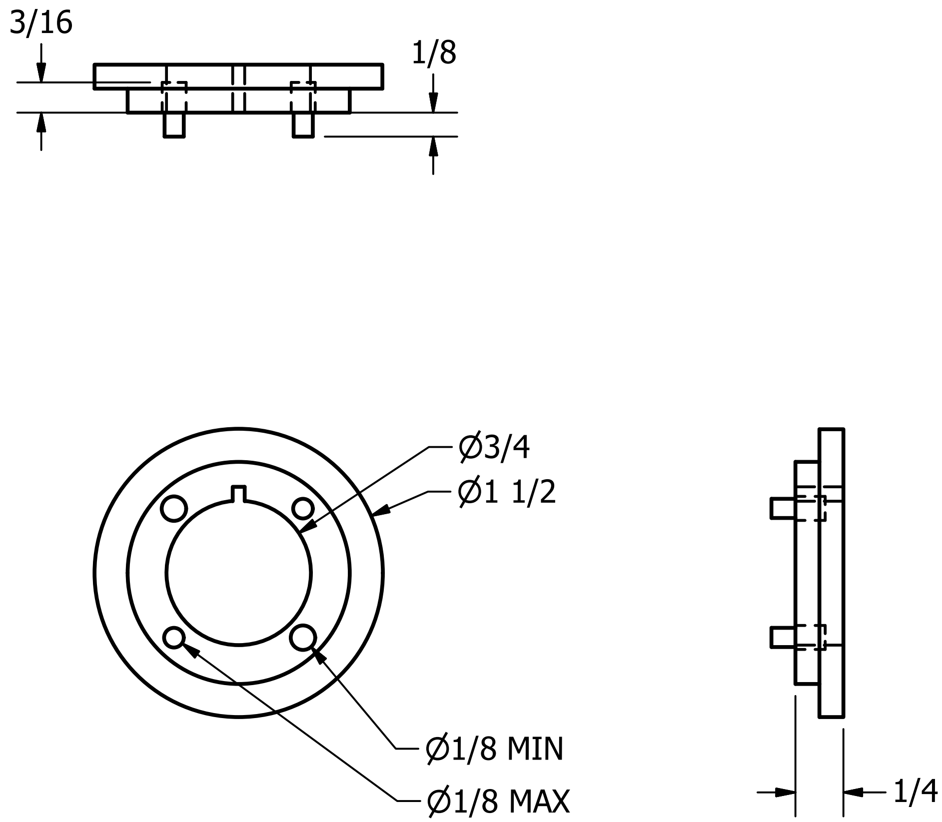

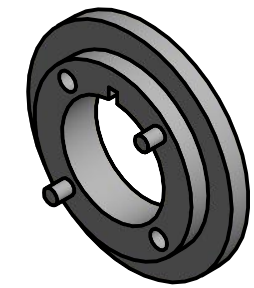

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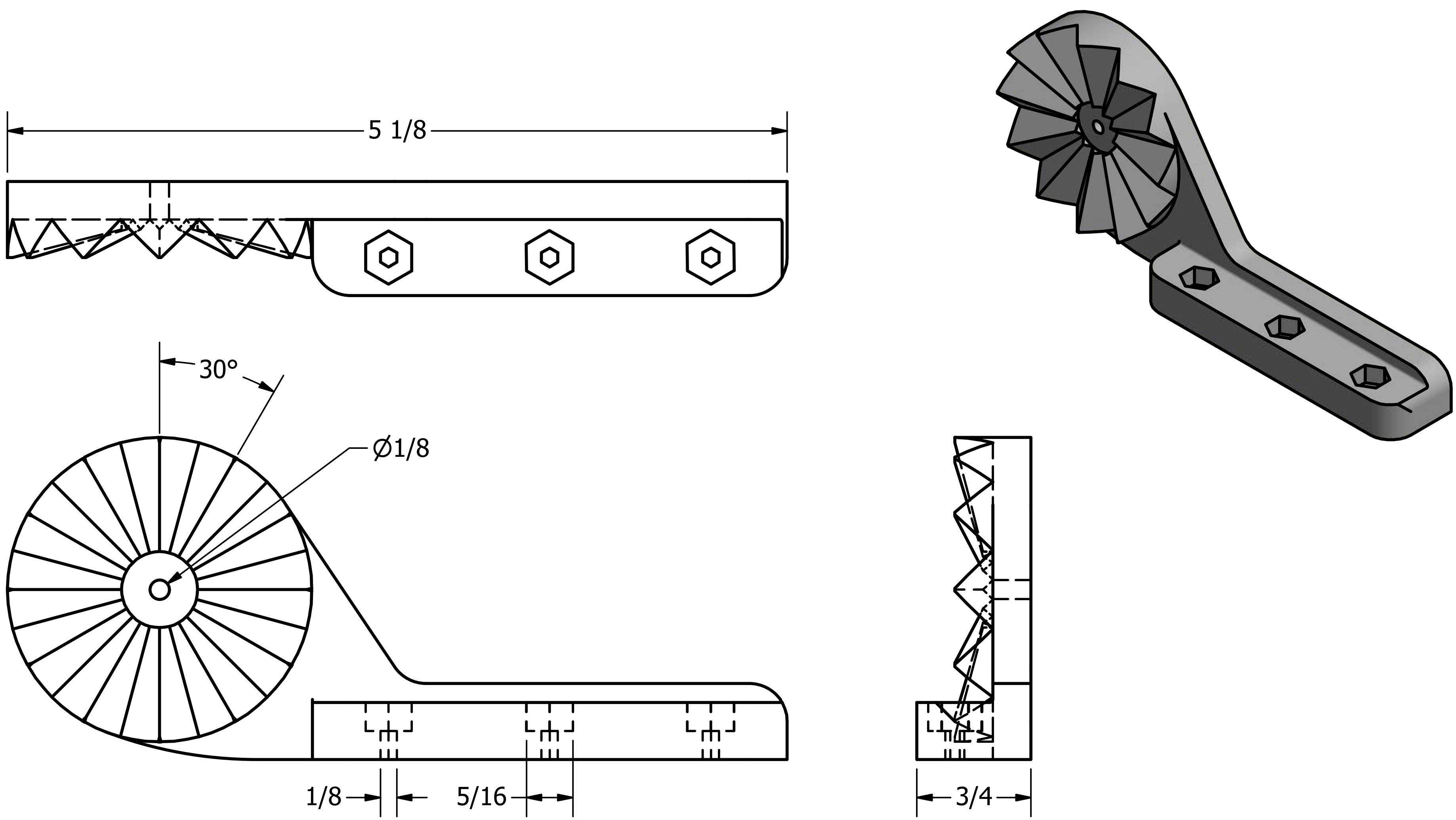

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MFG		
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Rice Machine 2018 - ENGI-2939

TITLE

Locking Hinge A

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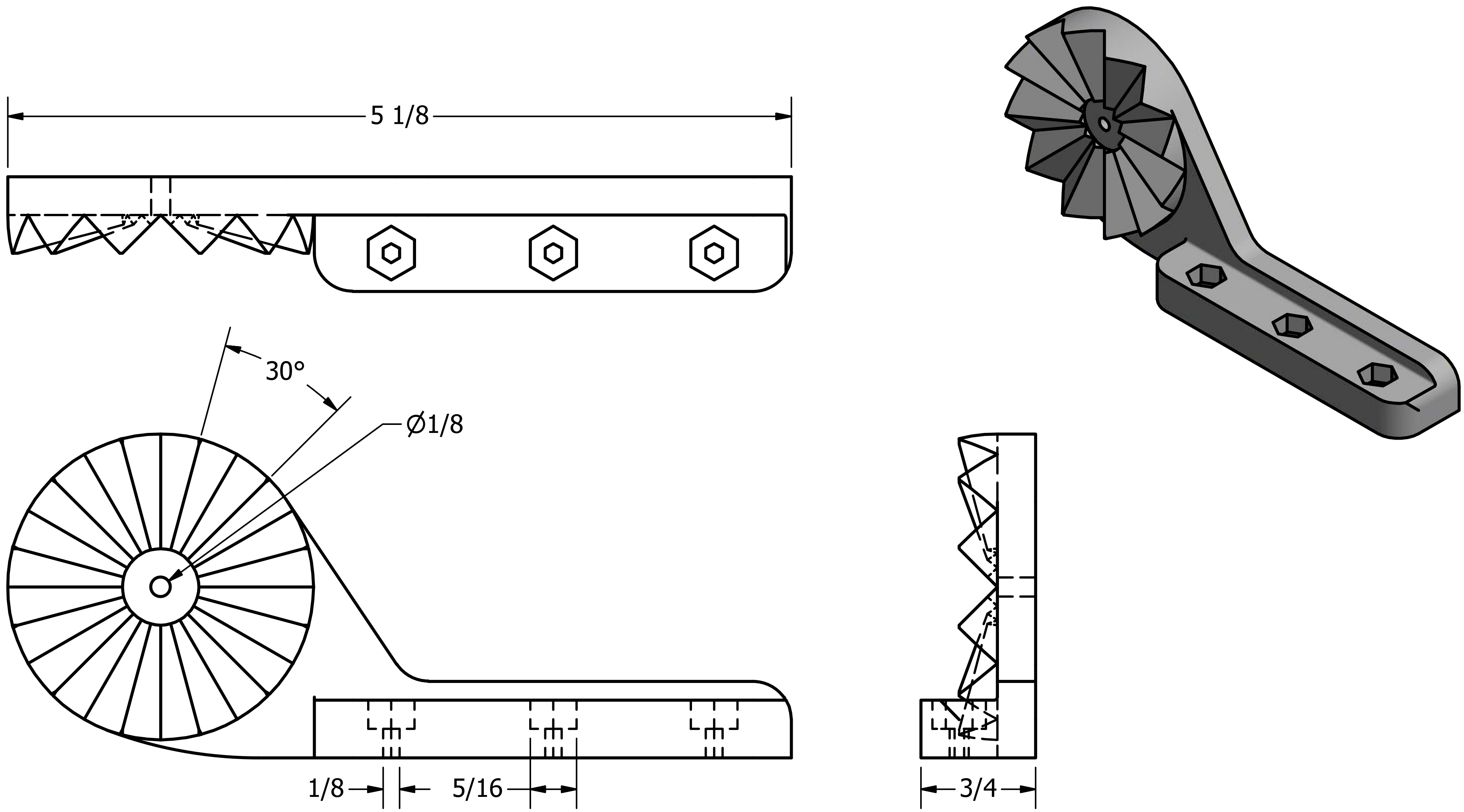
SCALE 1 : 1 SHEET 7 OF 25



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QA					
MFG					
APPROVED					
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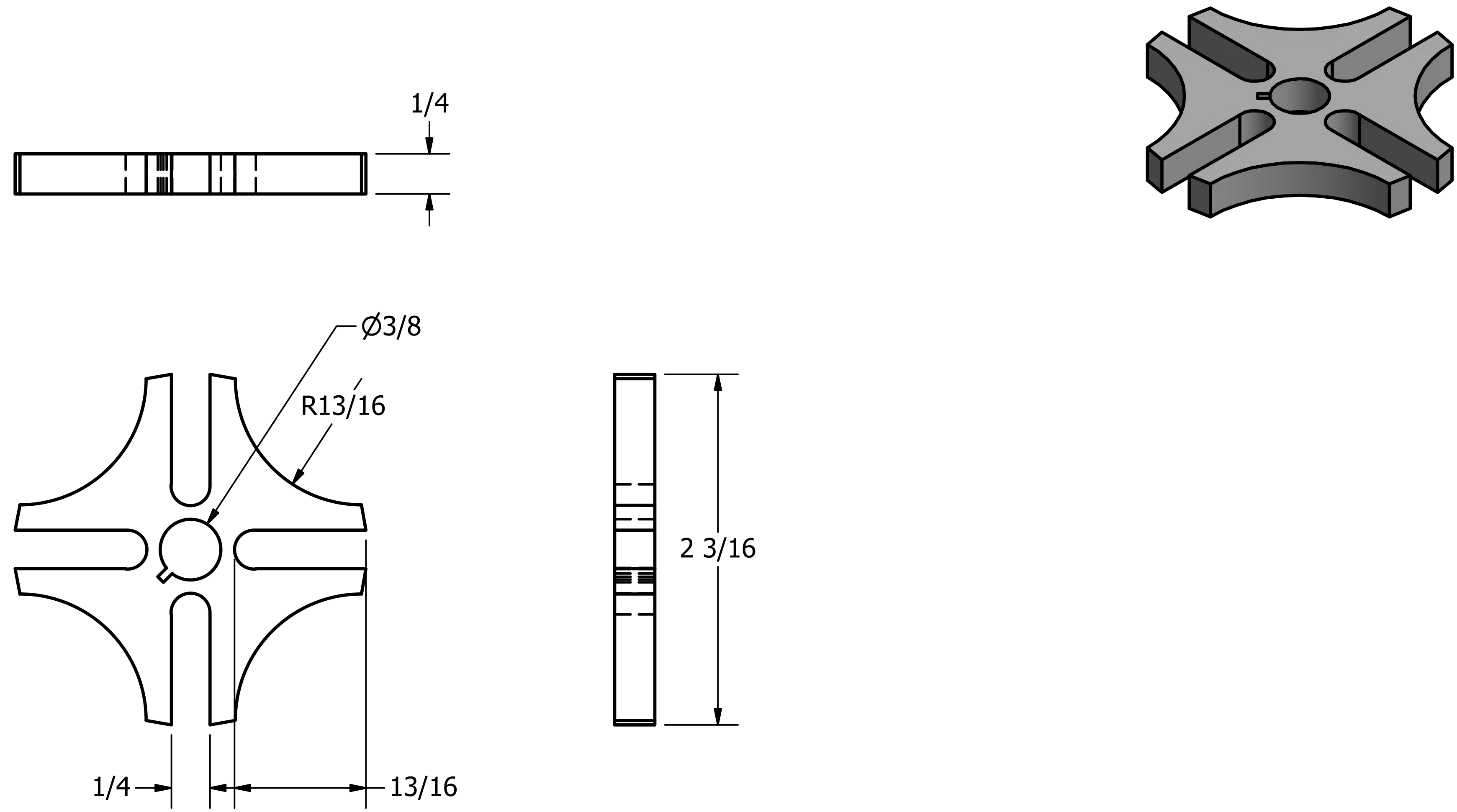

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APPROVED					
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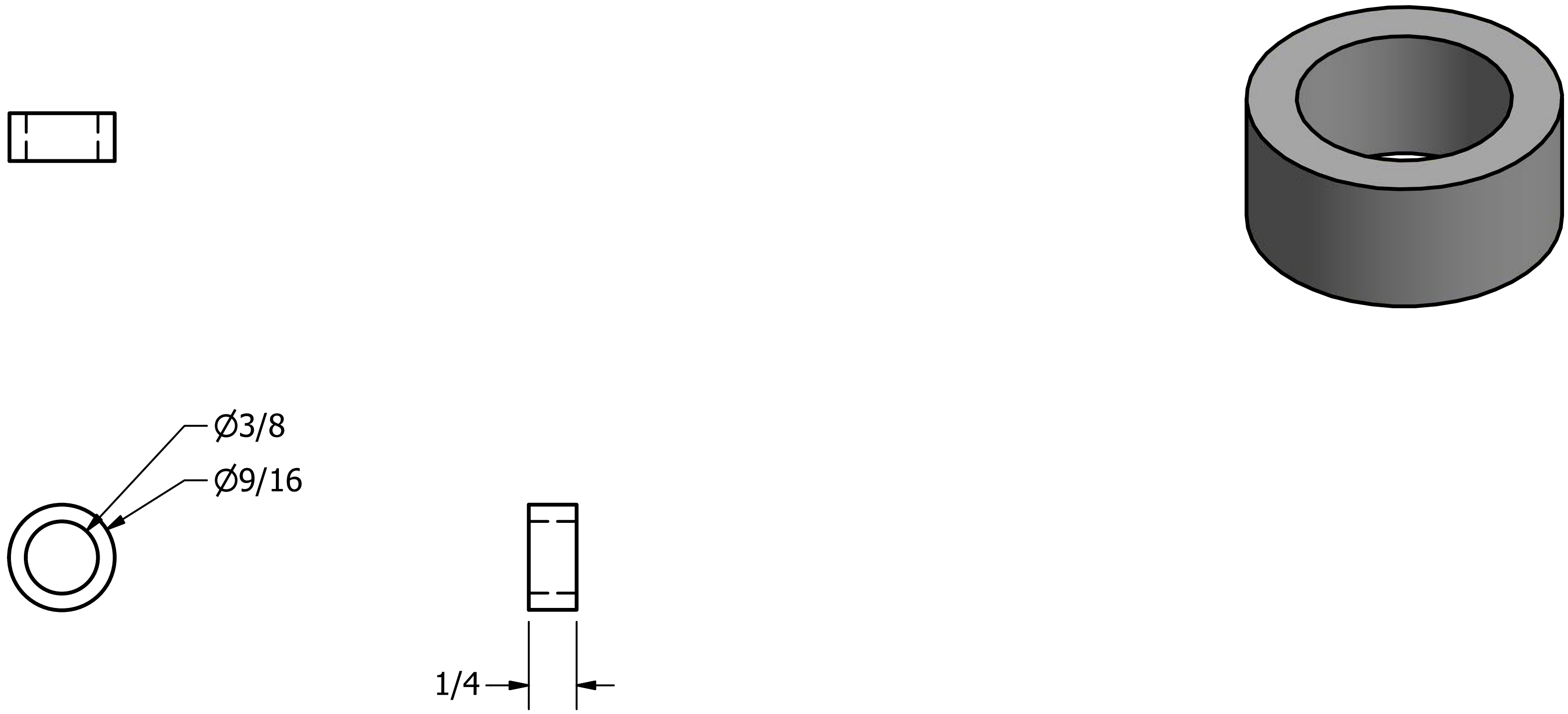

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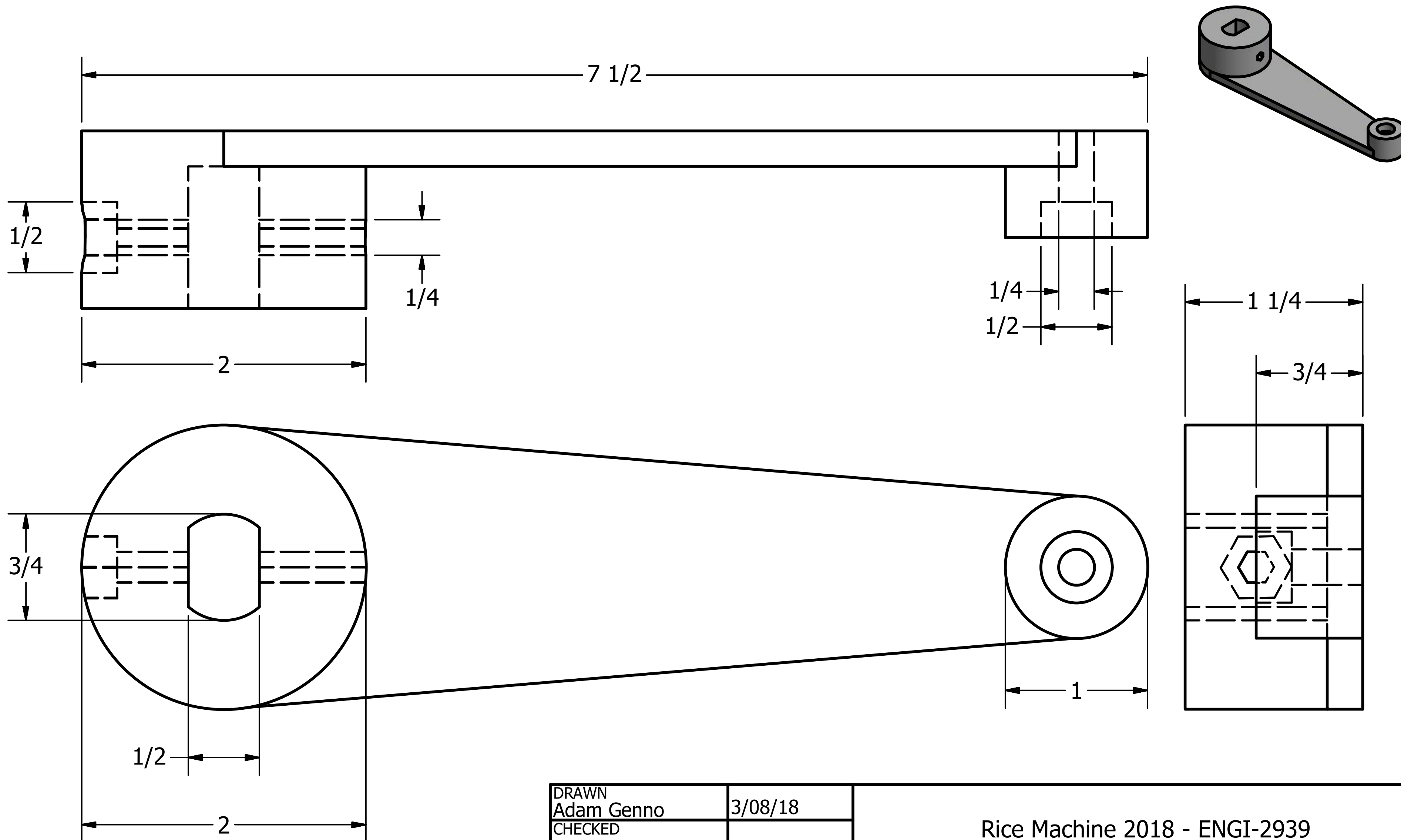

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MFG				
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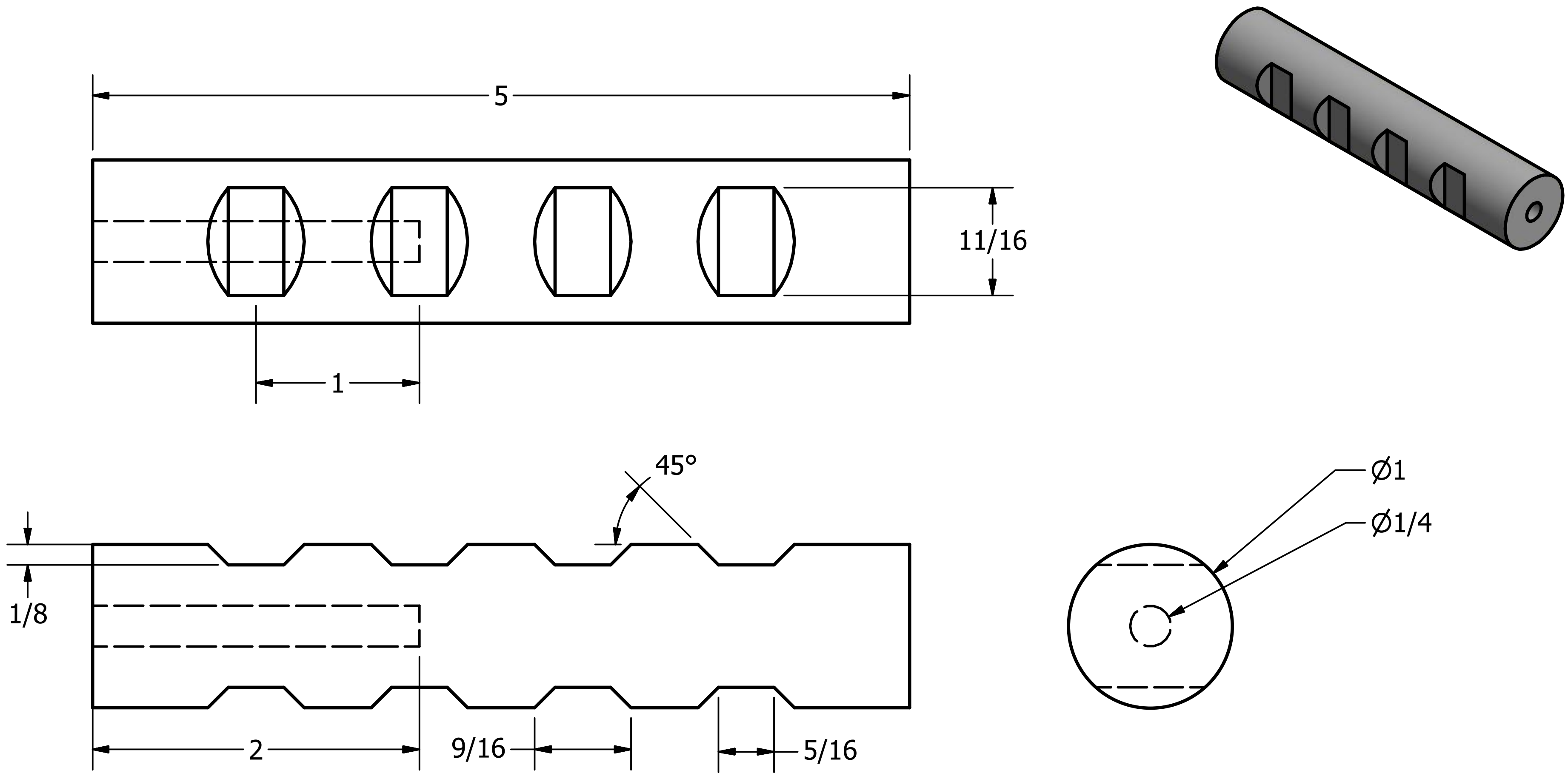

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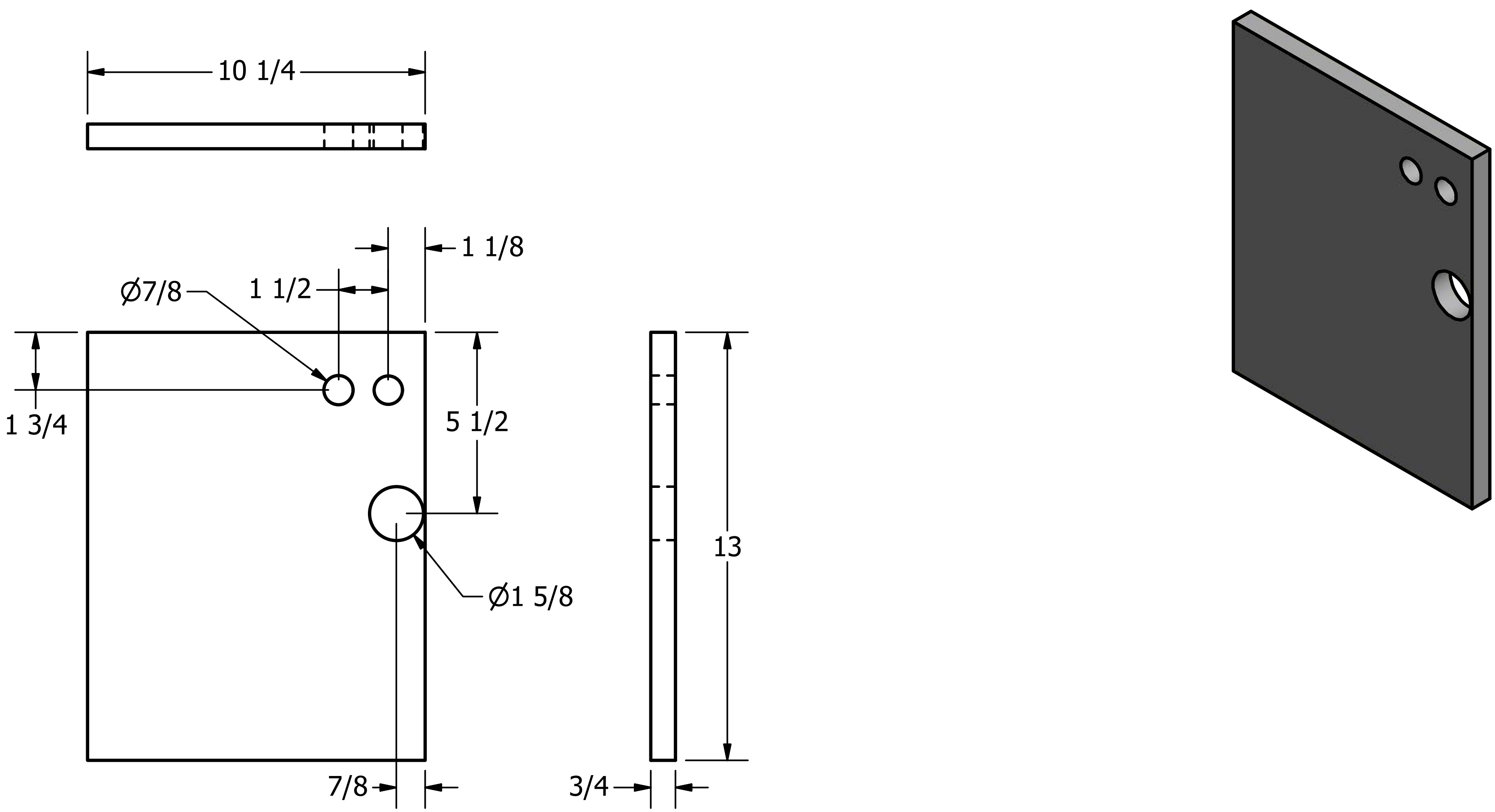

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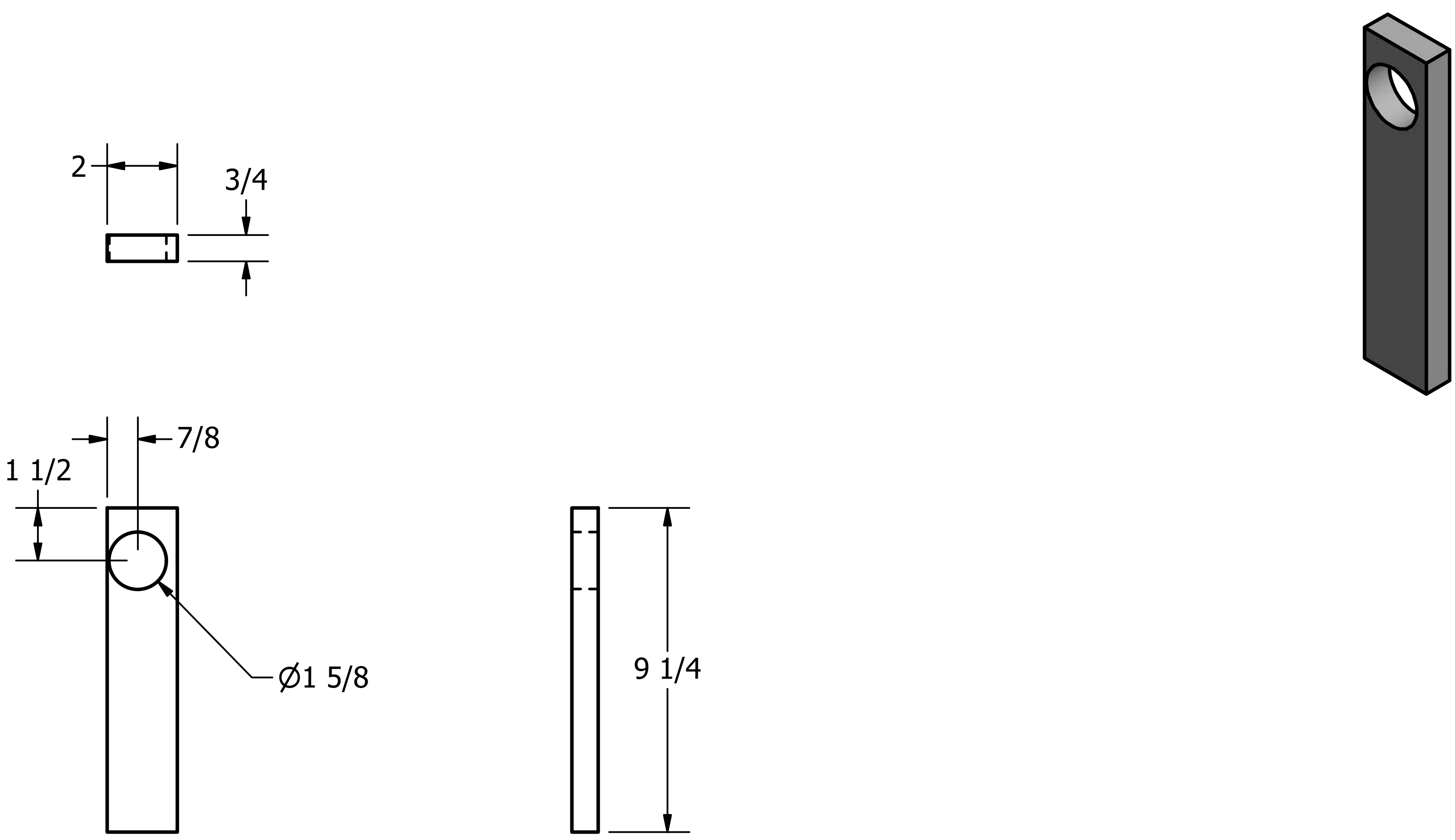

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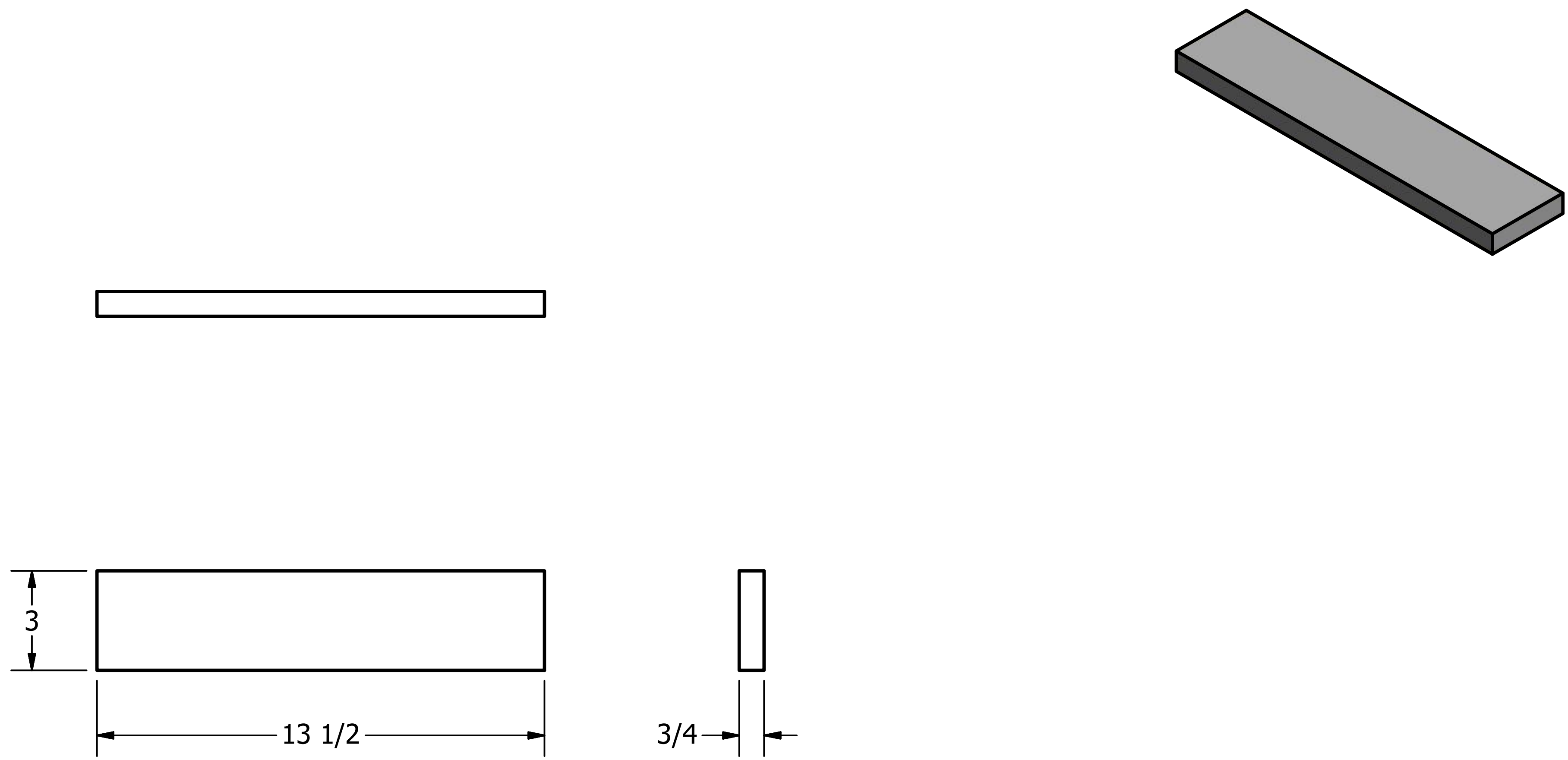

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MFG	
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Rice Machine 2018 - ENGI-2939

TITLE

Box C

SIZE	DWG NO	REV
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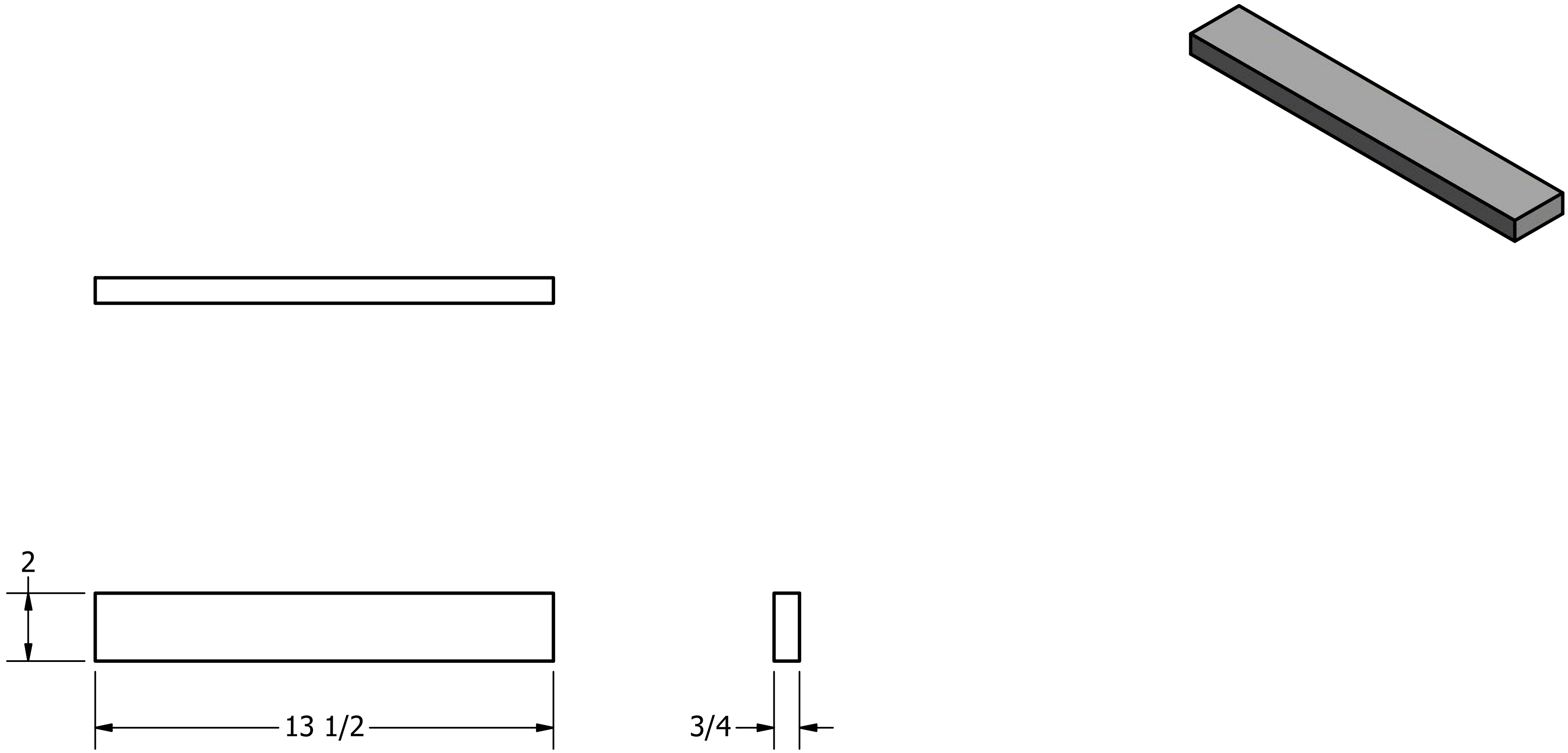

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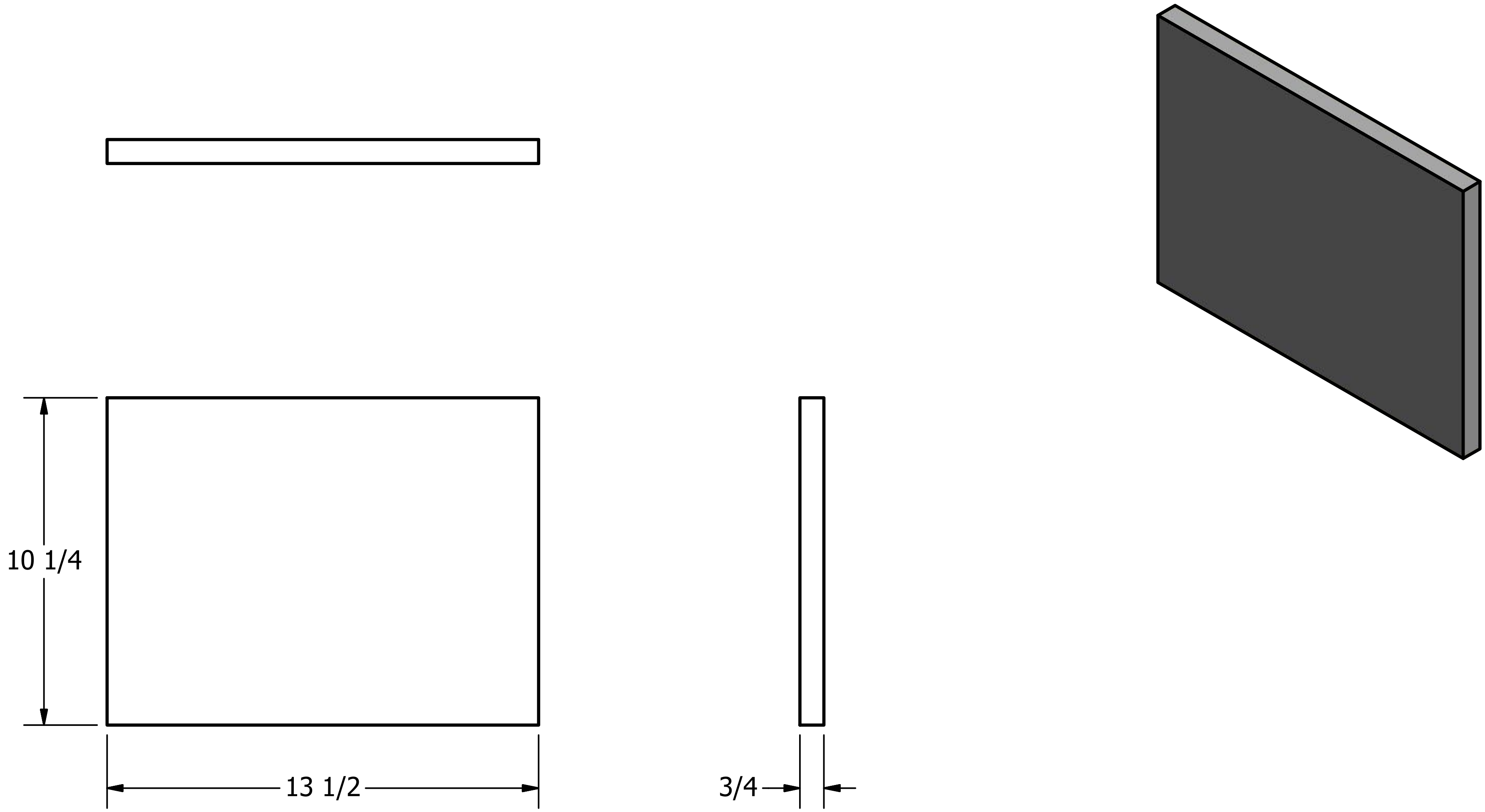

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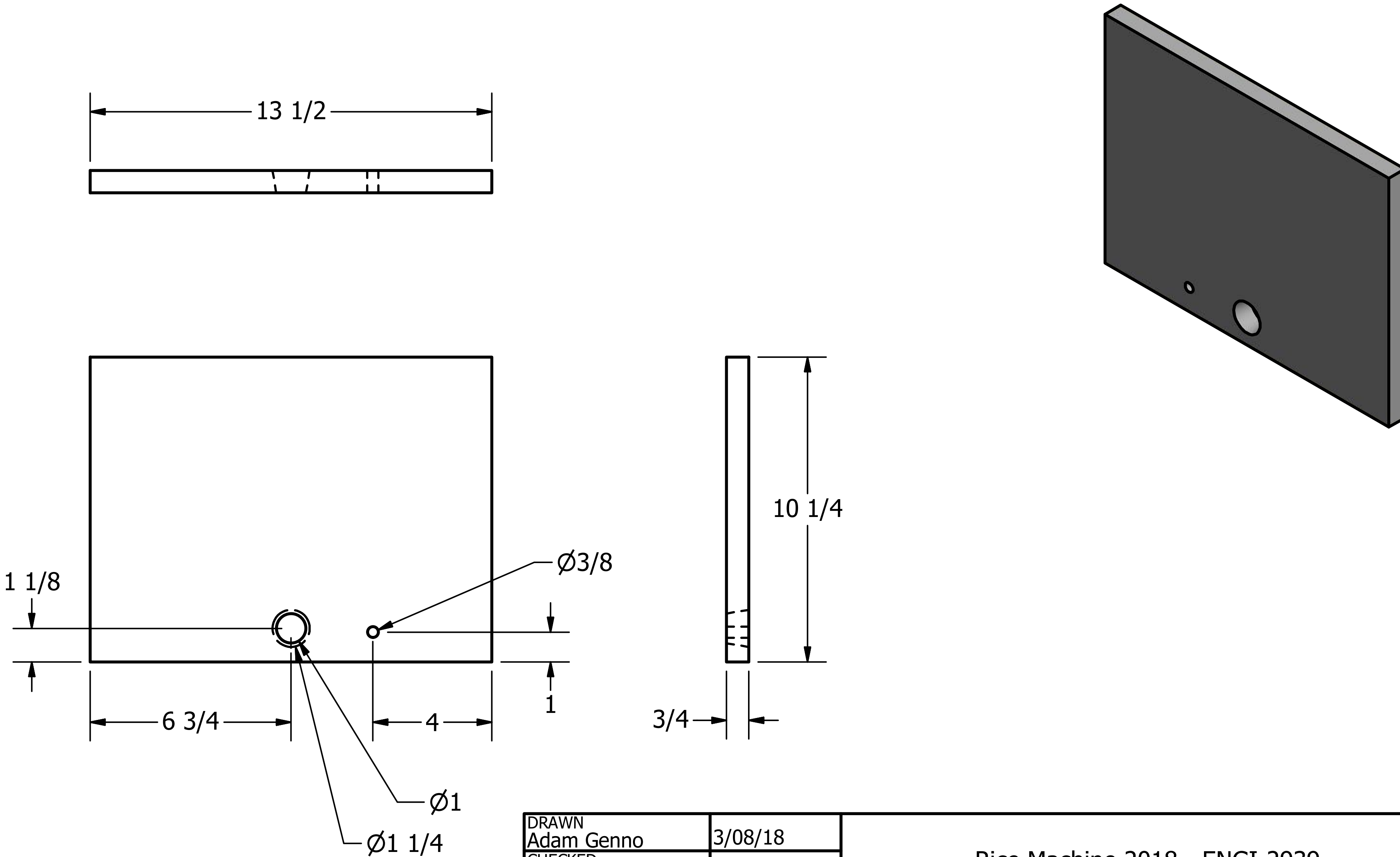
REV 1



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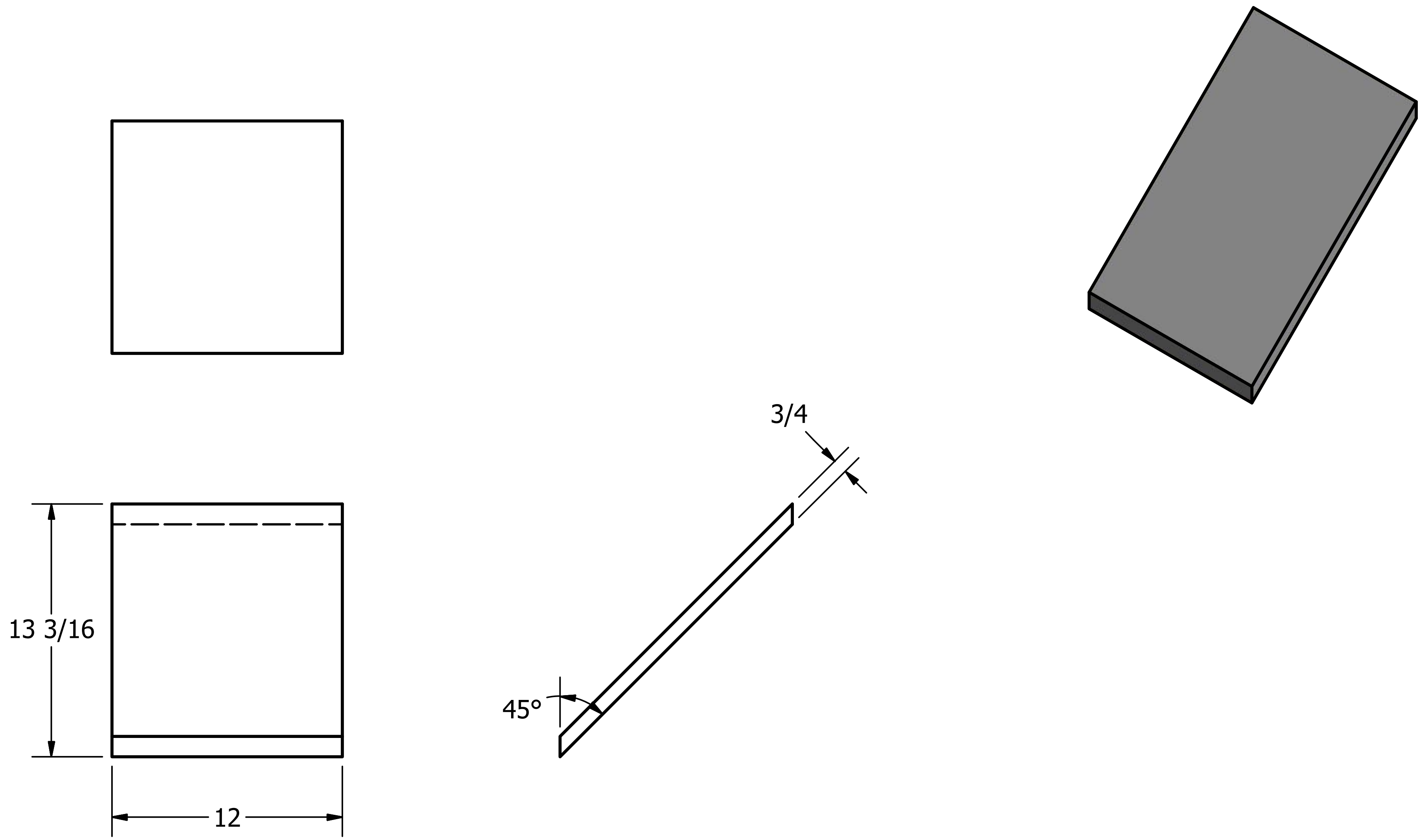

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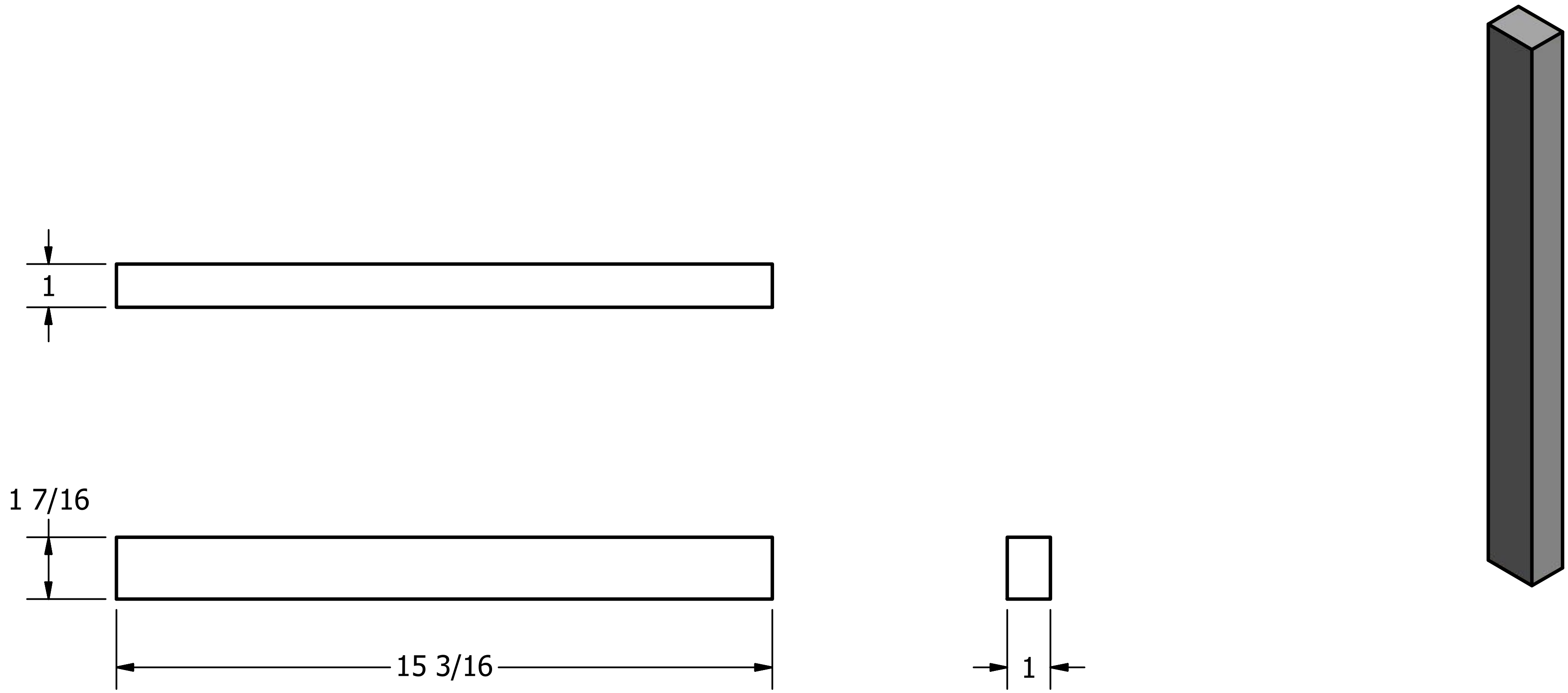

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QA		Leg A			
MFG					
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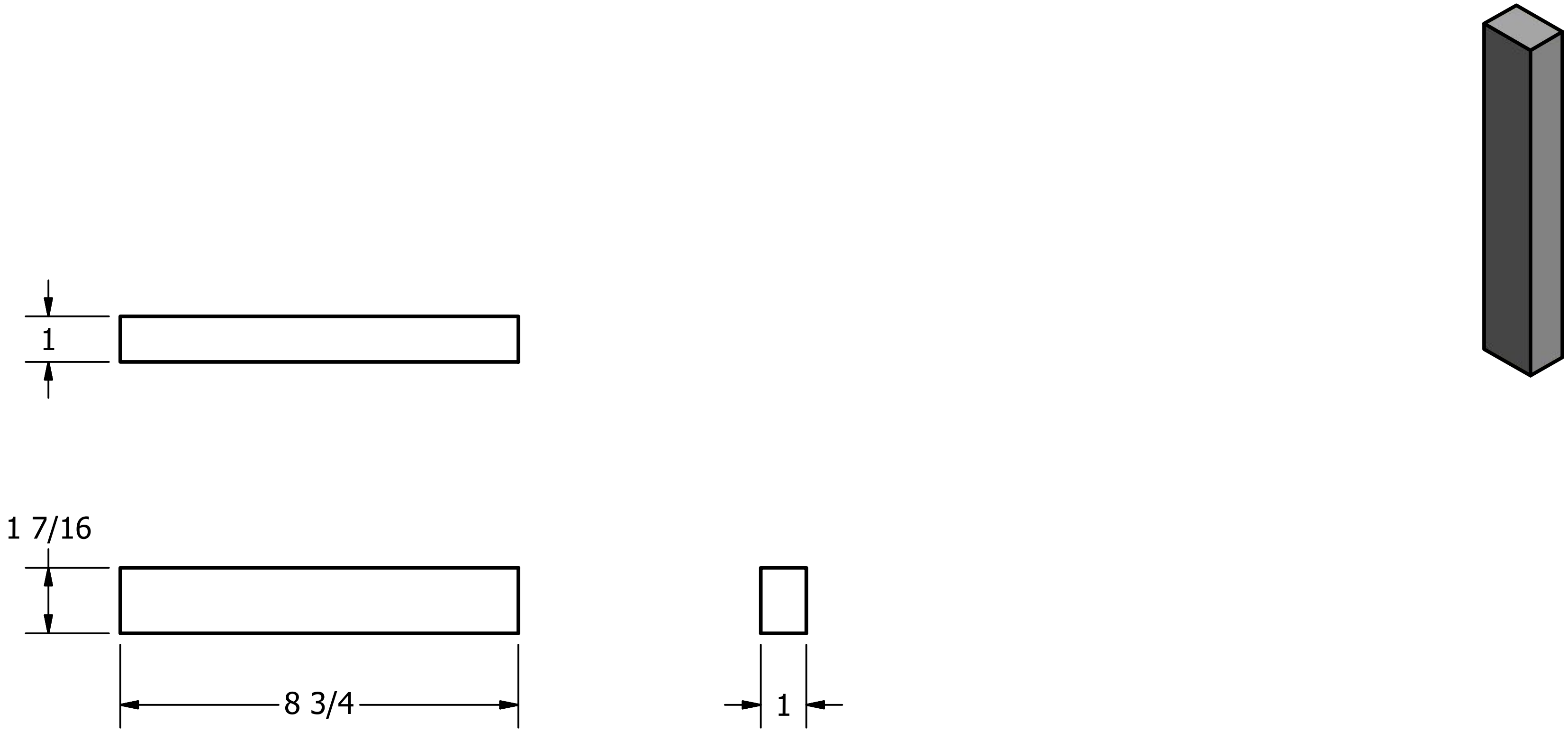

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QA		Leg B			
MFG					
APPROVED					
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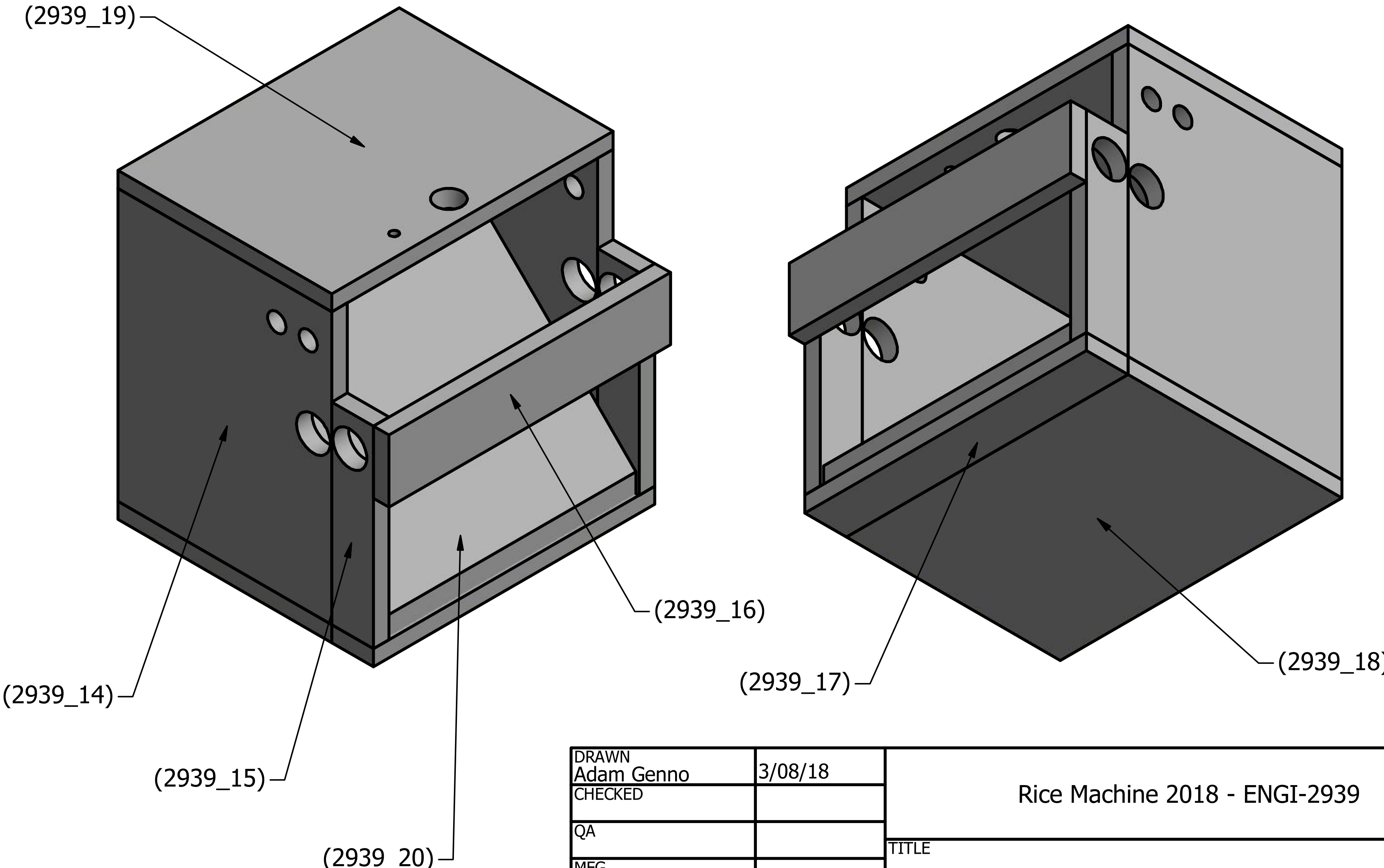

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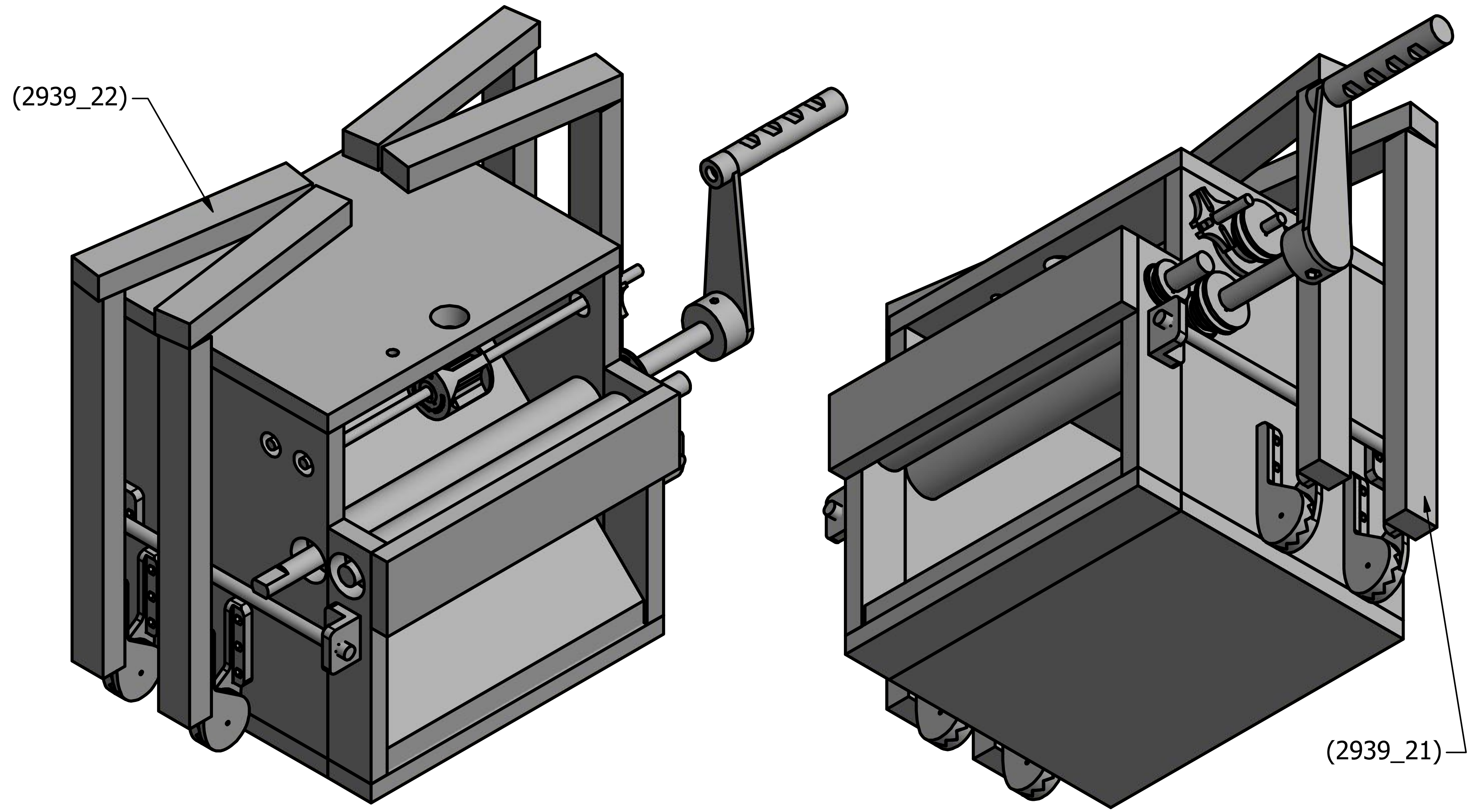

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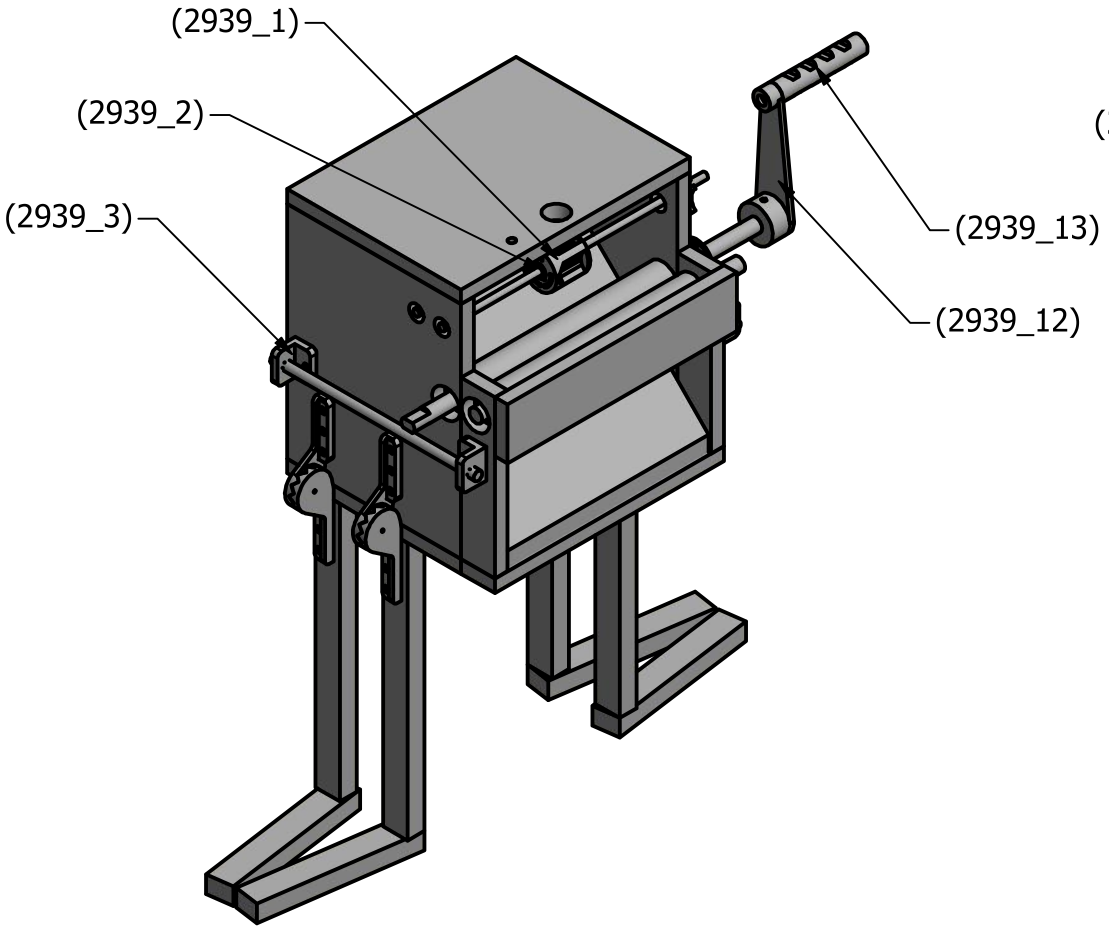
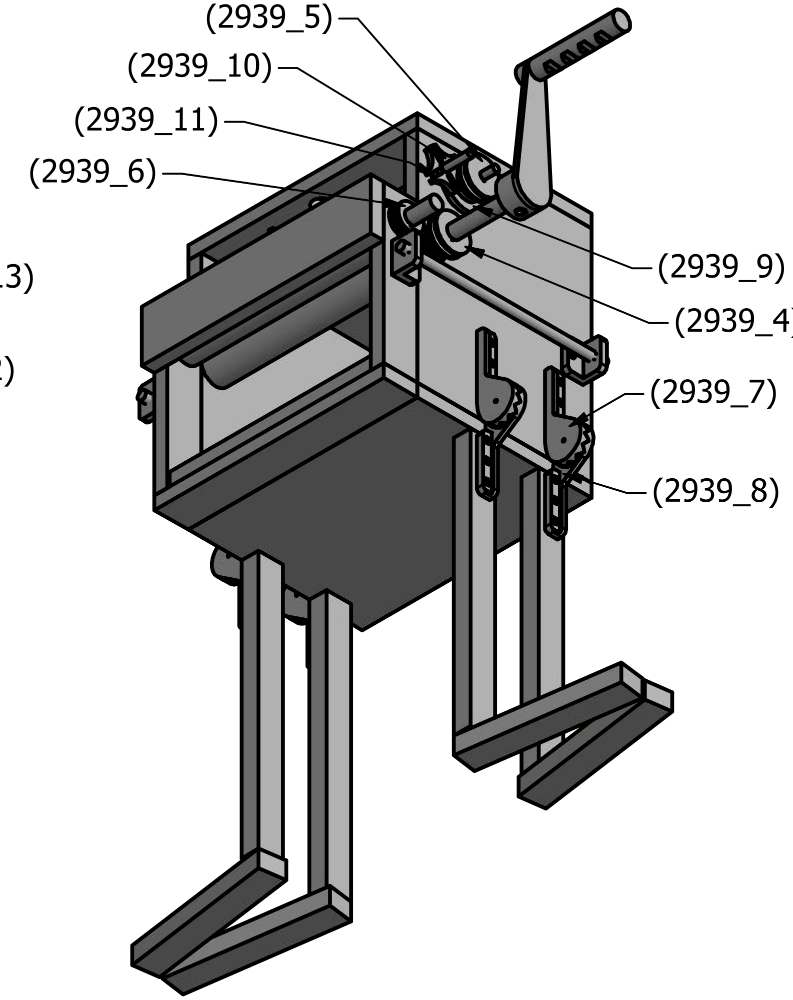




DRAWN Adam Genno	3/08/18	Rice Machine 2018 - ENGI-2939
CHECKED		TITLE Assembly - Unfolded
QA		SIZE A
MFG		DWG NO 2939_25
APPROVED		REV 1
		SCALE 1 : 8
		SHEET 25 OF 25

XIV. Appendix E: Bill of Materials (ENGI-2939)

Material	Price	Quantity	Total	Retailer
3/4" ID, 1" OD PVC	$21.79	1	$21.79	Lowe's
1" ID, 1-1/4" OD PVC	$9.58	1	$9.58	Lowe's
1-1/4" ID, 1-3/4" OD Braided PVC	$11.98	1	$11.98	Lowe's
5/8 x 2-1/2 Compression Spring	$2.08	2	$4.16	Home Depot
Utility Spring (Compression)	$2.21	2	$4.42	Home Depot
10-24 Brass Wing Nut	$0.93	4	$3.72	Home Depot
3/8-16 Steel Wingnut	$0.69	2	$1.38	Home Depot
3/8-16 x 12" Threaded Rod	$2.18	2	$4.36	Home Depot
3/8-16 Tensilock Nut	$0.93	6	$5.58	Home Depot
1/8 x 1-1/2 Flat Soc Stove Bolts w/nut	$2.97	2	$5.94	Home Depot
10-24 x 1-1/2 Machine Screw w/ nut	$0.34	4	$1.36	Home Depot
#6 Bs Sae Steel Locking Washer	$0.09	24	$2.16	Home Depot
8-2" Wood Screws	$9.44	1	$9.44	Home Depot
1/8 x 1-1/2 Machine Screw	$0.00	1	$0.00	Makerspace
10-24 Machine Screw	$0.88	1	$0.88	Home Depot
10-24 Flat Washer	$0.21	1	$0.21	Home Depot
3/8” ID, 7/8" OD Bearing	$7.04	3	$21.12	Canadian Bearings
3/4" ID, 13/8" OD Bearing	$12.19	4	$48.76	Canadian Bearings
3/4" x 11/16" Brass Hinges	$4.24	1	$4.24	Home Depot
1/16 x 3/4 x 3 Aluminum Angle Bracket	$8.34	1	$8.34	Home Depot
6 x 24 Sheet Metal 22G Galvanized	$8.46	1	$8.46	Home Depot
Plywood (3/4" x 4' x 8')	$56.22	1	$56.22	Home Depot
1 x 2 Poplar Boards	$1.93	4	$7.72	Home Depot
3/8" Wooden dowel	$1.29	1	$1.29	Home Depot
3/4" Wooden dowel	$3.80	1	$3.80	Home Depot
3D Printing Filament	$24.95	1	$24.95	Amazon.ca
Quick-set Epoxy	$5.97	1	$5.97	Home Depot
Wood glue	$10.67	1	$10.67	Home Depot
Bicycle inner tubes (used)	$0.00	1	$0.00	Bike Shack
5-gallon bucket	$3.97	1	$3.97	Home Depot
Funnel	$4.98	1	$4.98	Home Depot
			Total:	$301.25
			with tax:	$340.41

Table 15: Bill of materials (ENGI-2939)

XV. Appendix F: Fabrication Equipment

Description	Approximate Cost ($)		Ref.
Prusa i3 MK3 3D Printer Kit	749.00		[24]
Dremel Saw	188.27		[25]
Milwaukee Drill	199.00		[26]
RYOBI drill bit set	52.20		[27]
ToolMaster sawhorse	49.98 (x2) $= 99.96$		[28]
DEWALT clamps	20.88 (x2) $= 41.76$		[29]
Estwing hammer	29.98		[30]
	Total Cost:	1360.17	
	With tax:	1536.40	

Table 16: Fabrication equipment costs

XVI. Appendix G: 3D Printing Times

NOTE: All times based off a layer height of 0.02 mm, with rectilinear infill of 25%.

DWG NO.	Part	Printing Time (Hours)	Quantity	Total Time (Hours)
2939_1	Feeder Wheel	5	1	5
2939_2	Feeder Wheel Insert	1	1	1
2939_3	L-Bracket	2	4	8
2939_4	Belt Spindle (3/4 ID, 2 OD)	1	1	1
2939_5	Belt Spindle (3/8 ID, 2 OD)	1	1	1
2939_6	Belt Spindle (3/4 ID, 1 1/2 OD)	1	2	2
2939_7	Locking Hinge A	4	4	16
2939_8	Locking Hinge B	4	4	16
2939_9	Geneva Drive A	2	1	2
2939_10	Geneva Drive B	1	1	1
2939_11	Geneva Drive B Spacer	1	1	1
2939_12	Removable Handle	4	1	4
2939_13	Handle Grip	4	1	4
			Total Time:	62

Table 17: 3D printing times

XVII. Appendix H: Task Times

Task	Time to Complete (Hours)
Cut plywood for box assembly	4
Measure and cut dowels, assemble rollers	2
Mark plywood, bore holes for bearings	2
Assemble box and rollers	8
Cut legs for box assembly	1
Assemble legs, tighten fasteners	2
Total Time:	19

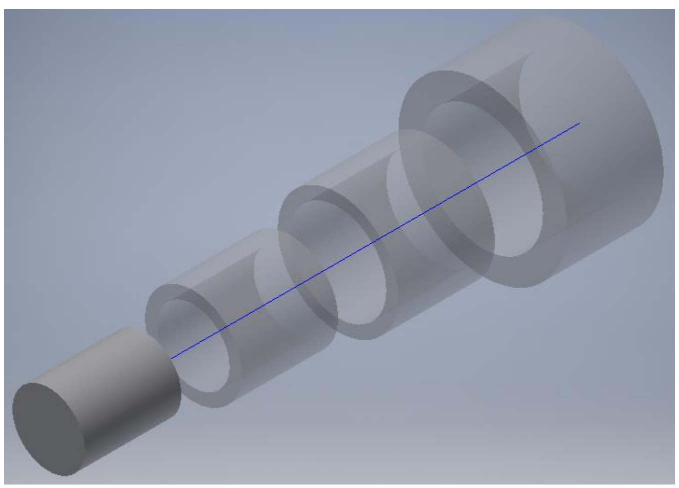
Table 18: Task times

XVI. Appendix G: Assembly Instructions

Step 1		
Part	**Description**	**Quantity**
3/4" ID, 1" OD	PVC tubing 12” length	2
1" ID, 1-1/4" OD	PVC tubing 12” length	2
1-1/4" ID, 1-3/4" OD	PVC tubing 12” length	2
3/4” Dowel	15-1/2“ long	1
3/4” Dowel	21-1/2“ long	1

Instructions:

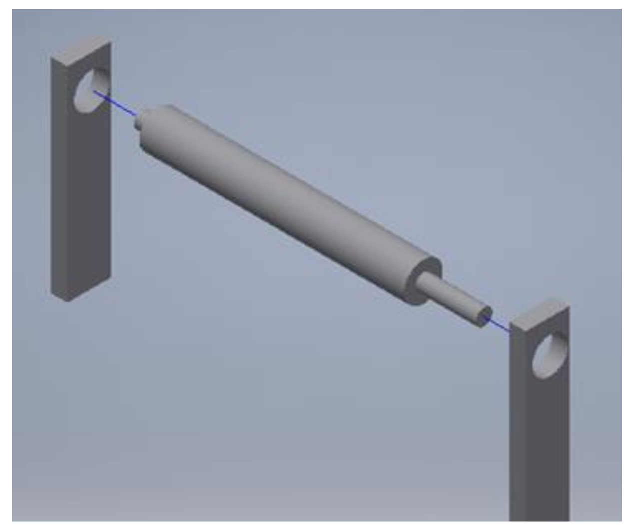
- Insert dowel into entire length of smallest size of PVC tubing. Repeat for next largest size until outer diameter is equal to 1-3/4”. Repeat for other dowel.
- Utilize *Assembly Reference A* for dimensions.



Step 2		
Part	**Description**	**Quantity**
DWG NO: 2939_15	Box B	2
Bearing	3/4” ID, 1-5/8” OD	2
3/4” Dowel	15-1/2“ long	1

Instructions:

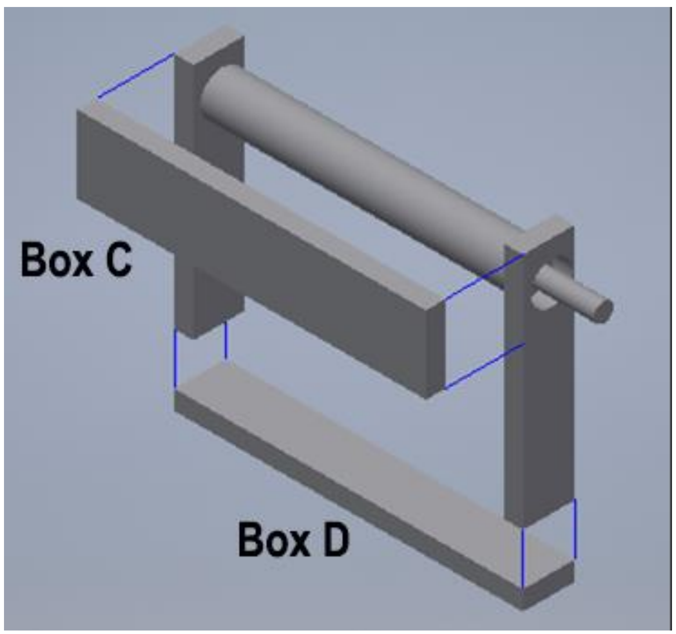
- Apply epoxy to outer perimeter of bearing and insert into *Box B*. Repeat with other bearing and part.
- Wait until epoxy cures, then insert dowel between each piece as pictured below.
- Utilize *Assembly Reference A* for dimensions.



Step 3		
Part	**Description**	**Quantity**
DWG NO: 2939_16	Box C	1
DWG NO: 2939_17	Box D	1
Screw	Wood Screw	8

Instructions:

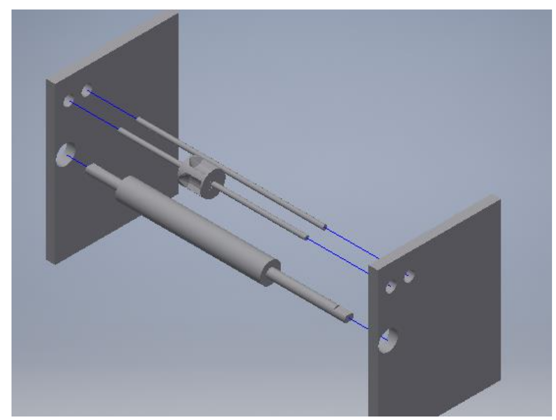
- Attach *Box C* as pictured below.
- Attach *Box D* as pictured below.



Step 4		
Part	**Description**	**Quantity**
DWG NO: 2939_1	Feeder Wheel	1
DWG NO: 2939_2	Feeder Wheel Insert	1
DWG NO: 2939_14	Box A	2
3/4” ID, 1-5/8” OD	Bearing	2
3/8” ID, 7/8” OD	Bearing	4
3/4” Dowel	21-1/2“ long	1
3/8” Dowel	15-1/2“ long	2

Instructions:

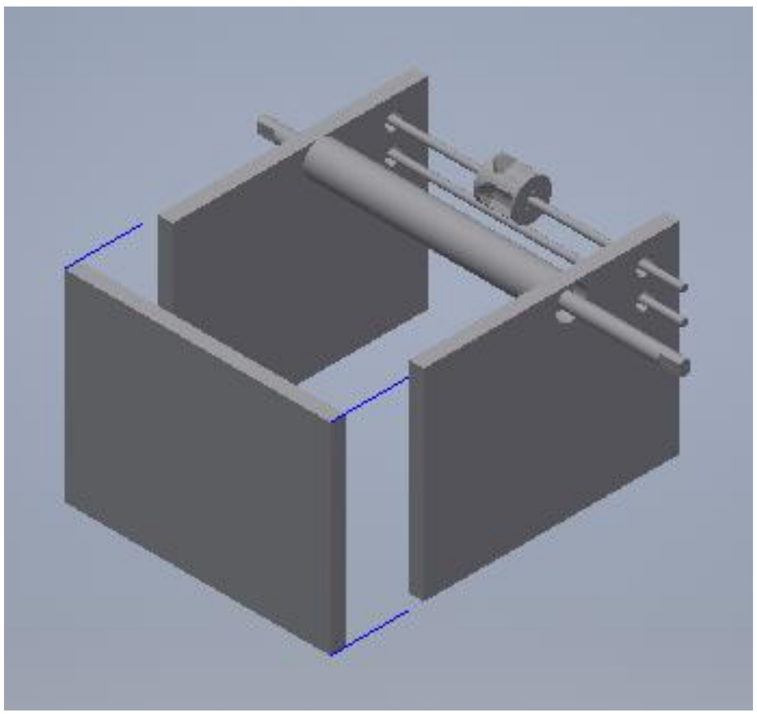
- Apply epoxy to outer perimeter of bearings and insert into *Box A*. Repeat with other bearings and part.
- Insert *Feeder Wheel Insert* into *Feeder Wheel*. Coat interior surface of *Feeder Wheel Insert* with epoxy and mount on 3/8” dowel.
- Insert dowel between each piece as pictured below.
- Utilize *Assembly Reference A* for dimensions.



Step 5		
Part	**Description**	**Quantity**
DWG NO: 2939_18	Box E	1
Screw	Wood Screw	4

Instructions:

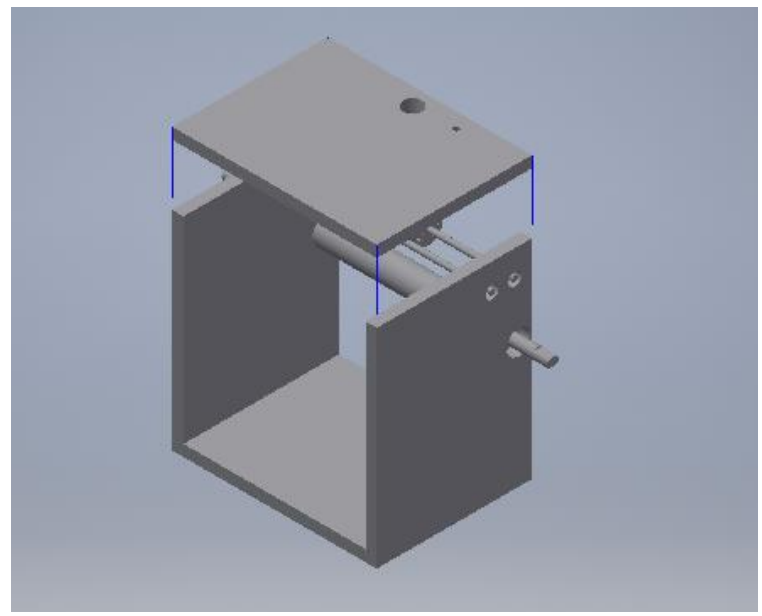
- Attach *Box E* as pictured below.



Step 6		
Part	**Description**	**Quantity**
DWG NO: 2939_19	Box F	1
Screw	Wood Screw	4

Instructions:

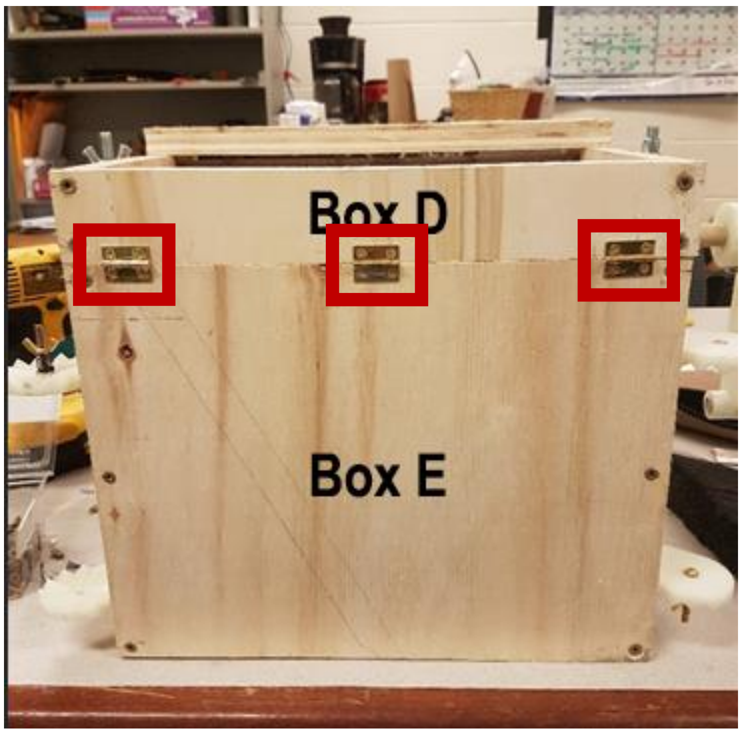
- Attach *Box F* as pictured below.



Step 7		
Part	**Description**	**Quantity**
Hinge	Brass Hinges	3
Screw	Included with hinges	12

Instructions:

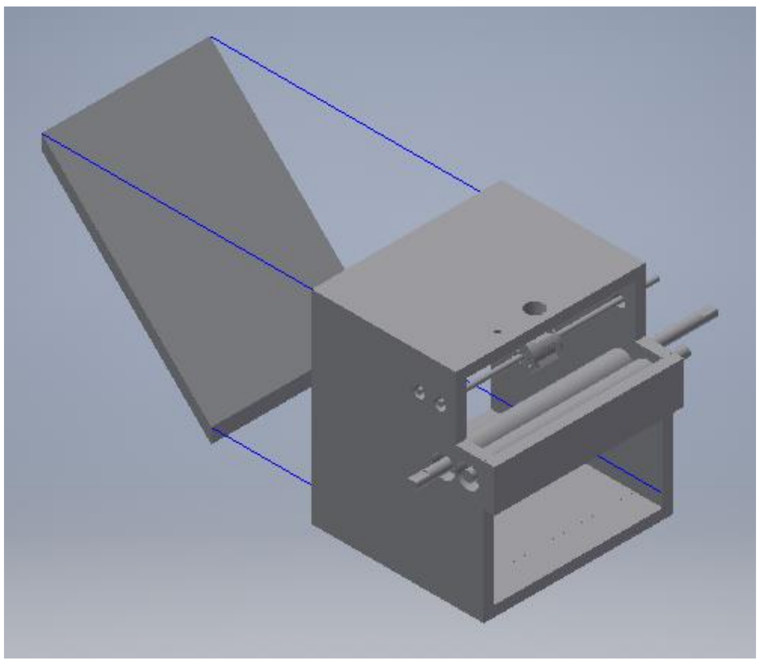
- Utilize hinges to attach *Box D* and *Box E* as pictured below.

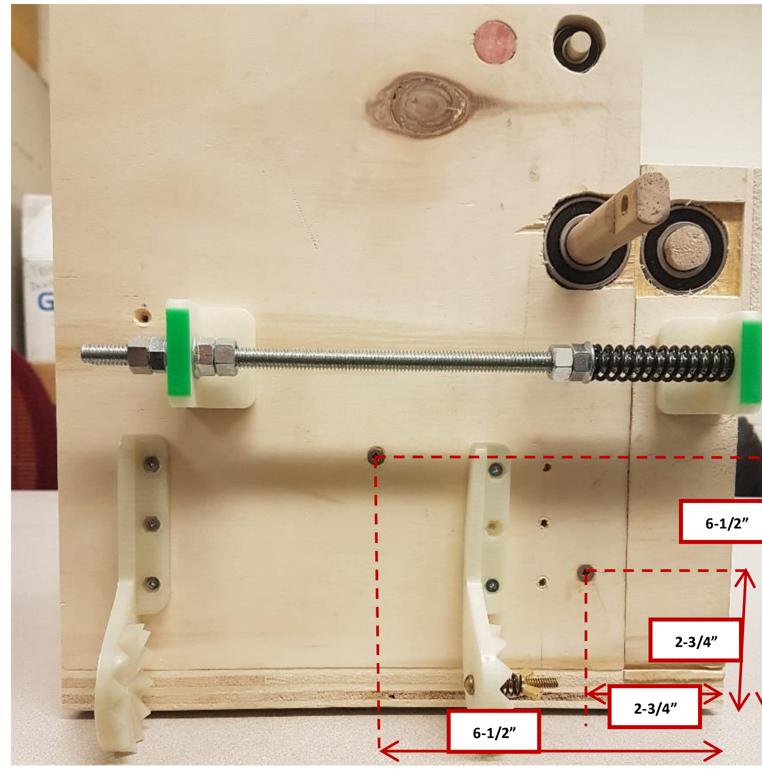


Step 8		
Part	**Description**	**Quantity**
DWG NO: 2939_20	Box G	1
Screw	Wood Screw	4

Instructions:

- Insert *Box G* as pictured below.
- Fasten with wood screws, inserted through *Box A*, as indicated below. Repeat for both sides.

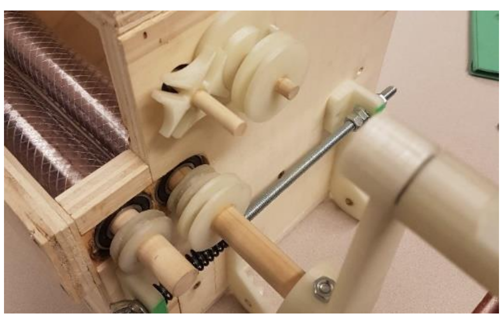


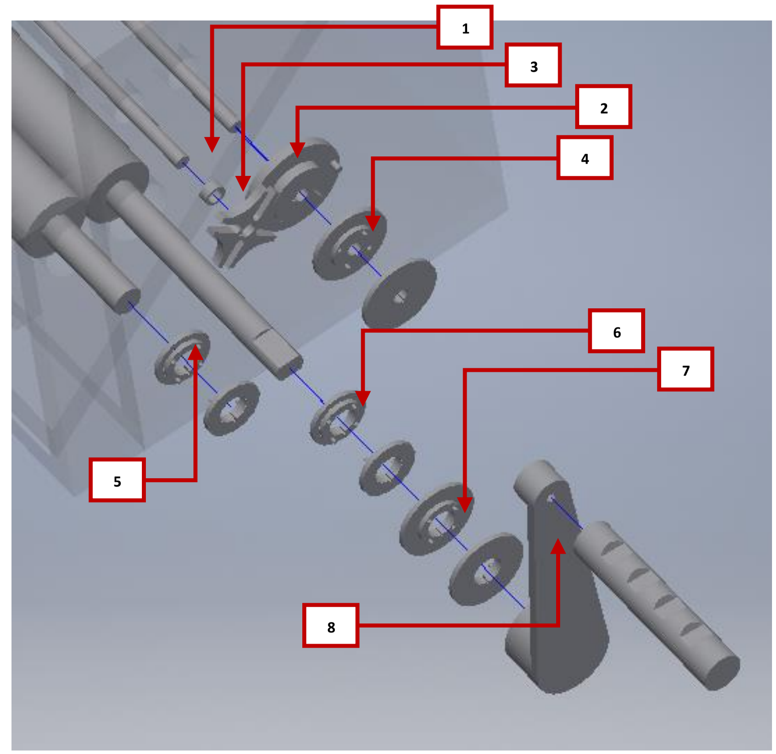


Step 9		
Part	**Description**	**Quantity**
DWG NO: 2939_4	Belt Spindle (3/4" ID, 2" OD)	2
DWG NO: 2939_5	Belt Spindle (3/8" ID, 2" OD)	2
DWG NO: 2939_6	Belt Spindle (3/4" ID, 1-1/2" OD)	4
DWG NO: 2939_9	Geneva Drive A	1
DWG NO: 2939_10	Geneva Drive B	1
DWG NO: 2939_11	Geneva Drive Spacer	1
DWG NO: 2939_12	Removable Handle	1
DWG NO: 2939_13	Handle Grip	1

Instructions:

- Attach each pair of *Belt Spindle* together with epoxy and let cure.
- Attach *Handle Grip* to *Removable Handle* with epoxy and let cure.
- Insert all parts in order indicated below.
- Utilize *Assembly Reference A* for dimensions.

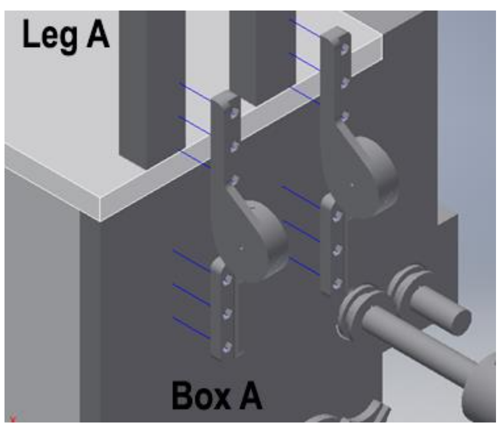




Step 10		
Part	**Description**	**Quantity**
DWG NO: 2939_7	Locking Hinge A	4
DWG NO: 2939_8	Locking Hinge B	4
DWG NO: 2939_21	Leg A	4
Machine Screw	1/8 x 1-1/2	24
Locking Washer	#6 Bs Sae	24
Nut	1/8 Nut	24
Machine Screw	10-24 x 1-1/2	4
Wingnut	10-24 Brass Wingnut	4
Spring	Compression Spring	4
Nut	10-24 Nut	4

Instructions:

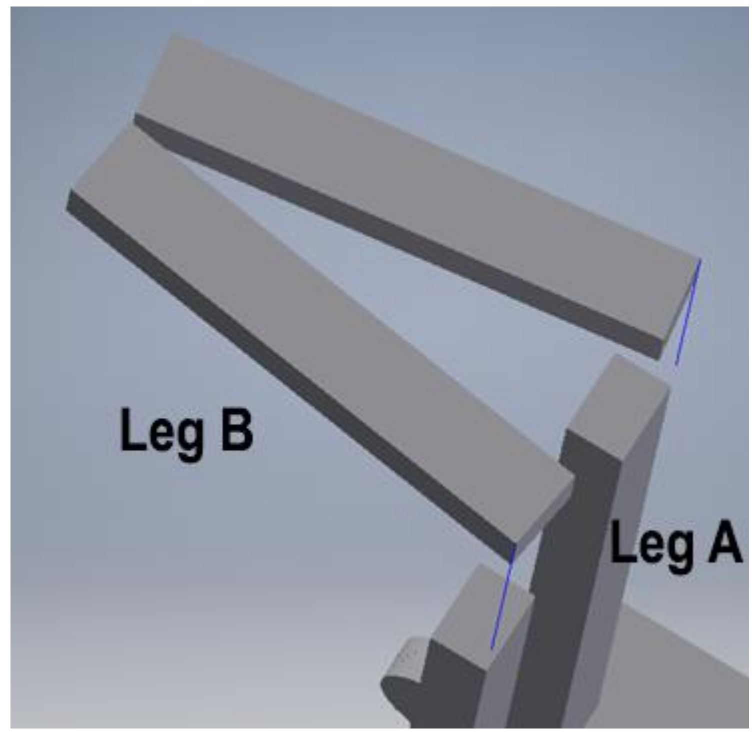
- Utilize *Assembly Reference E* for assembly of *Hinge A* and *Hinge B*. Repeat for all four pairs.
- Attach assembled hinges as indicated below.
- Utilize *Assembly Reference B* for dimensions.



Step 11		
Part	**Description**	**Quantity**
DWG NO: 2939_22	Leg B	4
Screw	Wood Screw	8

Instructions:

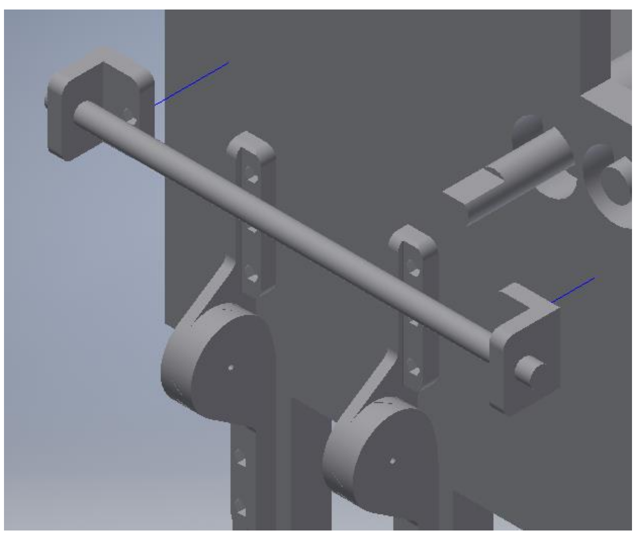
- Attach *Leg B* as indicated below.
- Utilize *Assembly Reference D* for dimensions.

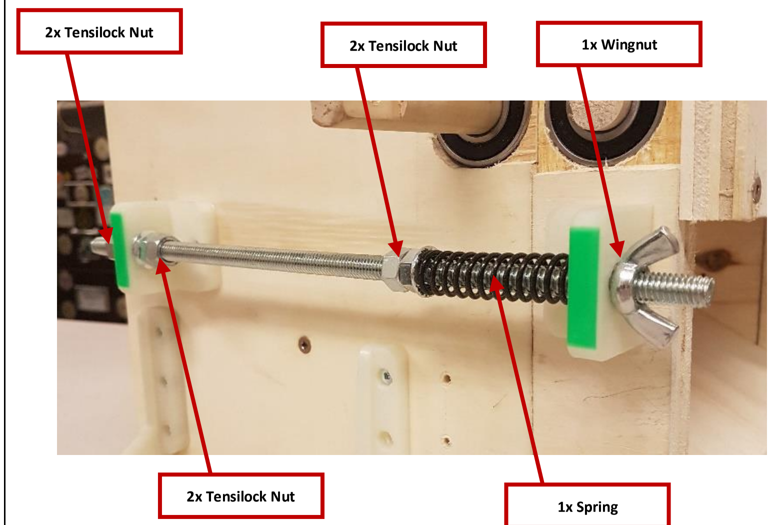


Step 12		
Part	**Description**	**Quantity**
DWG NO: 2939_3	L-Bracket	4
Threaded Rod	3/8-16 x 12"	2
Tensilock Nut	3/8-16	6
Wingnut	3/8-16	2
Spring	5/8 x 2-1/2	2
Machine Screw	1/8 x 1-1/2	4
Locking Washer	#6 Bs Sae	4
Nut	1/8 x 1-1/2	4

Instructions:

- Assemble threaded rod as indicated below.
- Attach *L-Bracket* to *Box A* as indicated below.
- Utilize *Assembly Reference C* for dimensions.





Step 13		
Part	**Description**	**Quantity**
Funnel	Funnel	1
3/8” Dowel	2“ long	1

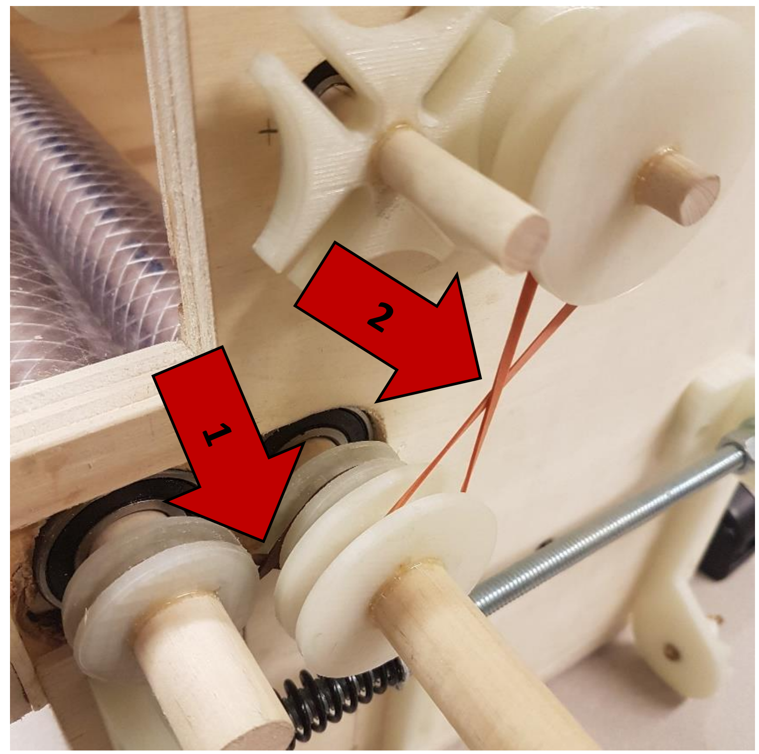
Instructions:

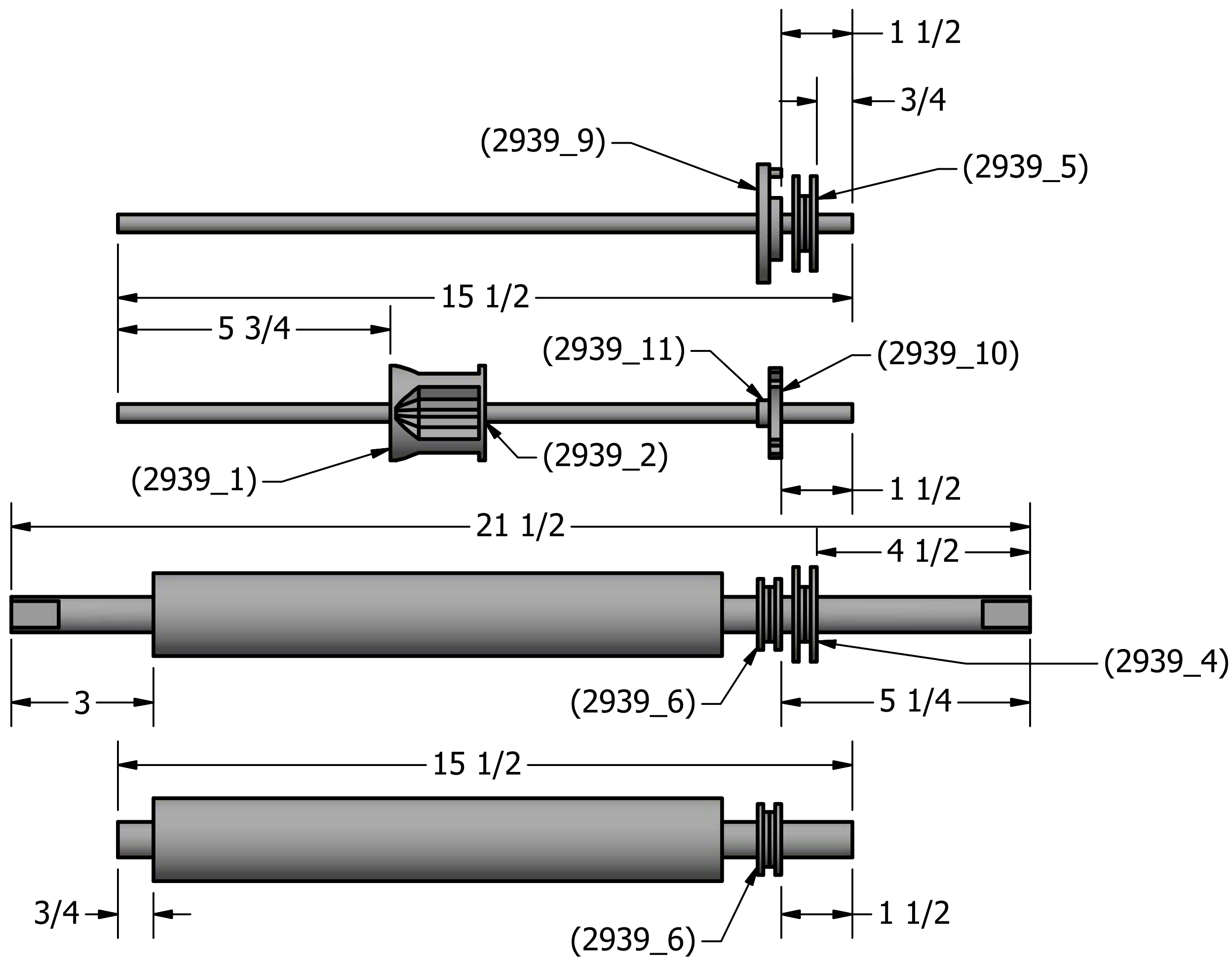
- Apply epoxy to dowel, insert as shown below.
- Attach Funnel to dowel.

Step 14		
Part	**Description**	**Quantity**
Drive belt	Twisted rubber band	2

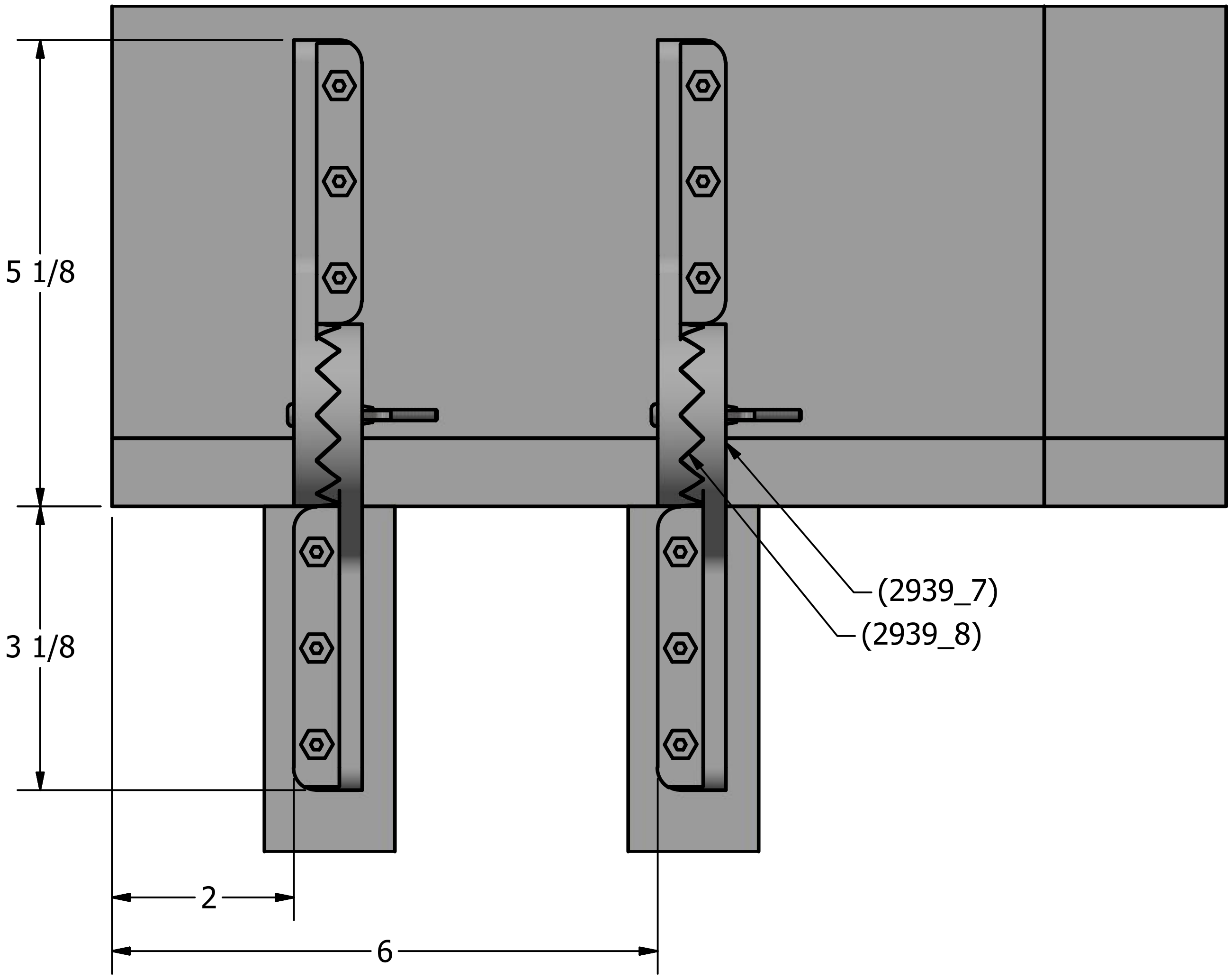
Instructions:

- Twist drive belts into ‘figure eight,’ and attach in sequence indicated below.





DRAWN Adam Genno	3/08/18	Rice Machine 2018 - ENGI-2939
CHECKED		TITLE
QA		Assembly Reference A
MFG		
APPROVED		
		SIZE A
		REV 1
		SCALE 1 : 4
		SHEET 1 OF 5



DRAWN Adam Genno	3/08/18	Rice Machine 2018 - ENGI-2939	
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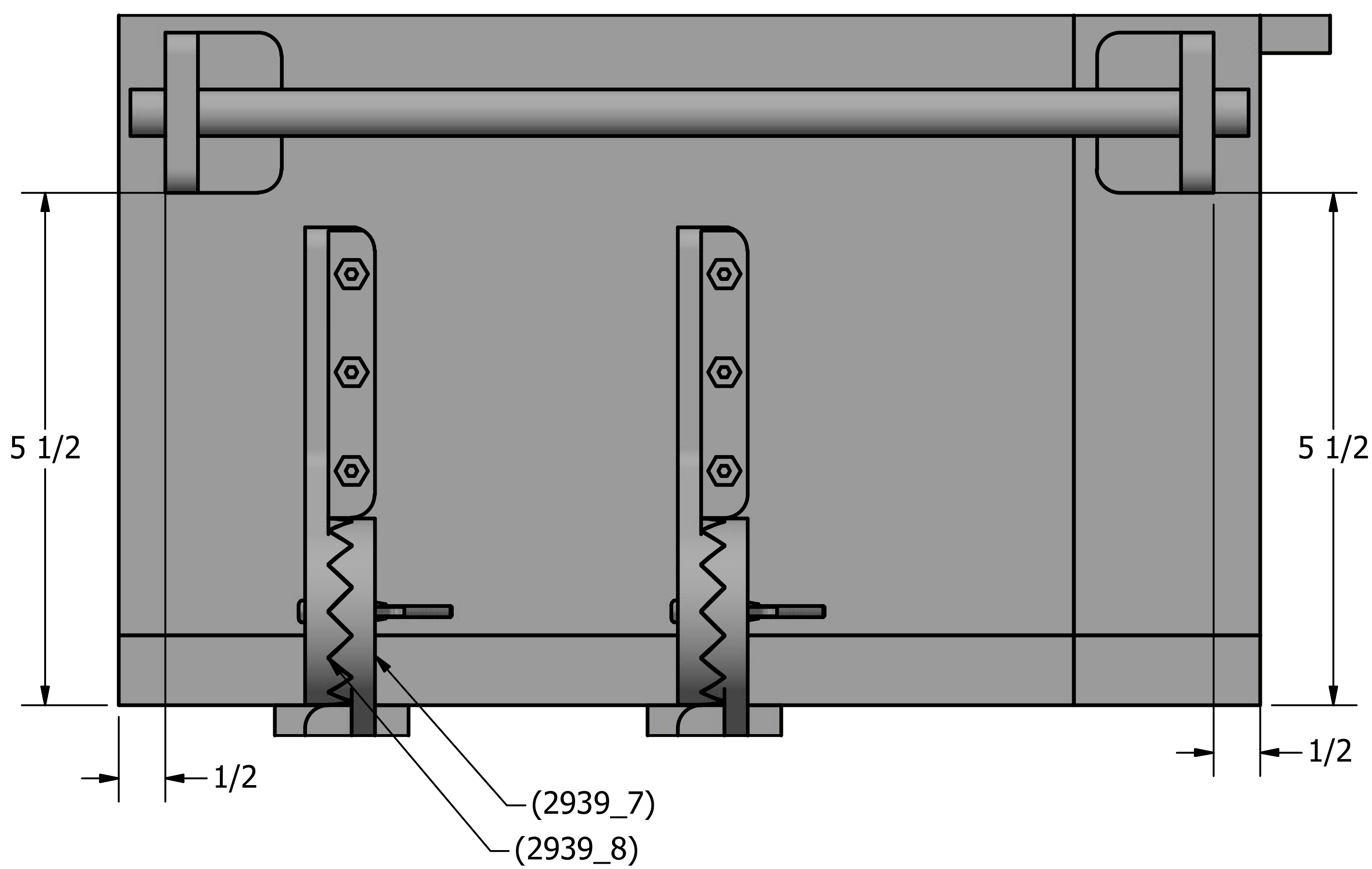
QA			
MFG			
APPROVED			
		SIZE A	REV 1
		SCALE 1 : 2	SHEET 2 OF 5



DRAWN Adam Genno	3/08/18	Rice Machine 2018 - ENGI-2939		
CHECKED		TITLE Assembly Reference C		
QA				
MFG				
APPROVED				
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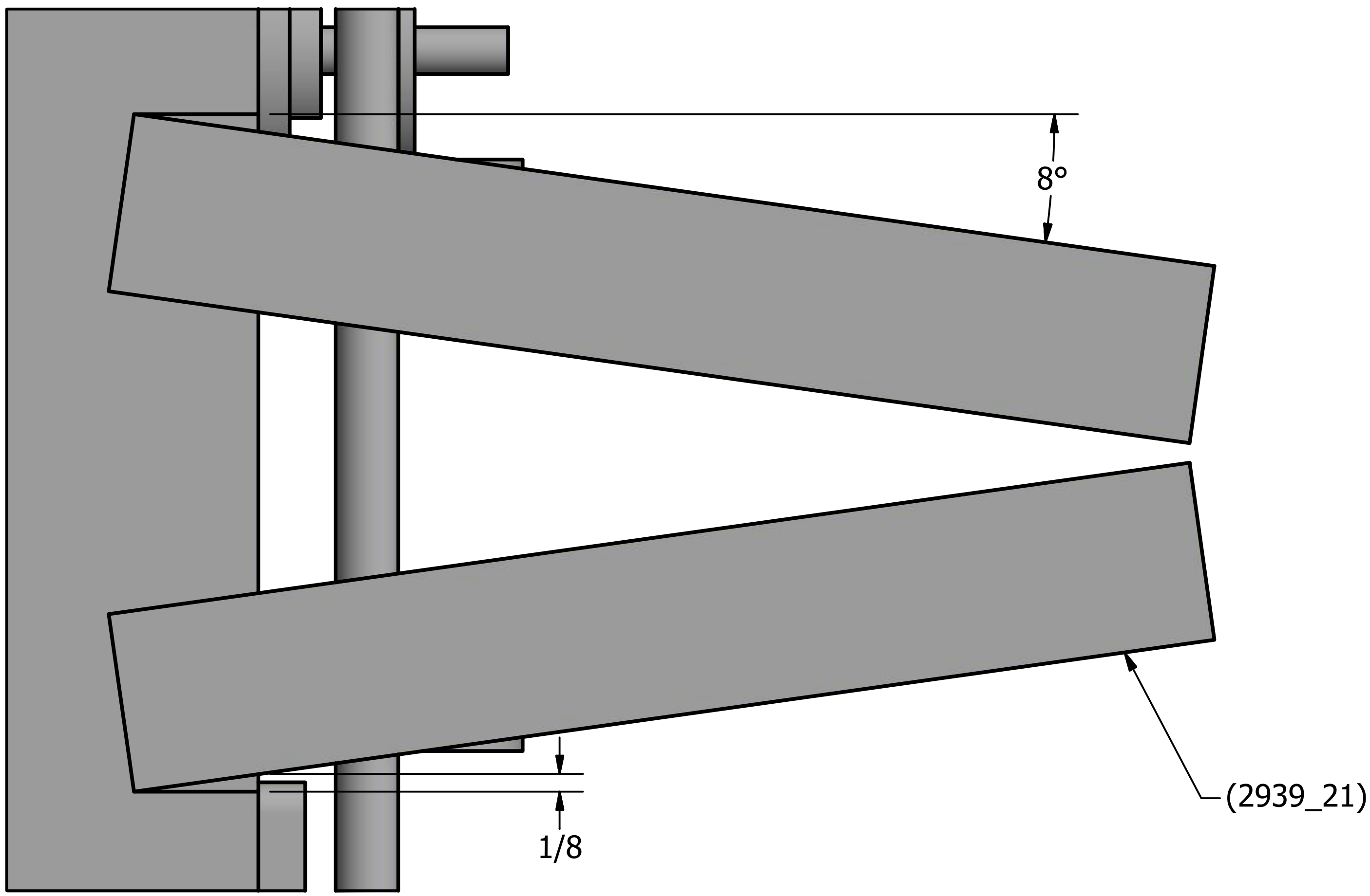

DRAWN Adam Genno	3/08/18	Rice Machine 2018 - ENGI-2939	
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QA		Assembly Reference D	
MFG			
APPROVED			
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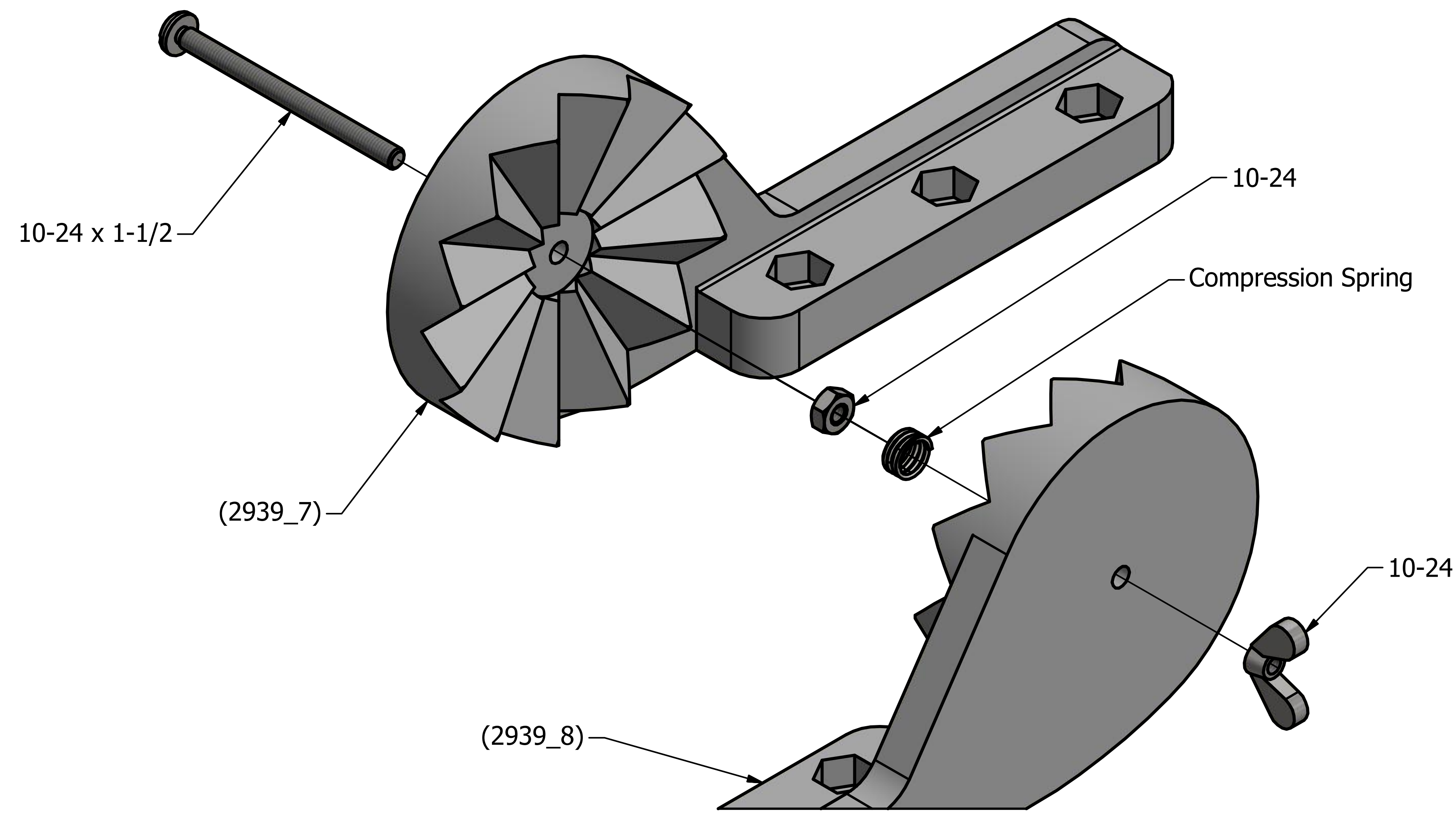

DRAWN Adam Genno	3/08/18	Rice Machine 2018 - ENGI-2939			
CHECKED					
QA		TITLE Assembly Reference E			
MFG					
APPROVED					
		SIZE A			REV 1
		SCALE 1 : 0.8		SHEET 5 OF 5	