Growth Innovations Kite Group

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Abstract

Our project involves the design of a transportable control system to manipulate a large traction Kite. The system will be used in yacht pleasure racing where the traction kite helps power the boat to optimum speeds. The mechanism consists of three planetary subsystems driven by electric motors that control the lines of the traction kite, a big advance compared to the traditional method of pulling the lines by hand.

Introduction

Kiteship™ Corporation is a manufacturing firm dedicated to extending the use of traction kites. These very large traction kites are used to power watercraft. The Outleader™ replacement kite is one of the newest kites and involves a size larger than man can handle. Due to their large dimensions, the need for a control system has become significantly important. Our senior design challenge consists of designing a mechanism that will deploy these traction kites and control its gliding through the air. The number of crewmembers needed to operate these kites will thus be decreased and the use of such a technology eased. We will introduce the traction kite technology and discuss steps taken to design, manufacture, and assemble a prototype.

1.0 Planning

1.1 Scope

The scope of the Growth Innovations Kite Group project is to design a mechanism that will maneuver a three line traction kite for sailing purposes. The mechanism needs to withstand the forces exerted by 100 m^2 kites. It must be light enough to be portable and be controlled by a single joystick.

1.2 Project Approach

A preliminary brainstorming session was held at the beginning of the design process. A decision matrix was then constructed to select the optimum idea. The information collected through research and customer specifications was applied while idealizing the prototype. Several calculations were performed on the gear system and line tension to select adequate components. The kite winch system was then designed using the selected components. After the completion of the design, the system was machined, welded, and assembled. Various tests were performed once the system was assembled.

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2.0 Project Specifications

Below is a list of design requirements given to the group by the sponsor, Jeff Phipps, president of Growth Innovations, L.C. The needs are listed in order from highest to lowest priority.

- Design a three-spool winch system controlled by a single joystick.
- System must withstand the load enforced by a $100m^2$ kite in a 30kt wind.
- System subsections must weigh less than 200 pounds.
- Be able to resist corrosion in an offshore marine environment.
- The spools must feed at a variable rate.
- The maximum line feed rate must be 5ft/sec for the turning function.
- Must have large non-marring feet on bottom of housing.
- Possibly use proposed planetary gear system.
- Ease of transfer from one vessel to another.
- Must involve a safety release system.

3.0 Background Research

3.1 Traction Kite Technology

Traction kites use wind energy as a reliable propulsion power. The towing kite is filled with compressed air creating a pressure differential that causes the vessel to move. The increase in stability provided is notably significant. Traditional sail boats experience a heeling moment causing the vessel to tilt. When equipped with a traction kite, the force a ship experiences has an upward and side component. The upward component, called the lifting force, generates an upward moment as shown in Figure 1. This moment counteracts the heeling moment and provides a higher degree of stability.

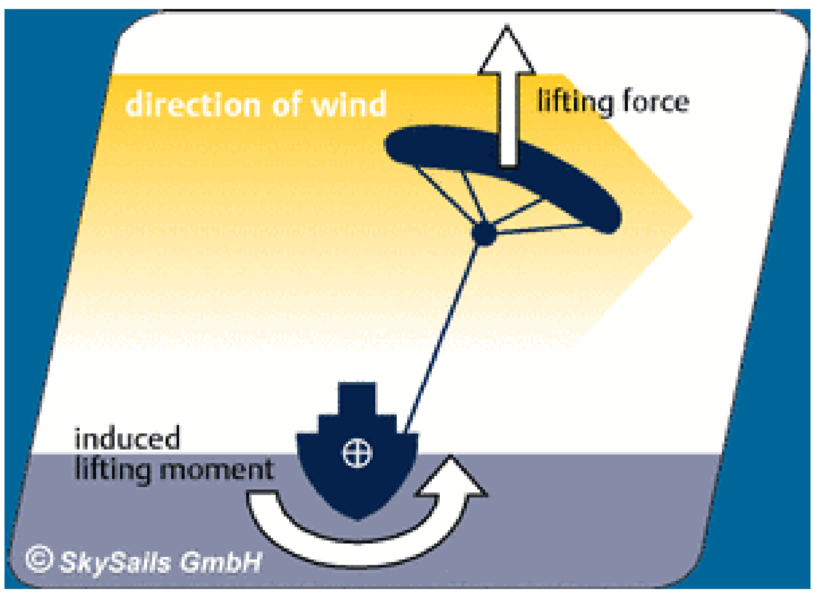

Figure 1: Lifting force on traction kite

Advanced textiles are used for the aerofoil allowing the kite to float and easing the recovery process. The most important advantage is the use of wind at a higher altitude. As shown in Figure 2, the kite can be flown at altitude ranges that a traditional sail can not achieve. Under most situations the wind speed increases with increasing altitude thus the towing kite can be used in sailing to achieve optimum speeds.

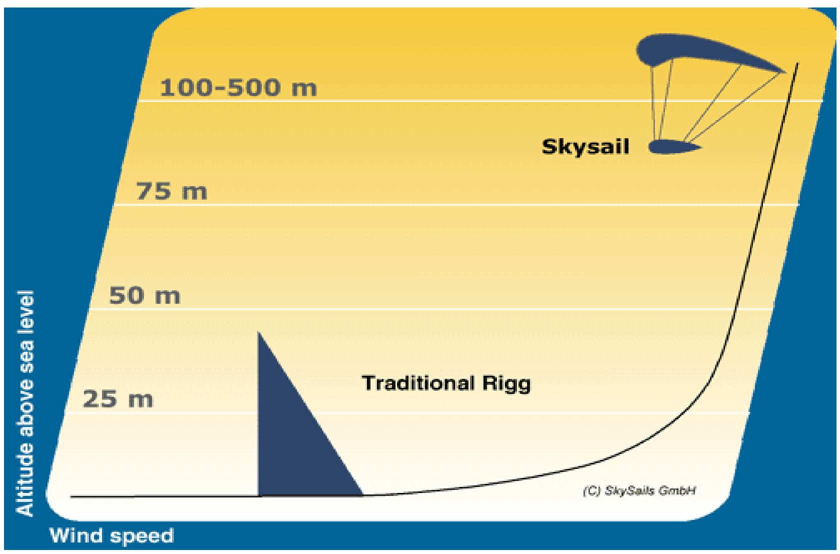

Figure 2: Use of wing at high altitudes.

3.2 Forces on Kite

As described by the sponsor, the maximum wind velocity relative to the kite is 30 knots. In order to calculate the drag force, the kite will be modeled as a flat plate. Its area will be computed as 75% of the area of the largest kite and its drag force will be given by the following equation:

$$F_d := \frac{C_d \cdot A \cdot \rho \cdot V^2}{2}$$

C_d is the drag coefficient and A is the area of the kite. The density of air is given to be 1.184 kg/m^3, and V is the wind velocity. The drag force applied to the kite is used to determine the tension applied to each line. The following free body diagram shows the forces felt on the kite:

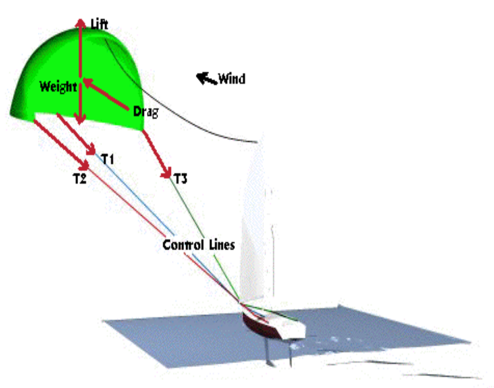

Figure 3: Free Body Diagram.

This tension is distributed among the three lines. This value is required in order to design a secure locking system that will prevent free spinning of the spool. Our calculation will include a design margin to prevent catastrophic failure of the mechanism.

4.0 Conceptualization

4.1 Concept Generation

4.1.1 Planetary Gear System

The planetary gear system is the first design that was worked with. This design was a suggestion made by Jeffery Phipps which utilizes planetary gear sets in order to give a mechanical advantage during the turning of the kite. This system will also distribute the load on the lines onto more gear teeth than one gear would normally provide. This system consists of two spools, each connected to four planet gears. The four planet gears are set on the inside of a ring gear and around a central sun gear. Both sun gears are in mesh with a sun drive gear, which is set between them. Also, the two ring gears are in mesh with each other and one of the ring gears in mesh with a ring drive gear. An example of this can be seen in Figure 4. Turning the sun drive gear and holding the ring drive gear will reel one line in on one spool and let the other line out off the other spool, turning the kite right or left. Holding the sun drive gear and turning the ring drive gear will cause both lines to be let out or drawn in depending on which way it is rotated.

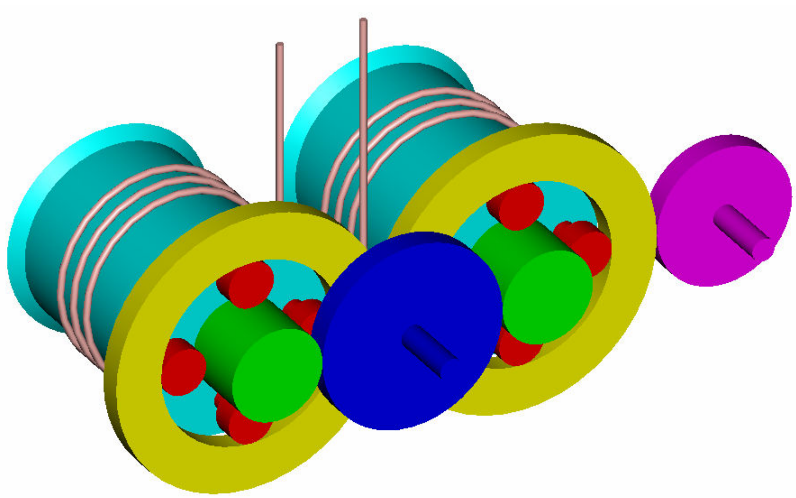

Figure 4: Planetary gear system

Pros:

- This system allows the use of a smaller motor to operate the sun drive gear because of the mechanical advantage that is obtained.
- The loads on the system are distributed onto four planet gears instead of a single driving gear.
- Having a smaller motor leads to lower costs as well as lower weight.

Cons:

- The system is very complex to design and manufacture.
- There is an added weight because of the additional gears.

4.1.2 Individual Gearbox and Motors

The individual gearbox and motors system is fairly simplistic. Each of the three spools has its own gearbox and its own motor. The motors will all have to be high powered and the gearboxes of each can be constructed in a way to allow the best usage of that power.

Figure 5: Individual gear boxes

Pros:

- The gearboxes will be sealed, so expensive corrosion resistant gears will not be necessary.
- This is an easy-to-design and manufacture system.
- Each spool can be placed in different locations on the boat, allowing for better versatility.
- Since each spool and respective gearbox and motor is separate from each other, they can each have a maximum weight of 200 pounds instead of a total weight of 200 pounds. However, they will most likely be less and this will aid in portability.

Cons:

- Lead lines will need to be run to each gearbox in order to control them all from a single joystick.
- All three controls for the movement of the kite will have to be integrated into an electrical system.
- Having three high-powered motors is expensive as well as heavy.
- Three separate housings have to be made for this system.

4.1.3 Powered Capstans

For the powered capstans system, three powered capstans would be purchased from a supplier and used to control the three lines to the kite. These capstans would have to handle loads of up to approximately 1500 pounds.

Figure 6: Powered capstans

Pros:

- Each capstan can be placed anywhere around the boat, increasing versatility of the system.
- The capstans are already in production.

Cons:

- Powered Capstans are expensive (In the range of $2000 with a max pull of 1000 pounds and a line speed of 1.45 ft/sec).
- All three controls of the kite will be done by the electronics of the system.
- Lead lines will need to be run to each capstan.
- Additional housings will be required in order to make them portable.
- The capstans are not necessarily variable speed.

4.1.4 Hydraulic motors

This is not really a system unto itself, but the use of hydraulic motors instead of electric motors. The hydraulic motors require a pump and hydraulic lines and a distribution block to power them.

Pros:

- Hydraulic motors are stronger and faster.
- They do not back feed.

Cons:

- Hydraulic motors are expensive.
- Control of the motors is complex.
- High-pressure hydraulic lines tend to leak over time.
- Since the system must be portable, the lines will be lying on the deck and will get in the way.
- Any change in energy type also infers an energy loss. This energy loss is the conversion from electrical energy to hydraulic pressure; also, there is only a small amount of electrical power on the ship to start with.

4.2 Concept Selection

4.2.1 Decision Matrix

Category	Cost	Weight	Power Consumption	Manufacturability	Performance	Durability	**Total**
Weight	15%	10%	25%	15%	25%	10%	**10**
Planetary Gear System	5	7	8	6	8	7	**7.05**
Individual Gear Box and Motors	8	8	4	7	7	4	**6.2**
Powered Capstans	7	8	4	10	3	7	**5.8**
Hydraulic System	2	3	7	4	2	6	**4.05**

4.2.2 Decision Matrix Reasoning

The values given for each concept in each category were based off the aforementioned pros and cons of each concept. In consideration of cost, the individual gearboxes and the powered capstans are the best choices mostly due to the availability of off-the-shelf components. The planetary gear system would require custom manufactured gears and many more bearings, increasing the price dramatically. The increase in the number of gears and bearings in the planetary gearbox also make it less desirable than the individual gearboxes and the powered capstan as far as weight is concerned. The hydraulic system and the planetary gear system have an advantage over the other concepts in the amount of power consumed. The hydraulics system can use regenerative braking/unspooling and the planetary gear system can work off a line-load differential. When comparing the manufacturability, the powered capstan received a ten because it is an existing product. While there is very little difference in performance between the two types of gearboxes, the planetary gearbox has a slight advantage due to the line-load differential. The individual gearbox is given the lowest durability rating because it has higher tooth loadings.

4.2.3 Decision Matrix Selection

As can be seen by the numerical values in the design matrix, the planetary gear system has been selected as our design. This concept will now be further developed into a detailed design.

5.0 Design

5.1 System Overview

After selecting the planetary gear concept, the details of the system were conceptualized and designed. The system has three spools, each controlling one line. The spools that control the lines is driven using the selected planetary gear system. These gear systems are contained in a housing, which must be mounted on the ship without damaging the deck.

The system needs to perform three discrete functions. The first is the ability to turn the kite. The system uses two spools for this, letting one line out while pulling the other in. The second of these functions is the ability to change the pitch of the kite. This is done by rotating the third spool to reel that line in and out. The last of these three functions is the ability to let all three lines in and out at the same time. This allows the user to set the orientation of the kite then let the kite out without changing its orientation. This is done by rotating all three spools at the same speed.

5.2 Subsystems

The design of the kite winch system can be broken up into three subsystems: the power transmission system, the housing, and the control system. These subsystems are further broken down in the following outline.

I. Power Transmission
    a. Planetary System
        i. Motors
        ii. Spools
        iii. Components (Gears, Shafts, Bearings)
        iv. Support Structure
II. Housing
    a. Frame
        i. Tie-down Points
        ii. Gear System Supports and Connections
    b. Legs
        i. Non-marring Feet
        ii. Adjustable-Height Feet
III. Control System
    a. Input
        i. Joystick
        ii. Interfaces
    b. Output
        i. Motor Controllers
        ii. Motors
    c. Power Supply
        i. Battery Array

5.3 Planetary Gearbox Design

The final design of the gearbox was based off the planetary gear concept. There were many aspects to the design of the gearboxes. These included the selected gears, the shafts, the bearings, and the support plates. Issues such as clearances, tolerances, and machinability had to be considered through out this portion of the design process. The first section of the gearbox that was designed was the individual planetary gearset. This system had a total of seven gears. The planetary set was designed to ensure alignment between each of the gears. It was also designed to support the load imparted by the kite lines and the weight of the system. The system was set up like a typical planetary gearset with a few exceptions. Because custom fabricated gears were too expensive, the chosen stock gears required additional spacing plates. Also, the ring gear had to be comprised of two separate gears because there were no stock gears with internal and external teeth. As can be seen in Figure 7, the planetary gear system is sandwiched together, pinned, and bolted to help ensure rigidity and alignment. In designing the planetary gearset, the group attempted to keep the shafts a single stock diameter. This was done to reduce the amount of machining required. Also, the system was designed using stock, inexpensive bearings to help reduce the cost. All of the bearings used in the design were deep groove, Conrad-type bearings.

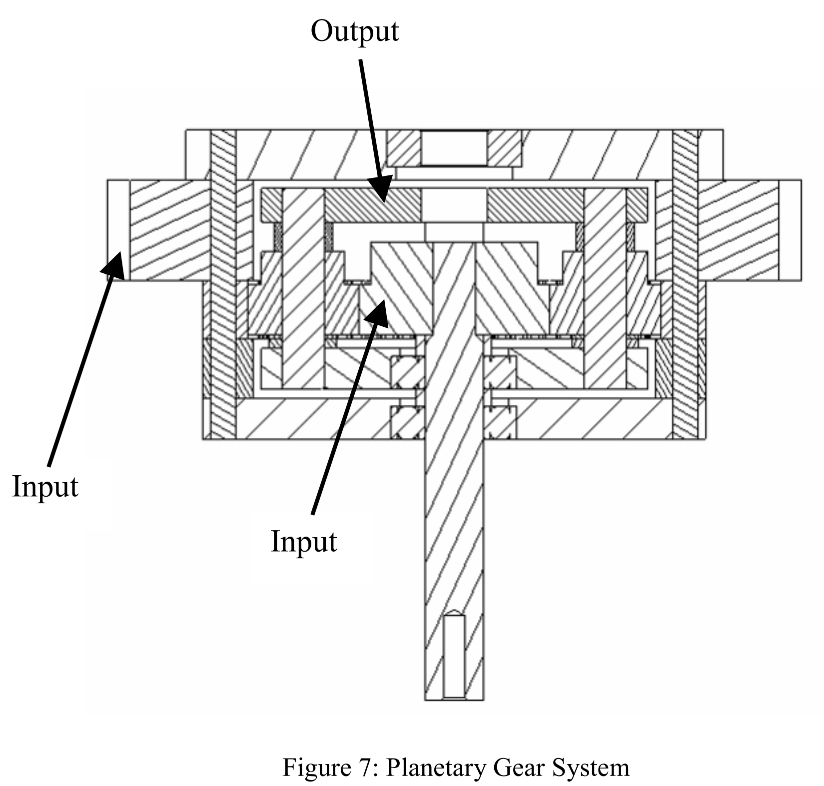

Figure 7: Planetary Gear System

5.4 Planetary Gearbox Interaction

The use of planetary gearboxes has an advantage that has not been discussed above. The design of the planetary gearboxes allows them to have multiple degrees of freedom. This means the planetary gearbox has multiple inputs while only having one output. This allowed the team to configure them in a particular way that allows for the three desired functions of the system: turning the kite, adjusting the pitch of the kite, and letting all three lines of the kite in and out at the same rate. This particular design of the planetary gearbox has two inputs and one output. The two inputs are the sun gear and the outer ring gear. The output is the planet carrier. The inputs and output can be seen in Figure 7.

In order to perform the three functions desired of the system, the team had to determine how the three planetary sets were going to interact with each other. By interconnecting the planetary gearboxes in particular ways, the team was able to constrain some of the degrees of freedom. The outer ring gears of each planetary set are connected and driven by one motor (shown in Figure 8). This enables the in and out function. Next, the sun gears on two of the planetary sets were constrained together. This allows the turning function. The final degree of freedom is the sun gear in the final planetary set. This input will be used to adjust the pitch of the kite.

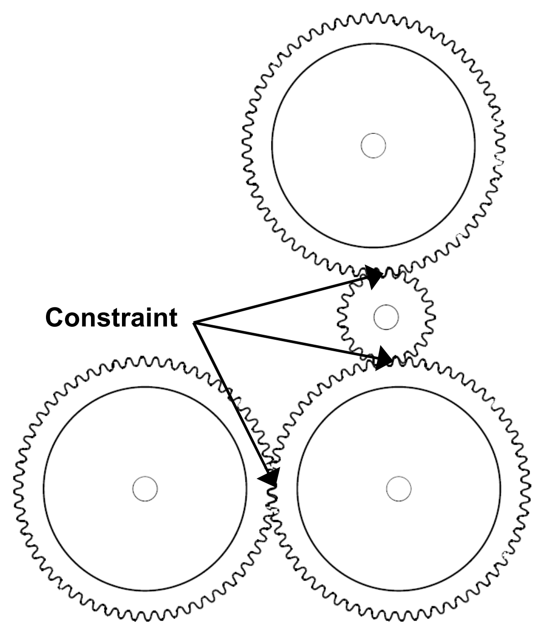

Figure 8: In and Out Function Constraints

5.5 Line Force

One of the constraints driving the design of the kite winch system is the ability to handle the loads applied by the kite. Aerodynamic drag and lift calculations were used to determine these loads. Due to its complex shape, the sponsor recommended modeling the kite as a flat plane with 75% of the cross-sectional area of the maximum kite that would be used. This idea for calculating the drag force on the kite was originally presented by Dave Culp, co-founder of kiteship.com. The system has been designed for a $100m^2$ kite. The calculations were done assuming air at sea level and at 25 degrees Celsius. Another assumption recommended by the sponsor was that the third line bear 75% of the load applied to one of the steering lines. Using these assumptions, the total force the kite applies to the ship is 3043 pounds. The individual line loads are 1107 pounds for each of the steering lines and 830 pounds for the third line. These calculations are shown in detail in document GIKG-M-001-1 in Appendix 11.1.

5.6 Gear Selections

According to the specifications, the system needs to feed lines in and out at a rate of five feet per second (5 ft/s) for the turning function. This specification drove the selection of the sizes of gears used in the design. Some initial selections and assumptions had to be made in order to do these calculations. First, a set of gears that could physically be used to make a planetary gearbox was selected. The gears were selected to make a planetary system that was slightly bigger than the spools, yet not overly bulky. The planetary assembly can be seen in Figure 9.

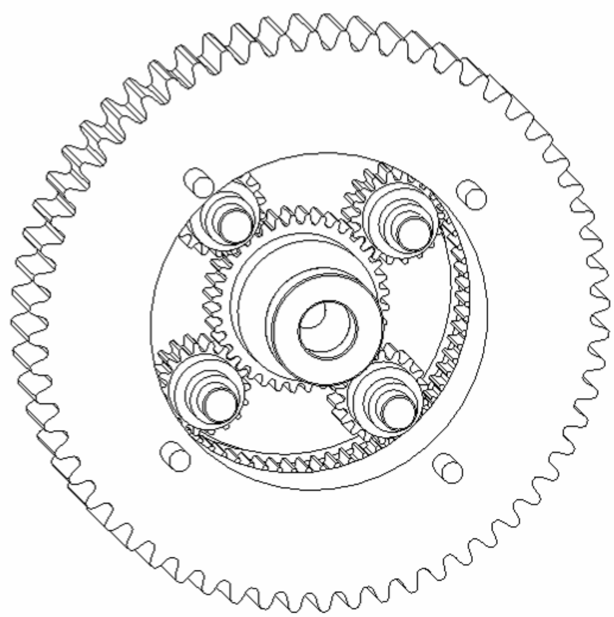

Figure 9: Planetary Gearbox Assembly

After selecting the gears used in the planetary system, a relationship between the angular velocities of the planetary gears and the line speed needed to be formulated. These relationships are shown in document GIKG-M-002-1 in Appendix 11.1. The final gear selections were calculated using these relationships, given specifications, and certain assumptions. The group decided to use a six-inch (6 in.) diameter spool. Through research on various DC motors, it was determined that the motor speed used in the calculations would be 4000 rpm. Another system specification is that worm gears should be used to prevent back drive. The chosen wormsets were selected for its ability to withstand high loads. The gear reduction on the turning wormset is 5:1. Using all of this information, the remaining gears were selected. First, a theoretical gear ratio was calculated. Next, a list of possible gears and the resulting ratios was tabulated. From this list the most applicable gears were selected. Finally the line speed was calculated from the specific gear set chosen and was compared to the specified line speed. This process was repeated for each of the three functions: the steering lines moving in and out, the steering lines rotating, and the third line moving in and out. In each case, the performance slightly exceeded the specification. See documents GIKG-M-002-1 and GIKG-M-003-1 in Appendix 9.1 for detailed calculations.

5.7 Gear Stress Calculations

When gears are loaded there is a stress in the teeth of the gears. The stress generated in the teeth is the main cause for failure in spur gears. An example of this can be seen in Figure 10. To determine the stresses in the gears, the Boston Gear catalogue and the formulas within were used. The first step was determining the load exerted on the gear tooth at the highest load point of contact. This load was calculated using the face width, diametric pitch, pitch line velocity, and the tooth form factor for the given gear and substituting these values into the formula as seen in document GIKG-M-004-1 in Appendix 11.1.

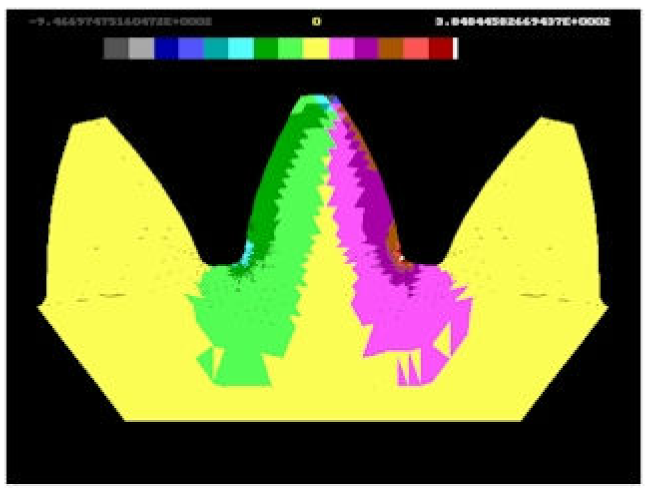

Figure 10: Stresses in Loaded Gear Teeth

After determining the load on the gears, the torque exerted on the gear teeth was calculated and compared to the maximum allowable torque from a table in the Boston Gear Catalogue (Boston Gear 43). Using this allowable torque and the torque calculated from the load on the gear teeth to calculate the safety factor of the gears will determine if the gears are of appropriate sizes. When the calculations for each of the gears were done and the factors of safety were calculated, the gears that were under the highest stresses were determined. The gears under the highest stresses were the outer ring gear driven by the ring pinion and the driven sun gear on the planetary gearsets. When the applied torque was compared to the allowable torque for the outer ring gear, the safety factor was 1.185. The maximum allowable stress in the steel gears is lower than the failure stress of the material so this value is acceptable. For the driven sun gear the safety factor is 1.106. Using the same information as above, this gear should be acceptable.

5.8 Torque Limiter

The tension on the lines can drastically increase if the kite starts to dive. This increase can be as much as five times the calculated line tension. A torque limiter is used to prevent this increase from damaging the system. A torque limiter is a device that will transmit torque from one shaft to another. It will transmit the torque up to a certain level then will start to slip. Once the torque is reduced to a safe level the torque limiter will resume power transmission. This device is similar to how a fishing reel works. It was determined that a torque limiter will be placed on the shaft that drives the in and out function.

5.9 Housing Design

The individual planetary gearboxes are interconnected and supported by the housing. The housing, as a whole, is a gearbox made up of smaller gearboxes and gears. It contains the three planetary gearboxes and the other various drive gears and worm gears. The motors are also mounted to the housing.

In designing the housing, the team tried to maximize strength while minimizing weight. Other factors affecting the design of the housing were the cost of material and the ease of machining. Aluminum was chosen as the housing material for its low cost, low weight, and machinability.

The housing is L-shaped due to the layout of the planetary sets. The majority of the plates in the housing are one-quarter inch thick aluminum plates. Half inch bearing mounting plates are bolted to these plates to hold the bearings. The design of the housing can be seen in Figure 11. See documents GIKG-PP-001-1 through GIKG-PP-059-1 in Appendix 11.2 for a detailed look at the housing.

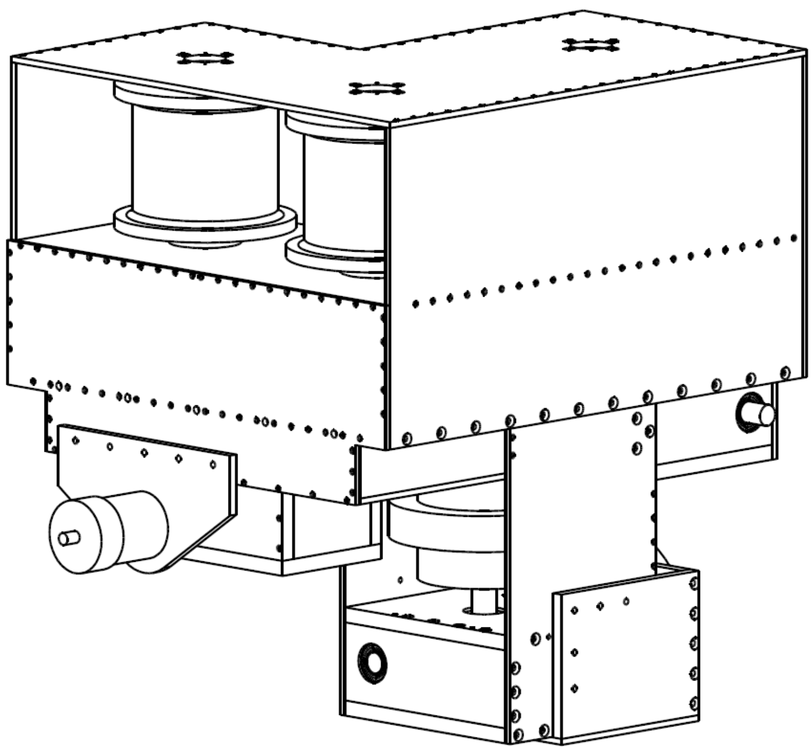

Figure 11: Layout of Housing

5.10 Frame Design

The housing needs to be supported by a freestanding frame. This frame has to be able to be mounted on the deck of a boat without damaging the boat. A welded steel-tube frame is the design chosen for the frame. The frame is rectangular and has angular cross-members to prevent twisting or trapezoidal collapse. The locations of the angular cross-members were carefully chosen to allow for the insertion and mounting of the motors and control system. Eyehooks are located on the frame to allow the system to be tied down to the deck of a boat. The frame also includes leveling feet that allow the system to ride securely on a surface which is not perfectly flat. Figure 12 shows the design of the frame.

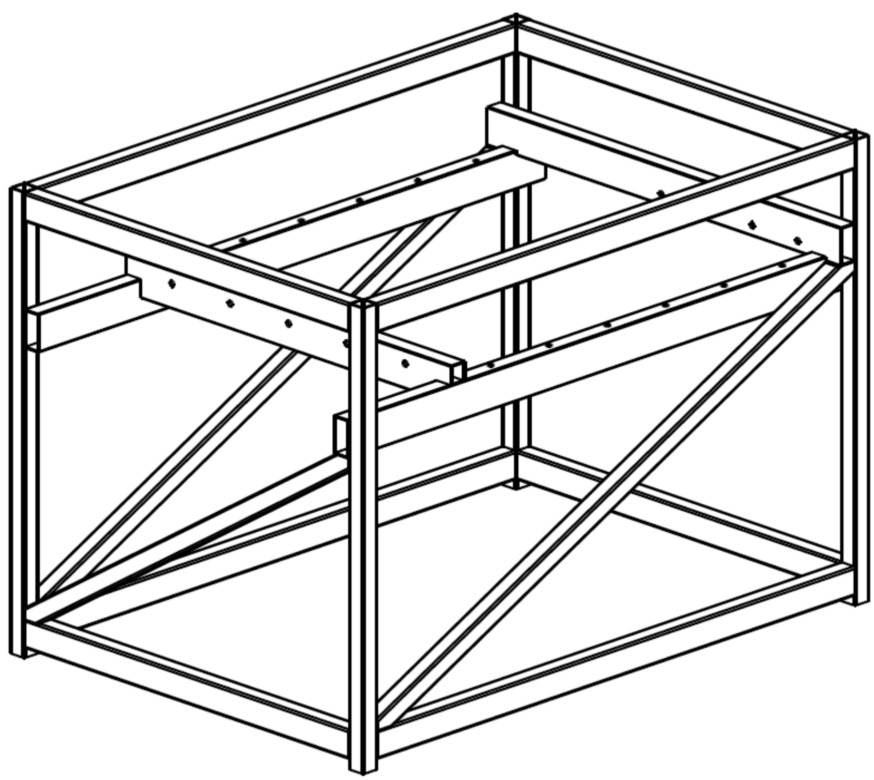

Figure 12: Assembled Support Frame

5.11 Electronics

One of the specifications of the kite winch system is that it is controlled using a single joystick. A three-axis joystick is required in order to control all three inputs. This joystick sends signals to three motor controllers. These motor controllers, in turn, send a signal to the motors, causing them to run.

The system was designed starting at the motors. Each motor was selected for its ability to perform the required tasks at the required rate and horsepower. The in and out function required a motor that could put out 10.6 horsepower. An Etek motor with a rating of 15-hp was chosen. The pitch function required a motor that could put out 2.1 HP. 3-hp Magmotor motors were chosen for both the pitch and turning functions. The Etek and Magmotor motors draw 285 Amps and 210 Amps, respectively.

Due to the large currents drawn by the chosen motors, heavy-duty motor controllers were chosen for the system. The motor controllers used for the system are Sevcon 4Q motor controllers. These are heavy-duty industrial motor controllers that are able to put out 330 Amps at voltages from twenty-four to forty-eight volts.

The motor controllers are driven by an analog signal from the joystick. A voltage circuit was designed to interface the three-axis joystick with the motor controllers. Another type of interface circuit came with the motor controllers. These interfaces allow the motor controllers to be easily controlled by a remote control transmitter. These interfaces were used in the testing phases.

6.0 Manufacturing

6.1 Machining

All support plates for the system where machined by the team at the College of Engineering. The lathe and the mill were the main machines used. All round plates and gear modifications were performed on the lathe. The lathe also allowed for the sizing of the spools from eight-inch solid aluminum rounds. The raw materials were first cut to size using the horizontal band saw. Faces where material was cut on the band saw had to be cleaned in order to obtain a good orientation when placing the pieces on the lathe. The automatic feed setting on the lathe helped establish a clean cut. Most of the material was cut at a speed of 136 rpm. The speed had to be slightly decreased when drilling holes of ½ inch or higher. Figure 13 shows Chris Boven using the lathe. Chris was working on the round planetary plates shown in Figure 14.

Figure 13: Chris Boven Using Lathe

Figure 14: Planetary Assembly

The mill was used to manufacture all rectangular plates, cut key ways, and drill holes. The mill has a digital readout that was used to cut plates to the right size and drill holes in the correct location. The majority of holes were tapped by putting the mill in neutral gear and spinning the chuck manually. Using this technique allows for a good alignment and therefore eases the assembly process by providing a good fit for the screws. Large sized holes, such as those located in the motor mounting plates, were done using an Indexable Boring Bar. This bar can be adjusted to bore holes with a diameter of one to four inches. Holes were first center drilled and then drilled with their respective drill bit. Sometimes a variety of drill sizes were used before obtaining the desired dimension due to friction and overheating of plates when a large quantity of material was cut off. The following picture shows Chris Boven and Trever Carnes working on the mill. Trever was keeping an accurate measurement of the cut using the digital read out while Chris cooled off the bit with lubricant.

Figure 15: Milling Process

6.2 Welding

A technique called metal inert gas welding (MIG) was used for the welding of the frame. MIG is a semi-automatic arc welding process in which a continuous and consumable wire and a shielding gas are fed through a welding gun. The following picture shows Brandon Henley performing the welding of the frame.

Figure 16: Welding of Frame

6.3 Assembly

The entire system was assembled over a span of three days. The first components assembled were the planetary sets. These were then assembled into the housing along with many other components. The housing was assembled with the frame. Finally, the motors were mounted and the electronics were connected to the system.

6.3.1 Planetary Sets

The planetary sets were the first subsystems to be assembled. They each contain seven gears, seven bearings, six shafts, five plates, and four bolts. The planetary set was assembled in sections. The sun, planets, and planet carriers were assembled. Then the outer plates and ring gears were assembled in layers around the outside of the plate carriers.

6.3.2 Housing

The housing was first assembled together without the inner components to test for fit problems. The following picture shows the entire housing assembly in conjunction with its frame and the three spools set in place.

Figure 17: Housing Assembly

The system was assembled through multiple steps. First the bottom boxes enclosing the worm gears were put together and attached to the bottom plate of the main housing. The team then set this plate on the frame and built the rest of the system including the side plates, support plates, and the top plate covering the spools. The entire housing was then bolted to the frame and the housing assembly completed.

6.3.3 Frame

The team chose to use steel members to build a rectangular shaped frame to support the entire mechanism. The frame measures 35-by-24 inches and has a height of 25 inches. It contains three angular members and two middle bars that interact with the mechanism and hold it in place. As mentioned in the Manufacturing section, all members of the frame were welded together. They were also coated using a heat resistant “Ford Blue” paint. Figure 18 depicts a representation of the frame. The angular members are used to prevent a trapezoidal collapse when outside forces, such as line tensions, are applied to the mechanism. These members allow easy access to the motor and the motor controllers.

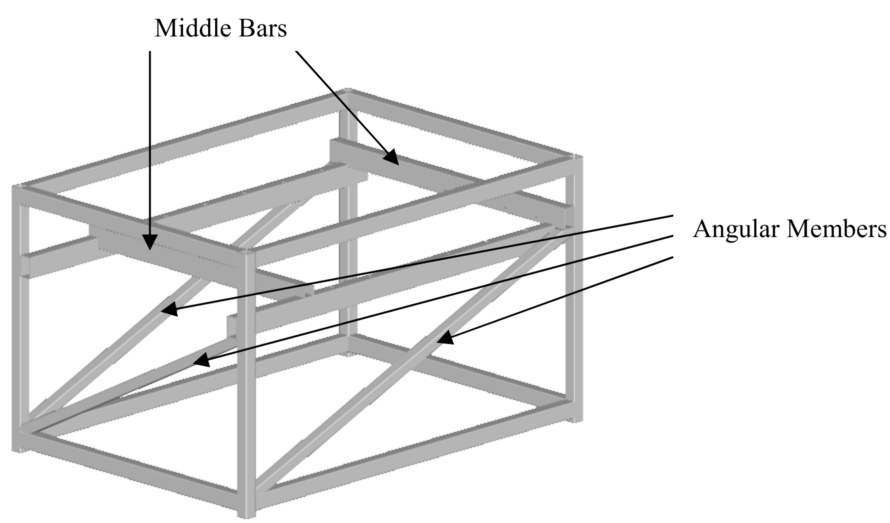

Figure 18: ProE Drawing of the Frame

6.3.4 Electronics

Our system is powered using four 12-volt batteries connected in series. These batteries are connected to three motor controllers that control the pitch, turning, and in/out movement of the traction kite. The largest motor is a 15 hp motor and is used for the deployment and retraction of the kite. The other motors provide 3 hp each and control the turning and pitch of the kite. Motors are represented in red in the following Pro/E assembly:

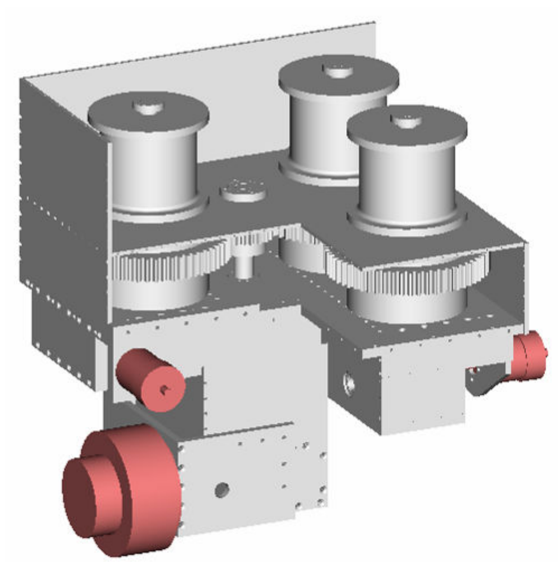

Figure 19: ProE Assembly

Figure 20 shows the electronics connected to the system. The three motor controllers sit on a plate attached to the bottom of the frame. Multiple cables connect the batteries to the controller, and each motor is connected to its respective controller.

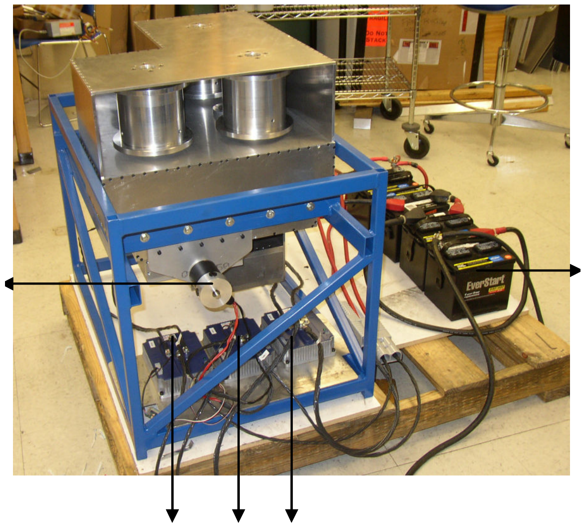

Figure 20: Assembled System with Electronics

6.4 Cost Analysis

The costs incurred during the manufacturing and assembly of this system was substantial. There were several orders placed to many different suppliers during the duration of this project as the need for materials arose and designs were completed. The orders were categorized into three main groups. The first category was the Bulk Metal group. The second set was the section for the Gears. The third group was titled Power Transmission. The final group was the Electrical Components group.

The Bulk Metal group includes all the material needed to make all of the plates in the spools, planetary sets, and the housing enclosure plates. The sub-total for the Bulk Metal section was \$1810.22. The Gears section included only the orders for the different worm and spur gears. The sub-total for the Gears category was \$6048.69. The Power Transmission grouping includes the orders placed for the shafts, bearings, fasteners, and also included were any necessary drills, taps, and finishing supplies. The Power Transmission category sub-total was \$1175.67. The Electrical Components Section includes all of the motors, motor controllers and any necessary wiring and connectors. The sub-total for this final group was \$2814.24

The total amount spent in purchasing the needed materials for this project was \$11,687.58 before applicable taxes and shipping/handling costs. For a further detailed breakdown of the costs incurred on this project see Appendix 11.3.

7.0 Testing

There were multiple levels of testing performed on the system. This included fit and clearance testing on the components, no-load testing on the assembled system, and loaded testing on the assembled system.

7.1 Fit and Clearance

This level of testing was performed in conjunction with the assembly. This level of testing was done to ensure compliance between the components. One of the main areas of interference was the insertion of the shafts into the bearings. Each shaft used in the assembly was hand-polished to fit in the proper bearings. Another problem encountered in the assembly was bowing of the plates; also, the thickness of the five-eighths inch aluminum plate was larger than the expected tolerance. Some plates had to be cut to a smaller size to facilitate the assembly. As the system was being assembled, the team had to adjust the size of the spacers to allow for the proper amount of clearance.

7.2 No-Load

Once the entire system was assembled it was necessary to perform unloaded testing to ensure the spools were obtaining the proper line speeds. This testing was performed in the assembly area with no lines attached to the spools. The motors were individually run to check the performance of each function. The rotational velocities of the spools were checked during each function test. This allowed the team to compare the actual line speeds to the theoretical line speeds. Initially, the speed of the spools was too slow during the turning function. The motor controllers had to be adjusted to bring the speed of the motor used during turning to the correct level. (The range of expected input voltages was initially set much larger than the actual input voltage. This caused the motor controller to run the motor at about half the expected speed. By adjusting the range of expected input voltages to the proper level, the motor controller ran the motor at the proper maximum speed.) Another problem the team encountered during this phase of testing was loose setscrews. It was determined the cause of this was the vibration of the system when running. The system was partially disassembled and Loctite™ was used to secure the setscrews. With the completion of this stage of testing, it was determined the system was ready for loaded testing.

7.3 Loaded

The final stage of testing was the use of a traction kite to test the system under load. This stage of testing was performed on 1 April 2006. It was performed on land owned by Jeffrey Phipps, the project sponsor.

The test setup was as follows: The system was securely attached to the back of a pickup truck. The traction kite lines were fed onto the spools by slowly driving the spools using the in and out function. The leading edge of the kite was then lifted by hand to allow the kite to fill with air (see Figure 21 on the following page). Once the kite started to fill with air the truck was slowly driven to create an artificial wind. This was needed because there was no wind on the day we tested the system. Once the kite was full of air and flying, the system was used to control the kite.

A couple of problems arose while we were doing the loaded testing. The main problem was that the line speeds for the turning function were much too fast. The kite could not be properly controlled with the turning speed at that level. It was determined that the specification decided upon for the turning line speed was too high. This problem can be corrected in the future by changing the worm screw and worm gear that drive the turning function. Another problem that arose during the loaded testing phase was that the lines were tangling beneath the spools. This happened when the lines went slack and dropped below the spools. This allowed coils to fall off the spools. When tension was applied to the lines after this happened, the line wrapped around the shaft beneath the spool and bound up tightly. This binding prevented any further manipulation of the line and required the top plate and spools to be removed to release the line. During the loaded testing phase we were able to set the length of the lines and support the full load of the kite. We were able to minimally control the kite with the system. However, with the incorrect turning line speeds we were not able to satisfactorily control the kite. The team feels that with a few changes the system will be able to fully control the kite.

Figure 21: The Team with the 40 meter^2 kite

8.0 Future Work

There are modifications that need to be applied to the design to give the system optimal control of a kite. Throughout the manufacturing and testing phases of this project the team has also recognized possible changes that could be considered in the future.

The changes that are necessary for the optimal performance of the system are as follows: The worm screw and worm gear driving the turning function need to be changed from a quad-lead type to a single-lead type. This will decrease the speed of the turning function by a factor of four. Also, the spools need to be modified to prevent the line from falling off the spool and binding on the shaft under the spool. With these changes the team believes the system will optimally control the kite.

Some of the possible changes for the future are not related to the control of the kite, but are ways of making the system easier to transport and set up. One of these ideas is to lighten the system by removing excess material. Another idea is to break the system down into modules. The system could also be scaled down by using high performance gears of a smaller size.

9.0 Acknowledgements

Jeffrey Phipps,
Growth Innovations, L.C.

Dr. Cesar Luongo,
FAMU-FSU College of Engineering

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KiteShip

Tim Gamble,
FAMU-FSU C.O.E., Machine Shop

Laurie Herring,
FAMU-FSU C.O.E., Computer and Multimedia Services

George Johns,
Palatka Bolt and Screw

Mr. Keith Larson,
FAMU-FSU C.O.E., M.E. Machine Shop

Susie Middlebrooks,
Growth Innovations, L.C.

10.0 References
10.1 Website References

Boston Gear: Spur Gears. October 17, 2005. <http://www.bostongear.com/>

eFunda: Engineering Fundamentals. September 10, 2005. <http://www.efunda.com/units/show_units.cfm?Alfa=no&String1=Velocity&String2=velocity>

Engineers Edge: Gearbox Design. October 9, 2005. <http://www.engineersedge.com/>

Friction Torque Limiters. Ringfeder Corporation. September 27, 2005. <http://www.ringfeder.com/RFC%20Products.htm>

GlobalSpec, Inc. The Engineering Search Engine. September 10, 2005. <http://www.globalspec.com/>

Joystick Directory. October 3, 2005. < http://www.joystickreview.com/joystick/>

MSC Industrial Supply Company. October 28, 2005. <http://www1.mscdirect.com/cgi/nnsrhm>

Paralax Inc.: BASIC Stamps. October 2, 2005. <http://www.parallax.com/html_pages/products/basicstamps/basic_stamps.asp>

Rush Gears Inc. October 28, 2005. <http://www.rushgears.com/>

Shape Effects on Drag. By Tom Benson. September 10, 2005. <http://www.grc.nasa.gov/WWW/K-12/airplane/shaped.html>

The RobotMarketplace Motors. October 16, 2005. <http://www.robotcombat.com/marketplace_motors.html>

10.2 Book References

Cengel, Yunus. Fundamentals of Thermal-Fluid Sciences. 2005. McGraw-Hill. Page 1113. Table A-22.

Cengel, Yunus. Fundamentals of Thermal-Fluid Sciences. 2005. McGraw-Hill. Page 666. Equation 15-5.

Norton, Robert L. Machine Design An Integrated Approach 2nd Edition. Upper Saddle River, New Jersey: Prentice-Hall Inc. 2000

11.0 Appendix

11.1 Calculations

Growth Innovations Kite Group

Chris Boven
Brandon Henley
Trever Carnes
Emmanuel Zoubovsky

Need Statement: Determine the drag force on a 100 m^2 Outleader kite in a 30 knot wind. Using this drag force, calculate the line tensions for each of the three control lines.

Assumptions: Kite is modeled as a flat plane oriented orthogonal to the wind. Aspect ratio of the kite is 75%. Air is at 25 degrees Celcius and is at sea level. Two control lines are of equal tensions. The third control line handles 75% of the load carried by one of the other lines.

Conversions:

$$kt := 0.514444\,\frac{m}{s}$$

*****http://www.efunda.com/units/show_units.cfm?Alfa=no&String1=-Velocity&String2=velocity**

Calculations:

Drag Coefficient

$$C_d := 1.28$$

*****http://www.grc.nasa.gov/WWW/K-12/airplane/shaped.html**

Wind Velocity

$$V := 30kt \qquad V = 15.43\,\frac{m}{s}$$

Cross-sectional Area of Kite

$$A := 100m^2 \cdot 0.75 \qquad A = 75\,m^2$$

Density of Air

$$\rho := 1.184\,\frac{kg}{m^3}$$

*****Cengel, Yunus. Fundamentals of Thermal-Fluid Sciences. 2005. McGraw-Hill. Page 1113. Table A-22.**

Drag Force on Kite

$$F_d := \frac{C_d \cdot A \cdot \rho \cdot V^2}{2}$$

*****Cengel, Yunus. Fundamentals of Thermal-Fluid Sciences. 2005. McGraw-Hill. Page 666. Equation 15-5.**

$$\boxed{F_d = 13537\,N} \qquad \boxed{F_d = 3043\,lbf}$$

Tension on Lines

Given

$$3043 = T_1 + T_2 + T_3$$

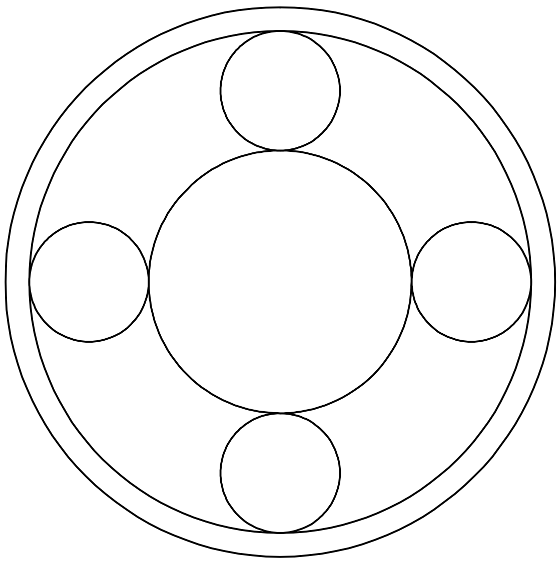
$$T_1 = T_2$$

$$T_3 = 0.75 \cdot T_1$$

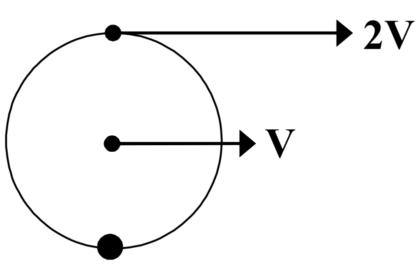
$$\begin{pmatrix} T_1 \\ T_2 \\ T_3 \end{pmatrix} := \text{Find}(T_1, T_2, T_3)$$

Tension of each control line (in lbf):

$$\boxed{T_1 = 1107} \qquad \boxed{T_2 = 1107} \qquad \boxed{T_3 = 830}$$



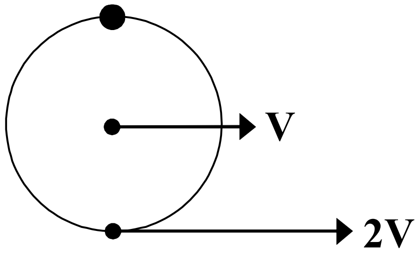
If the sun gear is stationary:



$$\omega_{spool} = \frac{V}{2.25} \qquad \omega_{ring} = \frac{2V}{3} \qquad \left(V = \frac{3}{2}\cdot\omega_{ring}\right)$$

$$\omega_{spool} = \frac{3}{2\cdot 2.25}\cdot\omega_{ring} = \frac{2}{3}\cdot\omega_{ring}$$

If the ring gear is stationary:



$$\omega_{spool} = \frac{V}{2.25} \qquad \omega_{sun} = \frac{2V}{1.5} \qquad \left(V = \frac{1.5}{2}\cdot\omega_{sun}\right)$$

$$\omega_{spool} = \frac{1.5}{4.5}\cdot\omega_{sun} = \frac{1}{3}\cdot\omega_{sun}$$

Summary

$$\omega_{spool} = \frac{2}{3}\cdot\omega_{ring} \qquad \omega_{ring} = \frac{3}{2}\cdot\omega_{spool}$$

$$\omega_{spool} = \frac{1}{3}\cdot\omega_{sun} \qquad \omega_{sun} = 3\cdot\omega_{spool}$$

Chris Boven   Trever Carnes
Brandon Henley   Emmanuel Zoubovsky

Calculations for the In/Out Function:

$V_{line} := 5\,\frac{ft}{sec}$ $r_{spool} := 3in$ $rpm := 2\pi\,\frac{rad}{min}$

$\omega_{spool} := \frac{V_{line}}{r_{spool}}$ $\omega_{spool} = 190.986\,rpm$

$\omega_{ring} := \frac{3}{2}\cdot\omega_{spool}$ $\omega_{ring} = 286.479\,rpm$

$\omega_{motor} := 4000rpm$ $wormratio := \frac{1}{5}$

$wormoutput := \omega_{motor}\cdot wormratio$ $wormoutput = 800\,rpm$

$\omega_{pinion} := wormoutput$ $\omega_{pinion} = 800\,rpm$

$ratio_{pinion\_ring} := \frac{\omega_{pinion}}{\omega_{ring}}$ $\boxed{ratio_{pinion\_ring} = 2.793}$

ring = 60 teeth

Choices:

pinion = 20 teeth   ratio = 3

pinion = 21 teeth   ratio = 2.857

pinion = 22 teeth   ratio = 2.727   **<--- We will select this gear**

pinion = 23 teeth   ratio = 2.609

Calculating In/Out line speed using selected gears:

$\omega_{motor} := 4000rpm$

$wormratio := \frac{1}{5}$

$wormoutput := \omega_{motor} \cdot wormratio$

$wormoutput = 800\,rpm$

$\omega_{pinion} := wormoutput$

$\omega_{pinion} = 800\,rpm$

$pinionratio := \frac{22}{60}$

$\omega_{ring} := \omega_{pinion} \cdot pinionratio$

$\omega_{ring} = 293.333\,rpm$

$\omega_{spool} := \frac{2}{3} \cdot \omega_{ring}$

$\omega_{spool} = 195.556\,rpm$

$V_{line} := \omega_{spool} \cdot 3in$

$V_{line} = 5.12\,\frac{ft}{s}$

Calculations for the Turning Function:

$V_{line} := 5\,\frac{ft}{sec}$ $\quad$ $r_{spool} := 3in$

$\omega_{spool} := \frac{V_{line}}{r_{spool}}$ $\quad$ $\omega_{spool} = 190.986\,rpm$

$\omega_{sun} := 3 \cdot \omega_{spool}$ $\quad$ $\omega_{sun} = 572.958\,rpm$

$\omega_{motor} := 4000rpm$ $\quad$ $wormratio := \frac{1}{5}$

$wormoutput := \omega_{motor} \cdot wormratio$ $\quad$ $wormoutput = 800\,rpm$

$\omega_{sundrive} := wormoutput$ $\quad$ $\omega_{sundrive} = 800\,rpm$

$ratio_{sundrive\_sundriven} := \frac{\omega_{sundrive}}{\omega_{sun}}$ $\quad$ $\boxed{ratio_{sundrive\_sundriven} = 1.396}$

center-to-center distance = 5 inches

Gear Pair Choices (that will fit the design):

10 DP gears

56-tooth/44-tooth ratio = 1.273

58-tooth/42-tooth ratio = 1.381 **<--- We will select these gears**

60-tooth/40-tooth ratio = 1.5

Calculating Turning line speed using selected gear:

$\omega_{motor} := 4000\text{rpm}$

$\text{wormratio} := \frac{1}{5}$

$\text{wormoutput} := \omega_{motor} \cdot \text{wormratio}$

$\text{wormoutput} = 800\ \text{rpm}$

$\omega_{sundrive} := \text{wormoutput}$

$\omega_{sundrive} = 800\ \text{rpm}$

$\text{drivedrivenratio} := \frac{42}{58}$

$\omega_{sun} := \omega_{sundrive} \cdot \text{drivedrivenratio}$

$\omega_{sun} = 579.31\ \text{rpm}$

$\omega_{spool} := \frac{1}{3} \cdot \omega_{sun}$

$\omega_{spool} = 193.103\ \text{rpm}$

$V_{line} := \omega_{spool} \cdot 3\text{in}$

$V_{line} = 5.055\ \frac{\text{ft}}{\text{s}}$

Chris Boven
Brandon Henley
Trever Carnes
Emmanuel Zoubovsky

Evaluation of the Outer Ring Pinion Gear

Safe Material Static Stress

$$S := 20000\,\frac{lb}{in^2}$$

Face Width

$$F := 1.5in$$

Tooth Form Factor

$$Y := 0.288$$

Diametral Pitch

$$P := 6\cdot\frac{1}{in}$$

Pinion Gear Diameter

$$D := \frac{22}{P}$$

Pitch Line Velocity

$$V := 3.5in\cdot 800\cdot\frac{rev}{min}$$

$$V = 1.466\times 10^{3}\,\frac{ft}{min}$$

Tooth Load

$$W := \frac{S\cdot F\cdot Y}{P}\left(\frac{600\,\frac{ft}{min}}{600\,\frac{ft}{min} + V}\right)$$

$$W = 418.184\ lb$$

Maximum Allowable Torque

$$T := \frac{W\cdot D}{2} \qquad T = 766.671\ lb\cdot in$$

Torque Rating for 22 tooth 6dp steel spur gear

$$T_{rating} := 867lb\cdot in$$

Safety Factor

$$SF := \frac{T_{rating}}{T} \qquad SF = 1.131$$

For a gear with the pitch line velocity of 1470ft/min the calculated torque rating is 732lb*in from the chart supplied by the gear manufacturer the torque rating for this gear at 800 rpm is 867lb*in giving a safety factor of approxiamately 1.2. This gear should be appropriate for this application.

Evaluation of the Driven Sun Gear

Safe Material Static Stress

$$S := 20000 \frac{lb}{in^2}$$

Face Width

$$F := 1in$$

Tooth Form Factor

$$Y := 0.338$$

Diametral Pitch

$$P := 10 \cdot \frac{1}{in}$$

Pinion Gear Diameter

$$D := \frac{58}{P}$$

Pitch Line Velocity

$$V := 5.8in \cdot 1100 \frac{rev}{min} \qquad V = 55.676 \frac{ft}{sec}$$

Tooth Load

$$W := \frac{S \cdot F \cdot Y}{P} \left(\frac{600 \frac{ft}{min}}{600 \frac{ft}{min} + V} \right)$$

$$W = 102.93\, lb$$

Maximum Allowable Torque

$$T := \frac{W \cdot D}{2} \qquad T = 298.496\, lb \cdot in$$

Torque Rating for 58 tooth 10dp steel spur gear

$$T_{rating} := 330lb \cdot in$$

Safety Factor

$$SF := \frac{T_{rating}}{T} \qquad SF = 1.106$$

For a gear with the pitch line velocity of 3300ft/min the calculated torque rating is 300lb*in from the chart supplied by the gear manufacturer the torque rating for this gear at 800 rpm is 330lb*in giving a safety factor of approxiamately 1.1. This gear should be appropriate for this application.

All Formulas and data from Boston Gear Open Gearing Catalogue

$T_1 := 1000$ $T_2 := 1000$ $T_3 := 1000$

$rev := 2\pi rad$

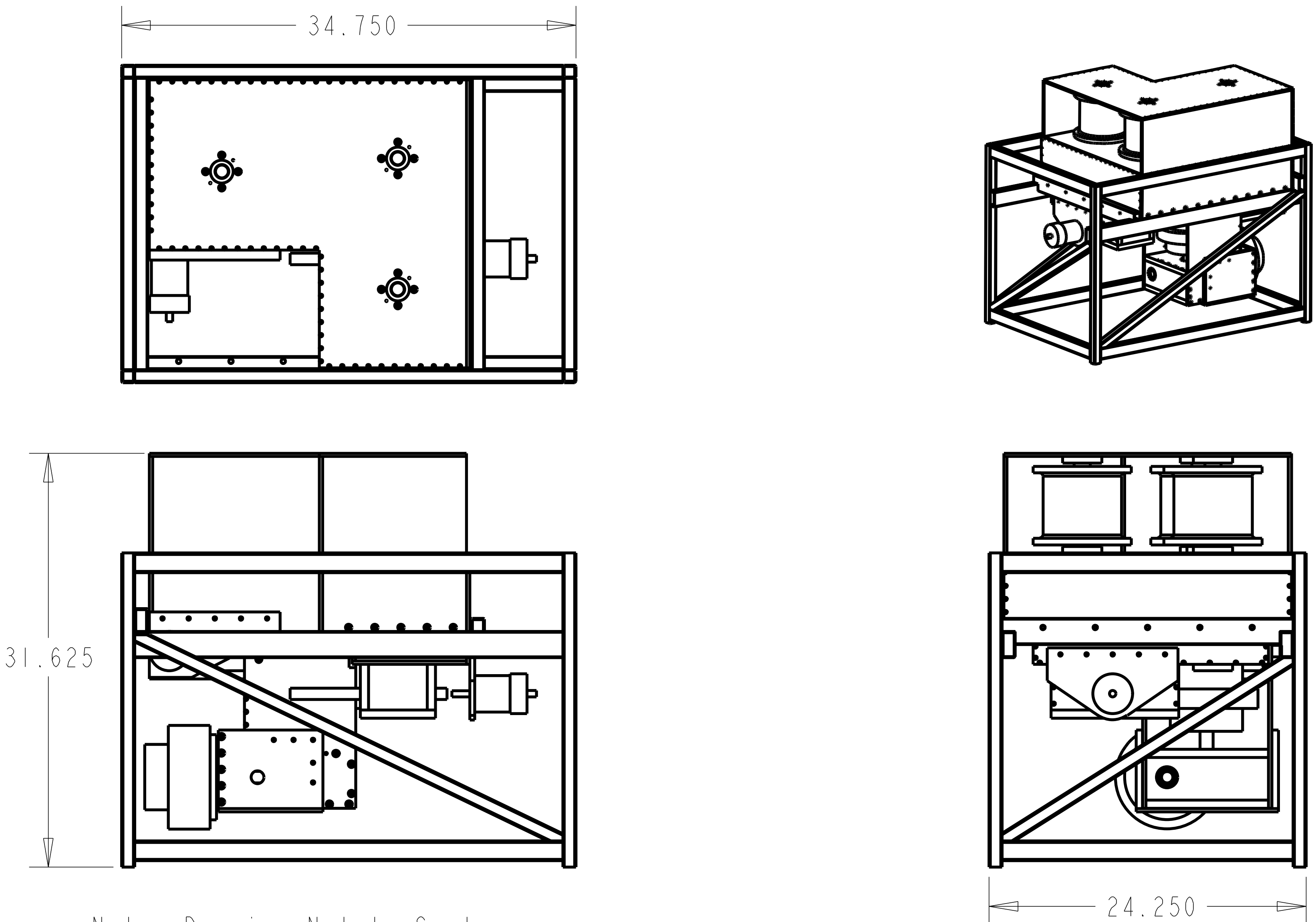
11.2 Pro-E Drawings

11.2.1 Part Drawings

GIKG-PP-001 thru GIKG-PP-059

11.2.2 Assembly Drawings

GIKG-PA-001 thru GIKG-PA-003



Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Complete Assembly	Quantity:1
FAMU-FSU	X.XX ± 0.01	N/A	T. Carnes
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PA-001

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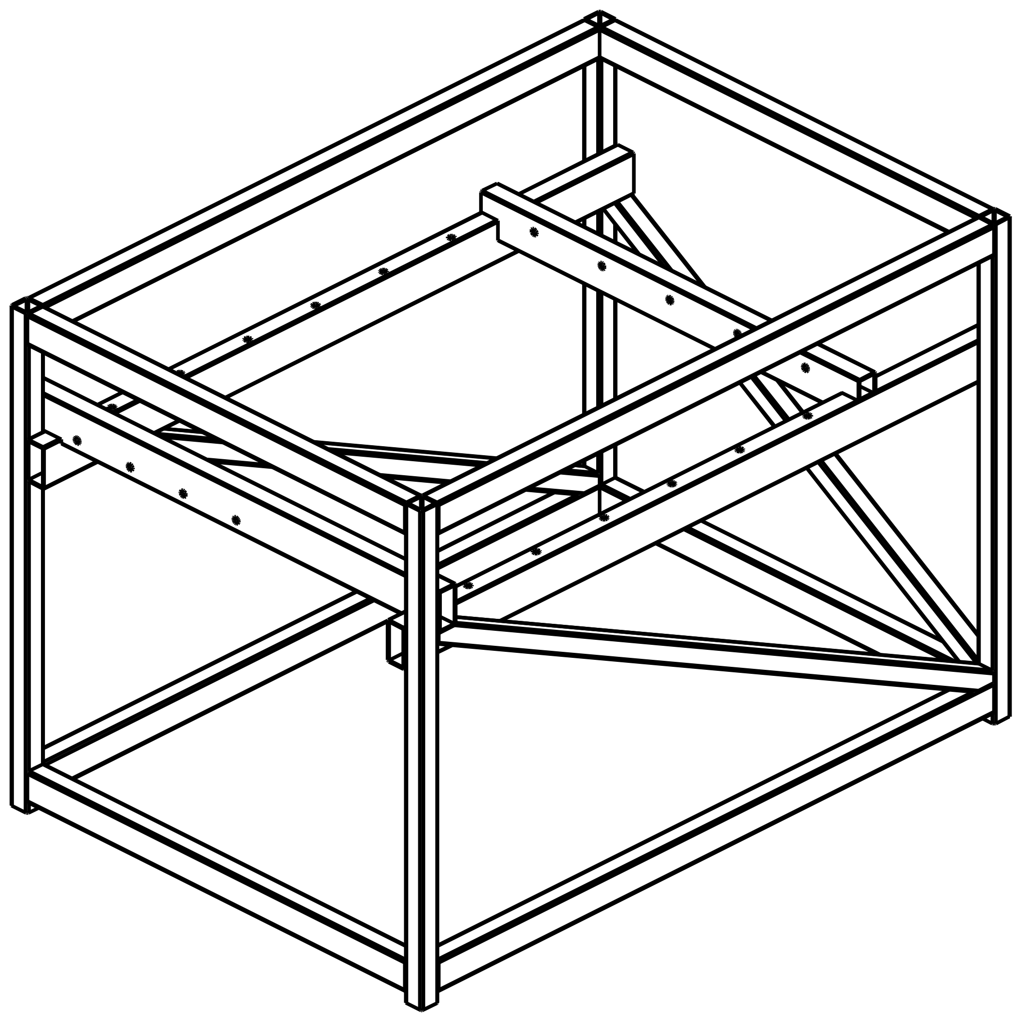

Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Frame Assembly	Quantity: 1
FAMU-FSU	X.XX ± 0.01	Steel	T.Carnes
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PA-002-1

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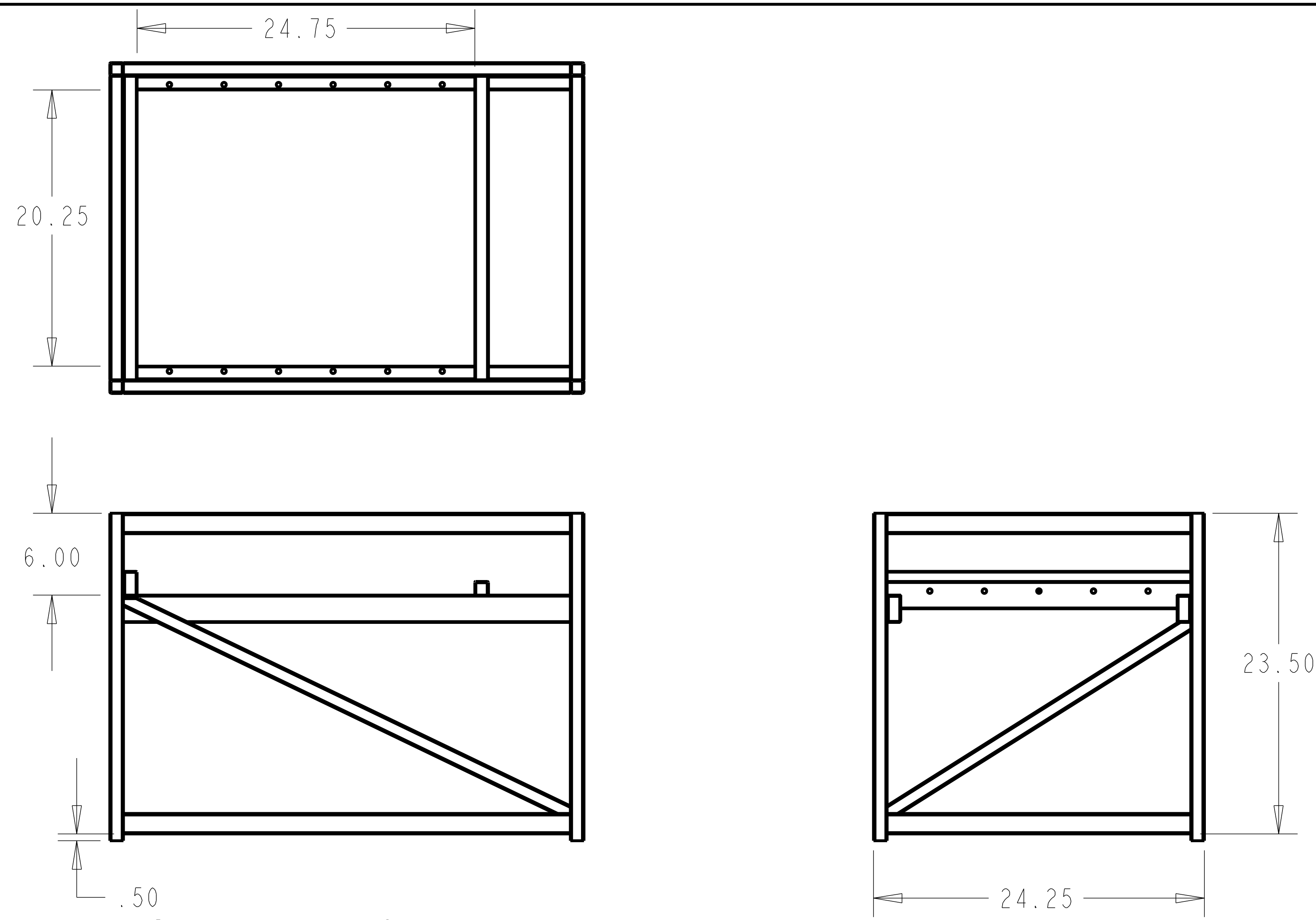

Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Frame Assembly	Quantity: 1
FAMU-FSU	X.XX ± 0.01	Steel	T. Carnes
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-002-2

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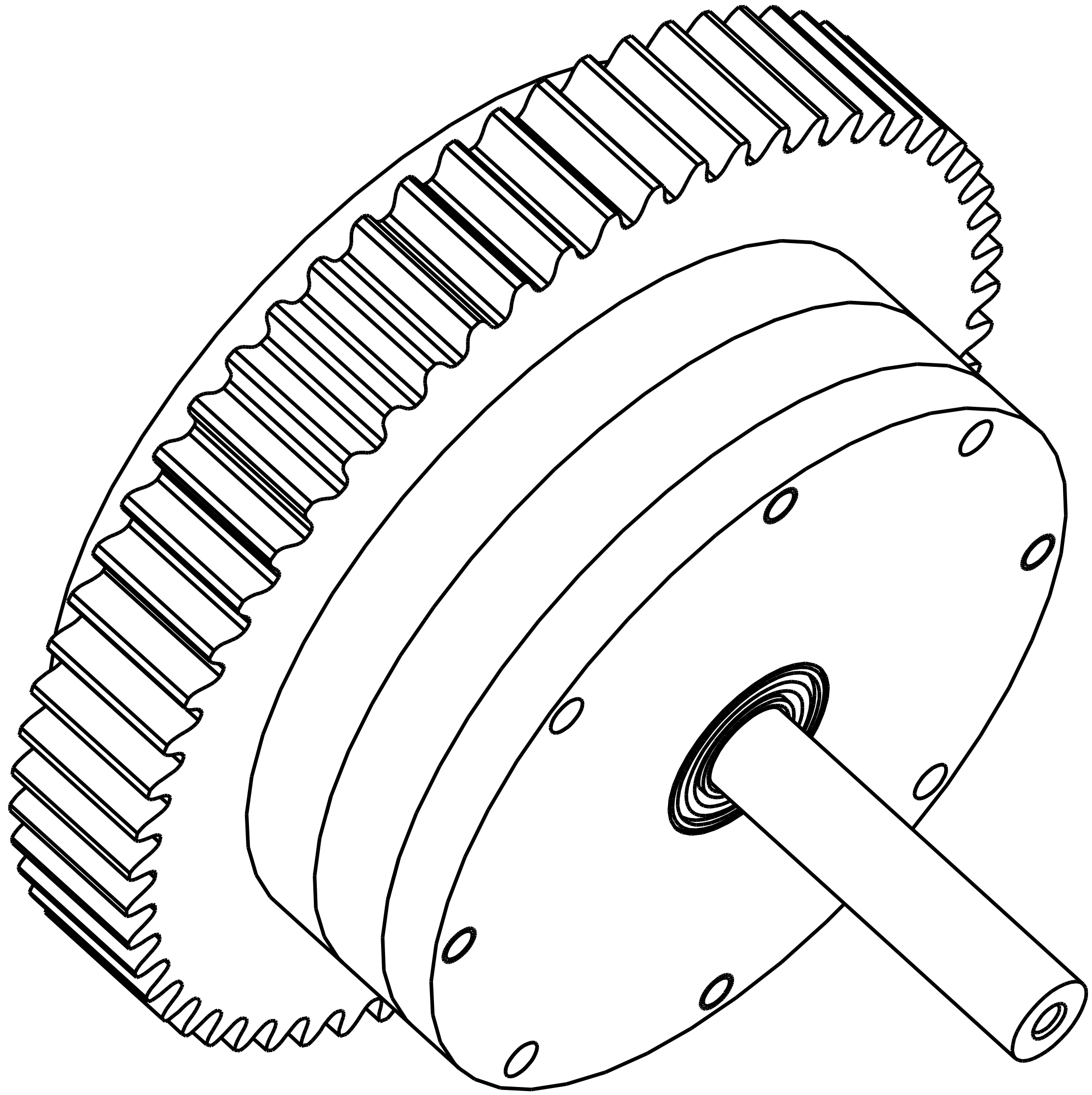
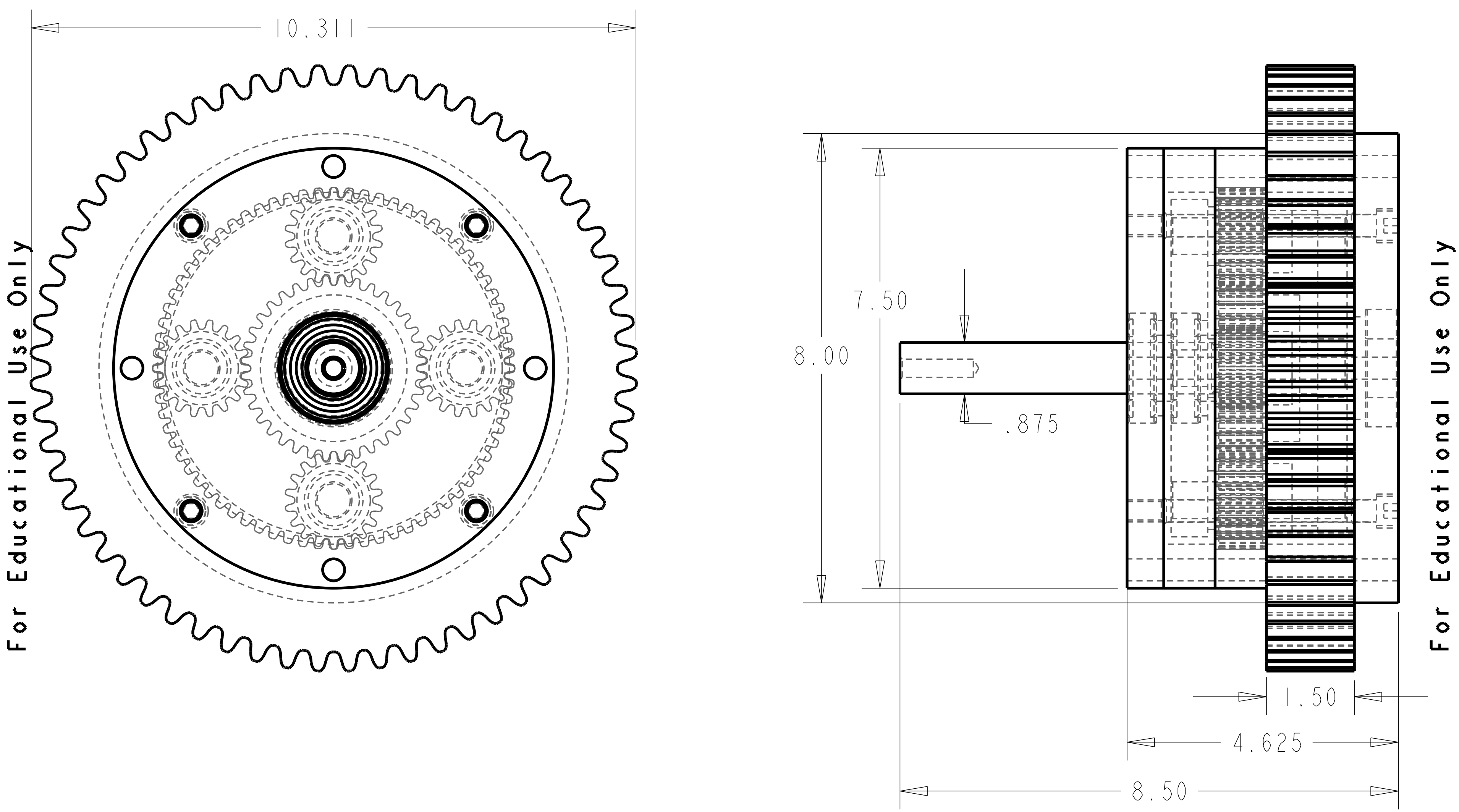


Note: Drawing Not to Scale

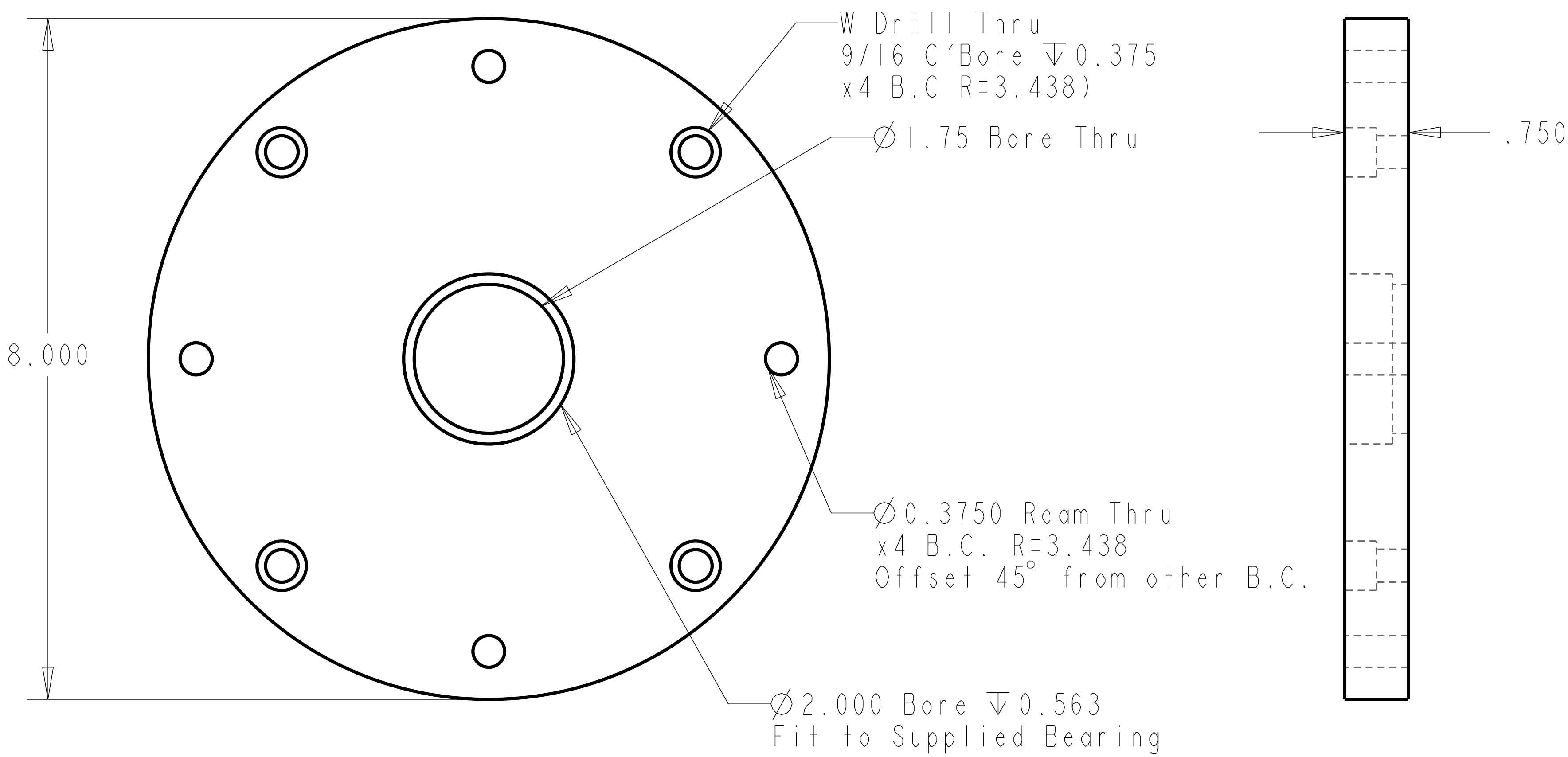
Growth Innovations Kite Group	X.X ± 0.1	Planetary Subsystem	Quantity: 3
FAMU-FSU	X.XX ± 0.01	N/A	T. Carnes
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PA-003-1



Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Planetary Subsystem	Quantity: 3
FAMU-FSU	X.XX ± 0.01	N/A	T. Carnes
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PA-003-2

SCALE 0.400



For Educational Use Only

For Educational Use Only

Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Ring Plate Drive	Quantity: 3
FAMU-FSU	X.XX ± 0.01	Aluminum 6061-T651	B. Henley
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-001-1

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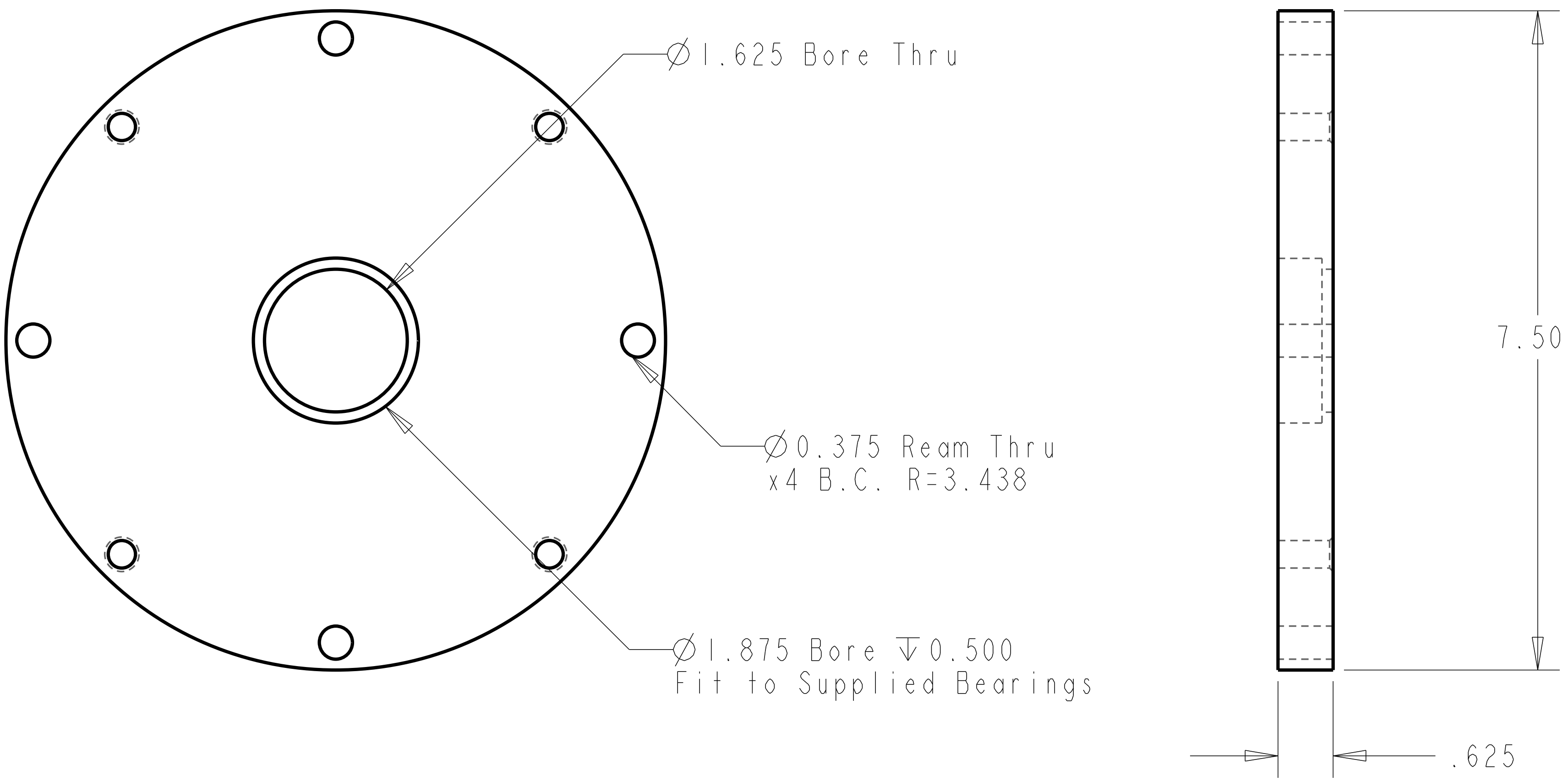
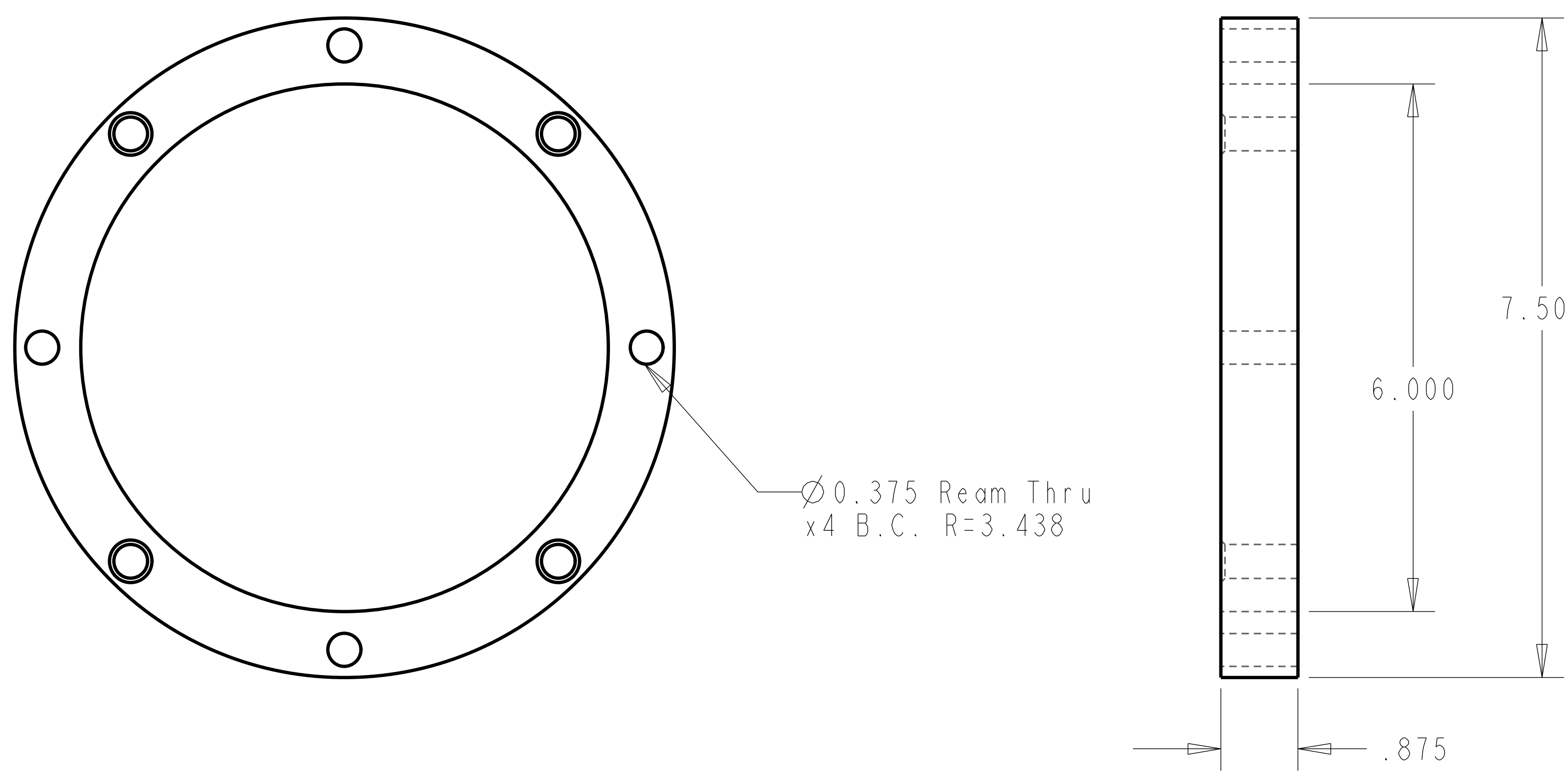


For Educational Use Only

Note: Drawing Not to Scale

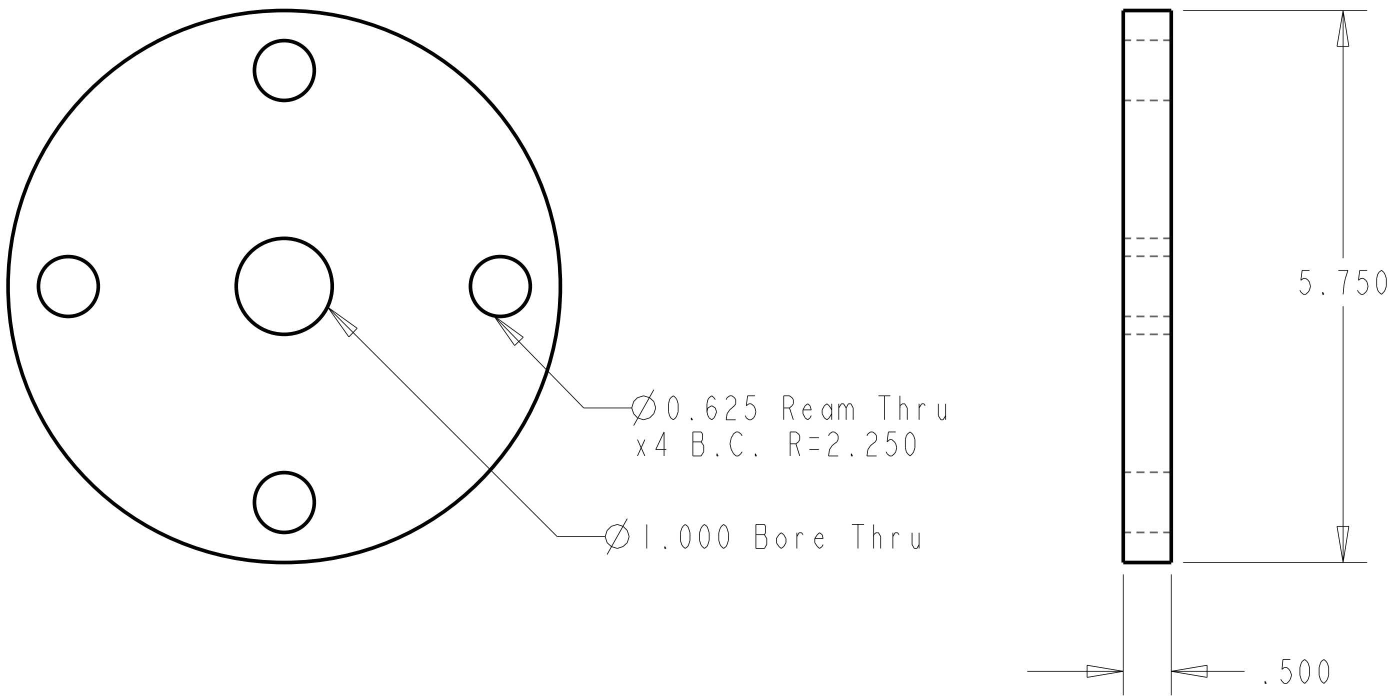
Growth Innovations Kite Group	X.X ± 0.1	Ring Plate Float	Quantity: 3
FAMU-FSU	X.XX ± 0.01	Aluminum 6061-T651	B. Henley
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-002-1

For Educational Use Only



Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Ring Plate Ring	Quantity: 3
FAMU-FSU	X.XX ± 0.01	Aluminum 6061-T651	B. Henley
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-003-1



Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Planet Plate Drive	Quantity: 3
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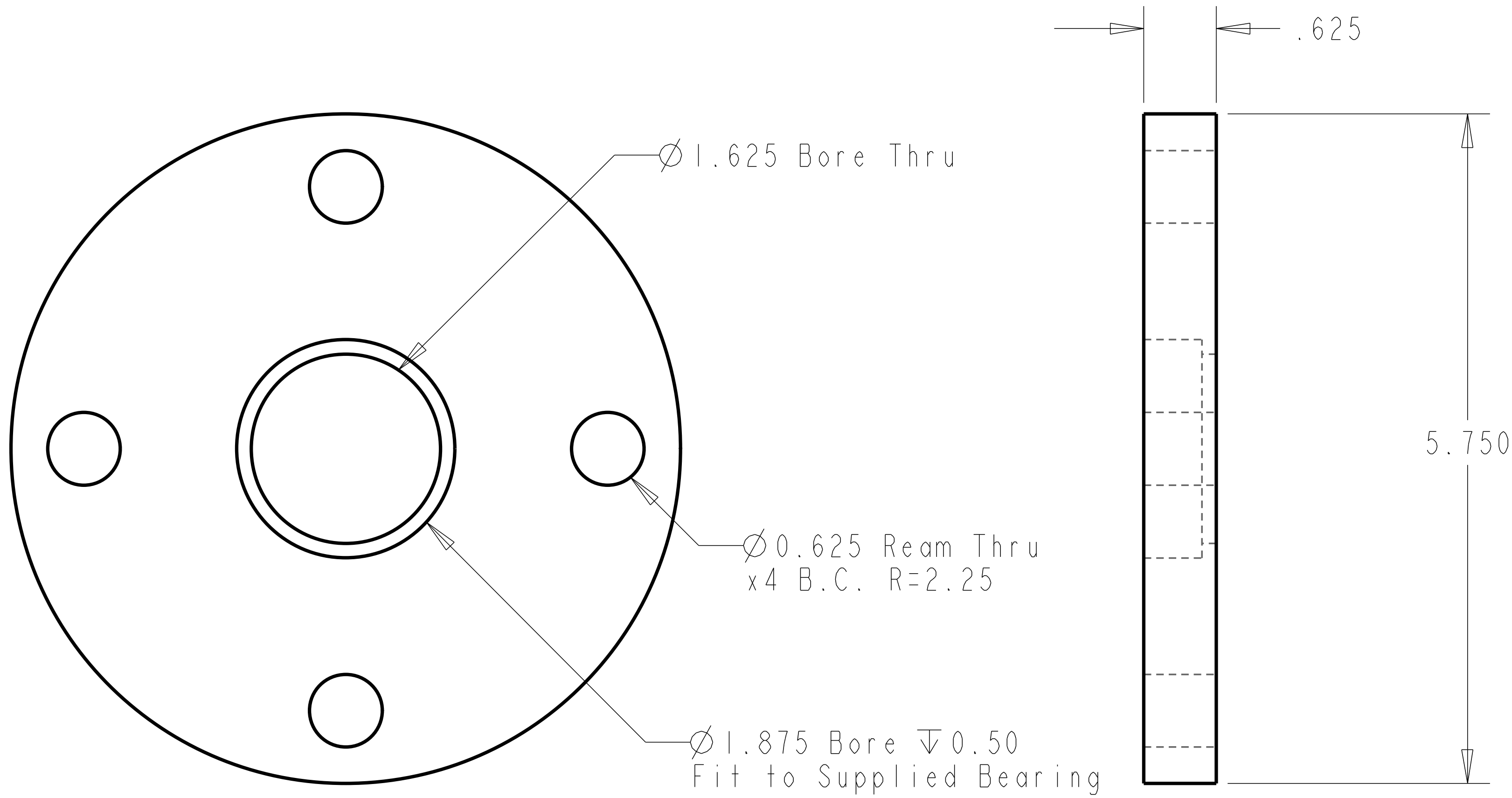
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-004-1



For Educational Use Only

Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Planet Plate Float	Quantity: 3
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College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-005-1

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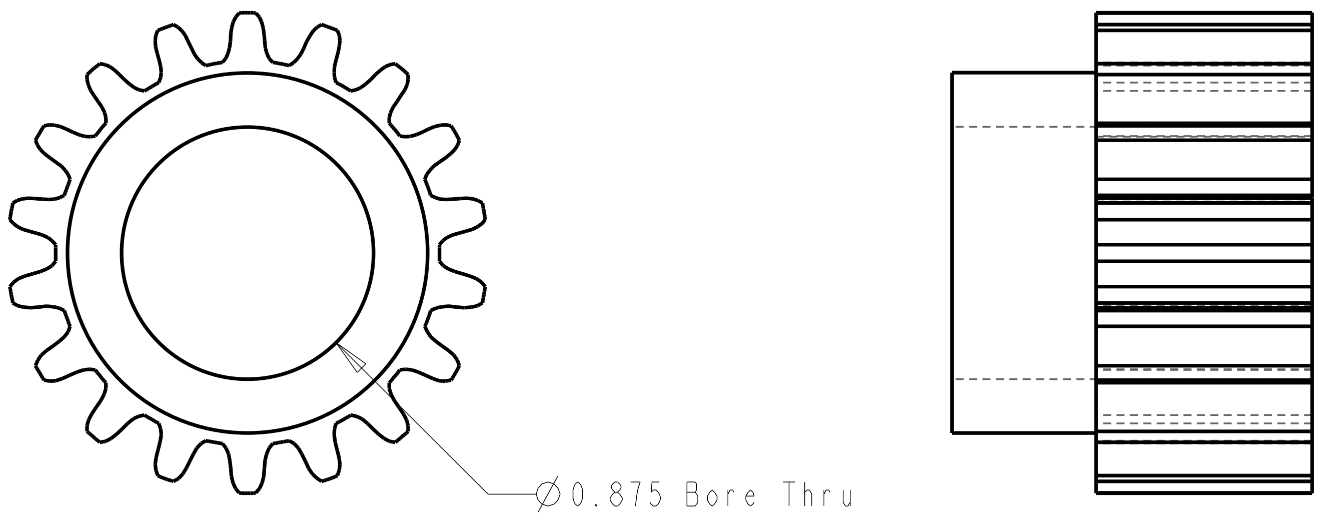

For Educational Use Only

Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Planetary Gear	Quantity: 12
FAMU-FSU	X.XX ± 0.01	Steel	B. Henley
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-006-1

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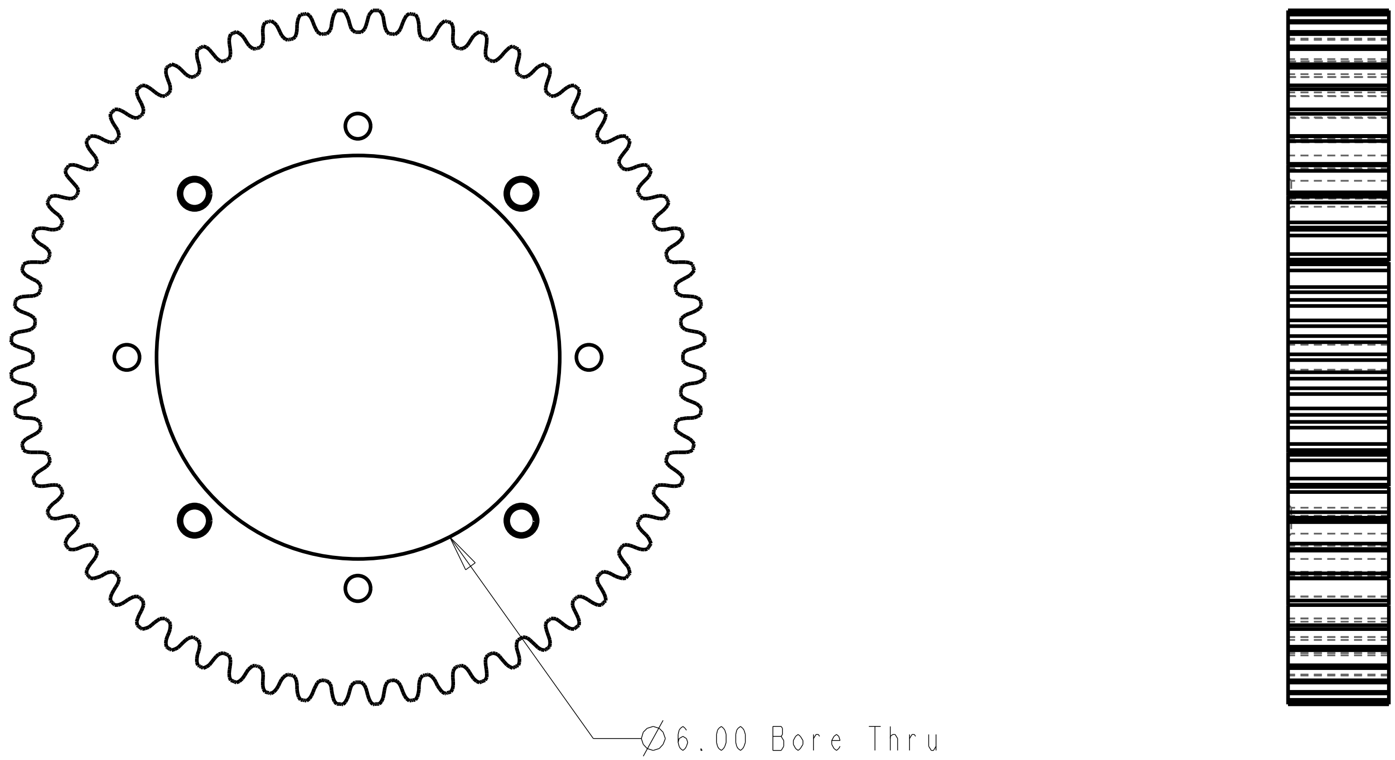
For Educational Use Only

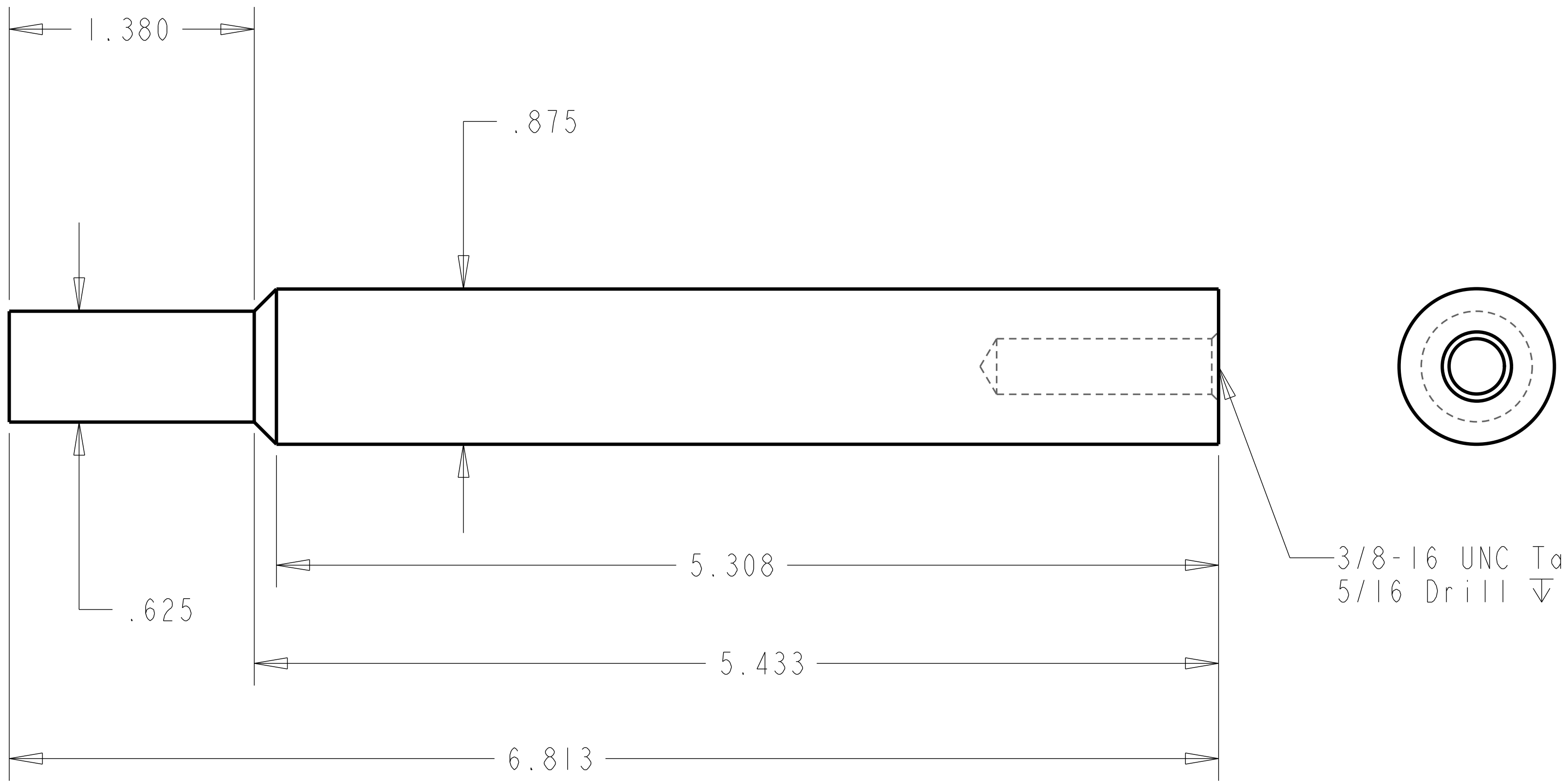


For Educational Use Only

Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Outer Ring Gear	Quantity: 3
FAMU-FSU	X.XX ± 0.01	Steel	B. Henley
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-007-1

For Educational Use Only



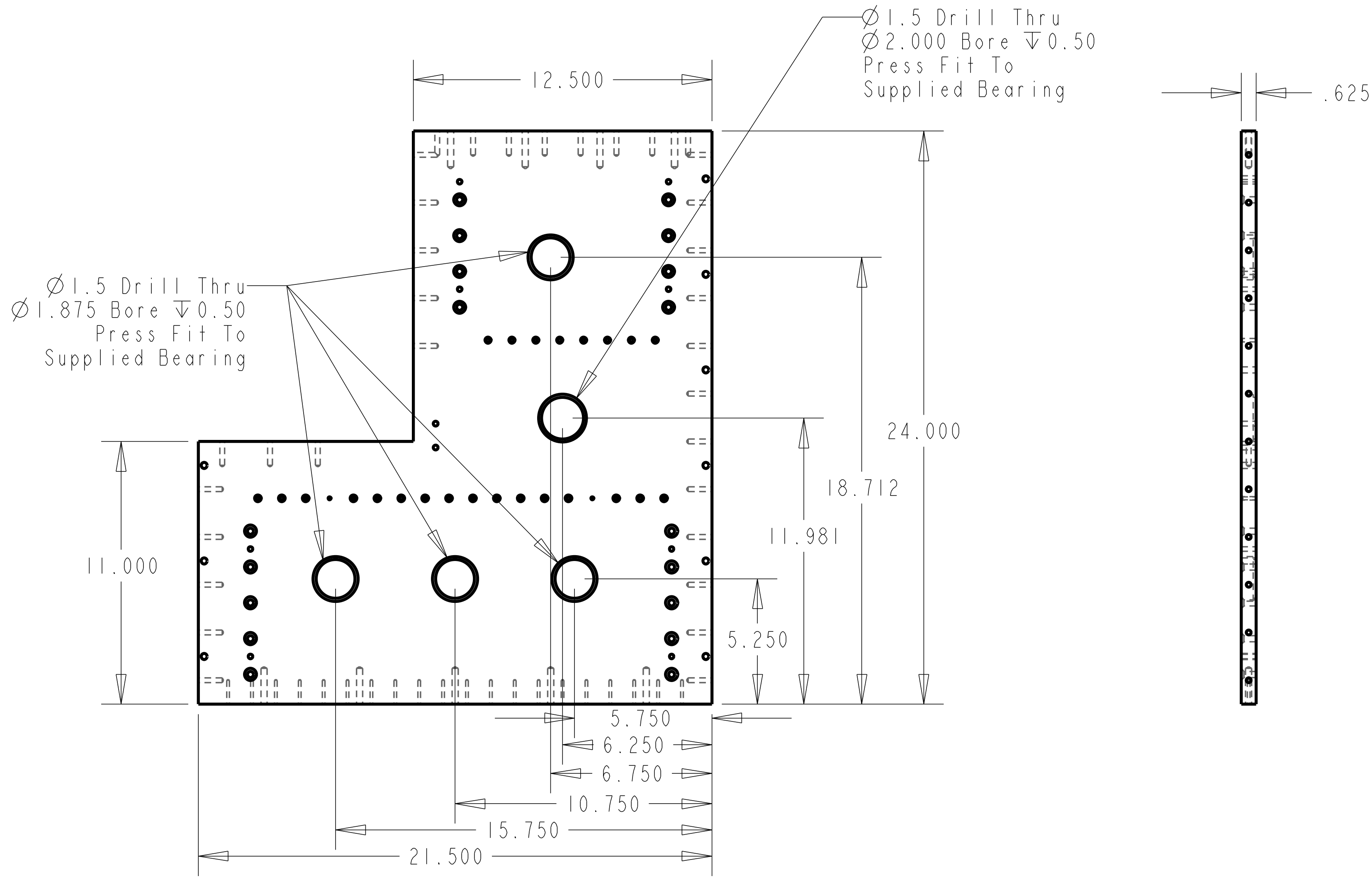
For Educational Use Only

For Educational Use Only

Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Shaft, Sun	Quantity: 3
FAMU-FSU	X.XX ± 0.01	O-2 Steel	B. Henley
College of Engineering	X.XXX ± 0.001	Inches	GIKG_PP_008_1

For Educational Use Only



Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Plate, Planetary Support	Quantity: 1
FAMU-FSU	X.XX ± 0.01	Aluminum 6061-T651	B. Henley
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-009-1

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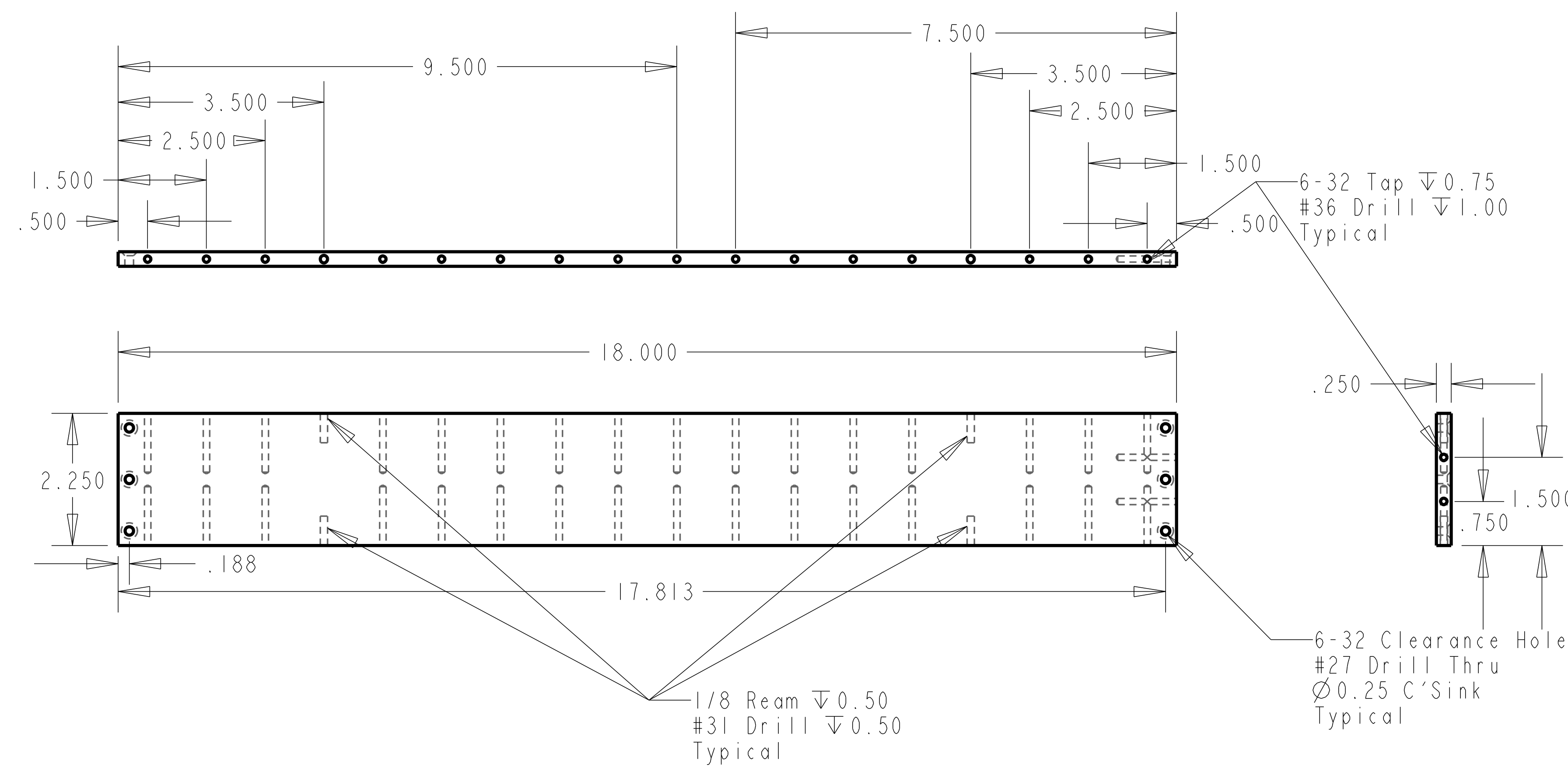
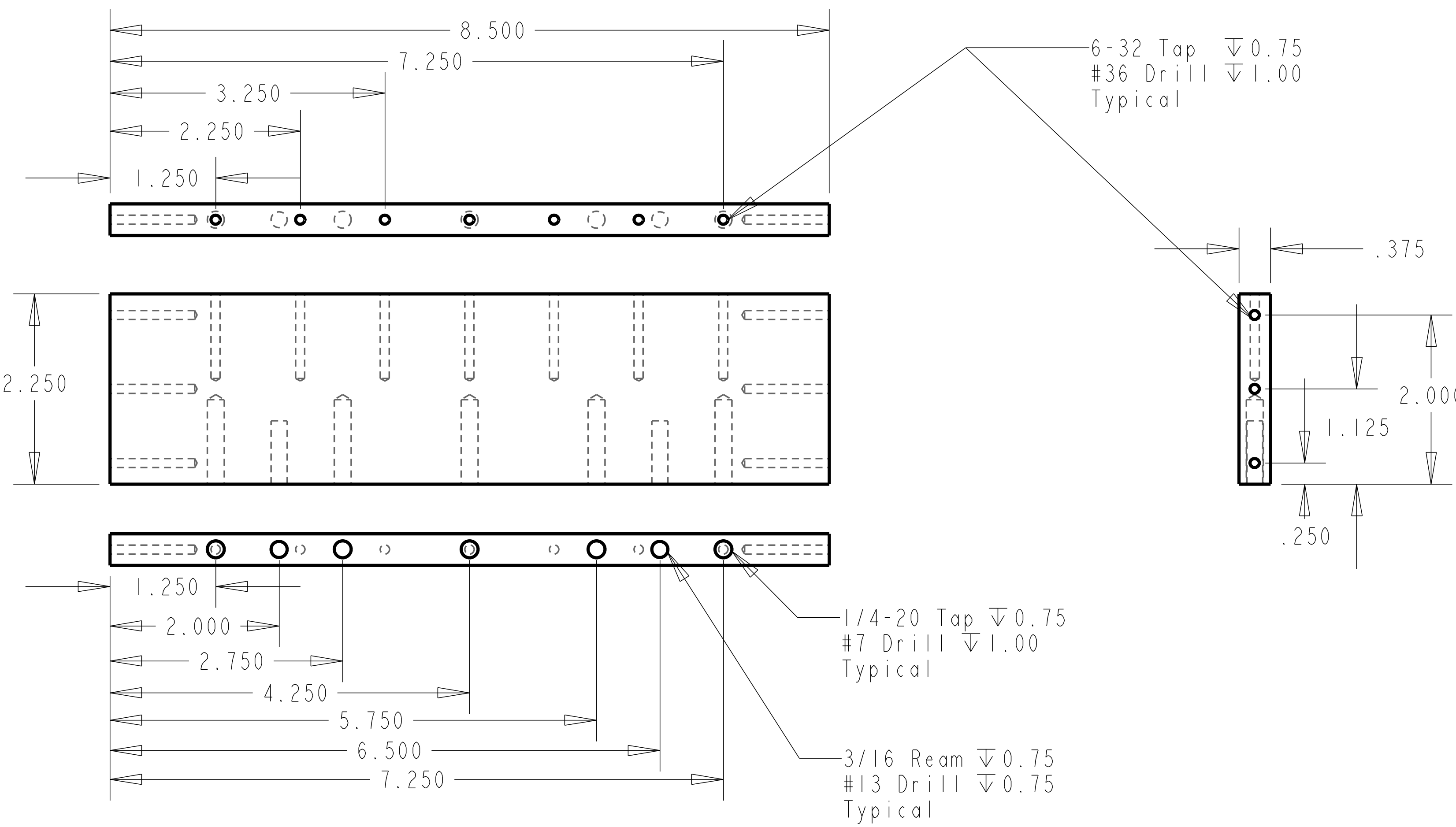
For Educational Use Only



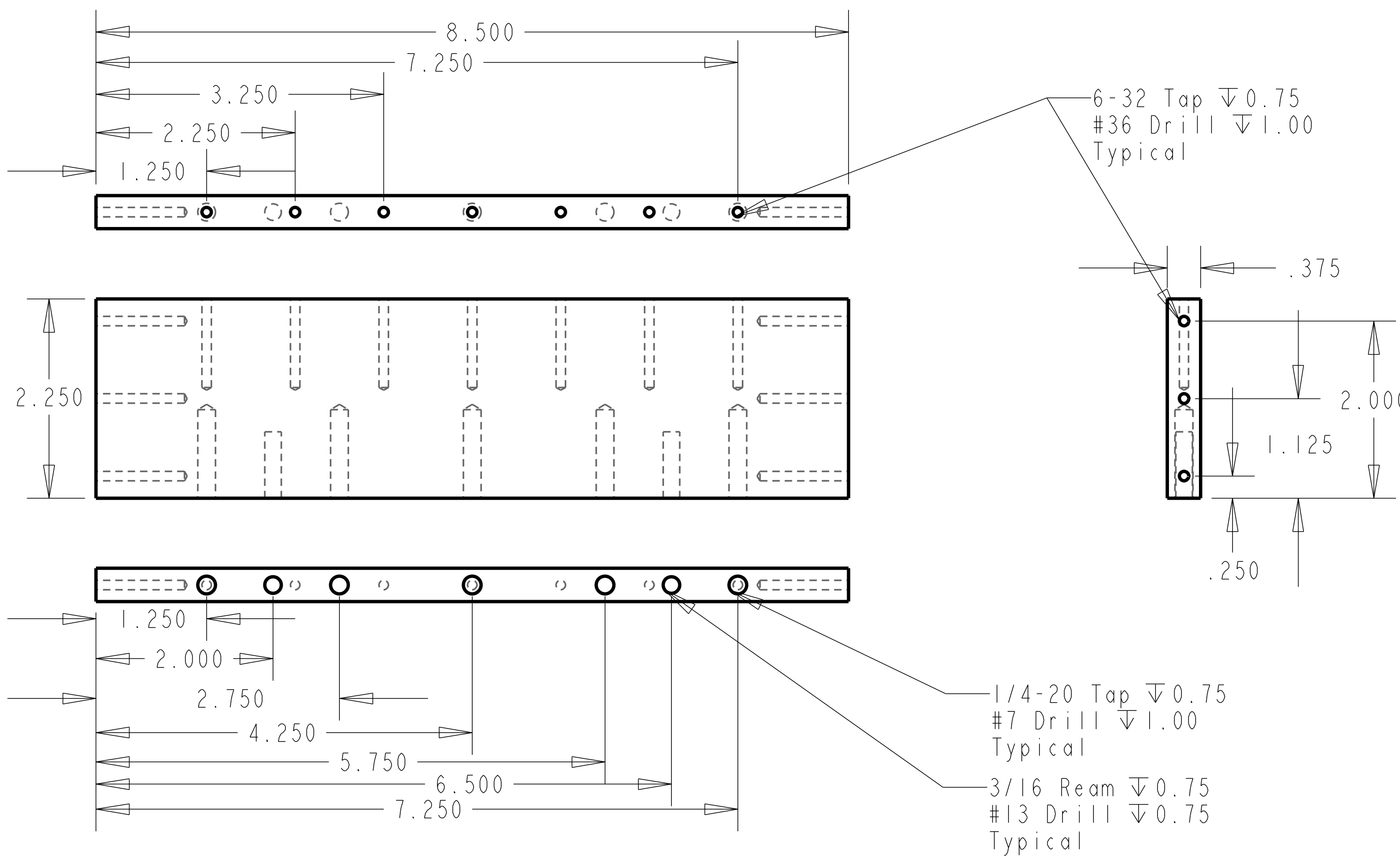
Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Plate Buildup 1	Quantity: 1
FAMU-FSU	X.XX ± 0.01	Aluminum 6061-T651	B. Henley
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-010-1



Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Plate Buildup 2	Quantity: 1
FAMU-FSU	X.XX ± 0.01	Aluminum 6061-T651	B. Henley
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-011-1



Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Plate Buildup 3	Quantity: 1
FAMU-FSU	X.XX ± 0.01	Aluminum 6061-T651	B. Henley
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-012-1

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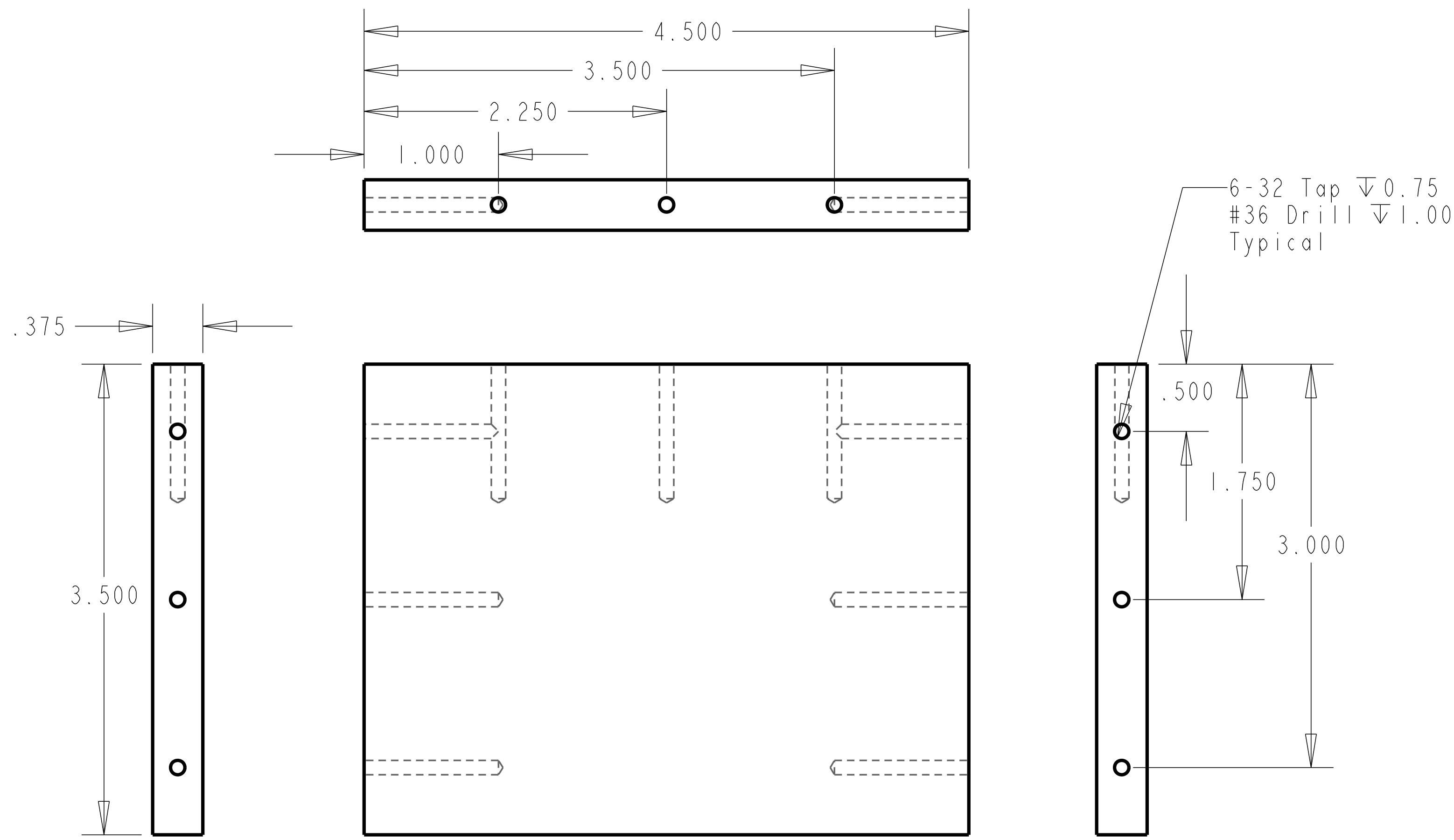
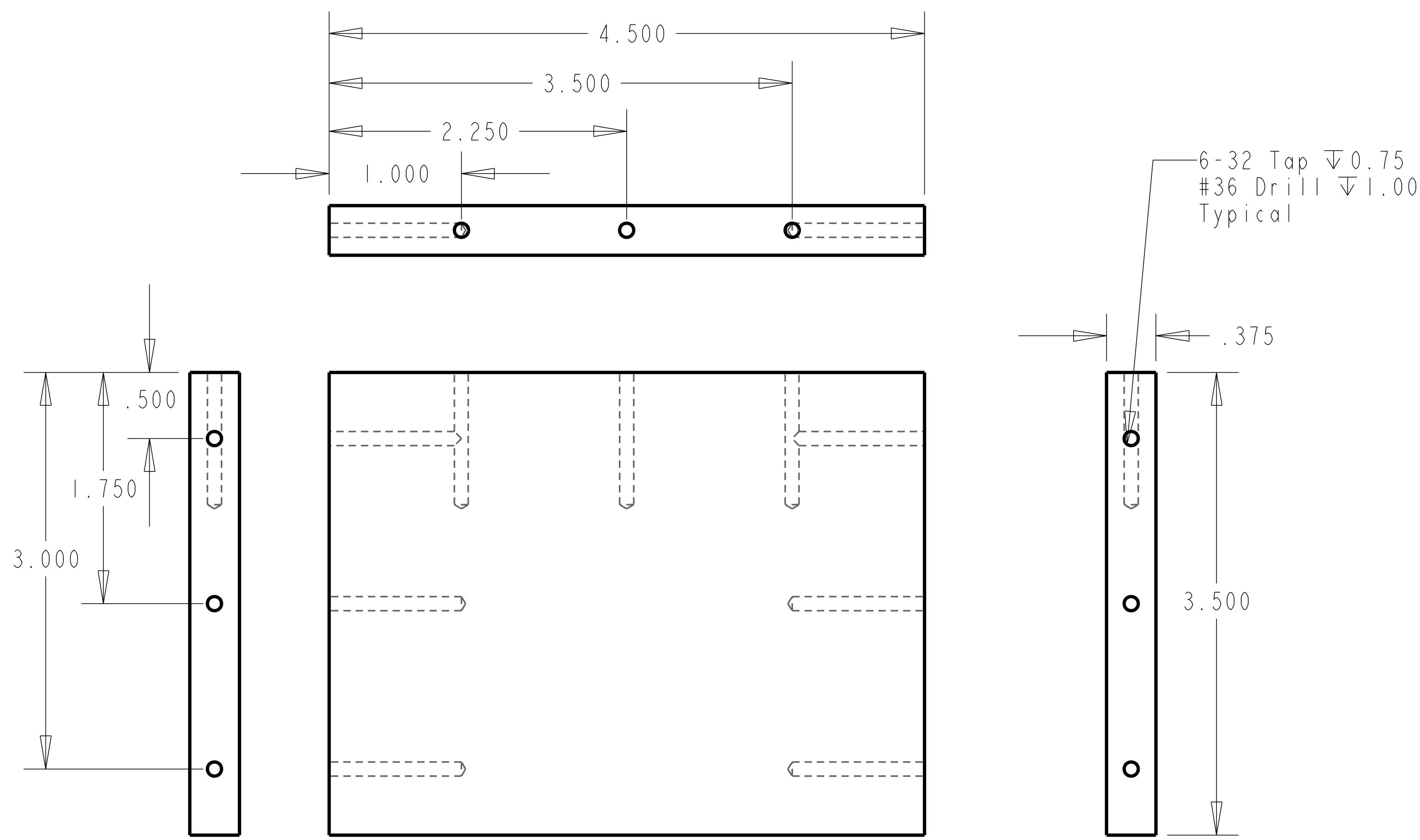


Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Plate Turnworm 3	Quantity: 1
FAMU-FSU	X.XX ± 0.01	Aluminum 6061-T651	B. Henley
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-013-1



Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Plate Turnworm 4	Quantity: 1
FAMU-FSU	X.XX ± 0.01	Aluminum 6061-T651	B. Henley
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-014-1

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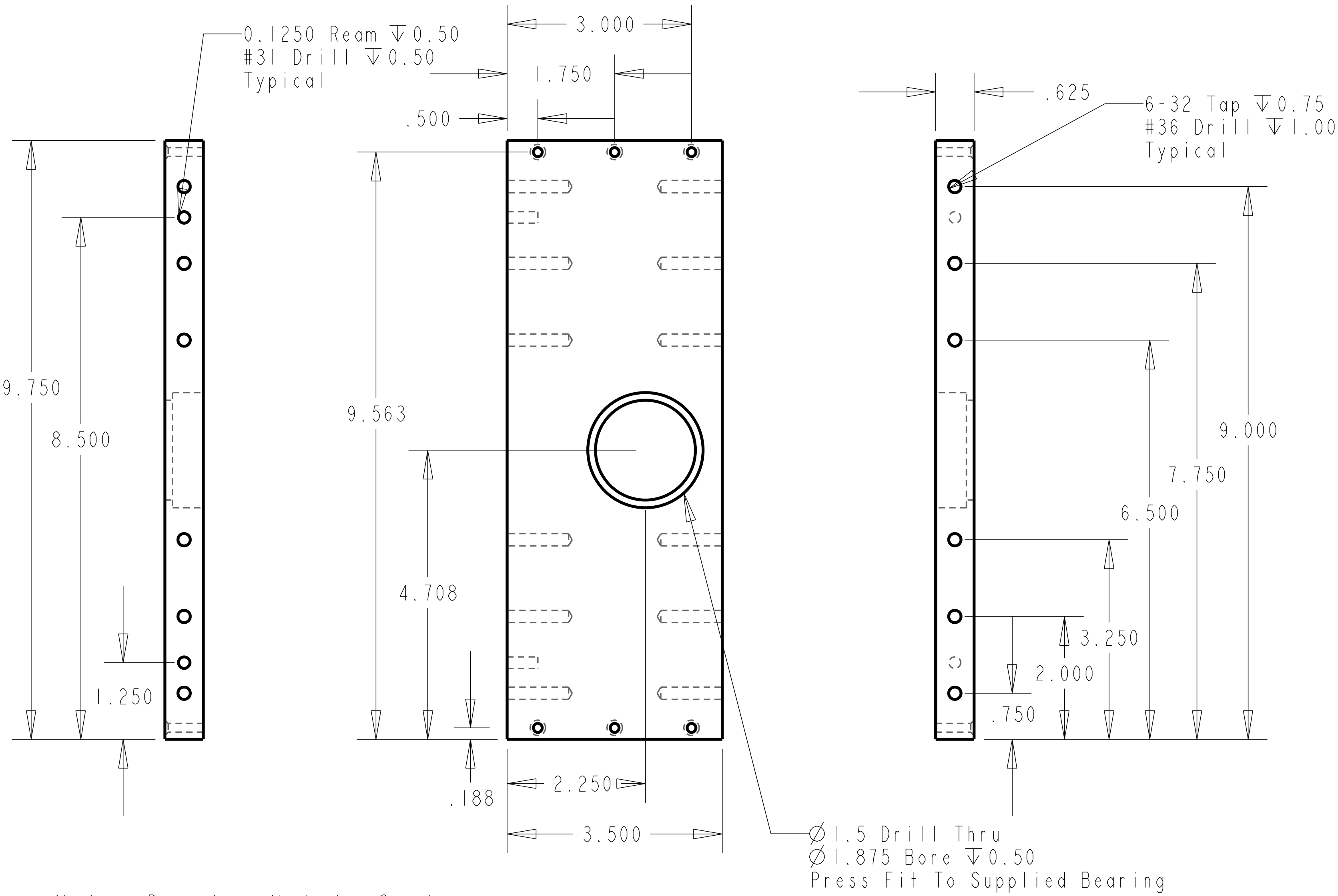

Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Plate Turnworm 1	Quantity: 1
FAMU-FSU	X.XX ± 0.01	Aluminum 6061-T651	B. Henley
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-015-1

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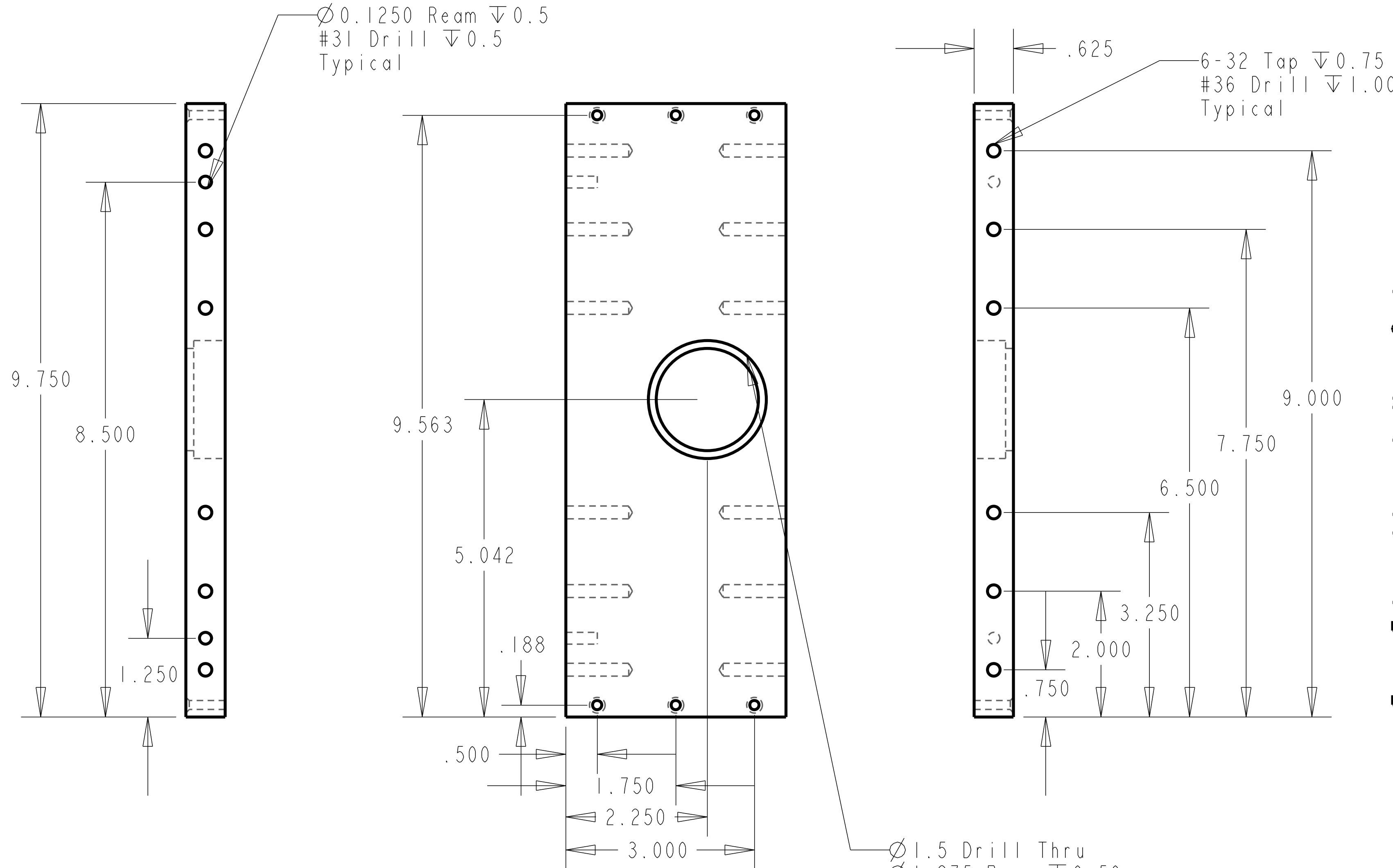

Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Plate Turnworm 2	Quantity: 1
FAMU-FSU	X.XX ± 0.01	Aluminum 6061-T651	B. Henley
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-016-1

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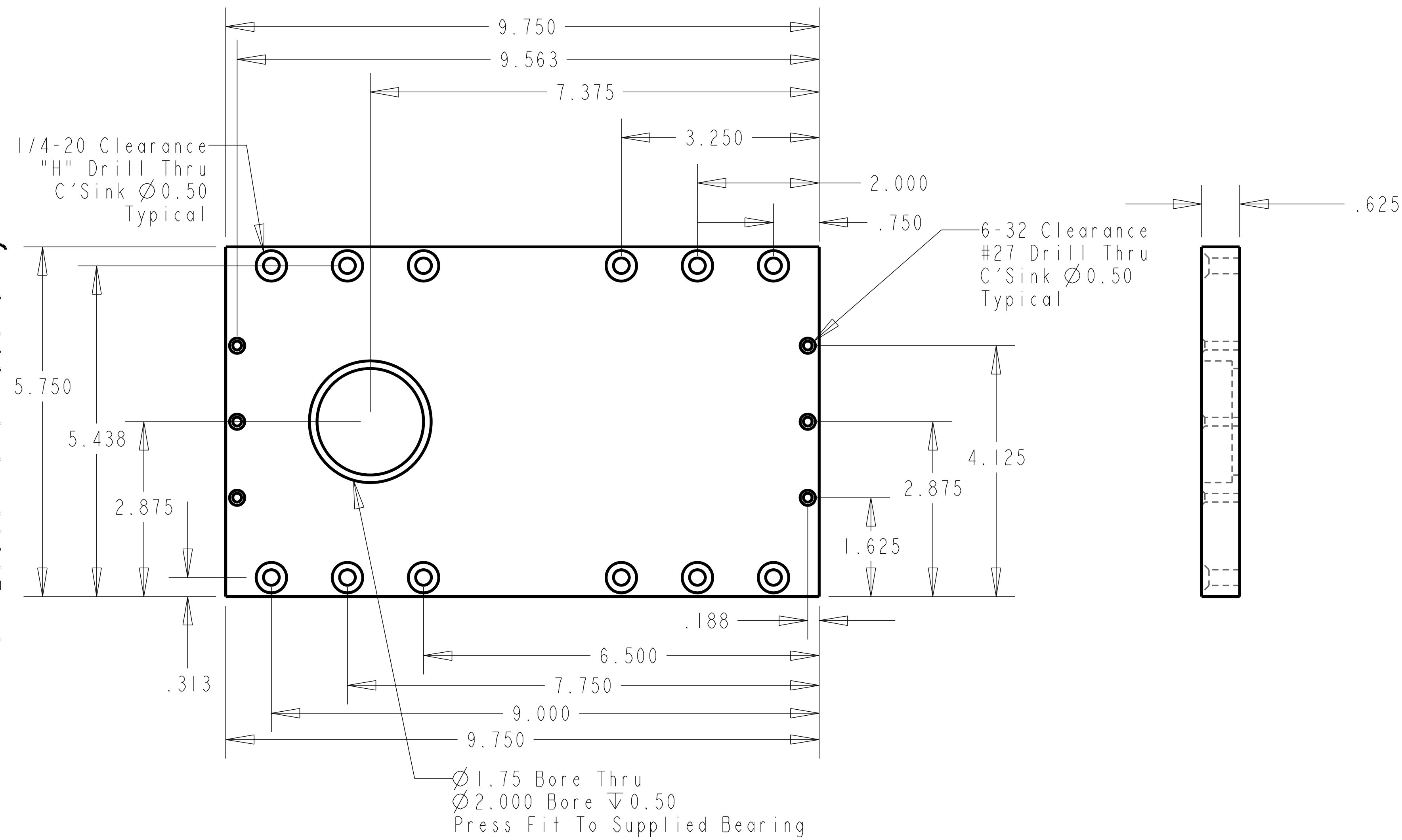

For Educational Use Only

Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Plate Turnworm 5	Quantity: 1
FAMU-FSU	X.XX ± 0.01	Aluminum 6061-T651	B. Henley
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-017-1

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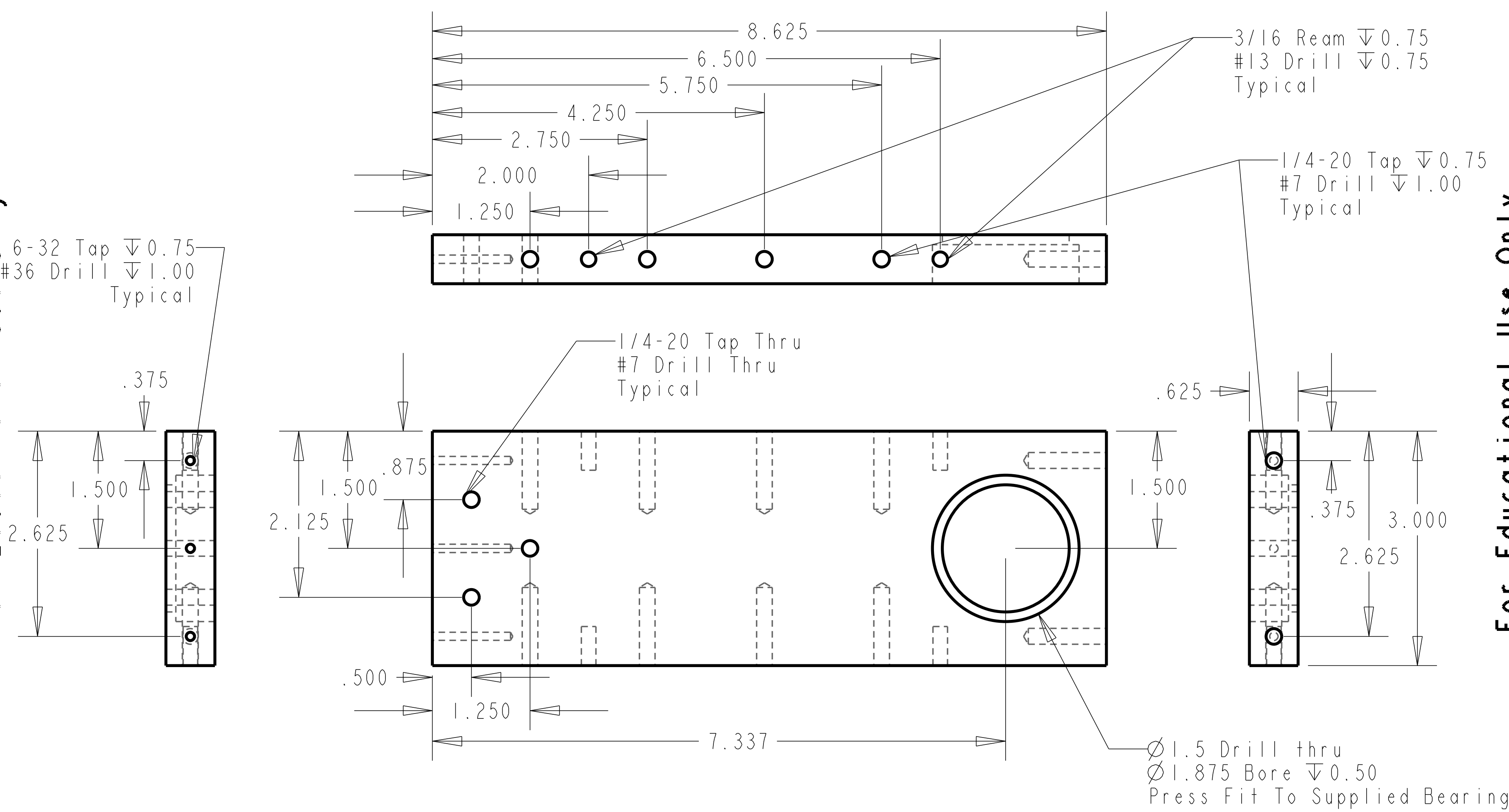
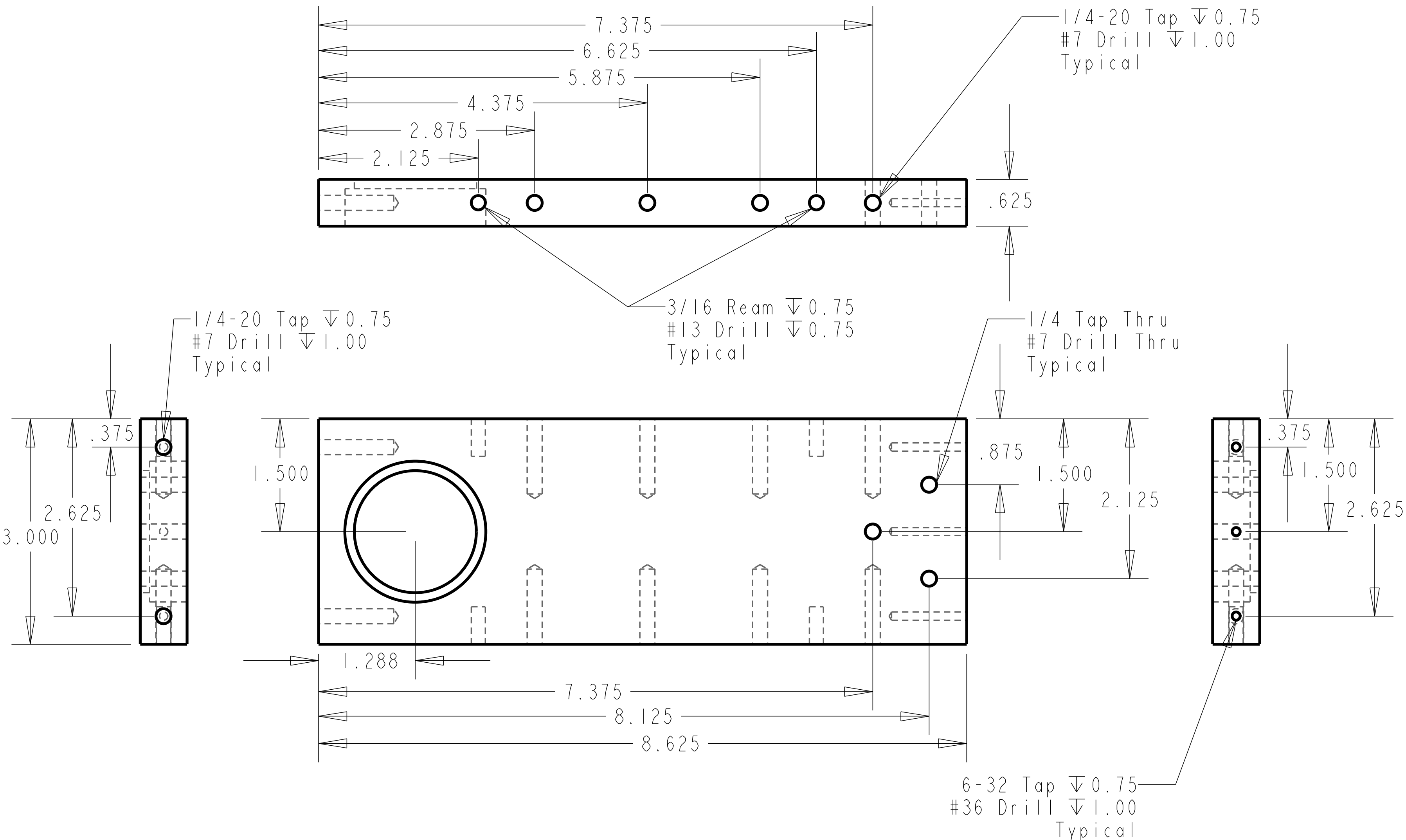


Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Plate Pitchworm 1	Quantity: 1
FAMU-FSU	X.XX ± 0.01	Aluminum 6061-T651	B. Henley
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-018-1



Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Plate Pitchworm 2	Quantity: 1
FAMU-FSU	X.XX ± 0.01	Aluminum 6061-T651	B. Henley
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-019-1

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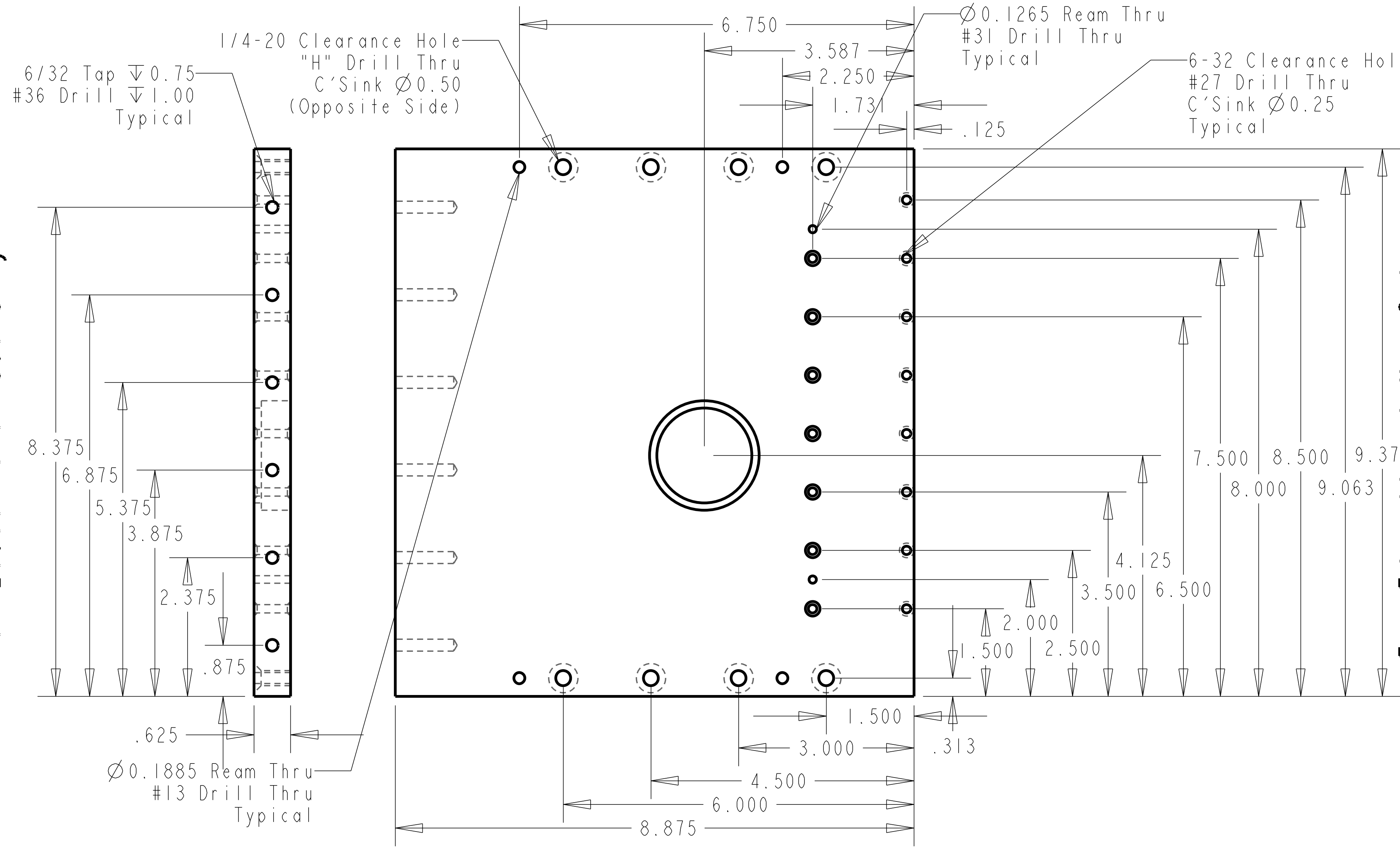

Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Plate Pitchworm 4	Quantity: 1
FAMU-FSU	X.XX ± 0.01	Aluminum 6061-T651	B. Henley
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-020-1

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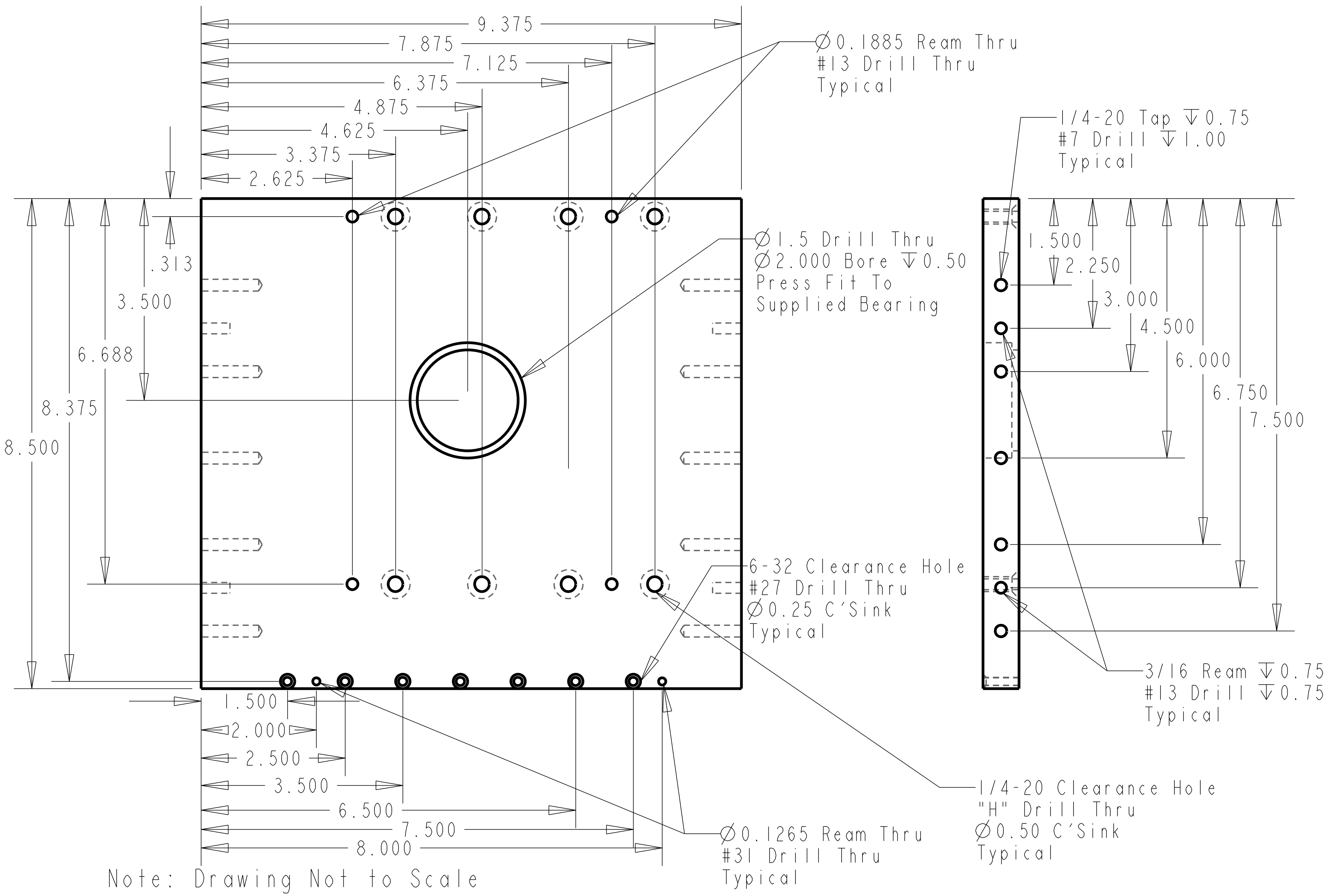

For Educational Use Only

Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Plate TL Support 1	Quantity: 1
FAMU-FSU	X.XX ± 0.01	Aluminum 6061-T651	B. Henley
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-021-1

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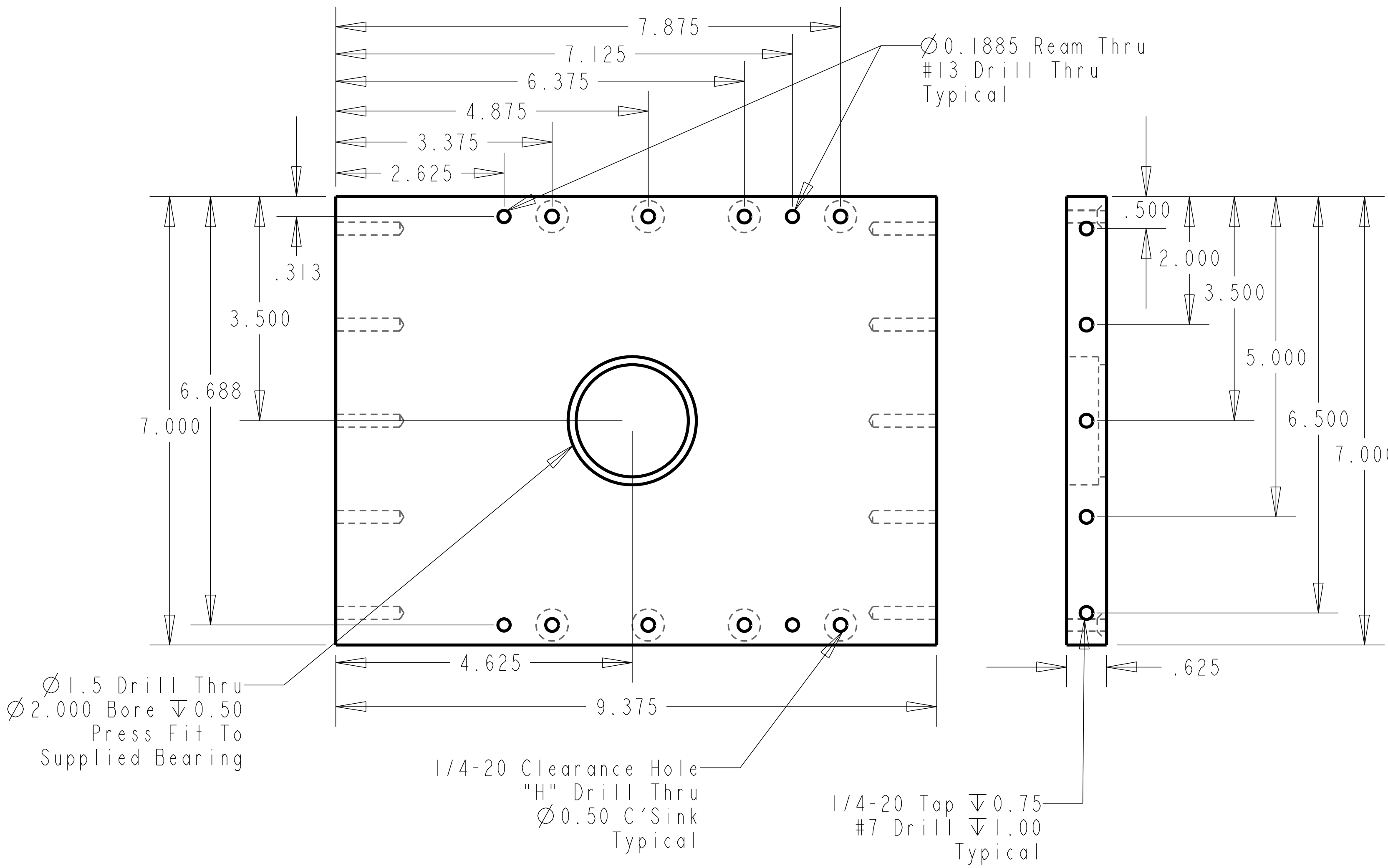
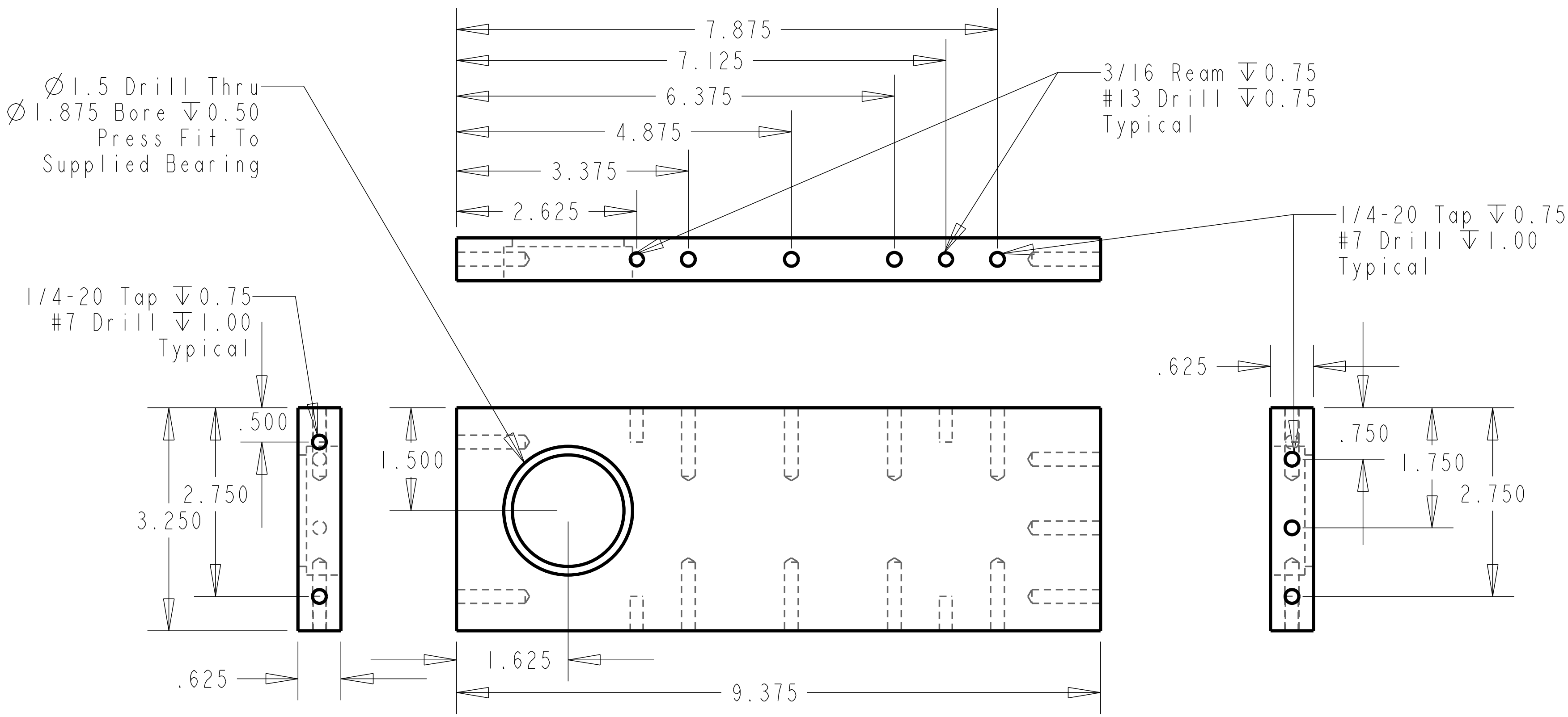


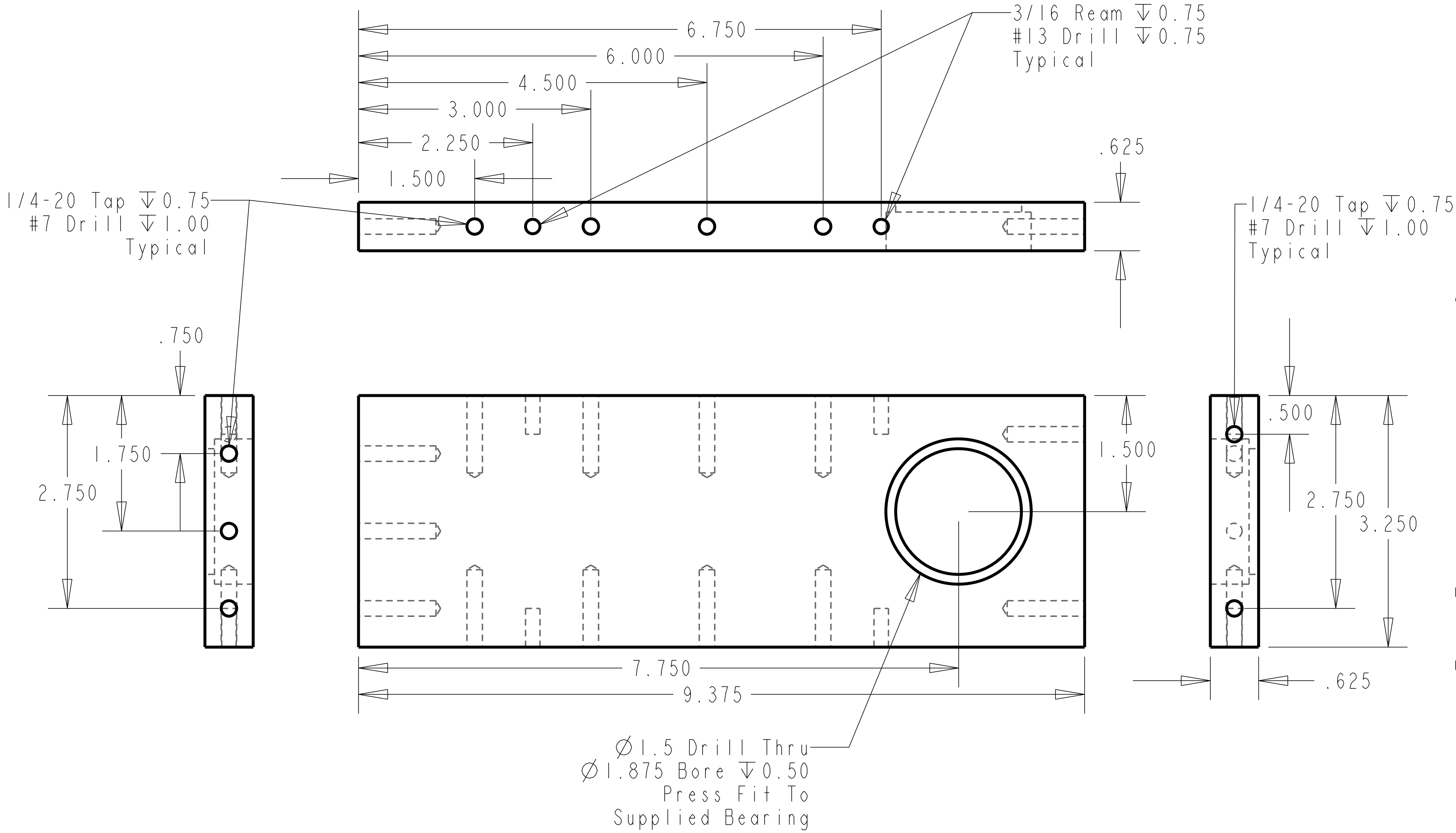
Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Plate TL Support 2	Quantity: 1
FAMU-FSU	X.XX ± 0.01	Aluminum 6061-T651	B. Henley
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-022-1



Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Plate TL Support 4	Quantity: 1
FAMU-FSU	X.XX ± 0.01	Aluminum 6061-T651	B. Henley
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-023-1



Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Plate TL Support 5	Quantity: 1
FAMU-FSU	X.XX ± 0.01	Aluminum 6061-T651	B. Henley
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-024-1

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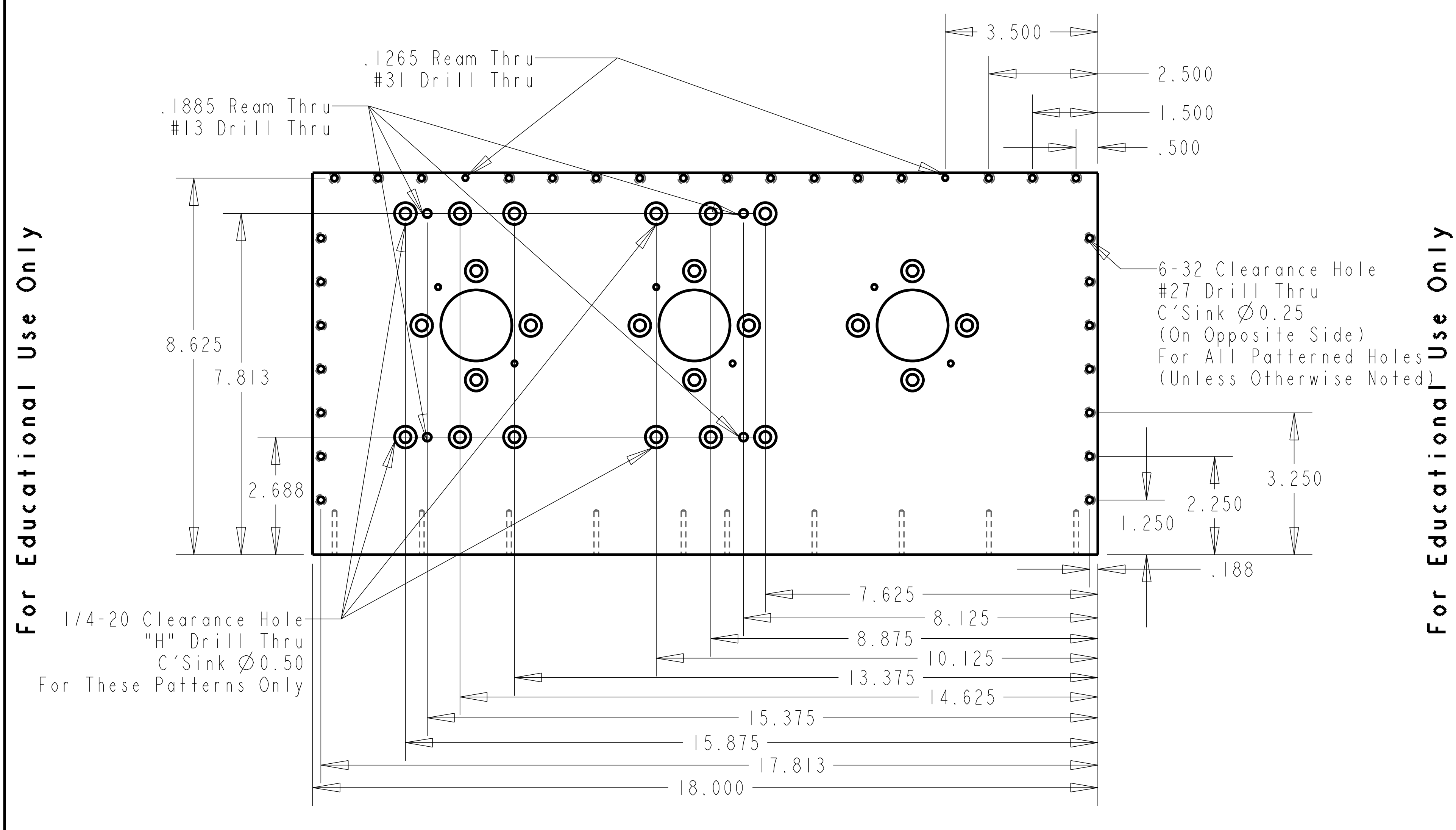

Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Plate Planetary Support 2	Quantity: 1
FAMU-FSU	X.XX ± 0.01	Aluminum 6061-T651	B. Henley
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-025-1

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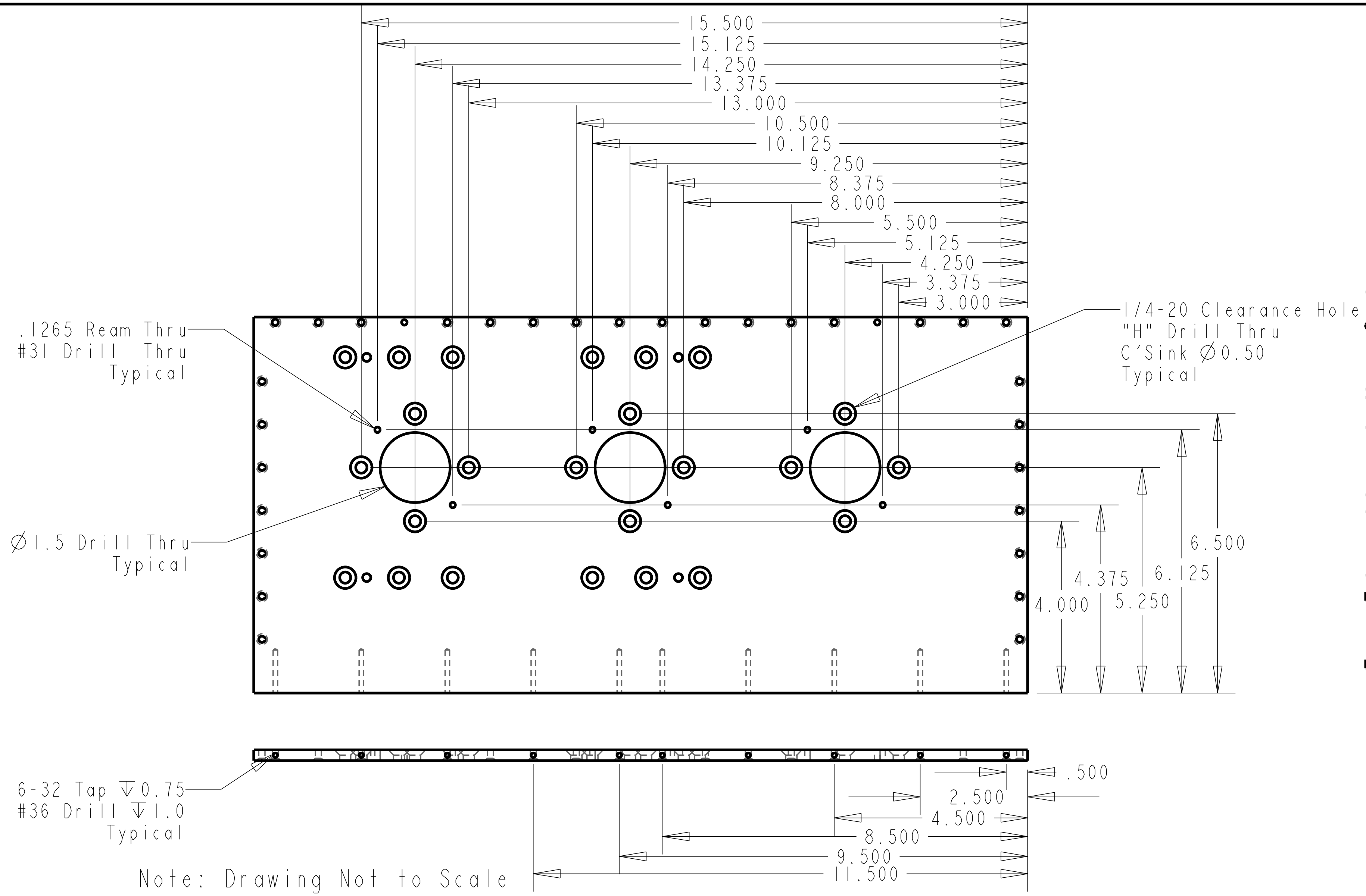
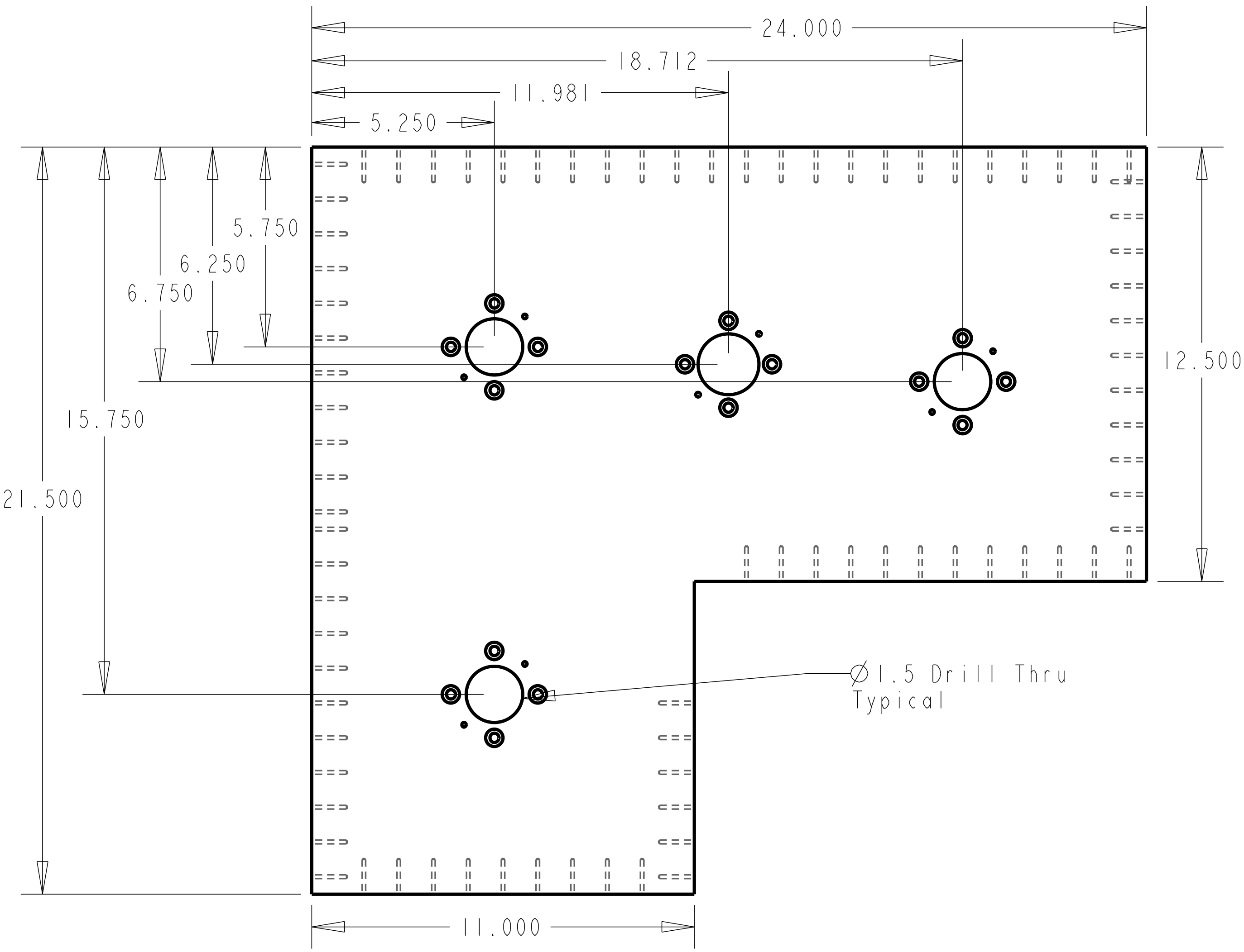
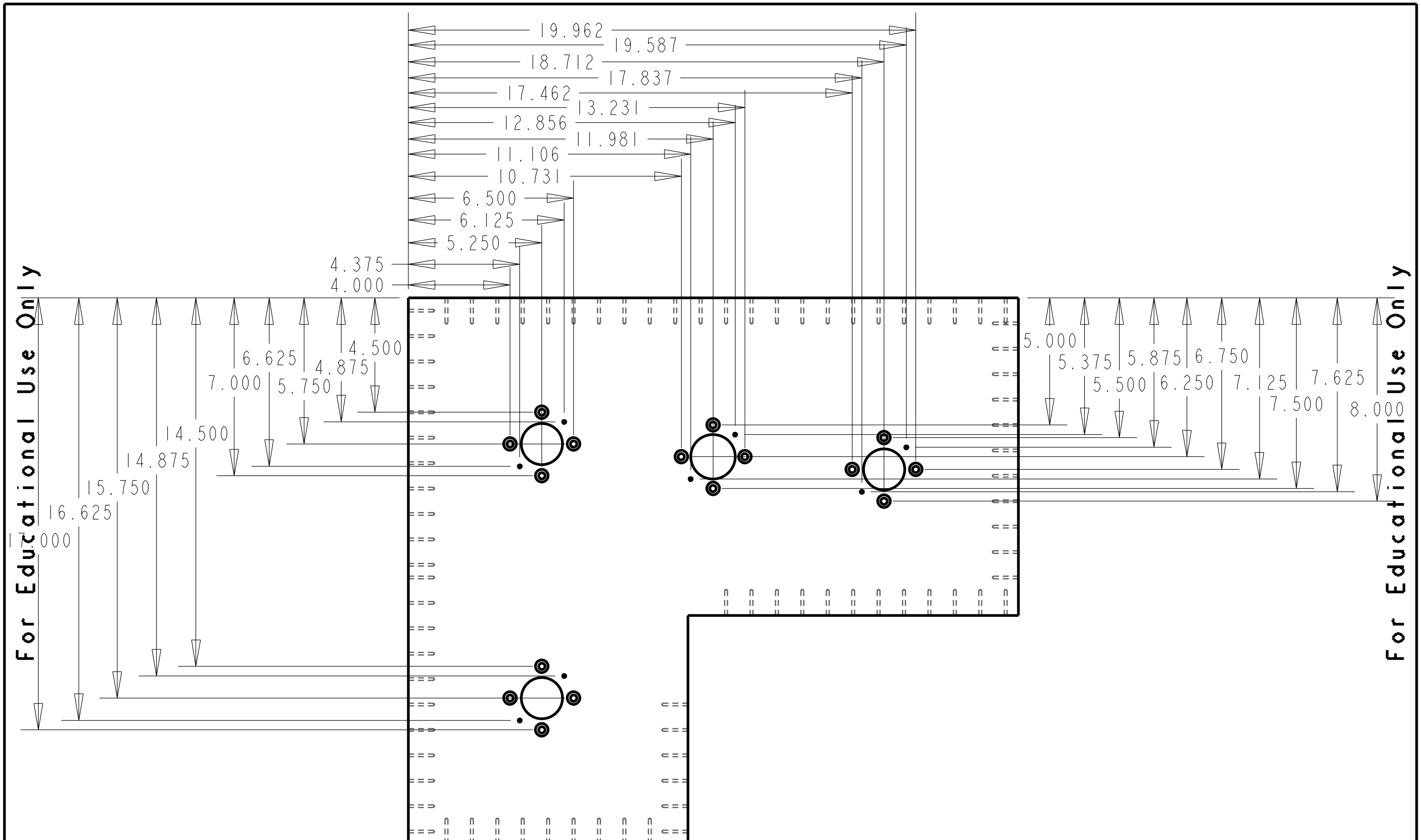


Growth Innovations Kite Group	X.X ± 0.1	Plate Planetary Support 2	Quantity: 1
FAMU-FSU	X.XX ± 0.01	Aluminum 6061-T651	B. Henley
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-025-2



Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Plate, Planetary Support 3	Quantity: 1
FAMU-FSU	X.XX ± 0.01	Aluminum 6061-T651	B. Henley
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-026-1



Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Plate, Planetary Support 3	Quantity: 1
FAMU-FSU	X.XX ± 0.01	Aluminum 6061-T651	B. Henley
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-026-2

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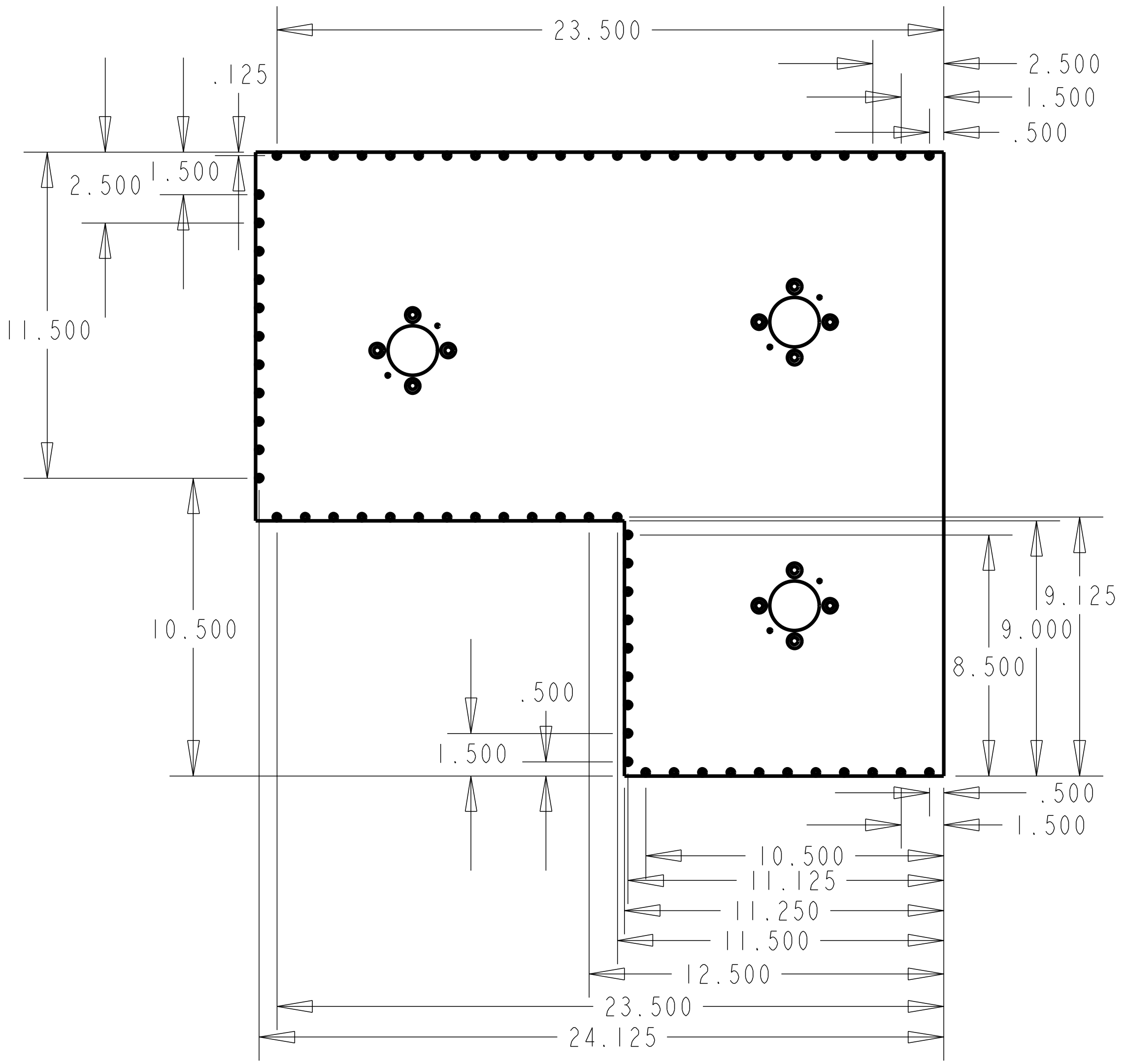

Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Plate, Planetary Support 4	Quantity: 1
FAMU-FSU	X.XX ± 0.01	Aluminum 6061-T651	B. Henley
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-027-2

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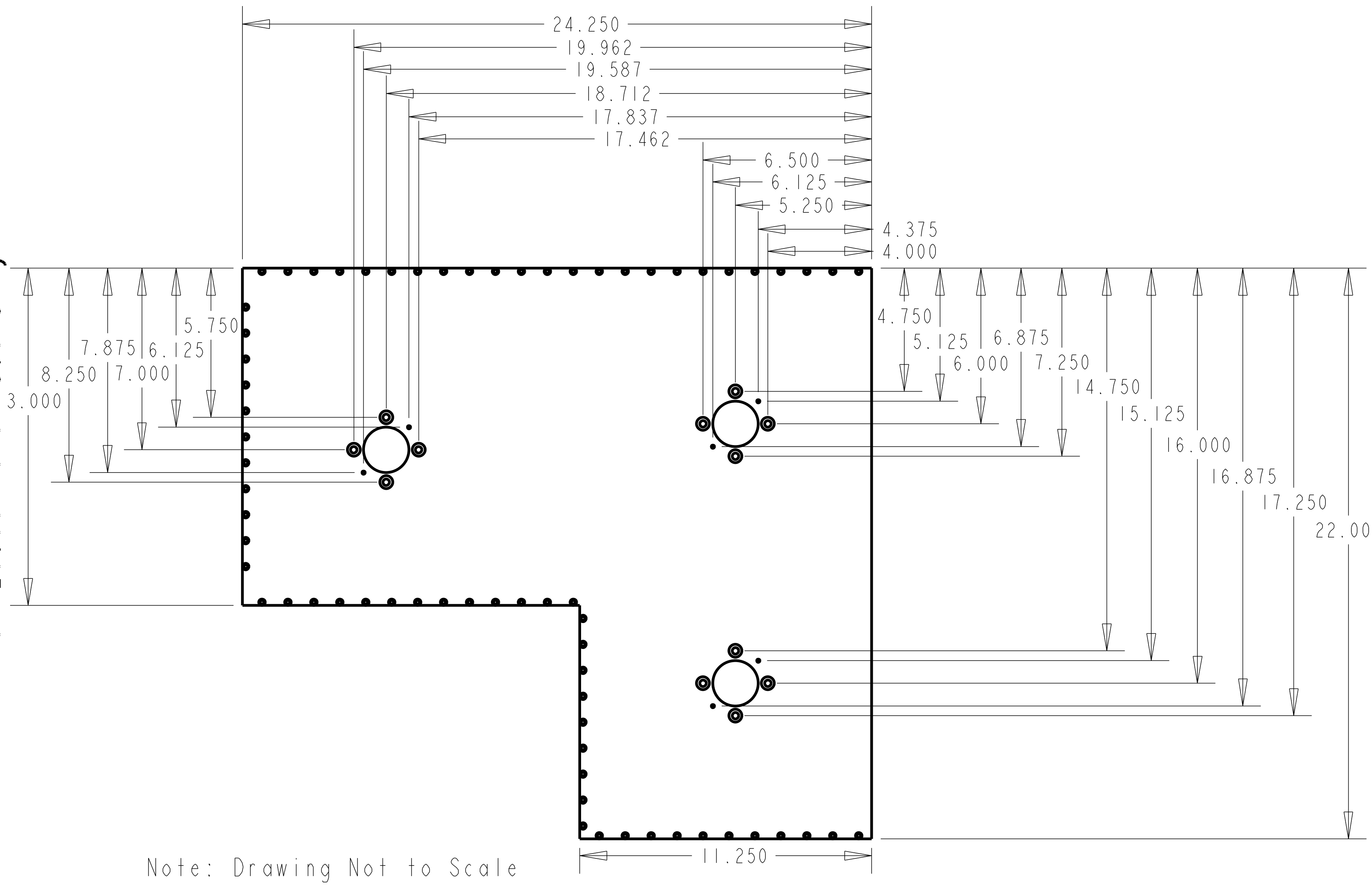
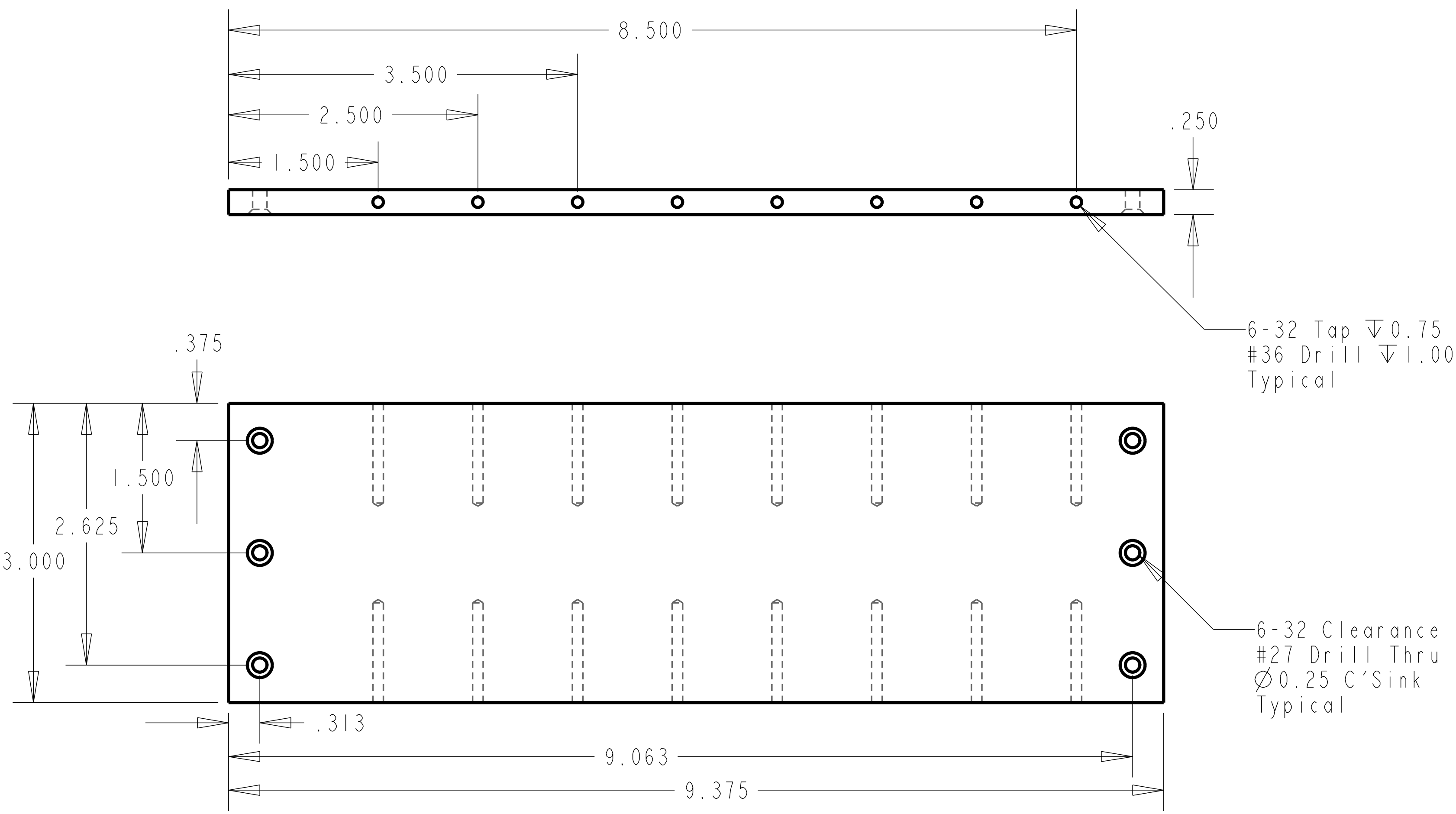


Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Plate, Planetary Support 4	Quantity: 1
FAMU-FSU	X.XX ± 0.01	Aluminum 6061-T651	B. Henley
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-027-1



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Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Plate, Pitchworm 3	Quantity: 1
FAMU-FSU	X.XX ± 0.01	Aluminum 6061-T651	B. Henley
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-028-1

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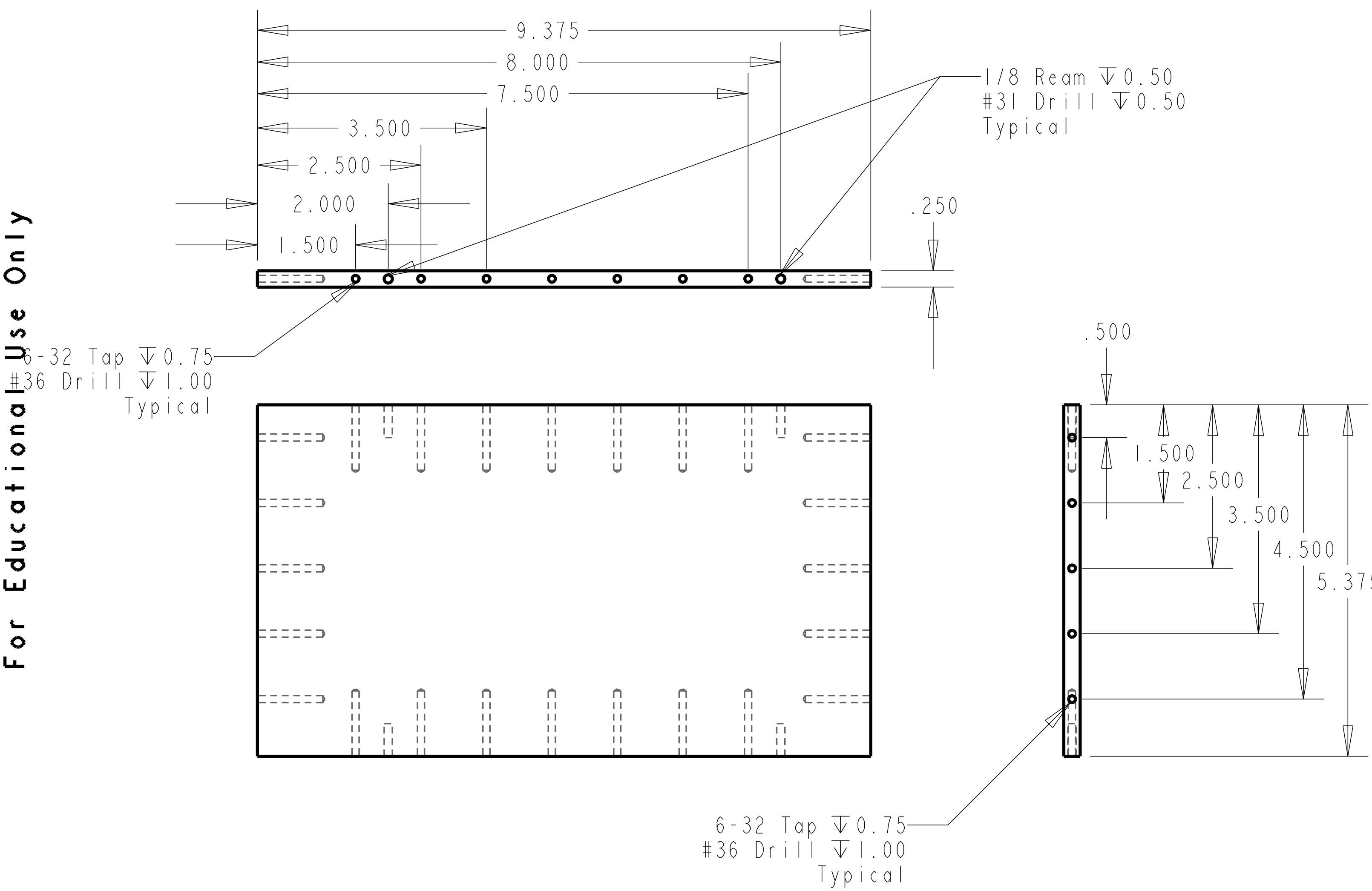

Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Plate, TL Support 3	Quantity: 1
FAMU-FSU	X.XX ± 0.01	Aluminum 6061-T651	B. Henley
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-029-1

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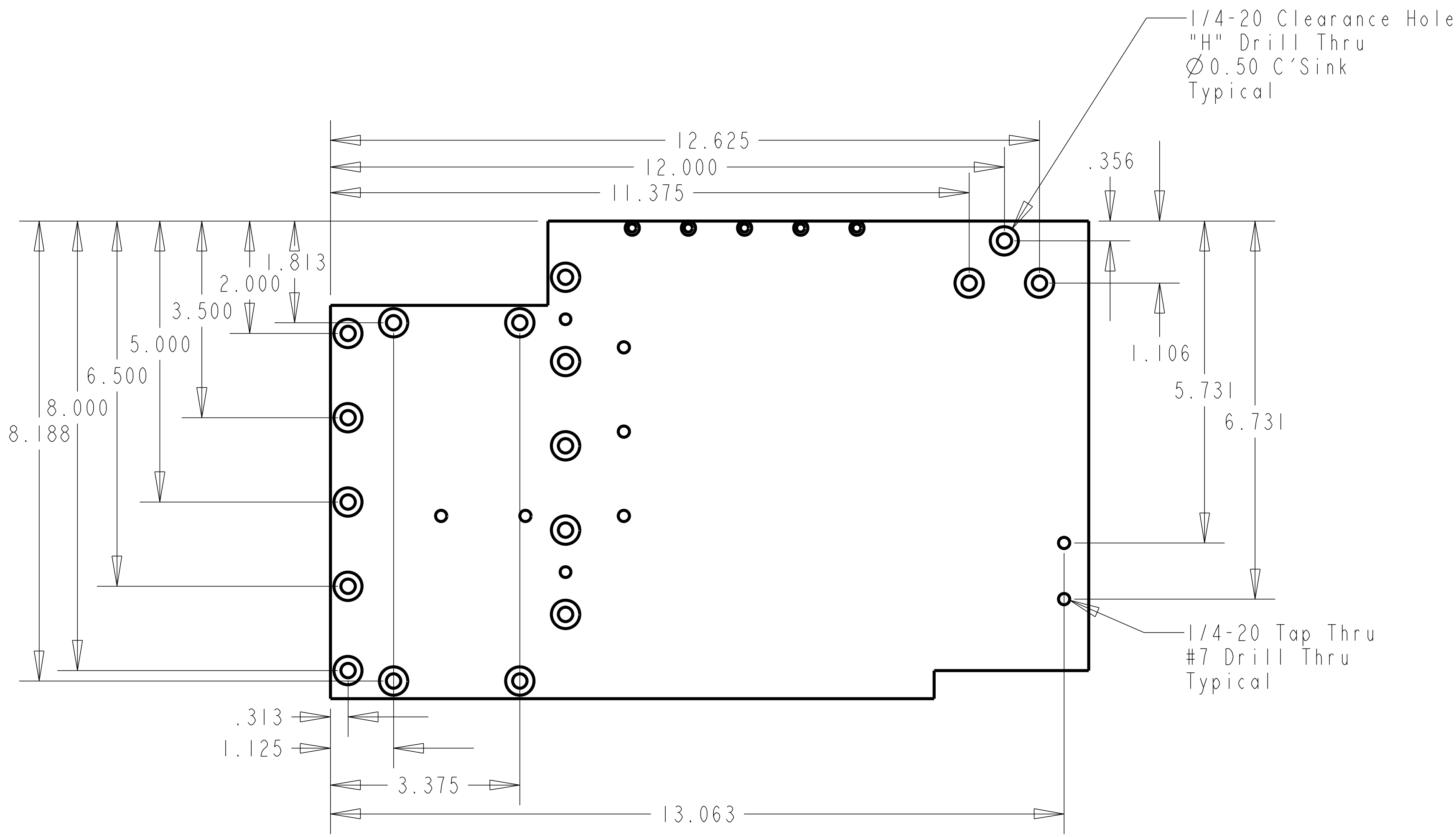
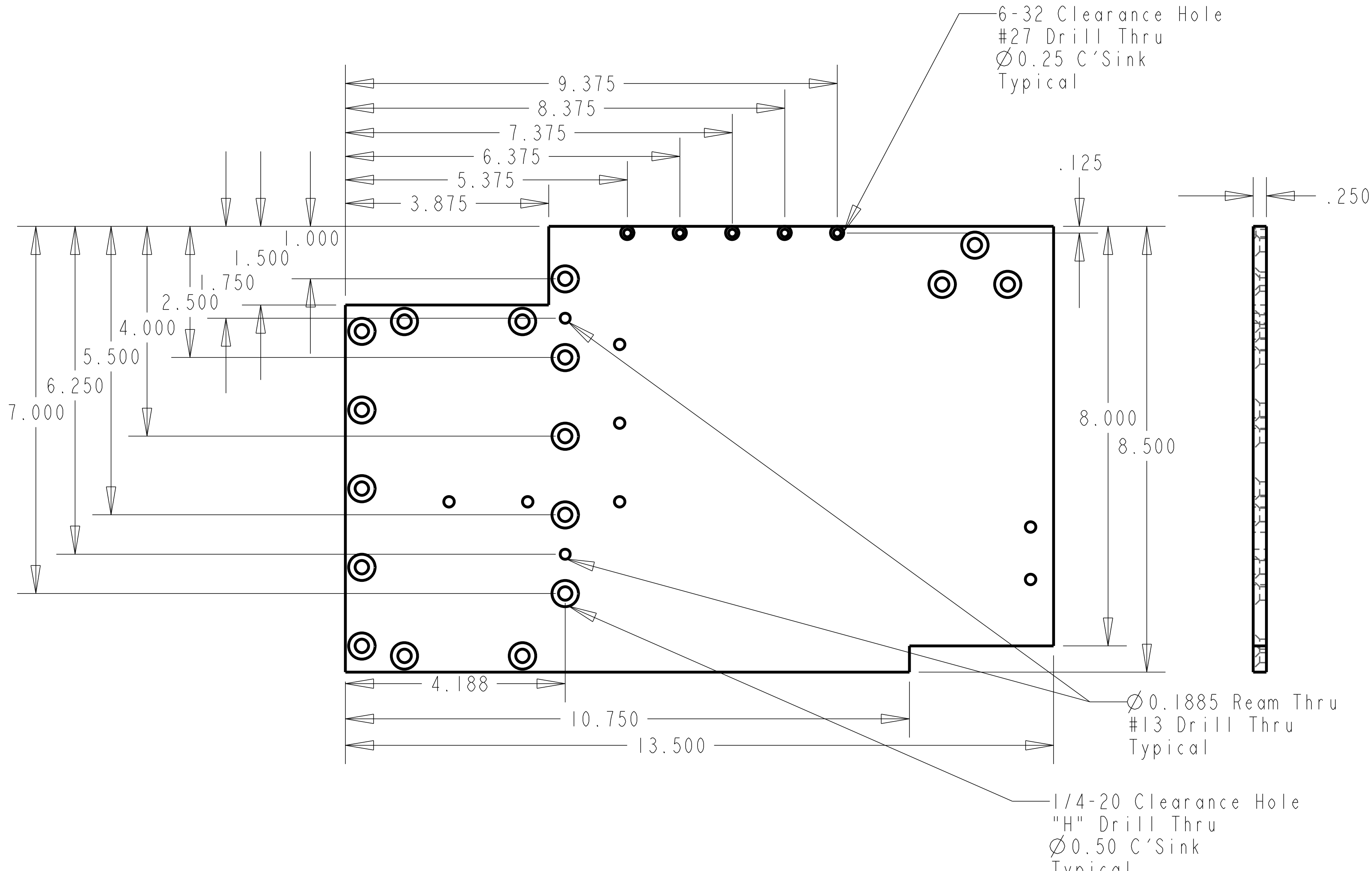


Note: Drawing Not to Scale

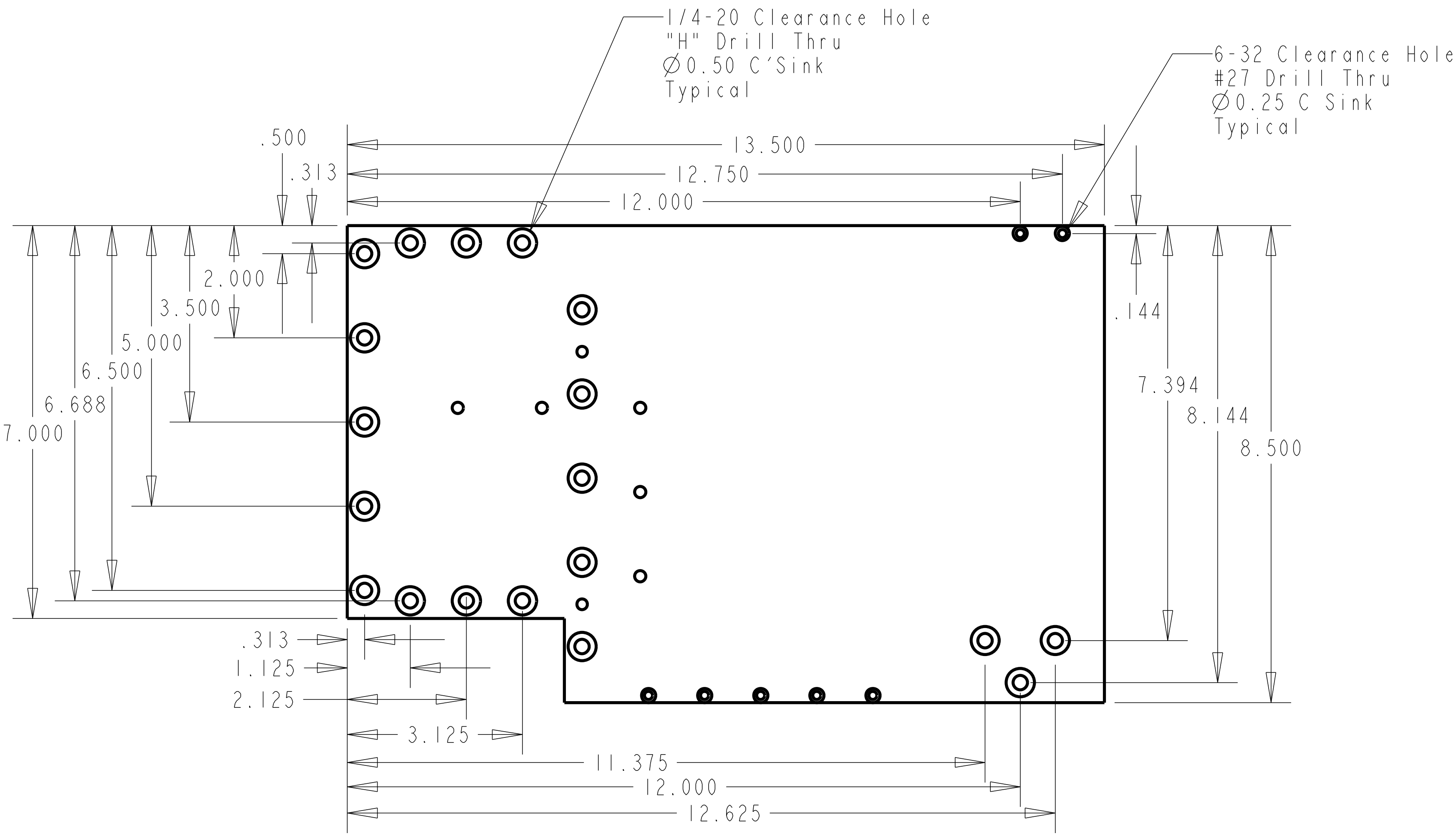
Growth Innovations Kite Group	X.X ± 0.1	Plate, TL Support 7	Quantity: 1
FAMU-FSU	X.XX ± 0.01	Aluminum 6061-T651	T. Carnes
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-030-1

For Educational Use Only



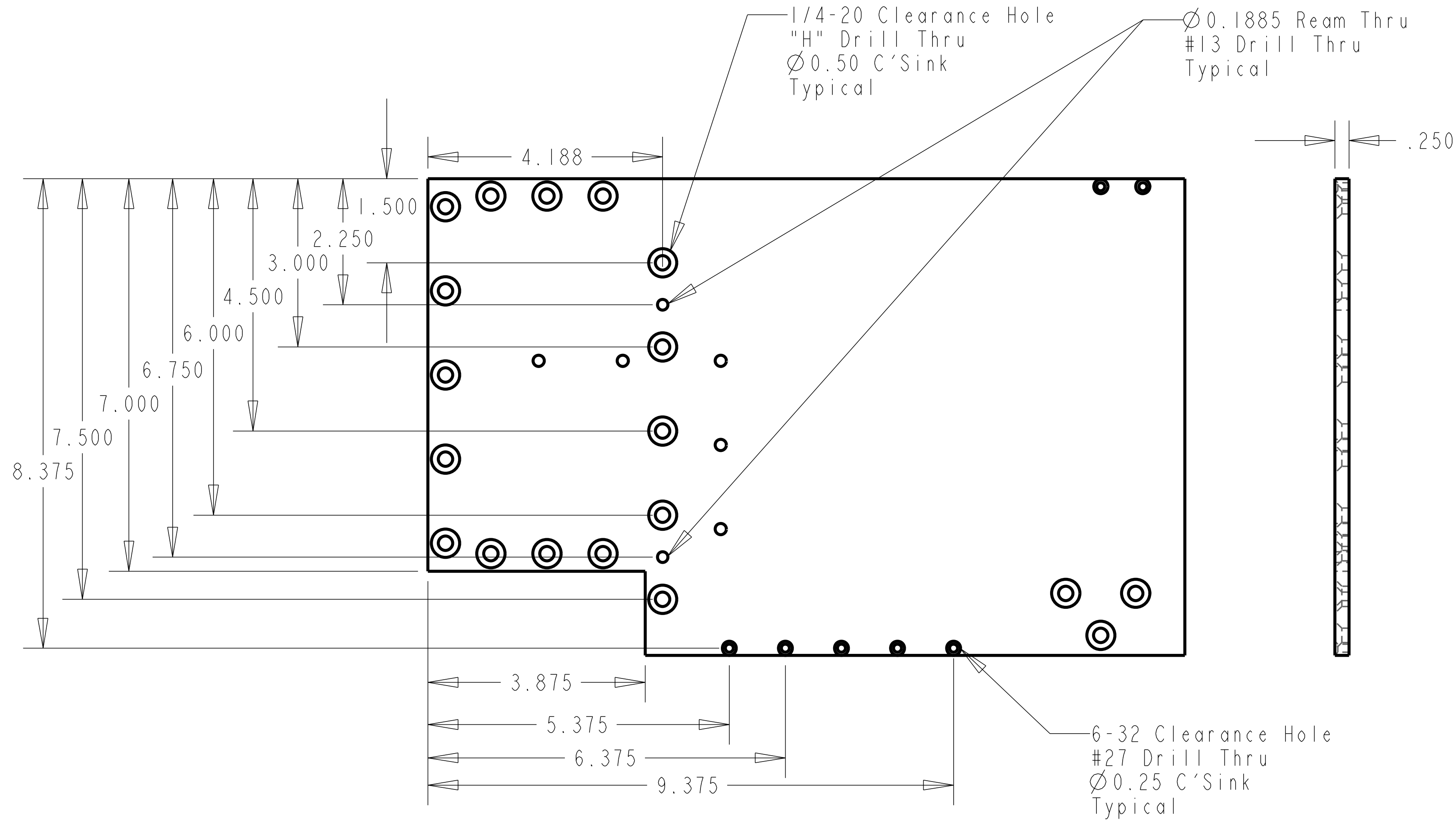
Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Plate, TL Support 7	Quantity: 1
FAMU-FSU	X.XX ± 0.01	Aluminum 6061-T651	B. Henley
College of Engineering	X.XXX ± 0.00	Inches	GIKG-PP-030-2



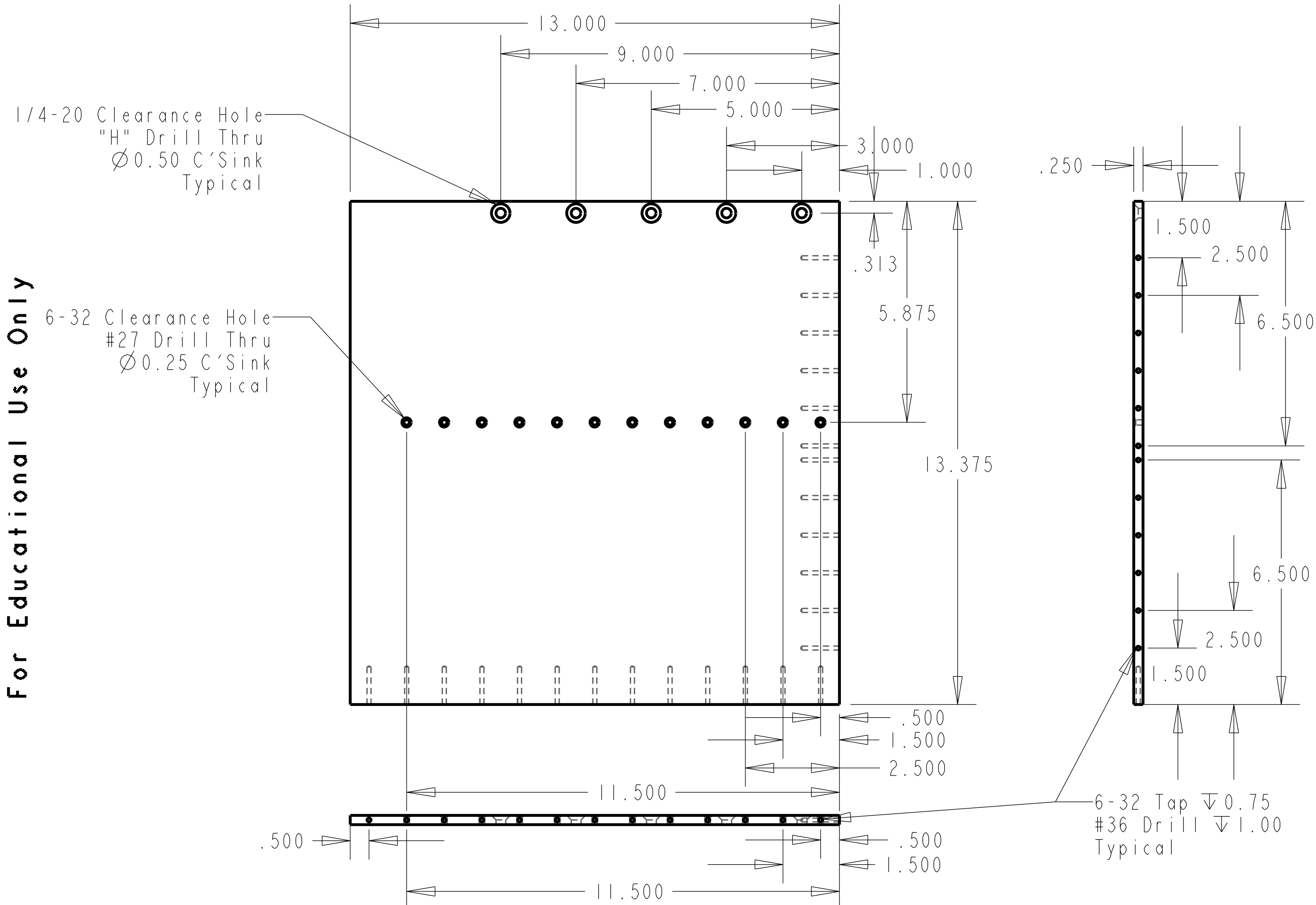
Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Plate TL Support 8	Quantity: 1
FAMU-FSU	X.XX ± 0.01	Aluminum 6061-T651	T. Carnes
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-031-1



Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Plate, TL Support 8	Quantity: 1
FAMU-FSU	X.XX ± 0.01	Aluminum 6061-T651	B. Henley
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-031-2



Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Plate, Enclose 1	Quantity: 1
FAMU-FSU	X.XX ± 0.01	Aluminum 6061-T651	B. Henley
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-032-1

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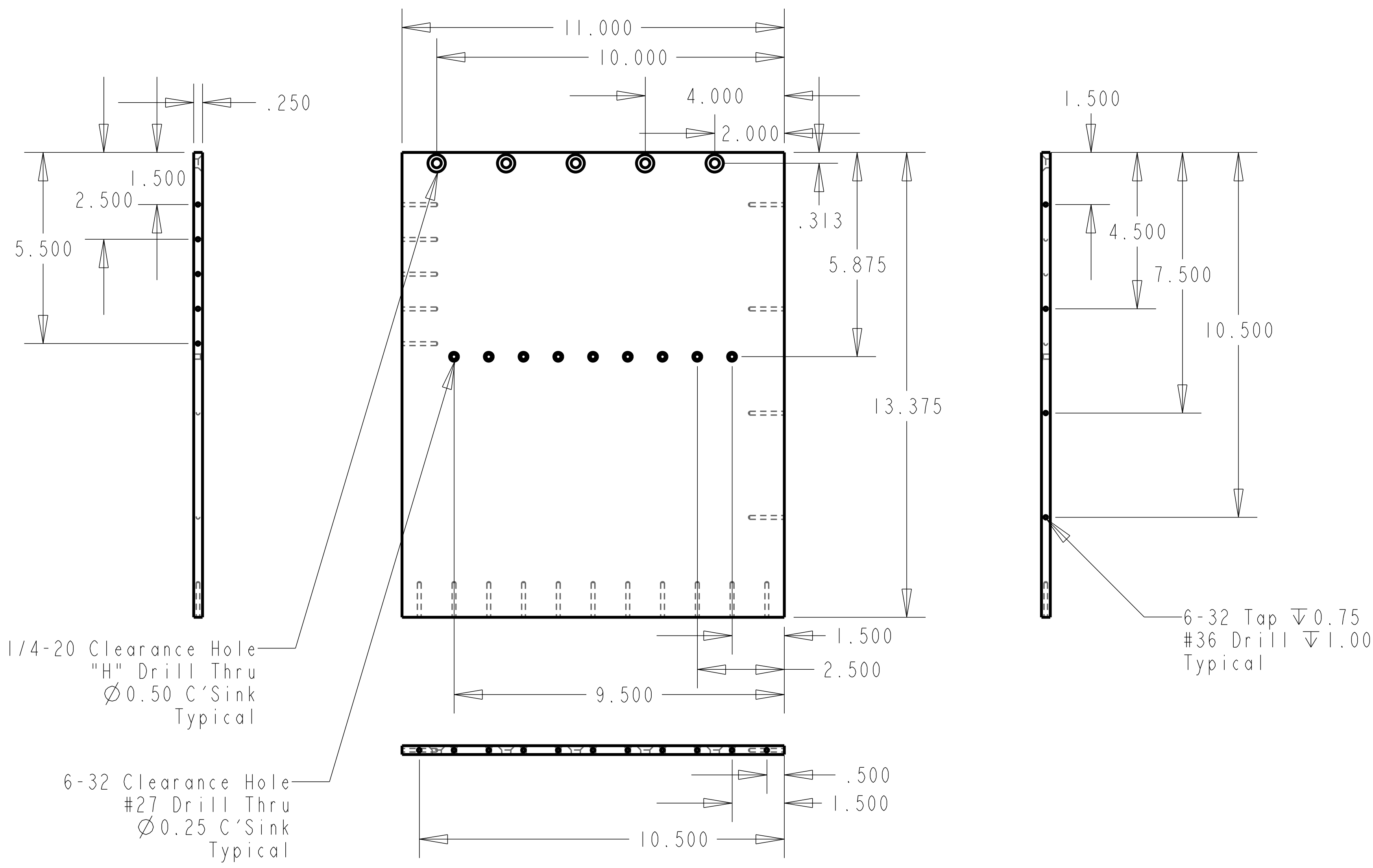
For Educational Use Only



For Educational Use Only

Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Plate, Enclose 2	Quantity: 1
FAMU-FSU	X.XX ± 0.01	Aluminum 6061-T651	B. Henley
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-033-1

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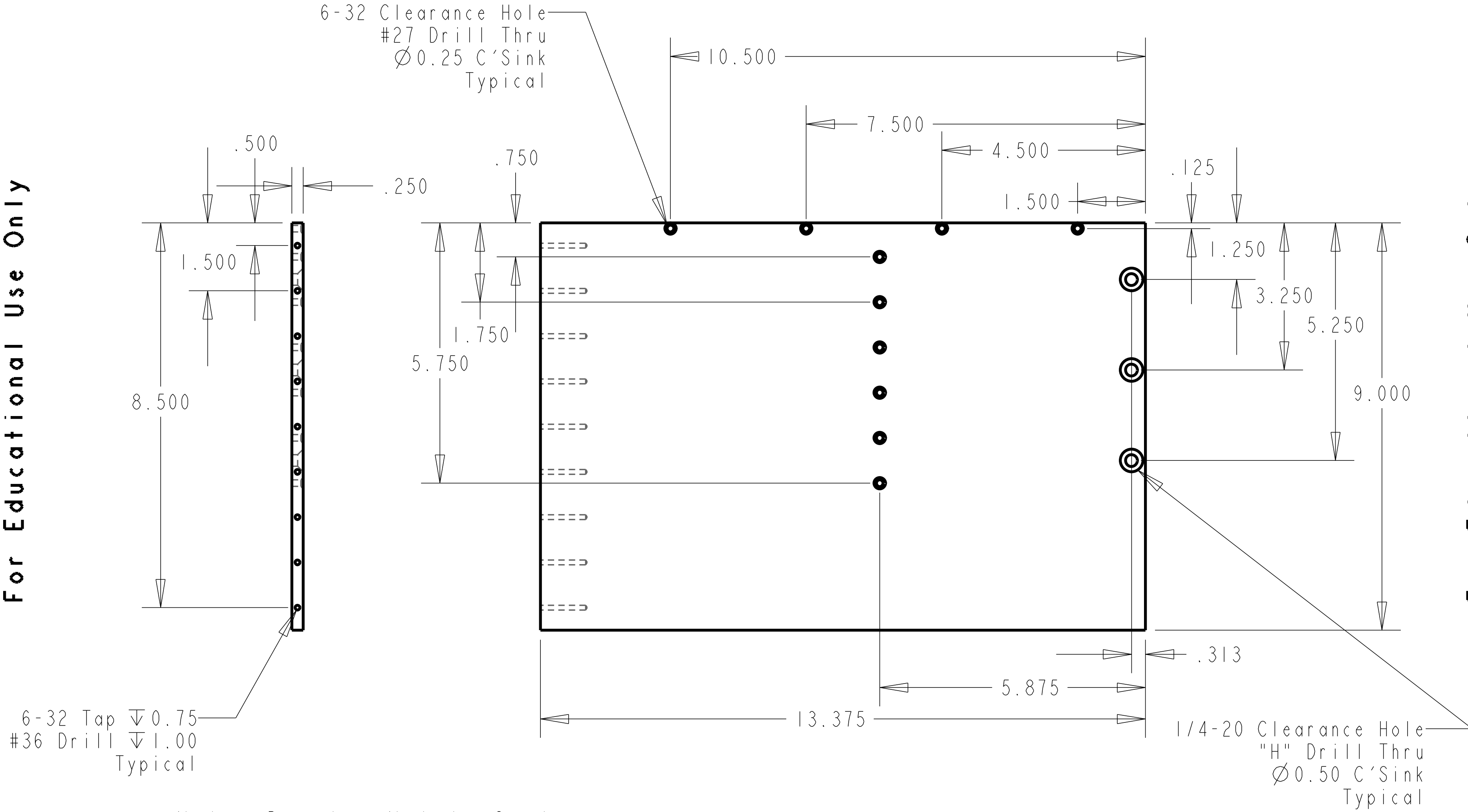

Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Plate, Enclose 3	Quantity: 1
FAMU-FSU	X.XX ± 0.01	Aluminum 6061-T651	B. Henley
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-034-1

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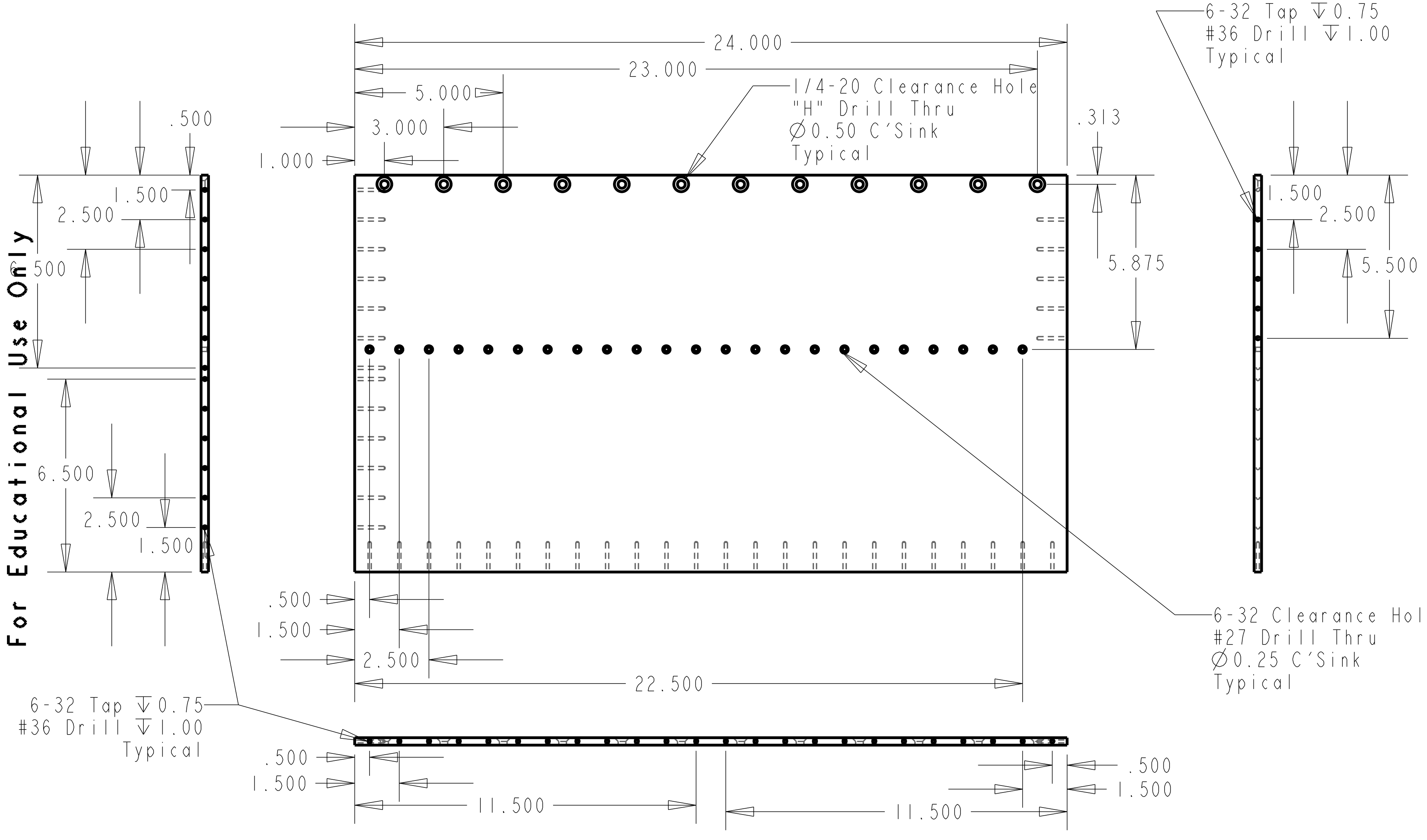

Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Plate, Enclose 4	Quantity: 1
FAMU-FSU	X.XX ± 0.01	Aluminum 6061-T651	B. Henley
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-035-1

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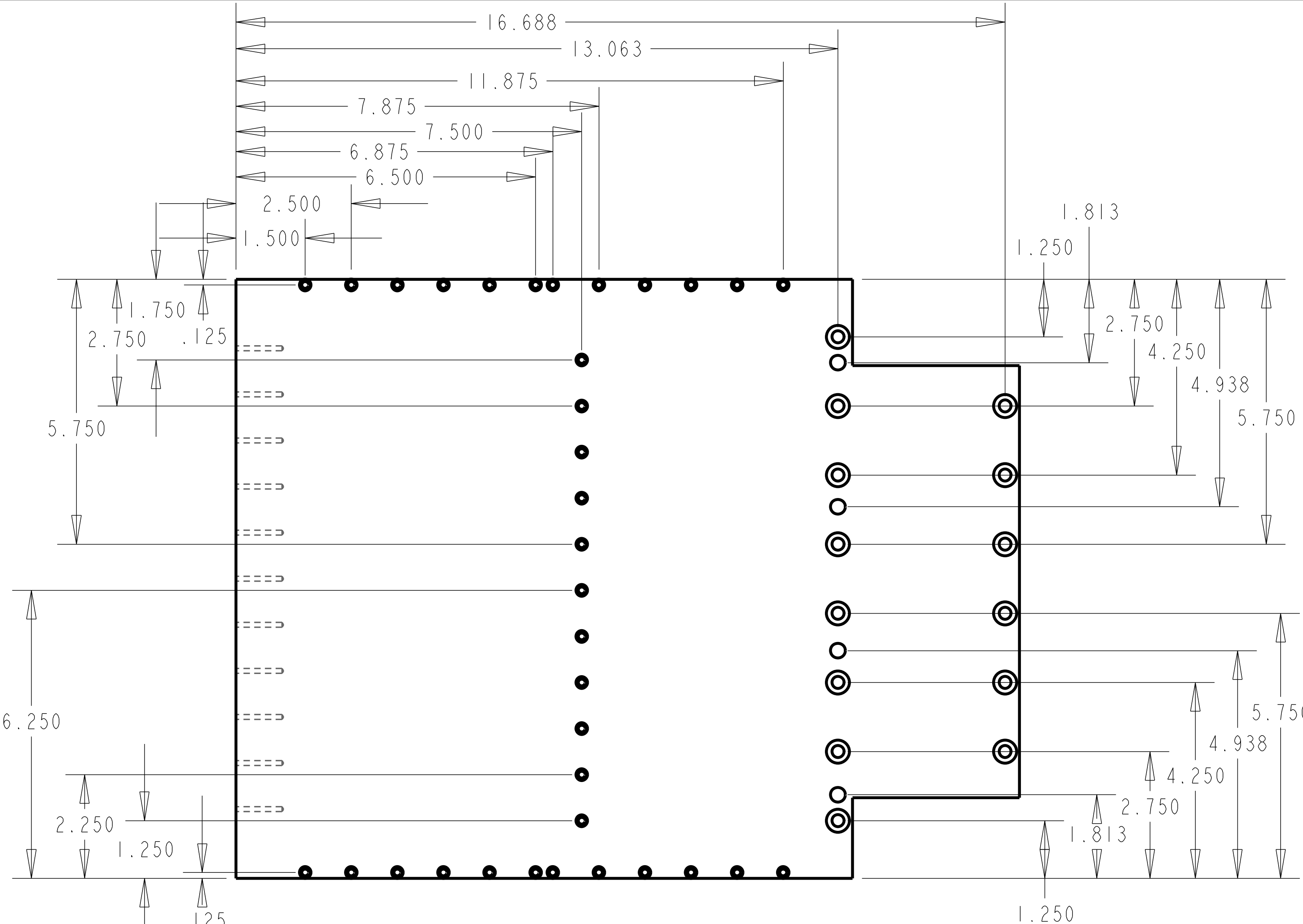

For Educational Use Only

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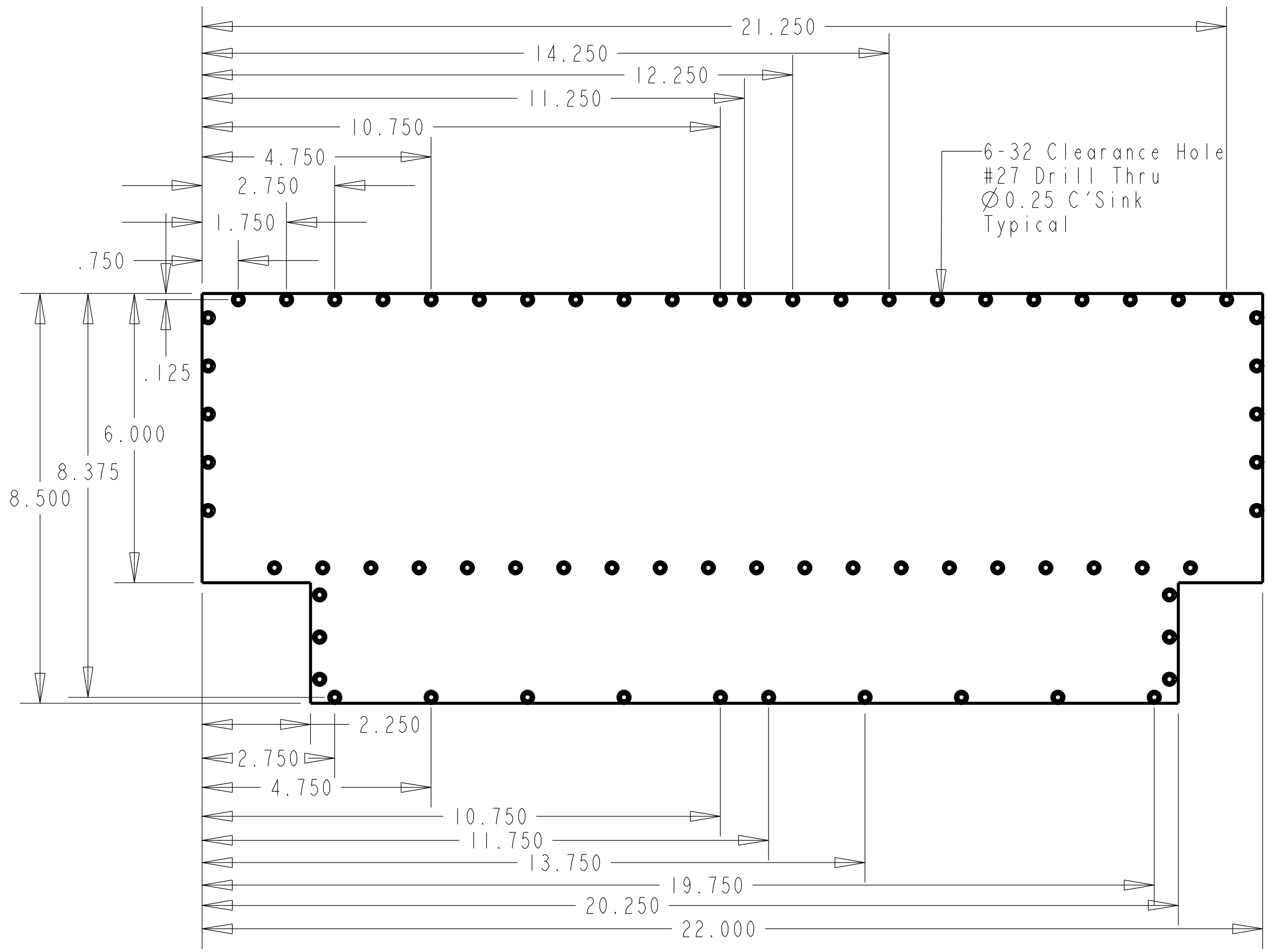
Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Plate, Enclose 5	Quantity: 1
FAMU-FSU	X.XX ± 0.01	Aluminum 6061-t651	T. Carnes
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-036-1

For Educational Use Only



Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Plate, Enclose 6	Quantity: 1
FAMU-FSU	X.XX ± 0.01	Aluminum 6061-T651	T. Carnes
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-037-1

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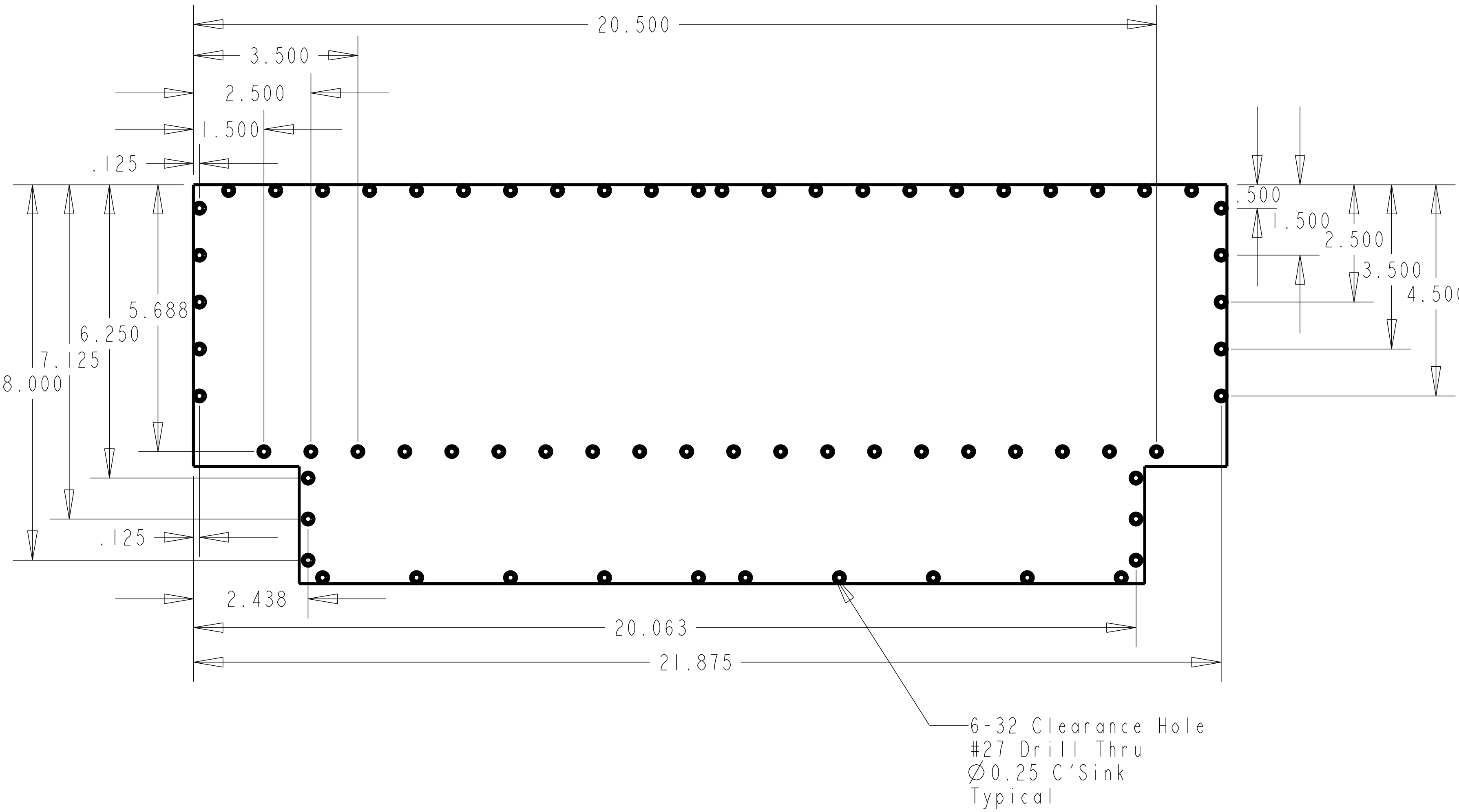
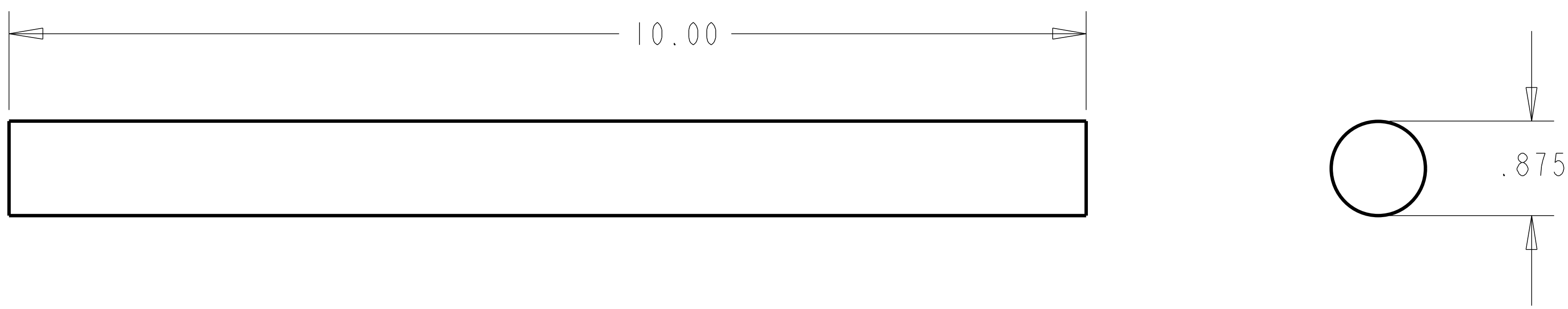
For Educational Use Only



Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Plate, Enclose 6	Quantity: 1
FAMU-FSU	X.XX ± 0.01	Aluminum 6061-T651	B. Henley
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-037-2

For Educational Use Only



For Educational Use Only

Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Shaft, 10 Input	Quantity: 1
FAMU-FSU	X.XX ± 0.01	Oil-Hardening Steel	B. Henley
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-038-1

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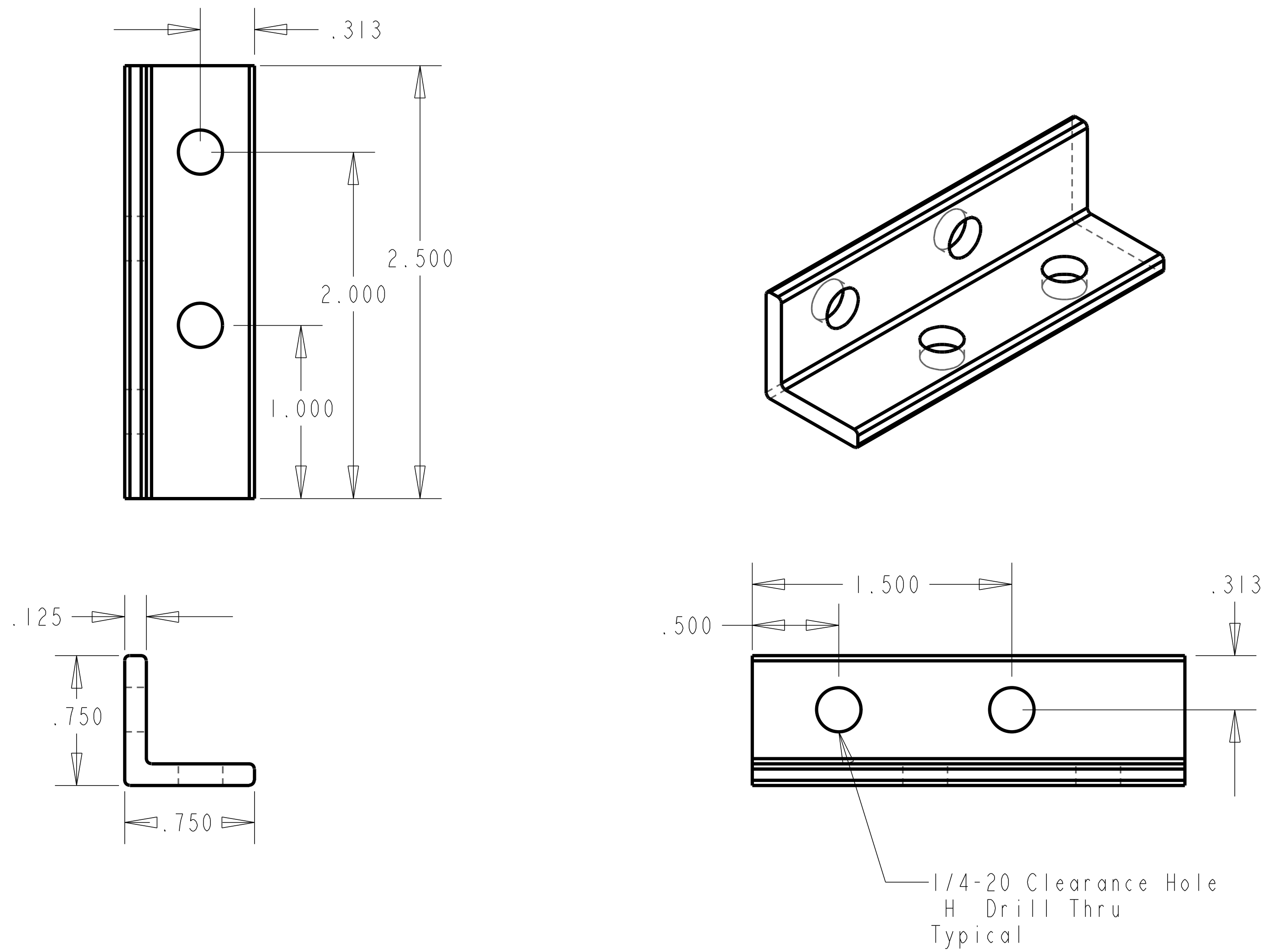
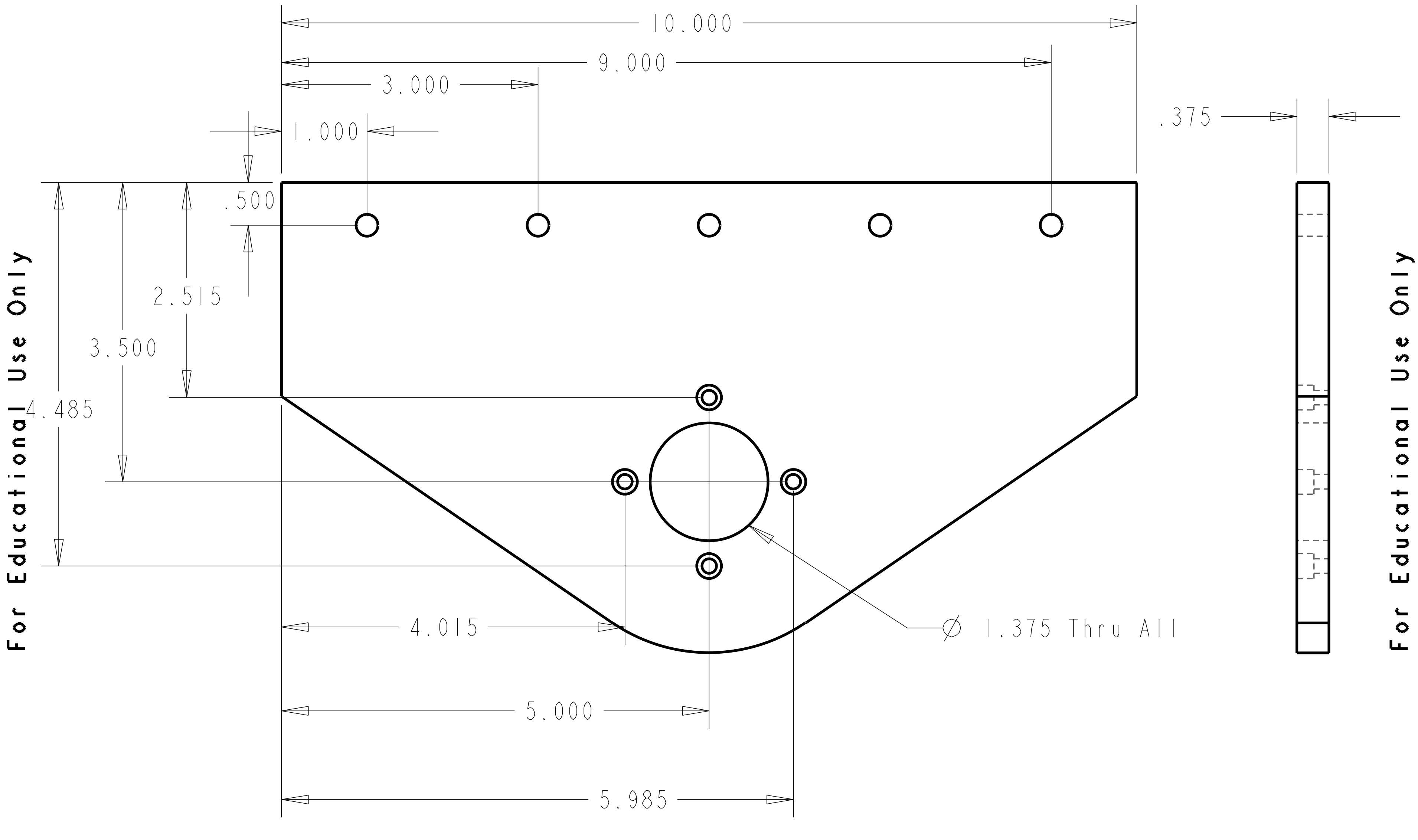


Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Connector Angle	Quantity: 1
FAMU-FSU	X.XX ± 0.01	Aluminum 6061-T651	B. Henley
College of Engineering	X.XXX ± 0.00[illegible]	Inches	GIKG-PP-053-1



Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Plate Motor Mount Turn	Quantity: 1
FAMU-FSU	X.XX ± 0.01	Aluminum 6061-T651	T. Carnes
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-054

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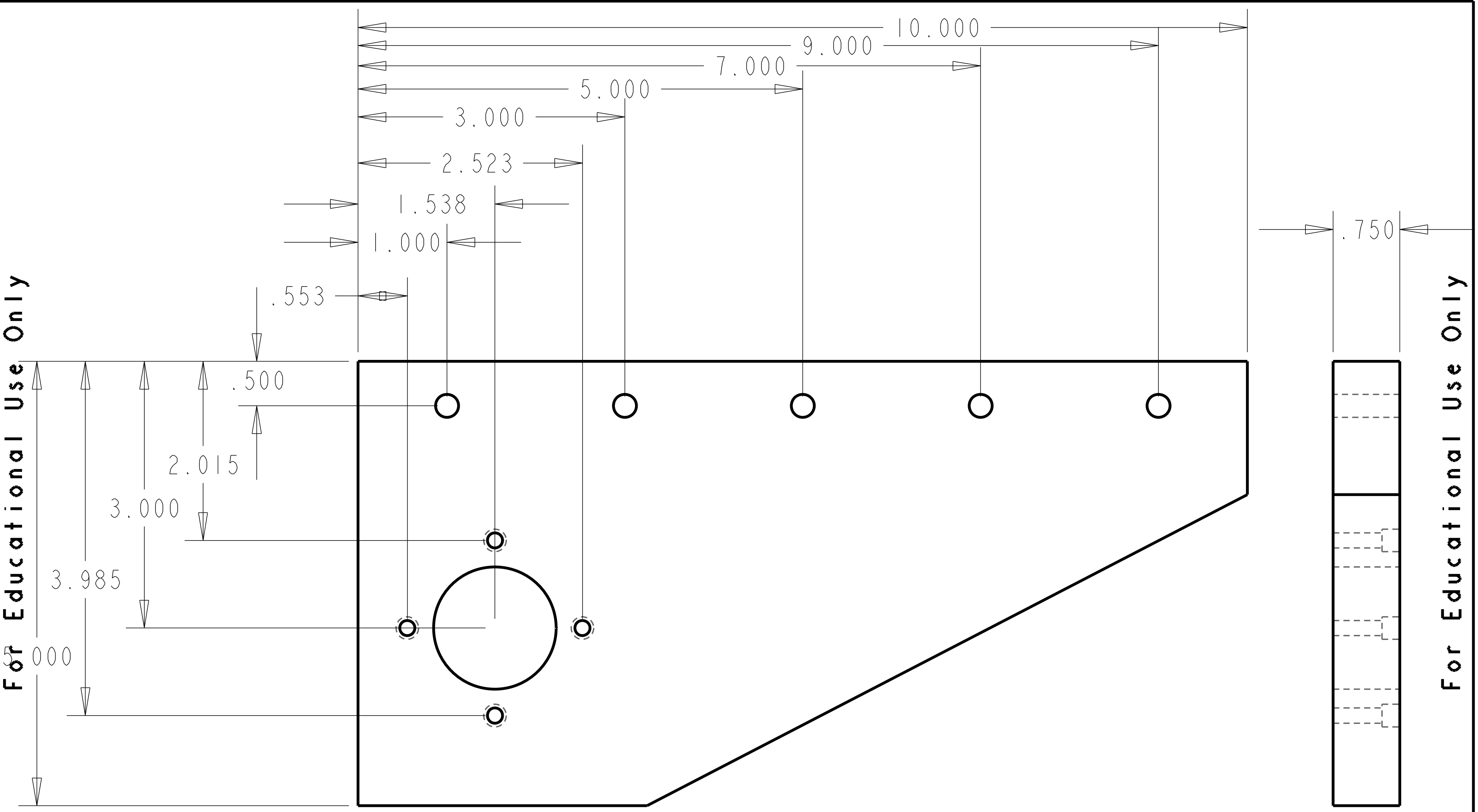
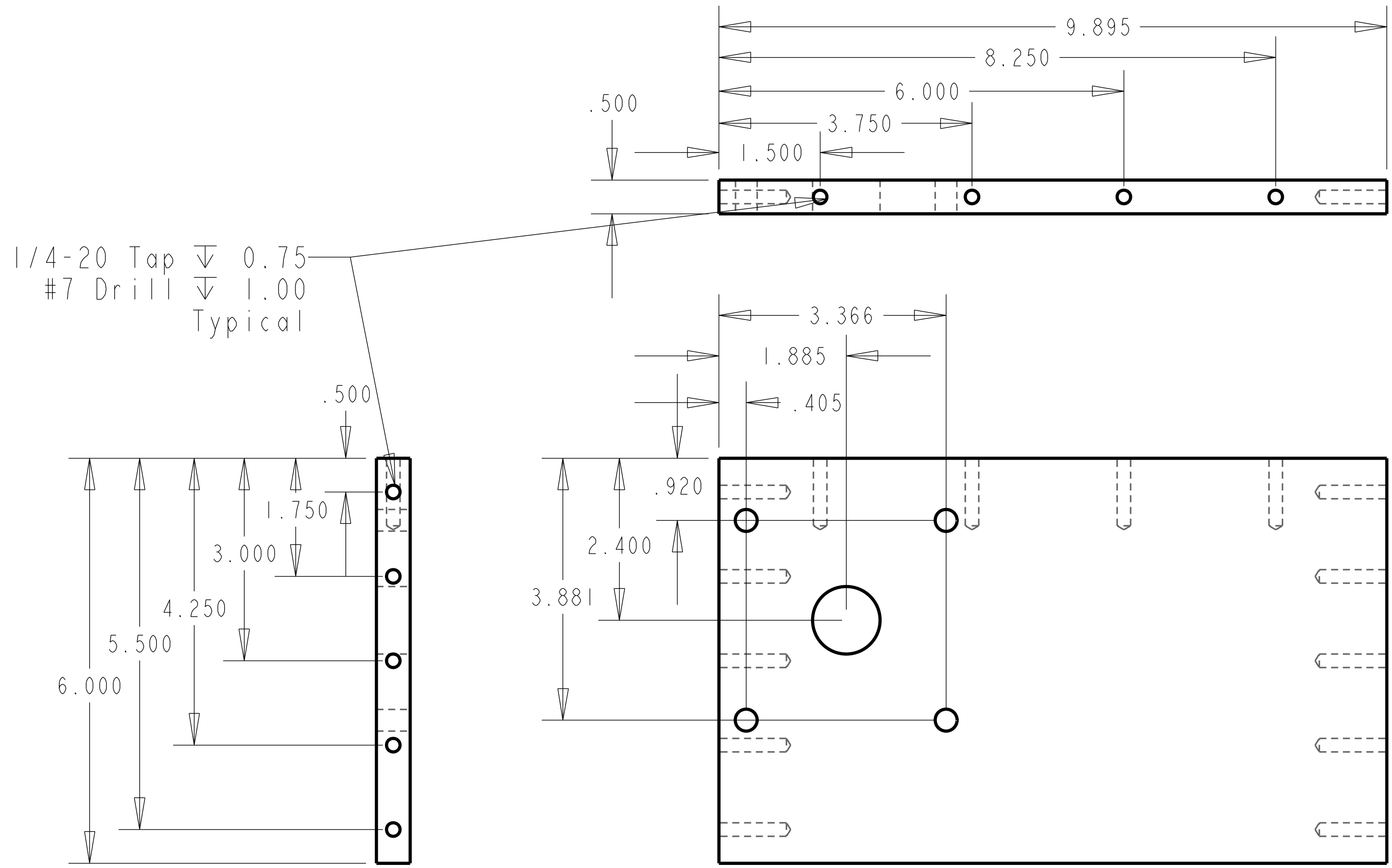


Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Plate Motor Mount Pitch	Quantity: 1
FAMU-FSU	X.XX ± 0.01	Aluminum 6061-T651	T. Carnes
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-055-1

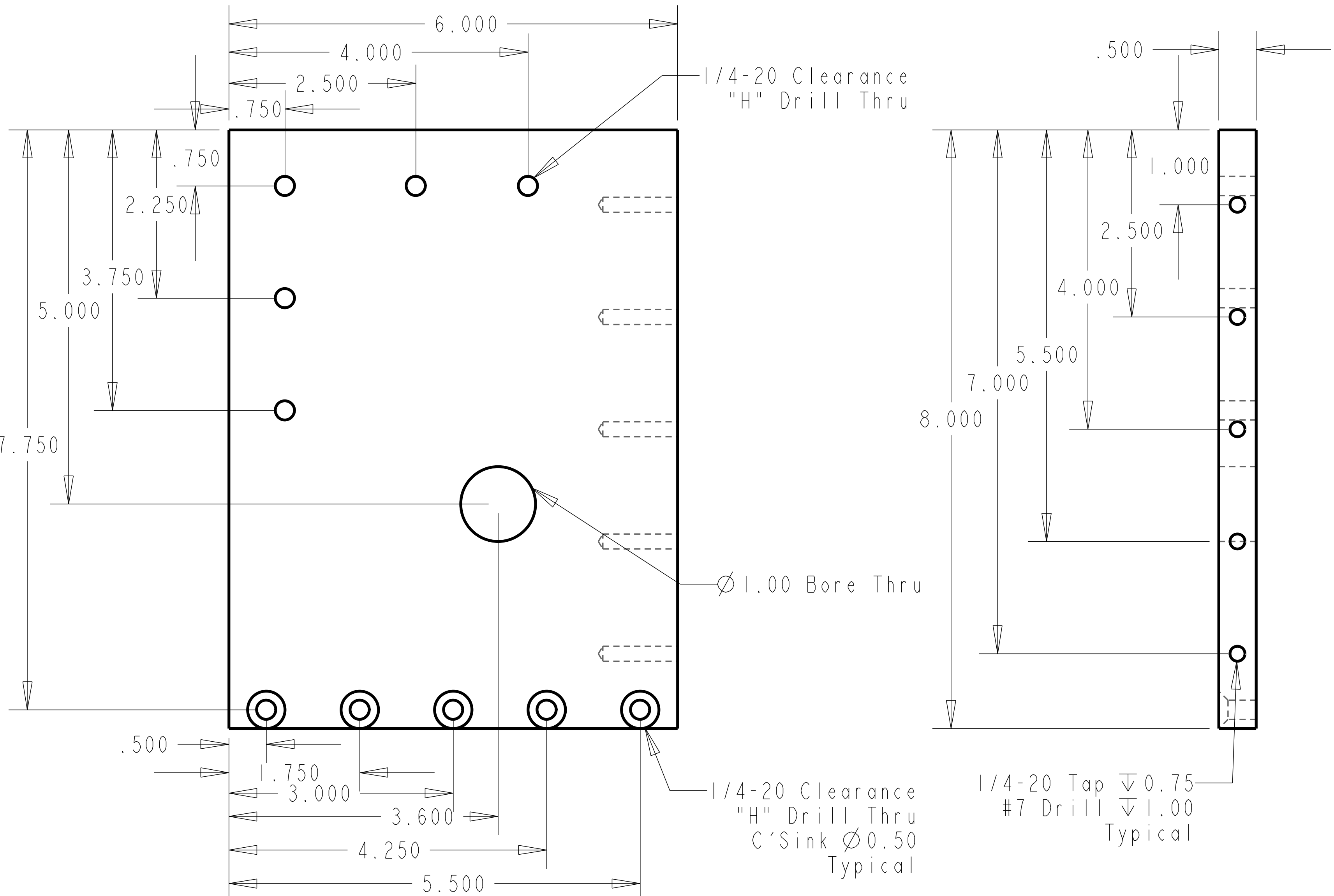


For Educational Use Only
For Educational Use Only

Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Plate Motor Mount ETEK I	Quantity: 1
FAMU-FSU	X.XX ± 0.01	Aluminum 6061-T651	T. Carnes
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-056-1

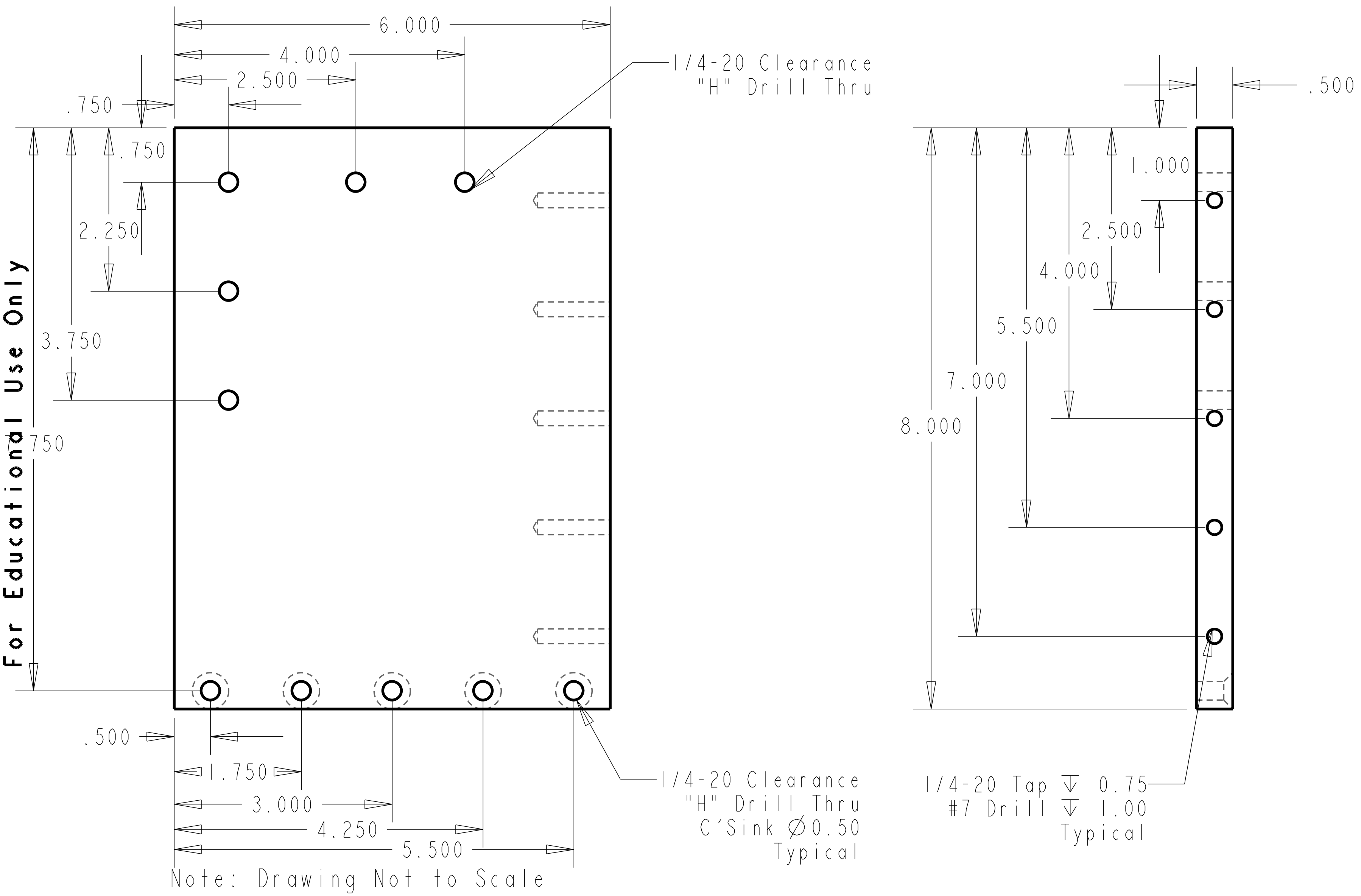
For Educational Use Only



Note: Drawing Not to Scale

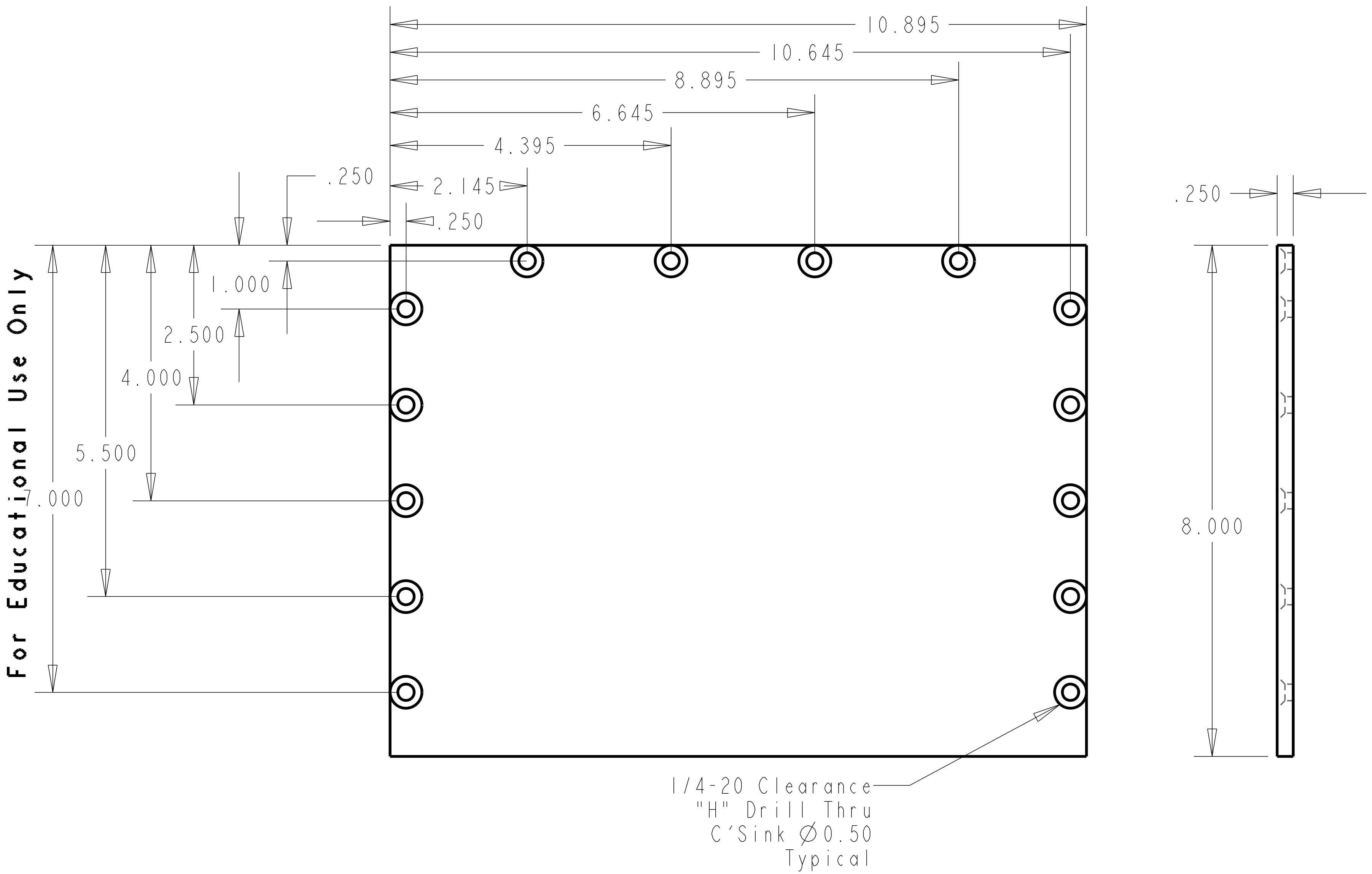
Growth Innovations Kite Group	X.X ± 0.1	Plate Motor Mount ETEK 2	Quantity:1
FAMU-FSU	X.XX ± 0.01	Aluminum 6061-T651	T. Carnes
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-057-1

For Educational Use Only
For Educational Use Only



Growth Innovations Kite Group	X.X ± 0.1	Plate Motor Mount ETEK 3	Quantity: 1
FAMU-FSU	X.XX ± 0.01	Aluminum 6061-T651	T. Carnes
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-058-1

For Educational Use Only



Note: Drawing Not to Scale

Growth Innovations Kite Group	X.X ± 0.1	Plate Motor Mount ETEK 4	Quantity: 1
FAMU-FSU	X.XX ± 0.01	Aliminum 6061-T651	T. Carnes
College of Engineering	X.XXX ± 0.001	Inches	GIKG-PP-059-1

11.3 Cost Analysis

Bulk Metal

Gears

Power Transmission

Electrical Components

Total

Bulk Metal

Metal Fabrication

Description	Quantity	Price (ea)	Amount
.375"x12"x36" 6061 Aluminum Plate	1	$153.33	$153.33
.25"x48"x72" 5052 Aluminum Plate	1	$343.32	$343.32
		Sub-Total	**$496.65**

Alro Metal Service Center

Description	Quantity	Price (ea)	Amount
8" Round 6061-T6511 Ext. Aluminum 36" long	1	$700.00	$700.00
.5"x6" Cold Formed C1018 Steel Plate 18" long	1	$36.61	$36.61
		Sub-Total	**$736.61**

MSC Industrial Direct

Description	Quantity	Price (ea)	Amount
0.625"x24"x24" 6061 Alum. Plate	2	$288.48	$576.96
		Sub-Total	**$576.96**

Grand Total **$1,810.22**

Gears

Motion Industries

Description	Quantity	Price (ea)	Amount
FCC-140-TL Friction Clutch	1	$1,250.00	$1,250.00
W636 Worm Gear	1	$133.32	$133.32
S660 Spurr Gear	3	$330.61	$991.83
S1060 Spur Gear	2	$90.42	$180.84
S1040 Spur Gear	1	$69.63	$69.63
S1218 Spur Gear	14	$22.30	$312.20
S1236 Spur Gear	3	$38.34	$115.02
NSS621	1	$67.95	$67.95
H1638 Quad Lead Worm Screw	1	$151.22	$151.22
W620Q Worm Gear	1	$107.81	$107.81
WG6 Worm Screw	2	$132.25	$264.50
W624 Worm Gear	1	$94.37	$94.37
		Sub-Total	**$3,738.69**

Rush Gear

Description	Quantity	Price (ea)	Amount
IST1272	3	$770.00	$2,310.00
		Sub-Total	**$2,310.00**

Grand Total	**$6,048.69**

Power Transmission

MSC Industrial Direct

Description	Quantity	Price (ea)	Amount
0.625"x1"x0.0625" Oil Impregneated Bronze Thrust Bearing	24	$0.61	$14.64
0.625"x1"x0.125" Oil Impregneated Bronze Thrust Bearing	24	$0.61	$14.64
0.625"x0.875"x1" Caged Needle Bearing	2	$6.54	$13.08
Iscar Cut-Off Blade	1	$63.39	$63.39
0.875"x72" 1018 Steel Round	1	$18.15	$18.15
1.25"x72" 1018 Steel Round	1	$34.55	$34.55
6-32x0.75" FHCS Alloy	300	$0.06	$19.44
1/4"-20x0.75" FHCS Alloy	200	$0.07	$13.50
1/4"-20x1/4" Socket Set Screw Cup Point	100	$0.05	$5.14
1"x1"x12" Cold Finished Bar	1	$12.03	$12.03
1/4"-20 2-Flute Plug Tap	5	$2.82	$14.10
6-32 2-Flute Plug Tap	10	$2.08	$20.80
5/64" Long Arm Allen Key	100	$0.06	$6.24
5/32" Short Arm Allen Wrench	100	$0.09	$8.92
1/2-12 Leveling Pads	4	$3.74	$14.96
Offset Bail Handle	6	$2.47	$14.82
1/2"-13X1 1/2" Plain Eyebolt	8	$3.62	$28.96
#36 Jobber Drill Bits	10	$1.64	$16.40
#7 Jobber Drill Bits	5	$2.67	$13.35
Ford Blue Krylon Engine Paint	3	$4.10	$12.30
White Lithium Grease	4	$6.07	$24.28
7/8" Locking Collars	12	$0.82	$9.84
1" Locking Collar	12	$0.93	$11.16
7/8" round Collet	1	$8.45	$8.45
0.875"x1.875'x0.5" DBL Shiedled Radial Bearing	18	$7.59	$136.62
1"x2"x0.5" DBL Shielded Radial Bearing	18	$8.53	$153.54
1"x2"x0.5625" Unground Retainer Type Radial Ball Bearing	6	$7.54	$45.24
0.875"x1.438"x0.078" Needle Type Thrust Bearing	8	$2.73	$21.84
0.625"x0.875"x1" Needle Type Roller Bearing	12	$6.54	$78.48
0.875"x36" Oil Hardened Drill Rod	3	$25.90	$77.70
1"x36" Oil Hardened Drill Rod	3	$29.29	$87.87
		Sub-Total	**$1,014.43**

Grainger

Description	Quantity	Price (ea)	Amount
12 Ga. Wire 500FT	1	$92.05	$92.05
3LL61 Lug	25	$1.87	$46.75
3LL42 Lug	12	$1.87	$22.44
		Sub-Total	**$161.24**

Grand Total	**$1,175.67**

Electrical Components

Grainger

Description	Quantity	Price (ea)	Amount
12 Ga. Wire 500FT	1	$92.05	$92.05
3LL61 Lug	25	$1.87	$46.75
3LL42 Lug	12	$1.87	$22.44
		Sub-Total	**$161.24**

The Robot Market Place

Description	Quantity	Price (ea)	Amount
Etek Motor	1	$450.00	$450.00
S28-150 Magmotor	2	$299.00	$598.00
TW 48330 Speed Controller	3	$455.00	$1,365.00
TW 48330 Calibrator	1	$240.00	$240.00
		Sub-Total	**$2,653.00**

Grand Total	**$2,814.24**

Grand Total

Metal Fabrication

Description	Quantity	Price (ea)	Amount
.375"x12"x36" 6061 Aluminum Plate	1	$153.33	$153.33
.25"x48"x72" 5052 Aluminum Plate	1	$343.32	$343.32
		Sub-Total	**$496.65**

Alro Metal Service Center

Description	Quantity	Price (ea)	Amount
8" Round 6061-T6511 Ext. Aluminum 36" long	1	$700.00	$700.00
.5"x6" Cold Formed C1018 Steel Plate 18" long	1	$36.61	$36.61
		Sub-Total	**$736.61**

Motion Industries

Description	Quantity	Price (ea)	Amount
FCC-140-TL Friction Clutch	1	$1,250.00	$1,250.00
W636 Worm Gear	1	$133.32	$133.32
S660 Spurr Gear	3	$330.61	$991.83
S1060 Spur Gear	2	$90.42	$180.84
S1040 Spur Gear	1	$69.63	$69.63
S1218 Spur Gear	14	$22.30	$312.20
S1236 Spur Gear	3	$38.34	$115.02
NSS621	1	$67.95	$67.95
H1638 Quad Lead Worm Screw	1	$151.22	$151.22
W620Q Worm Gear	1	$107.81	$107.81
WG6 Worm Screw	2	$132.25	$264.50
W624 Worm Gear	1	$94.37	$94.37
		Sub-Total	**$3,738.69**

Rush Gear

Description	Quantity	Price (ea)	Amount
IST1272	3	$770.00	$2,310.00
		Sub-Total	**$2,310.00**

MSC Industrial Direct

Description	Quantity	Price (ea)	Amount
0.625"x24"x24" 6061 Alum. Plate	2	$288.48	$576.96
0.625"x1"x0.0625" Oil Impregneated Bronze Thrust Bearing	24	$0.61	$14.64
0.625"x1"x0.125" Oil Impregneated Bronze Thrust Bearing	24	$0.61	$14.64
0.625"x0.875"x1" Caged Needle Bearing	2	$6.54	$13.08
Iscar Cut-Off Blade	1	$63.39	$63.39
0.875"x72" 1018 Steel Round	1	$18.15	$18.15
1.25"x72" 1018 Steel Round	1	$34.55	$34.55
6-32x0.75" FHCS Alloy	300	$0.06	$19.44
1/4"-20x0.75" FHCS Alloy	200	$0.07	$13.50
1/4"-20x1/4" Socket Set Screw Cup Point	100	$0.05	$5.14
1"x1"x12" Cold Finished Bar	1	$12.03	$12.03
1/4"-20 2-Flute Plug Tap	5	$2.82	$14.10
6-32 2-Flute Plug Tap	10	$2.08	$20.80

5/64" Long Arm Allen Key	100	$0.06	$6.24
5/32" Short Arm Allen Wrench	100	$0.09	$8.92
1/2-12 Leveling Pads	4	$3.74	$14.96
Offset Bail Handle	6	$2.47	$14.82
1/2"-13X1 1/2" Plain Eyebolt	8	$3.62	$28.96
#36 Jobber Drill Bits	10	$1.64	$16.40
#7 Jobber Drill Bits	5	$2.67	$13.35
Ford Blue Krylon Engine Paint	3	$4.10	$12.30
White Lithium Grease	4	$6.07	$24.28
7/8" Locking Collars	12	$0.82	$9.84
1" Locking Collar	12	$0.93	$11.16
7/8" round Collet	1	$8.45	$8.45
0.875"x1.875'x0.5" DBL Shiedled Radial Bearing	18	$7.59	$136.62
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1"x2"x0.5625" Unground Retainer Type Radial Ball Bearing	6	$7.54	$45.24
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0.625"x0.875"x1" Needle Type Roller Bearing	12	$6.54	$78.48
0.875"x36" Oil Hardened Drill Rod	3	$25.90	$77.70
1"x36" Oil Hardened Drill Rod	3	$29.29	$87.87
		Sub-Total	**$1,591.39**

Grainger

Description	Quantity	Price (ea)	Amount
12 Ga. Wire 500FT	1	$92.05	$92.05
3LL61 Lug	25	$1.87	$46.75
3LL42 Lug	12	$1.87	$22.44
		Sub-Total	**$161.24**

The Robot Market Place

Description	Quantity	Price (ea)	Amount
Etek Motor	1	$450.00	$450.00
S28-150 Magmotor	2	$299.00	$598.00
TW 48330 Speed Controller	3	$455.00	$1,365.00
TW 48330 Calibrator	1	$240.00	$240.00
		Sub-Total	**$2,653.00**

Grand Total **$11,687.58**

11.4 Additional Figures

Time Sheets

Motor Controller Data Sheets

Torque Limiter Data Sheets