Bi-directional Offset Lifting Bar

Interim Design Report

Team 5

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Submitted to: Dr. Nikhil Gupta and Dr. Scott Helzer

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ABOUT TEAM 5

Devin is from a small town called Lutz, which is just north of Tampa, Florida. As a candidate of the BS-MS Program, he will attain his Bachelor of Science in Mechanical Engineering in May 2015 and then a Master of Science in Mechanical Engineering in May 2016. He is still unsure of the career path he plans to follow, but is certain that it will involve Energy.

Coert was born in the small fishing village of Tequesta, Florida. After graduating from high school he first attended UCF for two years as a Finance major, before shifting gears and becoming a Mechanical Engineering student at Florida State University. Coert is interested in alternative energy.

Yoel is a native Floridian, raised in the Bay Harbor Islands of South Florida. Currently, Yoel is an active member of the Society of Automotive Engineers, where he currently holds the position of Vice President. After graduation, he plans to take time off to travel before entering the work force.

Originally from Coral Springs, Florida, Luke has always had a profound interest in mechanical systems and mechanisms. He realized his true passion lies in Mechanical Engineering. Driven by the worlds increasing desire for sustainable energy sources, Luke hopes to seek a career in the field of alternative energy after graduation.

Gabriel is an exchange student from Nigeria, to complete his undergraduate degree, he was a member of the Nigeria Institute of Mechanical Engineers. Presently, he is developing interest in aero propulsion, he will be graduating by the end of the spring semester as an undergraduate.

ACKNOWLEDMENTS

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ABSTRACT

Danfoss Turbocor has asked Team 5 to devise an innovative method to lift their new compressor to the testing height using the existing crane hoist and gantry system. The current gantry system is designed to lift the compressor to a height at which was adequate for previous compressor models, but does not lift the new, taller VTT compressor to the appropriate height for testing. The original request was for Team 5 to develop an offset lifting bar to lift their half ton compressor. However, after conceptualization of numerous designs and continuous consultation with Turbocor, Team 5 has instead proposed to increase the vertical lifting height of the compressor by redesigning the current gantry system and developing a separate lifting bar. Turbocor has been supportive of the team's progress and has assured Team 5 of full financial sponsorship. Team 5 believes that its solution to the problem at hand will be fully implemented at Turbocor after fabrication and prototyping in spring.

I. INTRODUCTION

Safety is the most important aspect due to the potential risk to human life. The current method used to lift the VTT compressor to testing position was not only unsafe, but required the use of many engineers and technicians. Turbocor, a company concerned with its employees safety above all else has come to ask Team 5 to devise an inventive method to use the existing crane hoist and gantry system for lifting its new compressor. This will allow Turbocor's employees to safely test each compressor before they go to market.

After the first tour of Turbocor's testing facility, team 5 immediately knew that implementing a solution was going to be challenging given the extremely tight spatial constraints. The team, eager to solve a true engineering problem using their equipped skillset, knowing that the challenge will test them and shape them into engineers ready for the working industry. They are also enthusiastic to work with Turbocor engineers, hoping to absorb every drop of information they receive along the way.

A. Background Research

"Danfoss Turbocor Compressors are transforming the commercial HVAC market with innovative technology that redefines lifetime operating costs for mid-range chiller and rooftop applications." [1] Before every compressor is approved for distribution, it must be tested in house by Turbocor on a chiller rig to test for its efficiencies and performance. Turbocor now has a new line of compressors, the VTT line, which is much larger and operates at higher pressures than previous models. Due to the high confidentiality of this compressor, background research has been obstructively difficult. The compressor at hand is shown below in Fig. 1, which has been a primary source of information about the compressor due to this confidentiality.

Presently, Turbocor has implemented a temporary solution that "requires too much manual labor and distracts an engineer from tasks that he could else wise be focusing on." [2] Turbocor is in need of a solution to create safer working conditions and allow the compressor to be lifted in to place safely, requiring less labor to ensure that more engineers can focus on their individual task uninterrupted.

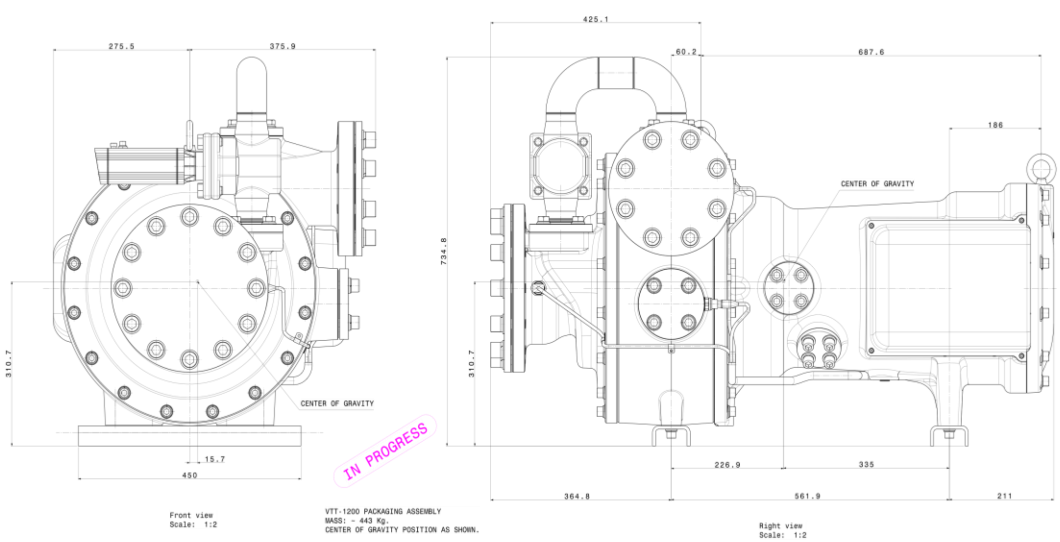

Figure 1 - Schematic of Turbocor's new VTT Compressor showing center of mass location

B. Need Statement

Danfoss Turbocor requires that each half-ton compressor be tested on the chiller system to ensure quality control. Each time the new compressor is ready for testing, a mechanical engineer must employ the use of a manual chain hoist to lift and install the compressor onto the chiller system. Danfoss Turbocor has sponsored a team of 5 mechanical engineering students to solve this problem. Currently, team 5 is in the process of routinely meeting with Turbocor to discuss project progress. During these meetings, the team presented risk assessments, detailed project specifications, a project plan, and proposed design concepts. After these documents were reviewed, Team 5 proposed an alternative design solution that does not implement the use of an offset lifting bar, but does raise the compressor to a sufficient vertical distance.

C. Goal Statement & Objectives

The current problem states that "a better lifting system must be designed and implemented in order to more easily install the compressor for testing." [2] Team 5 has scheduled team meetings as well as sponsor meetings in order to successfully establish a clear and concise goal to establish a firm starting point. The main objective is to increase the lifting height of the compressor. The solution must also have a means to vary the center of gravity to properly lift different versions of the VTT compressor, may they have a change in center of gravity. This new design must completely integrate with the existing equipment in the test room and shall not require a completely new procedure to lift the compressor for simplicity. Finally, this design must minimize all of the safety risks associated with lifting a half ton compressor.

D. Constraints

Due to the confidentiality involved in working with Turbocor, there is limited access to vital spatial dimensions in the chiller. Additionally, this prohibits Team 5's ability of taking pictures and viewing CAD drawings of various compressors in the chiller room to attain dimensions. Turbocor has numerous versions of the new VTT and current TT compressors that are designed to match the proper energy output for a given market. Consequently, the center of gravity in each compressor varies from compressor to compressor. Moreover, the points of lift on these two models are separated by a difference of 18 in. thus adding complexity to the lifting bar design. Therefore, Team 5 is required by Turbocor to produce a lifting bar that can not only lift the current smaller TT compressor and the new VTT compressor but, also account for the slight variation in center of gravity for each compressor. Shown below are the main constraints provided to team 5.

- Must be OSHA regulation compliant
- Primary load capacity: 1200 lb.
- Maximum operating weight (unloaded): 500 lb.
- <$1000 Provided by Danfoss Turbocor
- Extremely constricting dimensions available for compressor/lifting arm movement

II. DESIGN AND ANALYSIS

For this project to be considered a success, a few minimum standards must be met: must be able to safely lift a half ton compressor to an increased overall height and adjustment of lifting point for a variation of center of gravity. When designing the following concepts, these requirements were kept in careful consideration. Safety was of the upmost concern, but the performance of each design is absolutely necessary.

A. Design Concepts

During the design formulation process, a strong emphasis was placed on each team member to create a design that was original in its own way. Any design that was remotely unoriginal was reworked until it was unique. The reason for this was to ensure that with a group of five mechanical engineers, team 5 could consider every possible design solution to approach this problem abstractly. Four designs were submitted and ranked amongst teammates before being presented to Turbocor to receive feedback from experienced engineers. Shown below are four possible designs that were presented to Turbocor.

i. Counterweight

The initial goal of this project was to lift the compressor from a location that was offset vertically and horizontally from the two points of lift on the compressor. It did not take much analysis to realize this would result in a large moment caused by the center of gravity of the compressor. Thus, the concept of utilizing a counterweight in order to counterbalance the moment induced by the center of gravity of the compressor was introduced. Turbocor set a constraint of 500 lb. in total weight of the lifting bar. This meant that the distance of the point of lift to the center of gravity of the counterweight lifting bar had to be roughly twice that of the distance from the lifting point to the center of gravity of the compressor (~27.6 in.). A 3-D model of the counterweight lifting bar is shown below in Fig. 2.

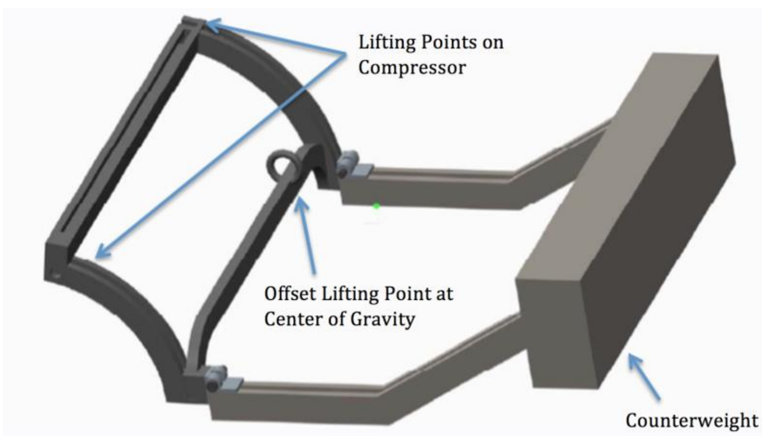

Figure 2 - CAD Drawing of the Counterweight Lifting Bar Concept

When taking this design into consideration, team 5 made sure not to overlook the safety of the operator and the tight working conditions in the chiller rig. It would cause a hazardous working condition to have a 500 lb. counterweight extended at over two feet from a compressor that weighs a half ton. Additionally, there is sensitive and expensive equipment in the chiller rig. There is a large risk in damage if a 500 lb. counterweight were to swing around and collide with any of this sensitive equipment. The cost of the raw material had to be taken into account as well. In order to minimize the size of the counterweight, a very dense material would need to be used, such as tungsten, which would be very expensive with a scrap price of roughly $20 per pound. [4] If the counterweight was to be made out of cheap steel, instead of Tungsten, in order to reduce cost, this would result in a much larger counterweight which could be detrimental for the tight working conditions. Furthermore, there was no clear solution as to how this lifting bar could be adjusted to account for a variation in center of gravity of the compressor being lifted.

ii. Two Points of Lift

In addition to the counterweight design, team 5 devised a way to lift the compressor without the use of a counterweight. This design utilizes a cable and pulley system in order to increase the lifting height of the compressor, which is shown in Fig. 3. The higher pulley (on the right in Fig. 3) would redirect the cable to a fixed location on the gantry system and the lowest pulley (on the left in Fig. 3) would redirect the opposite end of the cable to the crane hoist. An issue with this design is the lack of rotation allowed by the lifting bar due to the fixed point of lift and so a turntable would be utilized for rotation of the compressor, which can be seen in the figure.

When taking this design into consideration, key factors such as safety, performance, and cost stuck out the most. Safety is the number one goal of an engineer when finding the solution to a problem. For this design, the amount of moving parts and multiple pulleys concentrate points of possible failure and it was crucial that these components were engineered perfectly in order to prevent this. In addition to the safety concerns, there were concerns with the performance of the design. For one, this design requires a fixed point of lift on one side of the cable, requiring that one side of the lifting bar would be in a fixed horizontal location. The turntable is also subjected to torqueing due to any alteration of the center of gravity of the compressor, which is completely unacceptable. In addition to the performance of the turntable, models that are rated for the loading this lifting bar will be subjected to are upwards of $750, which is three-fourths of the budget.

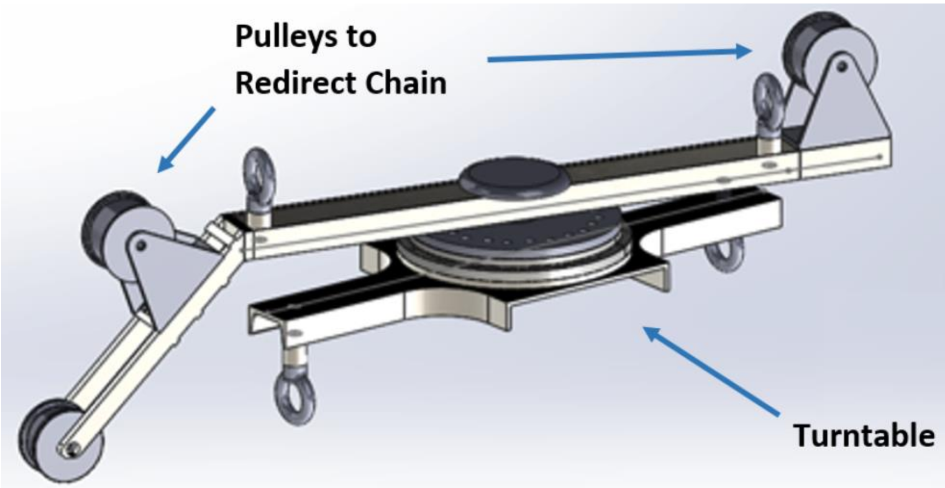

Figure 3 - CAD Drawing of the Two Points of Lift Concept

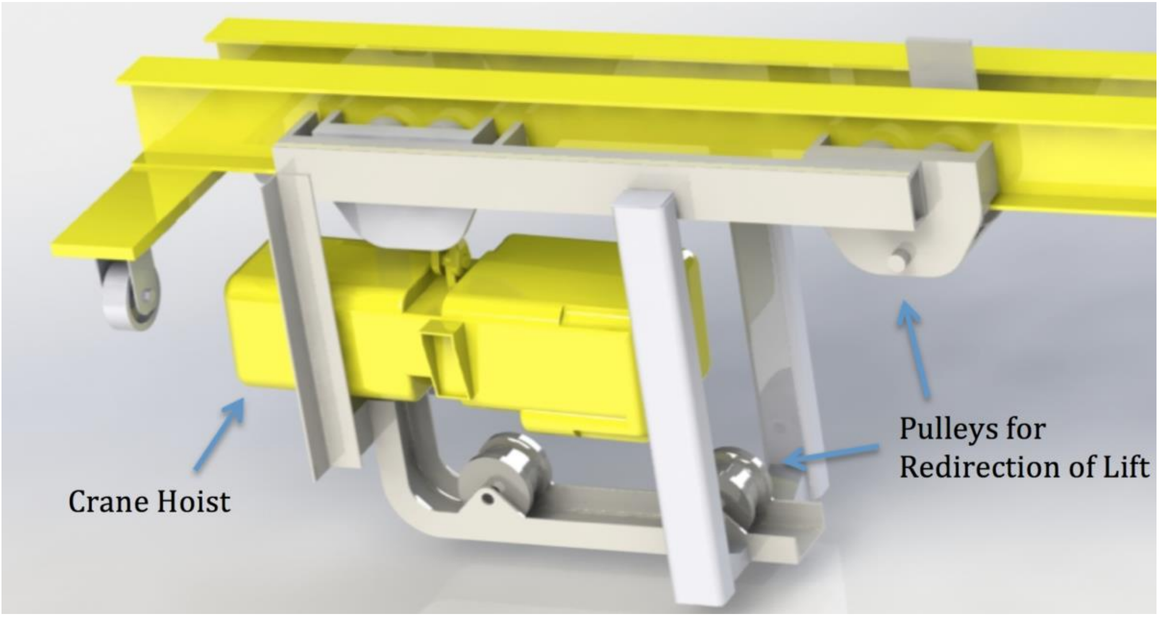

Figure 4 - CAD Drawing of the Redirection of Lift Concept

iii. Redirection of Lift

The team understood the true issue at hand was to be able to lift the new VTT compressor to a larger vertical distance and this could be achieved by redirecting the point of lift to a higher point than the crane hoist is capable of. This redirection of lift could be achieved by the use of a pulley system, which can be seen above in Fig. 4. The two lower pulleys would be used to redirect the chain horizontally away from the crane hoist, and the third pulley situated at the trolley on the right hand side would redirect the chain to a higher point.

Team 5 felt this design was a very strong candidate and could possibly be the solution that Turbocor is looking for. This redirection of lift is simple, effective, and came within the budget set by Turbocor. However, Team 5 ultimately rejected this design, for reasons following. This redirection of lift itself was affordable, but would require the design and manufacturing of a separate lifting bar that could adjust for a variation of center of gravity. This separate lifting bar would evidently reach beyond the scope of the budget. There is also a risk of failure concentrated at each pulley location due to the dynamic loading each pulley would experience. This design also required that a steel frame would be enclosing the crane hoist, as can be seen in the figure. This would cause a hazard for any personnel to hit their head while walking below the crane hoist. With the above points taken into consideration, team 5 collaborated to conceptualize a solution that had fewer drawbacks.

iv. Redesigned Gantry System

In order to increase the lifting height of the compressor, a concept to redesign the current gantry system and suspend the crane hoist between the two I-beams became the focus of the team’s attention. Seen below, in Fig. 5, a picture of the current gantry and crane hoist system can be seen.

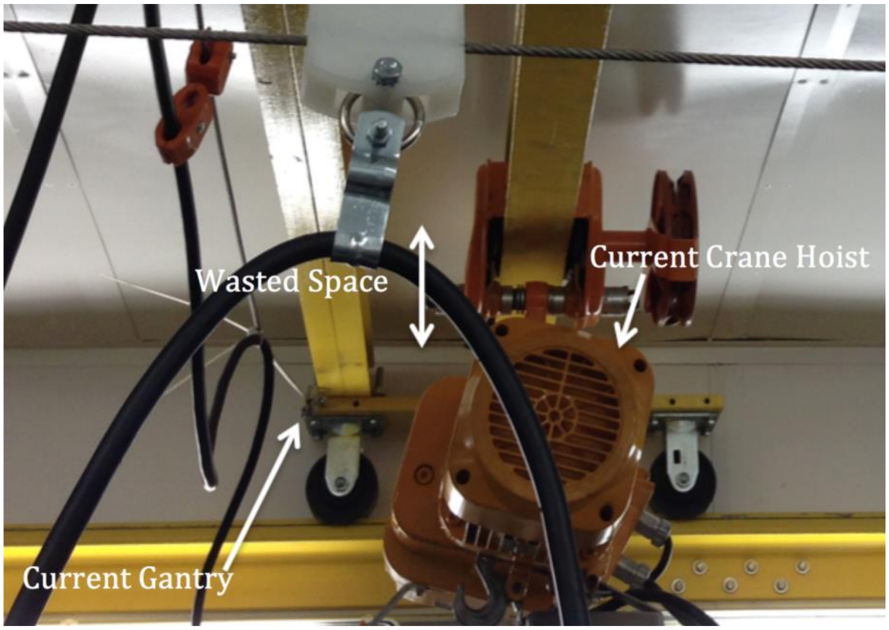

Figure 5 - Picture of the current gantry and crane hoist

As can be seen in Fig. 5, the current crane hoist is suspended below one of the I-beams and there is a substantial gap between the top of the hoist and bottom of the I-beam. Consequently, there is a large amount of wasted space between the hook of the crane hoist and the bottom of the I-beam. This led team 5 to the solution of increasing the crane hoist height to increase the overall lifting height of the compressor. The conceptual model of this solution is shown below in Fig. 6. Drawings for the lifting bar and gantry system can found in APPENDIX C - DRAWINGS.

As can be seen below in Fig. 6, the redesigned gantry requires the implementation of a trolley system that suspends the hoist between the two I-beams. In Fig. 6a, the increase in vertical height from the current system can clearly be seen. This redesigned gantry does not result in any additional hazards that are not already present in the chiller rig (unlike that of the redirection of lift design) and has a high level of durability. There are two major drawbacks with this design: the total cost and the need for a secondary lifting bar.

Team 5 proposed this design as the most favored, and the sponsor was so pleased with the ingenuity of the team that Turbocor has allowed for an increase in the budget as long as all spending requirements are presented to Turbocor

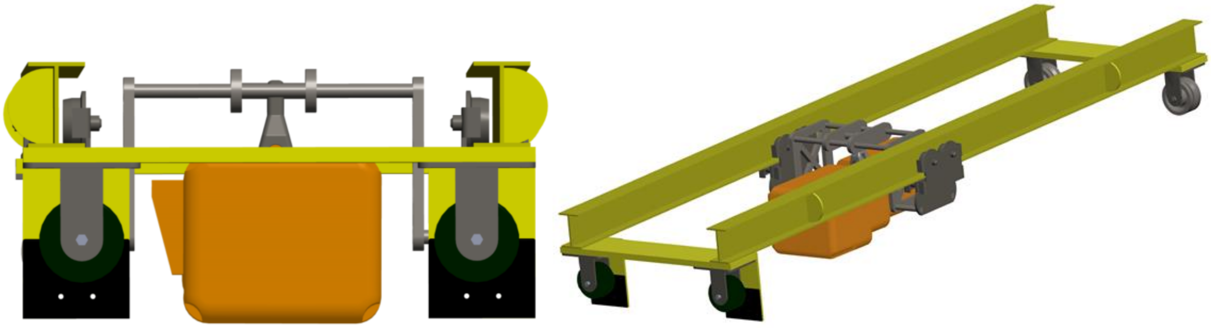

Figure 6 - (a) Front view of the CAD drawing (left), (b) dynamic perspective showing the components of the trolley system (right).

with justification of need. Thus, as long as team 5 is mindful of keeping costs to a minimum, there should not be any budgetary issues.

In addition to the redesigned gantry system, Team 5 has devised a lifting bar that is adjustable to account for a variation in center of gravity. The proposed lifting bar is shown below, in Fig. 7.

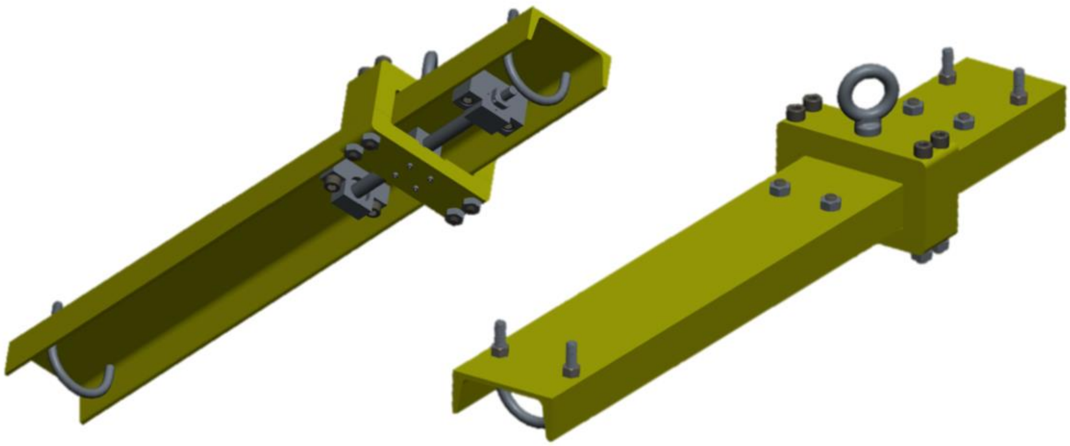

Figure 7 - CAD drawing of the proposed adjustable lifting bar, utilizing a power screw

This lifting bar was essentially designed from the current lifting bar being used by Turbocor, with the exception of the variable point of lift for a variation in center of gravity. A power screw is implemented in order to make adjustments of the location of the lifting point due to any variation in center of gravity of the compressor being lifted. It has a lead of 0.196 in., which means for every full rotation of the screw, the eyebolt will experience a linear movement of 0.196 in. (5 mm). It allows the eyebolt to be adjusted in a range of over 7.874 in. . Due to the nature of this lifting bar, Team 5 could not overlook the loading that this bar could possibly experience. Thus, the power screw selected has a static load rating of 2,360 lbf. (10,500 N) and a dynamic load rating of 1,146 lbf. (5100 N), which should be sufficient for the half ton compressor. This power screw is located inside the channel and is attached to the eyebolt by a machined block of steel that bolts together around the channel. This produces a low vertical profile. Even though this power screw is load rated, this block is designed so that all of the load is experienced by this block and the channel itself. A piece of delrin (a hard and slippery polymer) will be used in order to reduce the friction between the channel and the block to allow for easy adjustment of the lifting point. Additionally, the low profile of the lifting bar will be maintained by using U-bolts with shackles to lift the compressor (shackles not shown in the figure). While minimizing the height of the lifting bar, team 5 was able to produce a bar that is approximately 2 inches shorter than the current lifting bar that Turbocor is currently using.

Due to the moving parts of this lifting bar, it is crucial that team 5 designs this bar with the upmost engineering practices. It is imperative that the power screw experiences only axial loading. All components purchased from a vendor will be required to have a Factor of Safety (F.S.) of at least 1.5 for the load experienced by the lifting bar. Any components that are machined by the team will be load tested upon completion of prototyping with a F.S. of 1.25 (per OSHA requirements) [5].

III. EVALUATION OF DESIGNS

When deciding which of the previously mentioned designs would be selected, team 5 primarily focused on the safety of the operator and the performance of the design, followed by the cost involved. The ease of implementation and durability of the design were also very important to consider, but the constraints of the project deemed these to be less important. A visual representation of how each of the four designs ranked among the five categories is shown above in the form of a decision matrix in Table 1. Each of these scores were ranked out of a score of ten. Durability had the lowest factor in the decision making process because factors such as being able to implement the design and minimizing the cost of the design were more important to the scope of the project.

Table 1 - Decision matrix of the four designs

Design	**Safety (30%)**	**Performance (25%)**	**Cost (20%)**	**Implementation (15%)**	**Durability (10%)**	**Total**
Counterweight	2	5	3	6	6	3.95
Two Points of Lift	4	6	3	3	5	4.25
Redirection of Lift	6	9	6	6	7	6.85
Redesigned Gantry	9	9	8	8	9	8.05

A. Selection of Optimum Designs

The Redirection of Lift and Redesigned Gantry designs became the primary focus of Team 5. The decision matrix demonstrates this in a quantifiable way, with these two designs having the highest weighted score. Team 5 found that two offset lifting bars had too many drawbacks and were not surprised by the results of the decision matrix. When it came to the decision between the Redirection of lift and Redesigned Gantry, feedback from Turbocor and the safety of the operator were heavily considered. For reasons previously discussed, the Redirection of Lift design could cause potential hazards for the personnel working around the crane hoist and gantry. Thus, the Redesigned Gantry was chosen to be the safer of the two choices. When these ideas were presented to Turbocor, they were retentive to both ideas. It was clear, however, that they were much more open to the idea of redesigning their current gantry system. Turbocor agreed with our concerns about the safety issues related to the redirection of lift and were open to increasing the budget if necessary for redesigning the current gantry system. Thus, taking all of this into consideration, team 5 decided to move forward with the project focusing on redesigning the gantry system and developing a separate lifting bar.

B. Final Design Analysis

Stress analysis was performed on the redesigned gantry and lifting bar components in order to ensure that the materials and designs selected would be able to withstand the dynamic loading involved with raising and lowering the compressor. Turbocor made it very clear that the design had to be rated for a 1-ton load. A F.S. of 1.25 was used in this stress analysis so a total of 2500 lb. was applied to the different components.

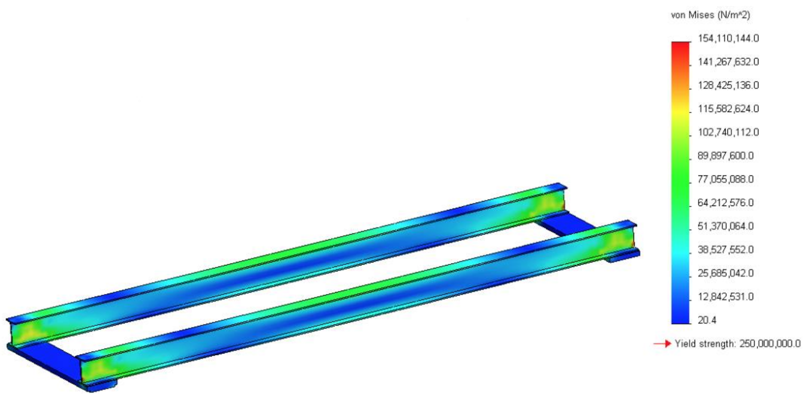

Figure 8 - Load analysis on the redesigned gantry from a 2500 lbf. load

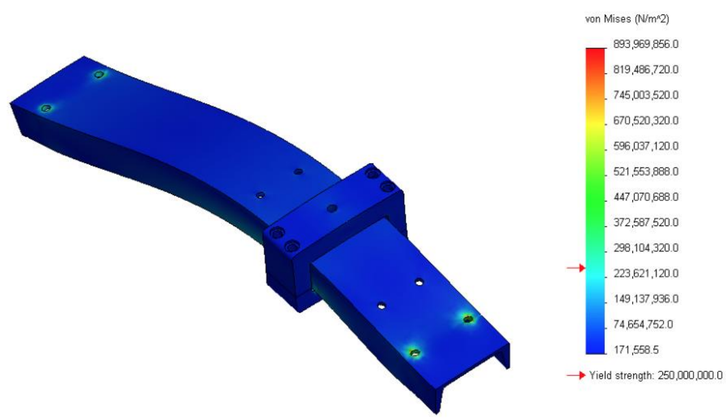

Figure 9 – Load analysis on the lifting bar with a 2500 lbf. load

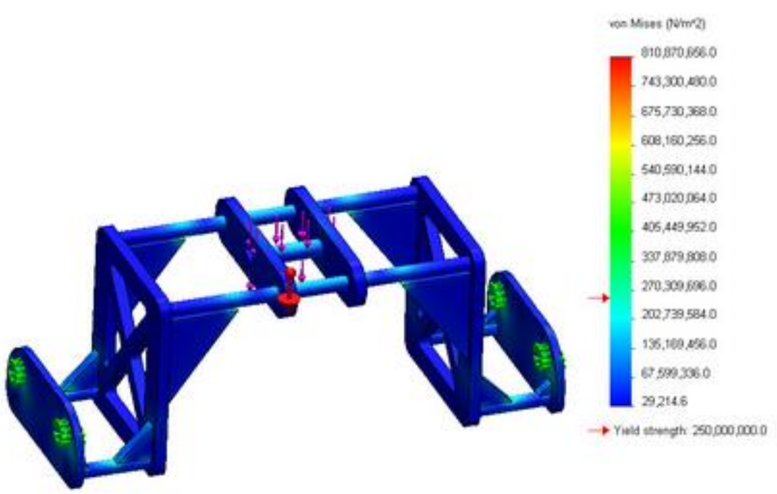

Figure 10 - Load analysis on the trolley system with a 2500 lbf. load

Shown above in Fig. 8 is a visual representation of how the I-beams would react under the immense loading. The center of the I-beam is where the trolley system would be applying a maximum stress on the beam considering it is at the center of the beam and furthest from either support location. The color spectrum depicts the range of stresses experienced by the beam (red being the most and violet being zero). With a safety factor of 1.25 applied to the loads, it can be seen that the beams are not stressed to plastic deformation at A36 Steel’s yield strength of 36,259 psi (250MPA). This analysis shows that the redesigned gantry does not come close to experiencing plastic deformation, proving that this particular design is a viable solution.

In addition to doing preliminary load analysis on the new gantry, team 5 completed load analysis on the final design of the lifting bar and power screw knuckle, which can be seen above in Fig. 9. The lifting bar was designed in such a way that the power screw is to experience no loading other than the axial load from turning the screw. Thus, the load analysis was performed on only the bar itself and loading was fixated at the locations where the material would be experiencing a load due to lifting the compressor. It was found through this analysis that tear out failure is of the most concern for the design. Using a stronger material for the bar and implementing the use of washers to increase the surface area where the tear out could occur will mitigate this risk.

Shown in Fig. 10 above is the load analysis data on the final version of the trolley system. The greatest challenge of designing this component is the very large deflection that occurs in the center of the trolley due to the hoist, lifting bar, and VTT compressor being hung on a hook in the very center of this bar. To mitigate this, gussets have been added to increase the surface area of material and improve the geometry of the trolley for increased strength. In this analysis, it can be seen that the maximum stress felt by this trolley is under the A36 Steel yield strength of 36,259 psi (250MPA), proving this design is a safe solution even with a safety factor of 1.25.

C. Final Detailed Design

Shown below in Fig. 11 is the finalized completed assemby of each component that will be prototyped in spring. The only two components that Team 5 will not be responsible for procuring and manufacutring, is the compressor and the crane hoist (both are in the figure). With just the gantry system alone, team 5 saved about 6 in. of vertical distance. The Lifting bar has also received a height reduction, saving 2 in. The combination of this system saves approximately 8 in., which is sufficient to lift the compressor to the required height.

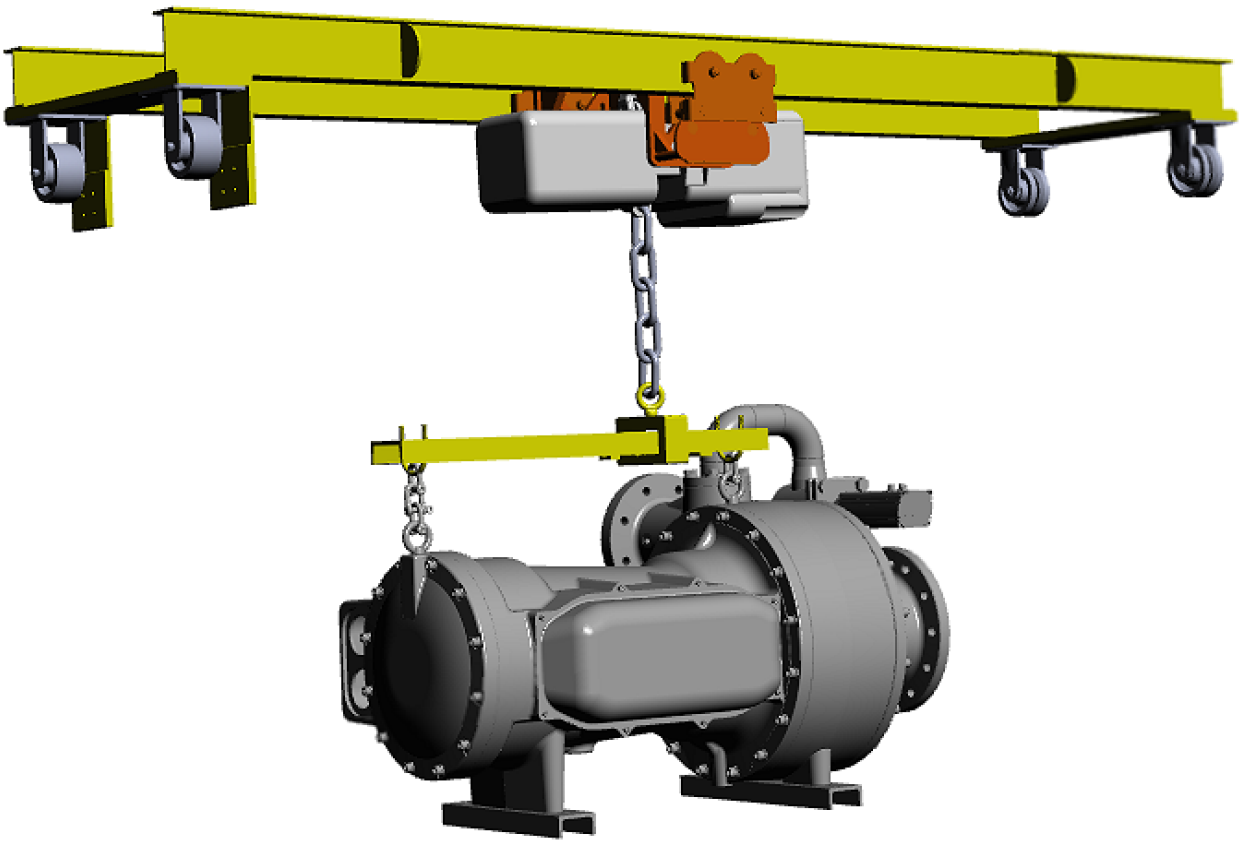

Figure 11 - Complete gantry, trolley, and winch assembly

IV. PROCUREMENT

Team 5's main goal in designing parts was to not only produce effective parts, but to create parts that are easy to machine. With that being said, Turbocor has allotted the team a crew of machinists so that the designs can be fabricated in house at Turbocor. The advantages of this are high quality machining work, oversight of fabrication by team 5, and fast post assembly testing.

In Table 2 below, a comprehensive list is shown for the parts that make up the lifting bar. The total cost comes in at $591.05. The most expensive part is the ball block screw that enables the adjustability of the lifting hook.

Table 2– Cost analysis for lifting bar

Parts Cost for Lifting Bar					
Part	Part #	Vendor	Cost	Quantity	Total
Eyebolt for lifting - M12 x 1.75, 30 mm eye	3040T15	McMaster	$6.63	1	$6.63
Steel Shackle - 3/8" x 1 7/16"	8494T14	McMaster	$7.68	2	$15.36
U-Bolt - 3/8" x 16, for 2" pipe	3043T41	McMaster	$6.33	2	$12.66
4" x 8" x 2" Steel Block (4"x4"X12")block	N/A	Speedy Metals	$103.00	1	$103.00
63 mm of chain					$0.00
Block Ball Screw	BSBR1505-250	Misumi	$245.92	1	$245.92
Support Bearing - Fixed Side	BSWE12	Misumi	$87.14	1	$87.14
Support Bearing - Support Side	BTN12	Misumi	$90.59	1	$90.59
Delrin for Adjusting Hook Block	8739K13	McMaster	$4.20	1	$4.20
U-channel C4x5.4 (36 inches)	N/A	Speedy Metals	$25.55	1	25.55
Total Cost					$591.05

In Table 3 shown below, the cost analysis for the trolley can be viewed. The total cost of the trolley is $456.11. The most expensive aspect of the design is the trolley system that mounts the wheels to the I-beam. This is the second most expensive component.

Table 3– Cost analysis for Trolley

Parts Cost for Trolley					
Part	Part #	Vendor	Cost ($)	Quantity	Total ($)
1/2" x 24 " x 24 " Steel Plate	P112	Metals Depot	110.24	1	$110.24
3/4" x 72" steel rod	R134	Metals Depot	14.28	1	$14.28
Grade 9, 3/4" x 5" bolt	90201A660	McMaster-Carr	11.25	1	$11.25
Trolley	3267T62	McMaster-Carr	160.17	2	$320.34
Total Cost					$456.11

Table 4– Cost analysis for Gantry

Parts Cost for Gantry					
Part	Part #	Vendor	Cost	Quantity	Total
I Beam 4" x 3" x 20'		Trident	$240.00	1	$240.00
4" Track Wheels	8745T89	McMaster_Carr	$31.99	2	$63.98
4" Cast Wheels	2453T1	McMaster_Carr	$26.63	2	$53.26
1/4" x 12" x 24" Steel Plate guide and bumpers	P114	Metals Depot	$31.02	1	$31.02
Delrin	8739K13	McMaster	$4.20	1	$4.20
Total Cost					$392.46

Shown above in Table 4, the cost analysis for the gantry can be seen. The total cost of this component is $392.46, which is the least expensive out of the gantry, trolley, and lifting bar. The total cost of these three components is $1,439.62, which is over the original budget of $1,000.00. Turbocor has agreed to supply a larger budget as long as it is justified. This budget will be presented to Turbocor before the end of fall semester, and pending their approval, the parts will be ordered. Refer to APPENDIX B – DRAWINGS for drawings which comprise of the individual components shown above.

V. METHODOLOGY

The first step in the project plan was to begin communication with Turbocor in order to facilitate a good working relationship. An initial meeting was scheduled on Wednesday, September 10, in order to discuss the preliminary constraints of the project and to visit the task at hand in person. Team 5 was allowed access to Chiller 3 system and was able to better understand the difficulty of the project. We then scheduled a meeting that Friday, September 12th, in order to take measurements of the chiller. Turbocor shut down testing for two hours to allow us to do so.

Since those two preliminary meetings, the team has met weekly in order to discuss possible design implementations, budgetary constraints, and formulate a project timeline. On Friday, September 26, the team met with the team Advisor, Dr. Hollis, in order to discuss the team's possible designs and for new design suggestions. Team 5 has continued to meet every Monday at 4:00 pm and on alternating Tuesdays with Dr. Gupta and Dr. Helzer. Starting the second week of October, team 5 met with Turbocor bi-monthly in order to maintain strong communication and to meet Turbocor's desired deadlines. Additionally, team 5 maintains a relationship with Dr. Hollis for further assistance in the design and manufacturing of the project.

During the meeting that took place the second week of October, a complete project plan and timeline was discussed with Turbocor. Team 5 also presented four preliminary design prototypes and received positive feedback. The team is approaching this issue abstractly and proposed to dismiss the design and implementation of an offset lifting bar, and instead introduce a redesigned lifting bar that will complement the new gantry system. This method will require a larger budget and team 5 has requested more funding in order to do so. Turbocor is pleased with the progress of the team thus far and has ensured that any spending requirements will be met with proper cost justification. In the third week of October, team 5 met with Turbocor once again to review the progress of the project. An updated project plan was presented and the preliminary cost analysis of the redesigned gantry system was proposed. Turbocor has offered to allow team 5 to utilize the company relationships with vendors in order to receive reduced cost of material and shipping.

At the Turbocor meeting on November 27, a final cost analysis of the redesigned gantry system using the pricing of the Turbocor vendors was presented. A preliminary cost breakdown and analysis was presented for the new trolley system and lifting bar. Turbocor provided feedback as to where costs can be minimized and where the team should be focusing their attention.

By the conclusion of the semester, a final cost and FEM analysis will be completed of the gantry system, trolley, and lifting bar. Team 5 will present this analysis to Turbocor. Upon their approval of Team 5's decision, purchasing will begin before the end of fall semester to ensure all parts will arrive at the start of spring semester.

When approaching the problem at hand, Team 5 was sure to use a dynamic methodology. This meant understanding the true goal of the project was to lift the compressor to a higher vertical distance. The method in which Team 5 achieved this is outlined below in Fig. 12 as a flow diagram.

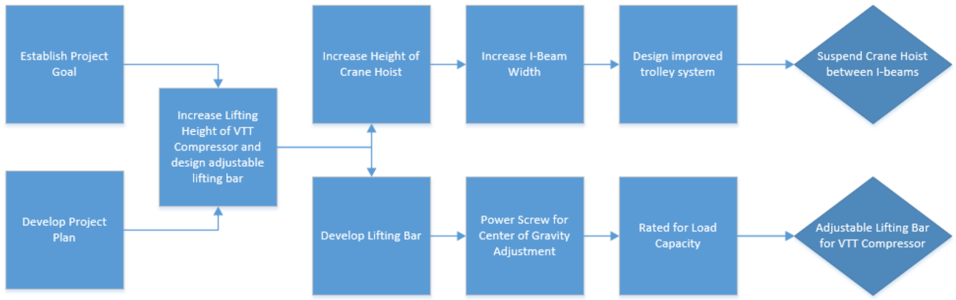

Figure 12 - Flow Diagram of the design process

Figure 13 - Gantt chart short

A. Schedule

In order to ensure that Team 5 will meet required deadlines for the project, a project plan and schedule has been established. This project plan will be followed as closely as possible and when scheduling changes are necessary, the project plan will be updated. A visual representation of the current project plan can be viewed above in Fig. 13 in the form of a Gantt chart, which can be found in full in Fig. 14 Appendix A – GANTT CHART. As can be seen, the schedule was broken into three major sections: Planning, Concept Creation, Design Proposal.

The Planning stage was very important. Team 5 first utilized this time period in order to delegate roles to each member and schedule routine meetings for the team. The team leader went over project deadlines and ensured all members were clear on their responsibility within the team in order to create a cohesive work effort. As a team, a project plan was developed before any engineering was performed as to maximize the proficiency of the team. Team 5 then presented this project plan to Turbocor and moved on to the Concept Creation stage of the project.

To initiate the Concept Creation stage, all team members were required to produce a concept that could possibly be a solution for Tubocor's problem. Some members conceptualized multiple design solutions. The team then went over all of the concepts in order to rank each concept against one another. Team 5 then eliminated the ones that were obsolete until there were four remaining designs, which were discussed previously. The team then completed rough analysis on these designs, including FMEA, cost, and performance. How these designs ranked against each other was discussed in section III. Team 5 then presented their design concepts to Turbocor and placed a heavy focus on their plan to redesign the gantry system. Turbocor provided positive feedback on the redesigned gantry system, Team 5 began to focus their attention on that design, and the Design Proposal stage began.

Currently, team 5 is completing the Design Proposal stage and working on finalizing the design by completing initial FMEA (Failure Mode Effects Analysis) and assessing the risks team 5 can foresee with this design. Completing these analyses prior to development will promote strong project progression and will be useful in mitigating any risks the team may encounter in the future. The concept development stage has been created, and the next step for the team is to present to Turbocor a finalized design and budget.

B. Resource Allocation

The development and implementation of the improved gantry system with adjustable lifting bar requires several tasks that are dependent on each other in order for team 5 to perform in an organized and efficient manner. Before any of these tasks could be completed, team member roles were assigned to each member, and their responsibilities within the team will be discussed in the paragraphs following.

Devin Stubbs is responsible for submitting machinist approved drawings to team 5's sponsor, Turbocor. He will oversee the machining of each component per drawing. Devin will also take part in the assembly of the gantry and trolley. Devin will help maintain project milestones to make sure goals are met in a timely manner.

Luke Leelum will also aid Devin in submitting machinist approved drawings to Turbocor. Similar to Devin, he will also oversee the machining of each component per drawing. Luke will take part in the assembly of the lifting bar. Luke will maintain communication with Turbocor to ensure all parties are on the same page.

Yoel Bugin will assist in assembly of every component as well as manage the gantry and lifting bar optimization sector. In this sector, Yoel will make sure that the fabricated components of the lifting bar and gantry system are in accordance to the design. He will inspect the assemblies to make sure there are no problems. Yoel will be in charge of water jetting the particular parts that require this process.

Coert Maraist will come up with a design in order to test the gantry, trolley, and lifting bar. He will be responsible for ordering the necessary components and the assembly of the testing rig. Coert will oversee the testing phase and make sure everything is tested properly. Coert will help get the Gantry system approved for use in Turbocor's chiller 3.

VI. CONCLUSION

Turbocor is in need of a new lifting system in order to lift the new VTT compressor into place for chiller testing. The current gantry system was sufficient for previous compressors, but is inadequate for the new design. Turbocor has requested that a new, offset lifting bar be designed and implemented with the current crane hoist in order to lift the compressor to the appropriate height. Team 5 has proposed that, in order to safely solve this issue, a new gantry system be designed in order to suspend the crane hoist between the I-beams and also develop a lifting bar that will be able to adjust for a variation in the center of gravity for each compressor. Turbocor has shown full support of this proposal and team 5 plans to submit a complete design and cost analysis for procurement to begin before fall semester ends.

VII. FUTURE WORK

Team 5 will be presenting the completed finalized design to Turbocor on the week of finals. This complete design will include a budget with purchase orders. Upon approval, the purchase orders will be submitted and the parts will be ordered. In the start of spring, the parts should already have arrived at Turbocor. Following this, prototyping will begin as soon as possible. Within this stage, team 5 will allot time for trial and error to account for any problems that might arise in fabrication. Following fabrication and prototyping, testing will begin to assess the structural integrity of the redesigned gantry and lifting bar. This will be done at Turbocor under the supervision of an engineer who will assess whether the testing satisfies Turbocor's requirements for OSHA compliance. Pending the successful results of testing, the gantry system will be installed into the testing room "chiller 3" and perform a lift of the VTT compressor.

VIII. REFERENCES

[1] "OEM Customers." *Danfoss Turbocor Compressors Inc.* N.p., n.d. Web. 23 Sept. 2014.

[2] Lohman, Kevin. "Project 5 - DTC Bi-directional Lifting Bar." *Www.campus.fsu.edu*. Florida State University, 31 Aug. 2014. Web. 26 Sept. 2014.

[3] "Lifting Beams Design." *Lifting Beams Design*. N.p., n.d. Web. 26 Sept. 2014

[4] "Metal-Pages - Tungsten Prices." *Metal-Pages - Tungsten Prices*. N.p., n.d. Web. 23 Oct. 2014.

[5] "OSHA Law & Regulations." *OSHA Law & Regulations*. N.p., n.d. Web. 21 Oct. 2014.

IX. APPENDIX A – GANTT CHART

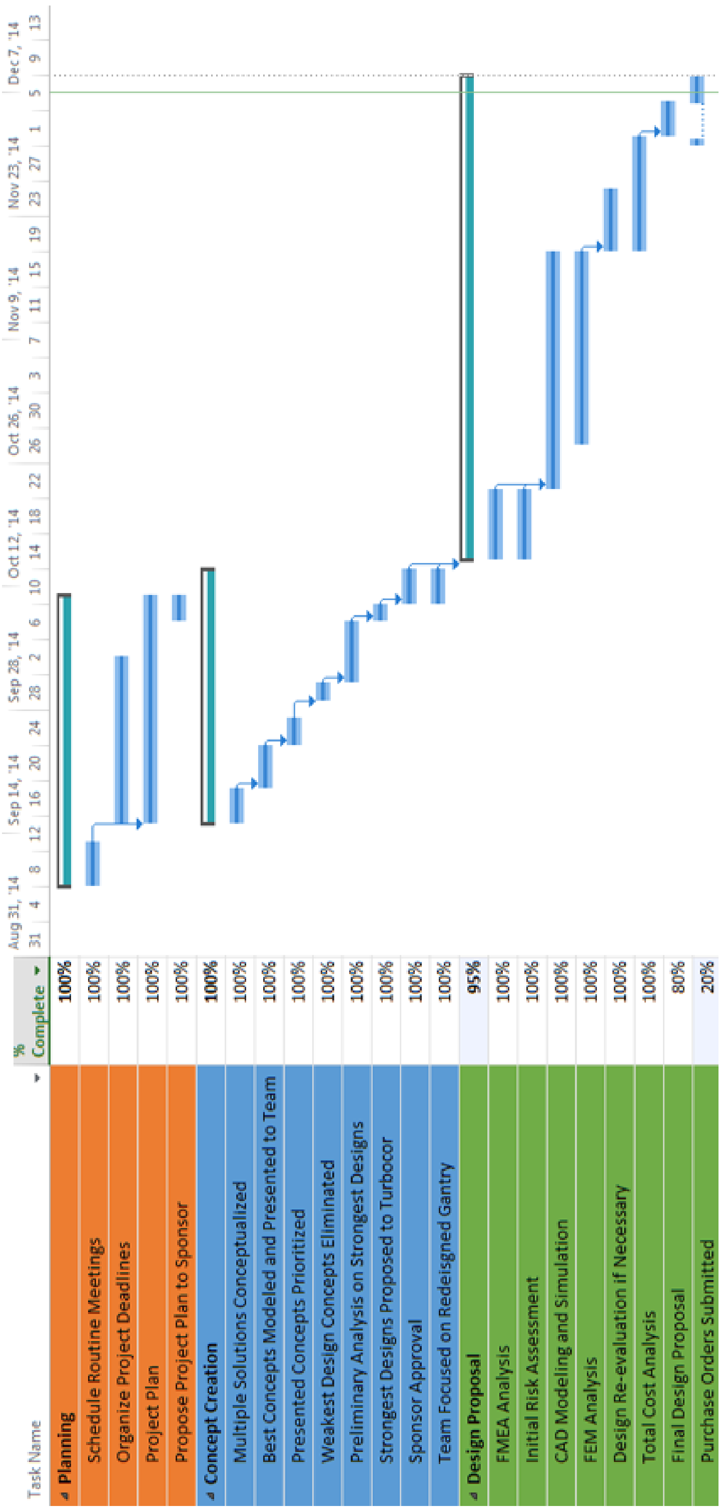

Figure 14 - Gantt chart

X. APPENDIX B - DRAWINGS

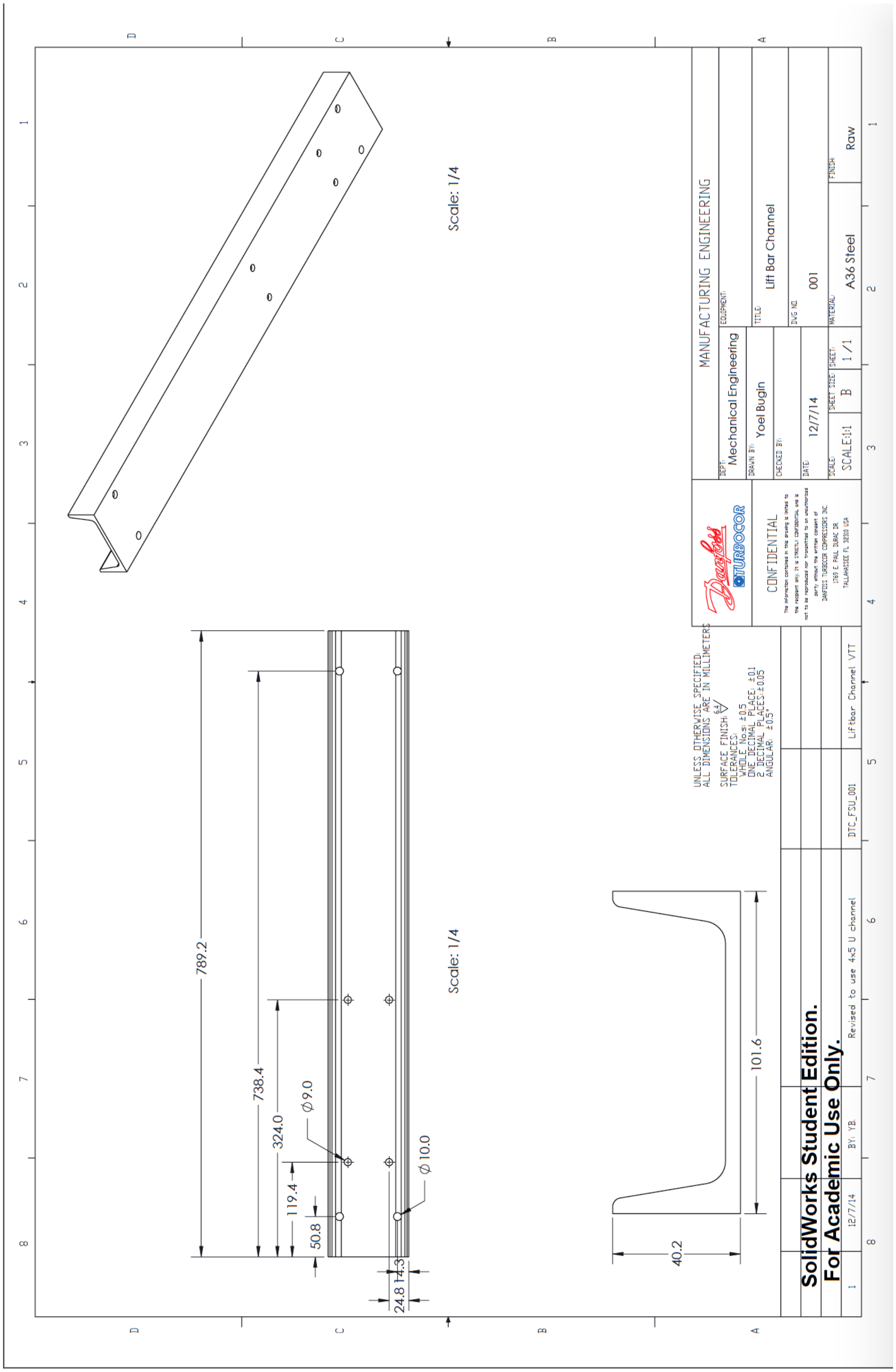

Figure 15 - Drawing of C-Channel

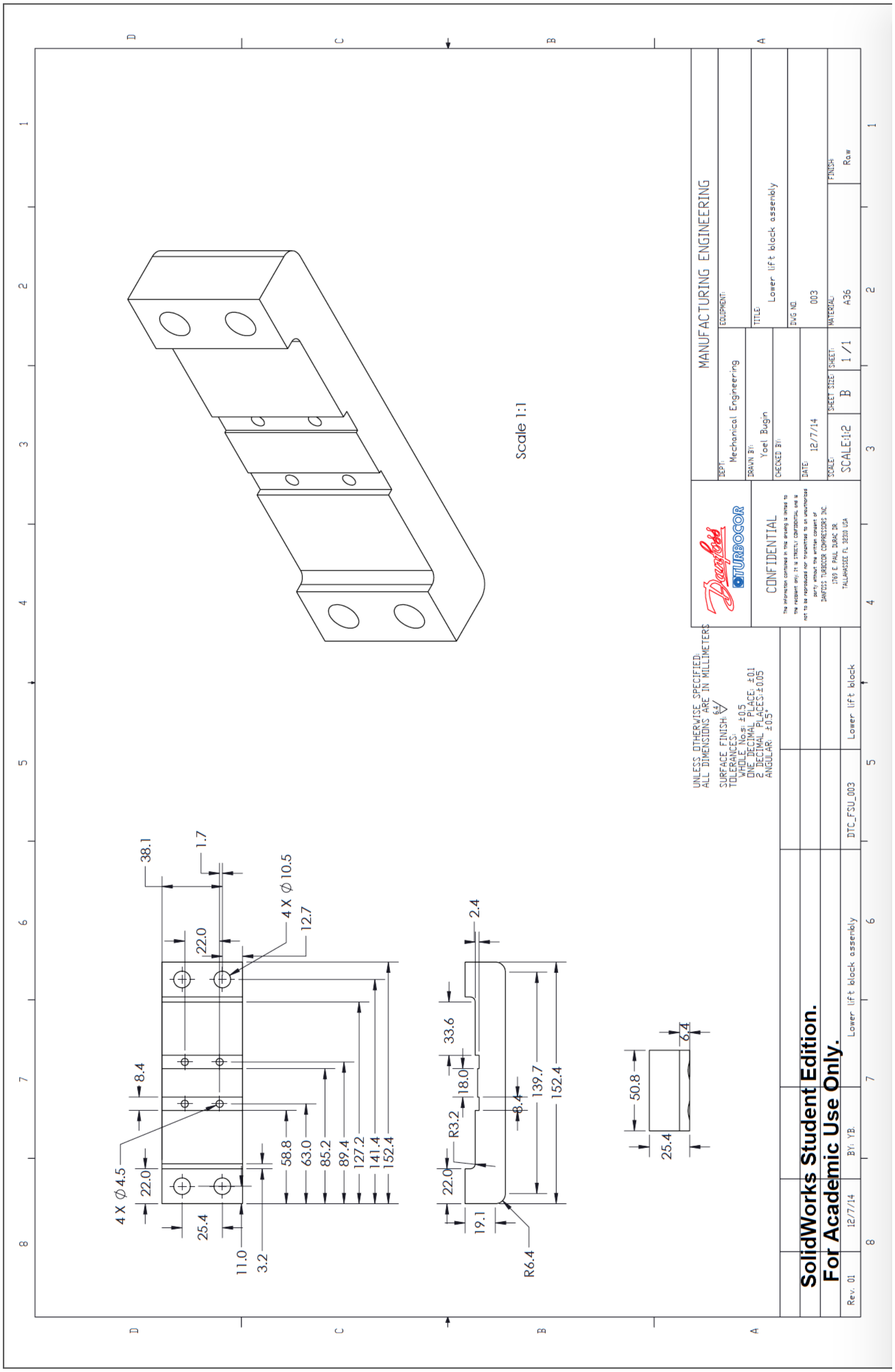

Figure 16 - Drawing of Lifting Point Adjustment Block (1)

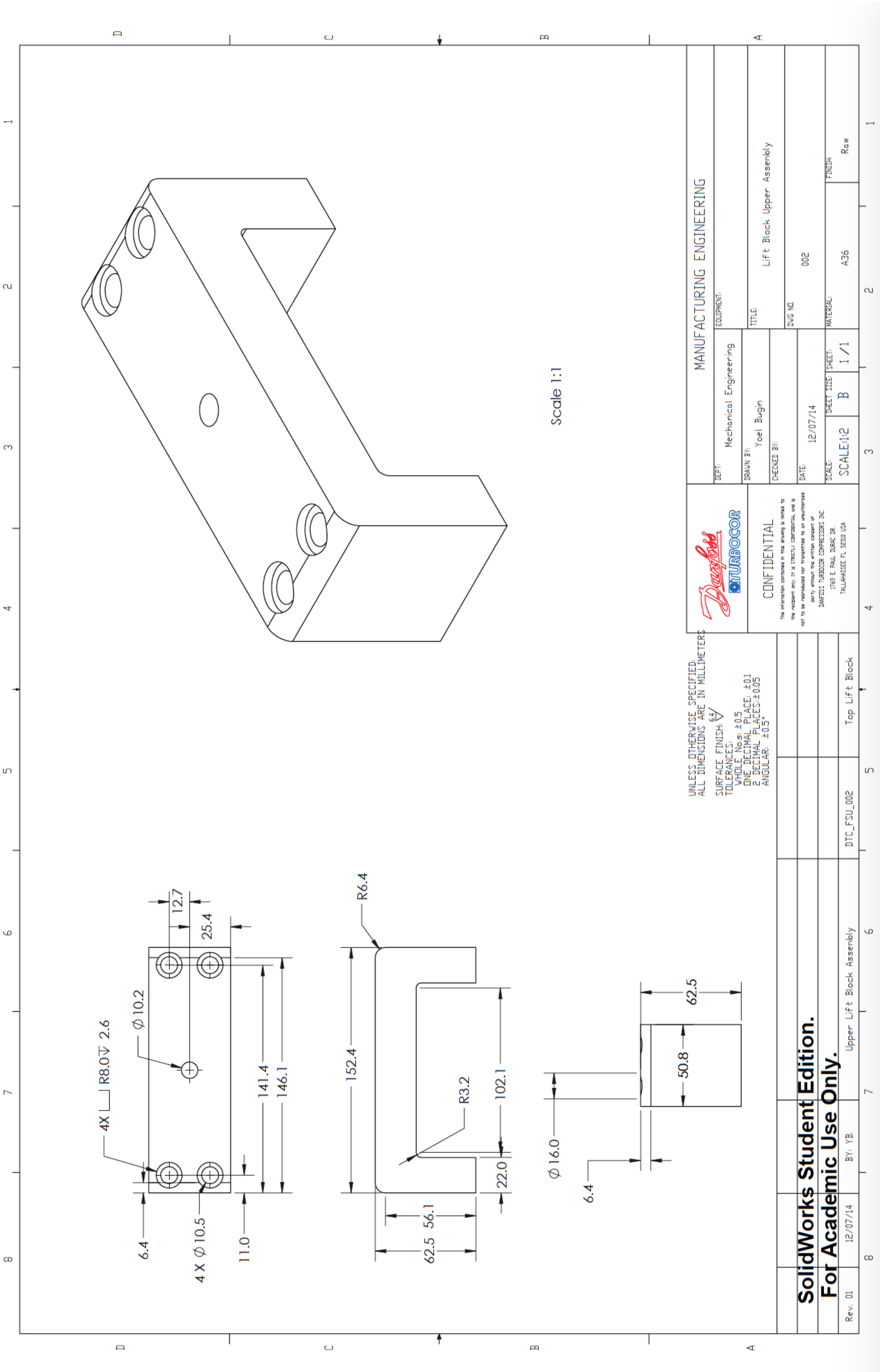

Figure 17 - Drawing of Lifting Point Adjustment Block (2)

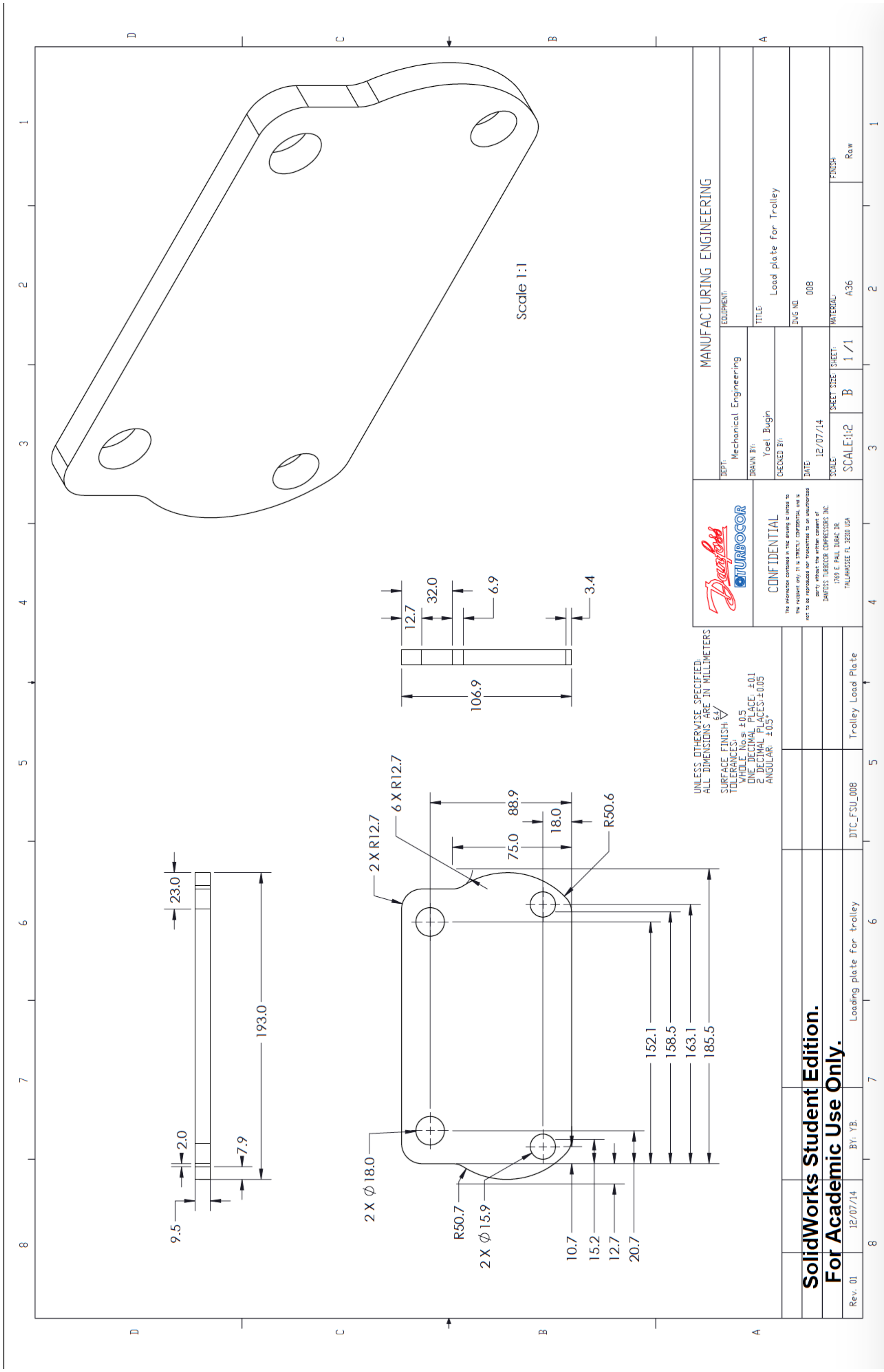

Figure 18 - Trolley Load Plate

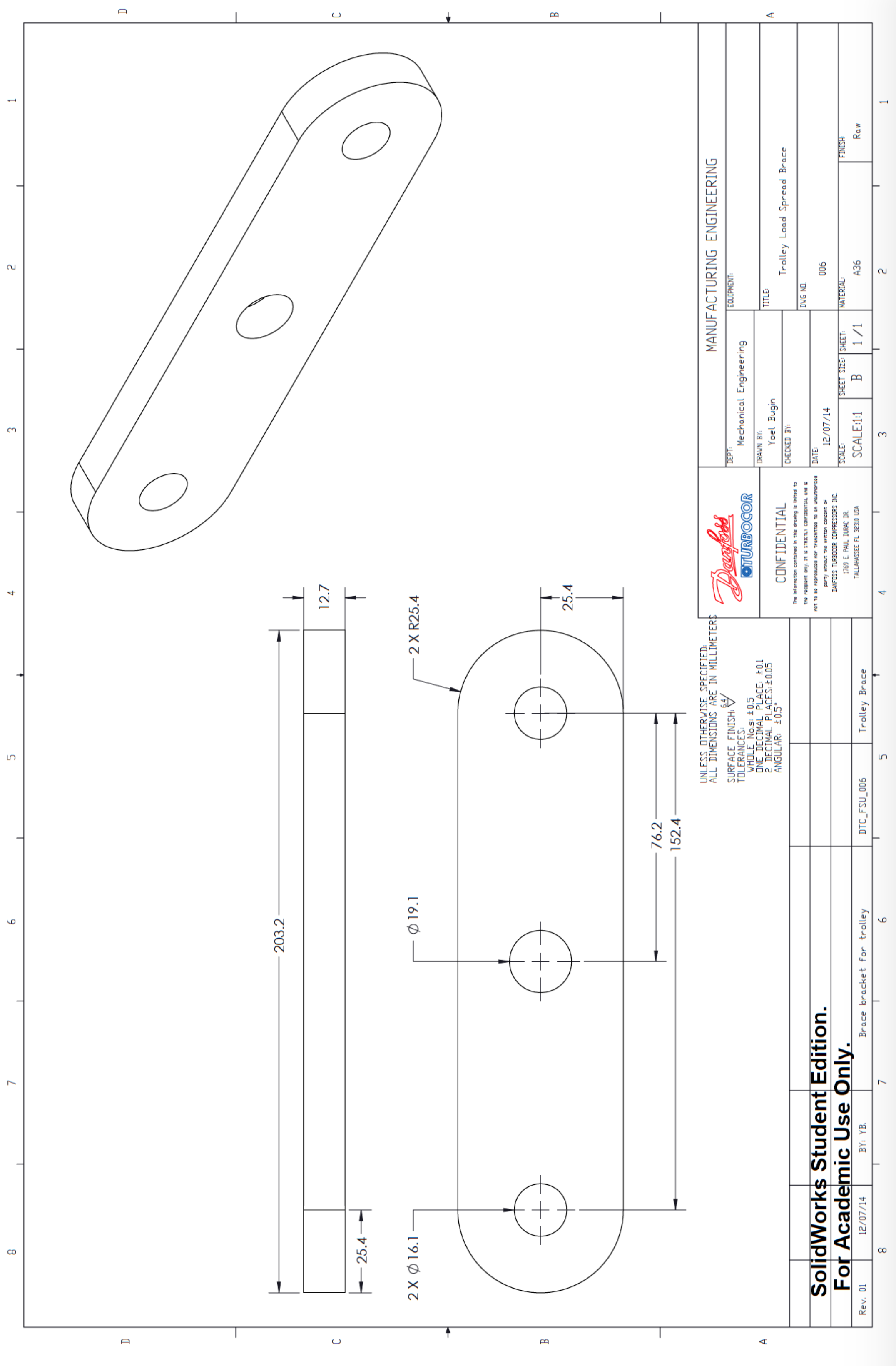

Figure 19 - Trolley Support Brace

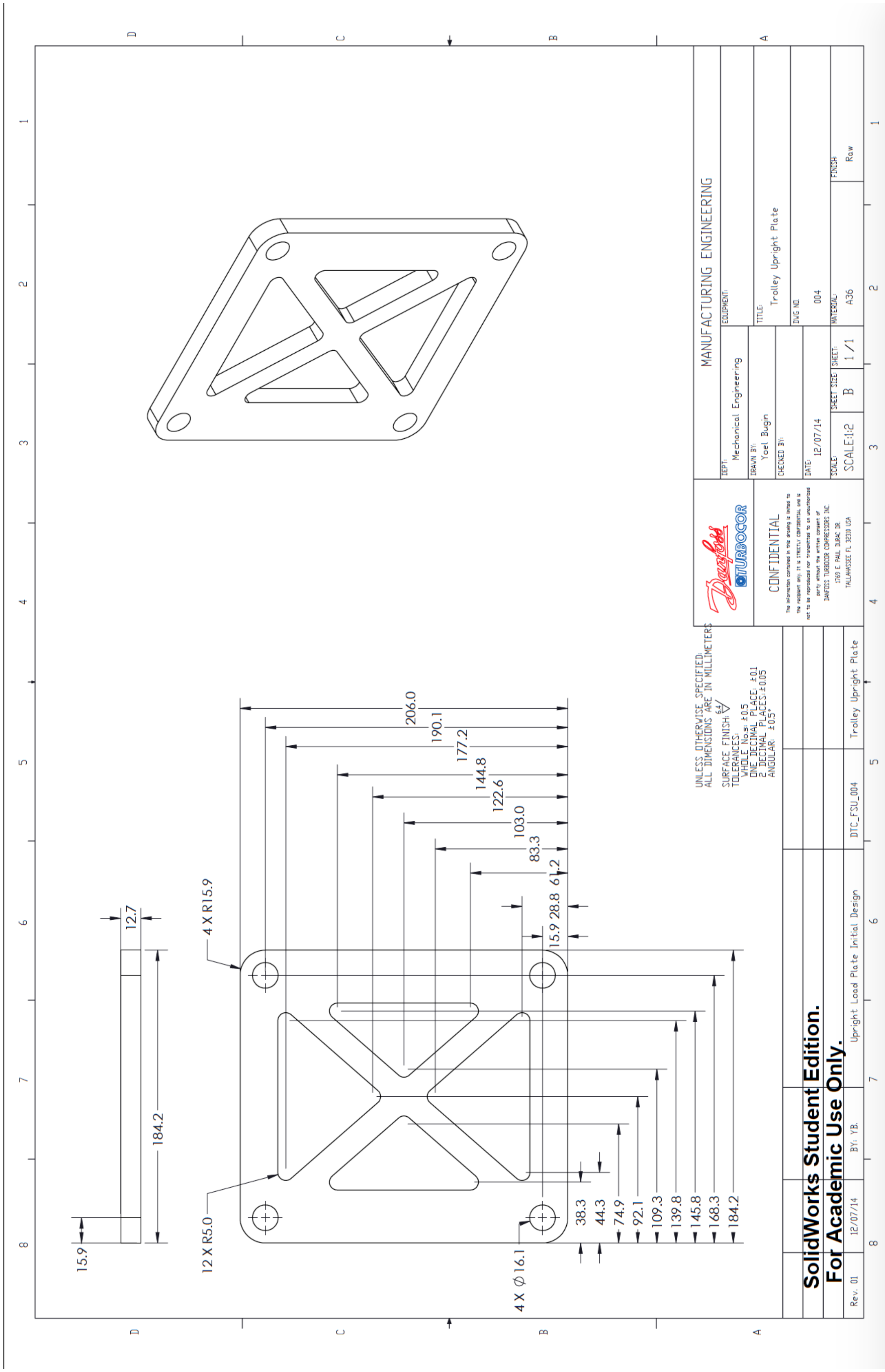

Figure 20 - Trolley Vertical Load Support