Variable Center of Gravity Lifting System

Final Spring Report

Team 5

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Submitted to: Dr. Nikhil Gupta

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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

Team 5 would like to thank their Turbocor liaison Kevin Lohman for guidance along this semester. Additionally, Team 5 would like to thank their advisor Dr. Patrick Hollis and senior design professors, Dr. Nikhil Gupta and Dr. Scott Helzer.

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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 is complete.

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.

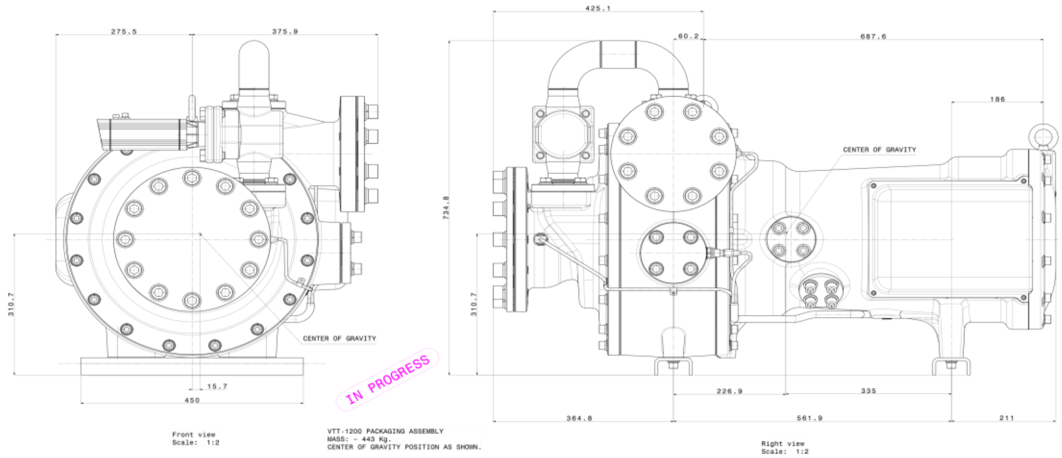

Figure 1 - Schematic of Turbocor's new VTT Compressor showing center of mass location

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, should 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. Listed 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. CONCEPT GENERATION

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.

1. 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.

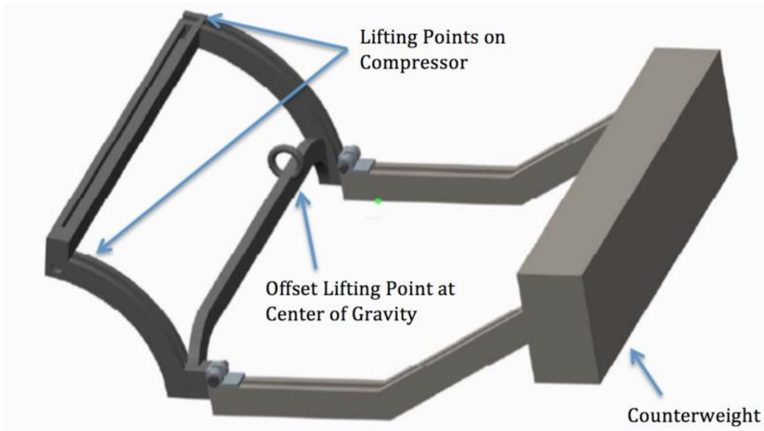

Figure 2 - CAD Drawing of the Counterweight Lifting Bar Concept

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.

2. *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.

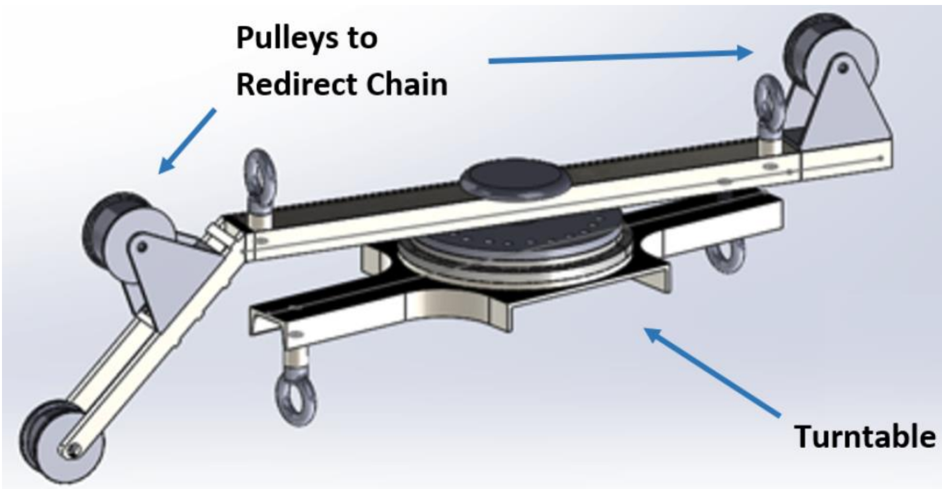

Figure 3 - CAD Drawing of the Two Points of Lift Concept

3. Redirection of Lift

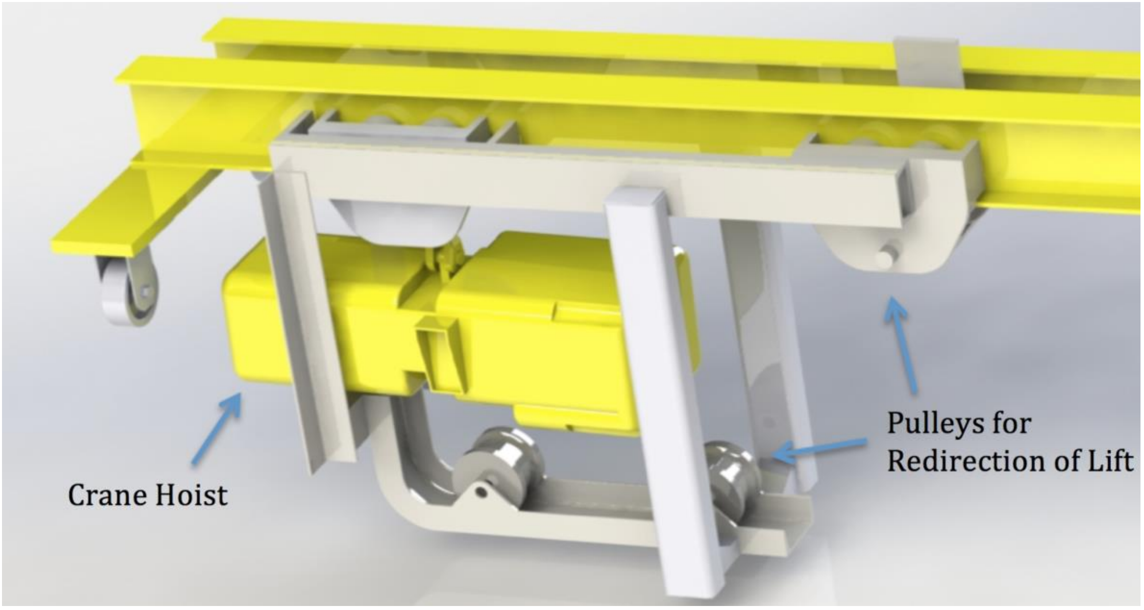

Figure 4 - CAD Drawing of the Redirection of Lift Concept

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.

4. Redesigned Gantry and Lifting Bar

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.

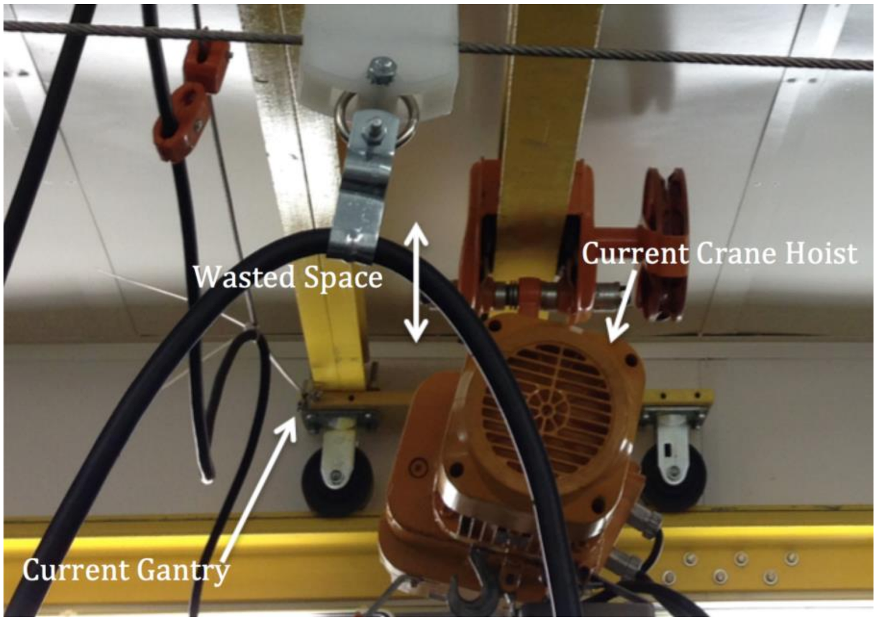

Figure 5 Picture of the current gantry and crane hoist

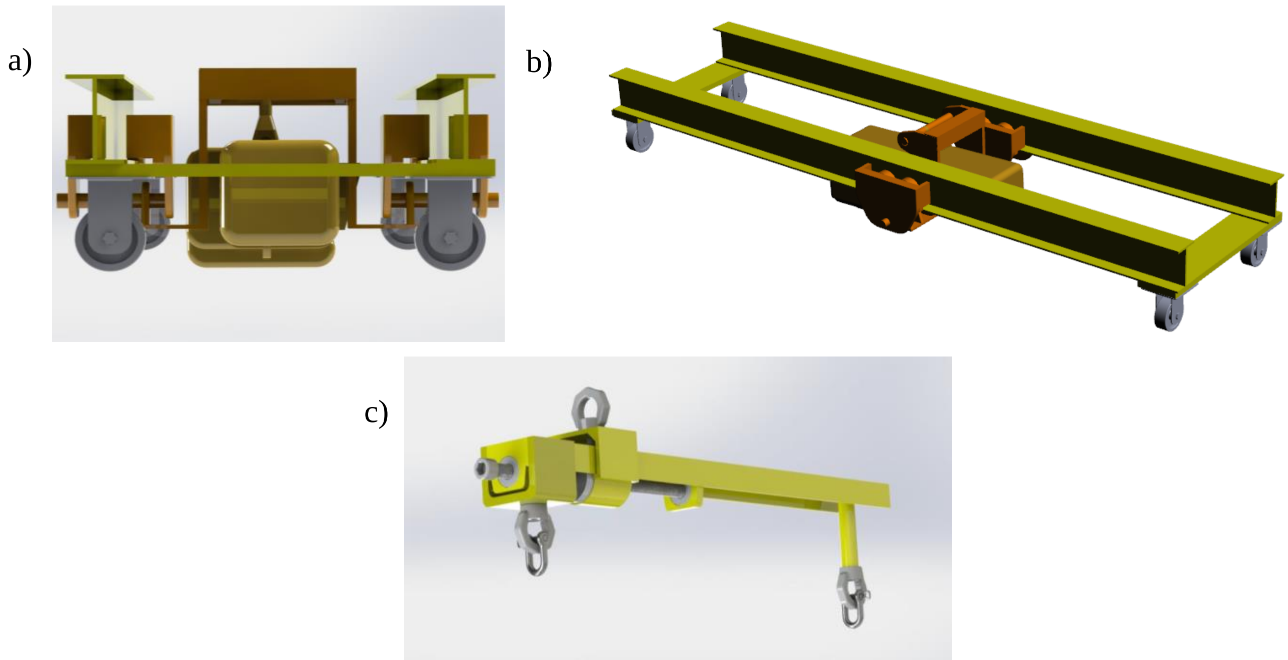

Figure 6 (a) Front view of the CAD drawing (left), (b) dynamic perspective showing the components of the trolley system (right), (c) dynamic view of lifting bar (bottom).

In Fig. 5 above, 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 above in Figure 6. Drawings for the lifting bar and gantry system can also found in APPENDIX C -

B. Decision Matrix

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 & Lifting Bar	9	9	8	8	9	**8.05**

The Redirection of Lift and Redesigned Gantry designs became the primary focus of Team 5. The decision matrix demonstrates this in a quantifiable manner, 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 concepts 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.

III. Final Design

A. Design Overview

The Redesigned Gantry along with the newly designed Lifting Bar was declared as the final design to solve Turbocor's problem by adding approximately 8" of lifting height to the system. The increase in vertical height from the current system can clearly be seen in Fig.7 below. The redesigned gantry required the I-beams to be spread apart with enough space so that the hoist could be suspended between them and the implementation of a custom trolley. Additionally it was designed to maintain the original gantry dimensions to avoid any complications that may come about when implementing and testing the system in chiller 3 rig. Team 5 was also able to use smaller I-beams than the ones utilized on the original gantry which saved time during fabrication, avoiding the need to shave off parts of the I-beam. This was due to the small constraints and the sloped celling, with the center of the room being the highest point and the lowest point where the celling met the walls.

Figure 7 Picture of the painted and fully assembly gantry and trolley system

The 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 of center of gravity. The power screw, located inside the C-channel of the lifting bar, is used to translate the lifting hook along the axis of the lifting bar and will be adjusted manually. The point of lift, represented by the U-bolts assembly, was designed in such a way that the load of the compressor is felt by the C-channel itself and not by the power screw. The bearings ensured ease of movement of the power screw and also supported the load of the compressor as to relieve any loading on the power screw itself. The final lifting bar design can be view in Fig. 8 below.

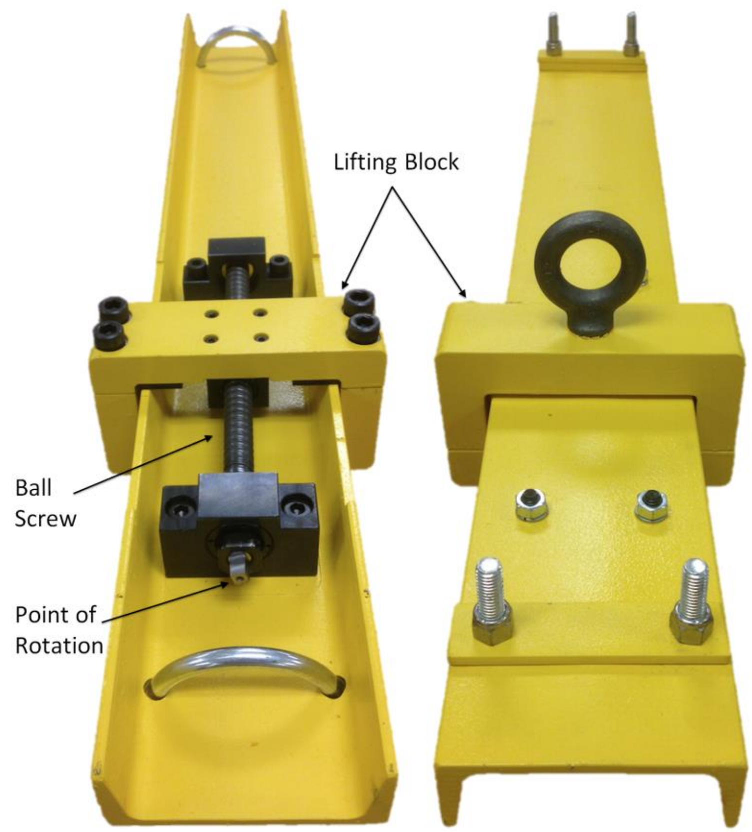

Figure 8 Picture of the painted and fully assembly lifting bar

Due to the moving parts of this lifting bar, it was crucial that Team 5 designed the bar with the upmost engineering practices. It was imperative that the power screw experienced only axial loading and that the bearings between the lifting assembly and the C-channel were rated for the proper amount of loading. All components that were purchased from a vendor had 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 was also load tested upon completion of prototyping with a F.S. of 1.25 (per OSHA requirements5).

B. Components of Design

Team 5's design to increase the lifting height of the VTT compressor hoist is made up of three main components. These components consist of the gantry, trolley, and lifting bar. All three of these components consist of 154 parts in total including nuts, bolts, and washers. A comprehensive list of each part belonging to its respective component can be viewed in Appendix C – Complete Parts List. The Trolley consists of 36 parts, most of which are additional support pieces to the structure of the trolley. If a revision for the trolley was possible, there certainly is room to significantly reduce the amount of parts. This could be done by fabricating a structure with a more efficient geometry. Instead of using round bar with support gussets, team 5 could have used small I-beam shaped steel as the framework for the trolley or a similar shape, eliminating the possibility of deflection at the magnitude of stress which is exerted on the trolley. This was suggested to team 5 by its advisor, Dr. Hollis after the trolley had already been built. If more time and budget was given to team 5, a more efficient trolley with less parts would be implemented. The lifting bar and gantry were designed to be as simple and effective as possible while maintaining lightweight and low cost. Any additional complexities to the lifting bar and gantry would be unnecessary. There could be room to improve the lifting bar, but team 5 has determined that any changes would be too costly.

A necessary component of this design was the need for a redesigned trolley system that could suspend the crane hoist between the two I-beams, which can be viewed in Figure 7. At this point in the design process, Team 5 has gone through several revisions of this redesigned trolley. However, the visual representation in Fig. 9 is the final design of the trolley. Team 5 was aware of the immense stresses that the trolley will endure and so the materials chosen and their dimensions was of the upmost importance. Also, it was imperative that the trolley remained square on the gantry system while in operation. The low overhead clearance above the gantry system due to the ceiling of the chiller room was also very important when designing this trolley. It was crucial that the trolley and/or crane hoist never come into contact with the ceiling, and so a compact trolley design will be the most effective.

C. 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 Factor of Safety of 1.25 was used in this stress analysis so a total of 2500 lb. was applied to the different components.

Fig. 21 APPENDIX B - FEA 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 below in Fig. 23 APPENDIX B - FEA. 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.

Figure 9 Final trolley design

Shown in Fig. 22 APPENDIX B - FEA below 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.

Shown below in Fig.10 and Fig. 11 is the finalized completed assemby of each component that was 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.

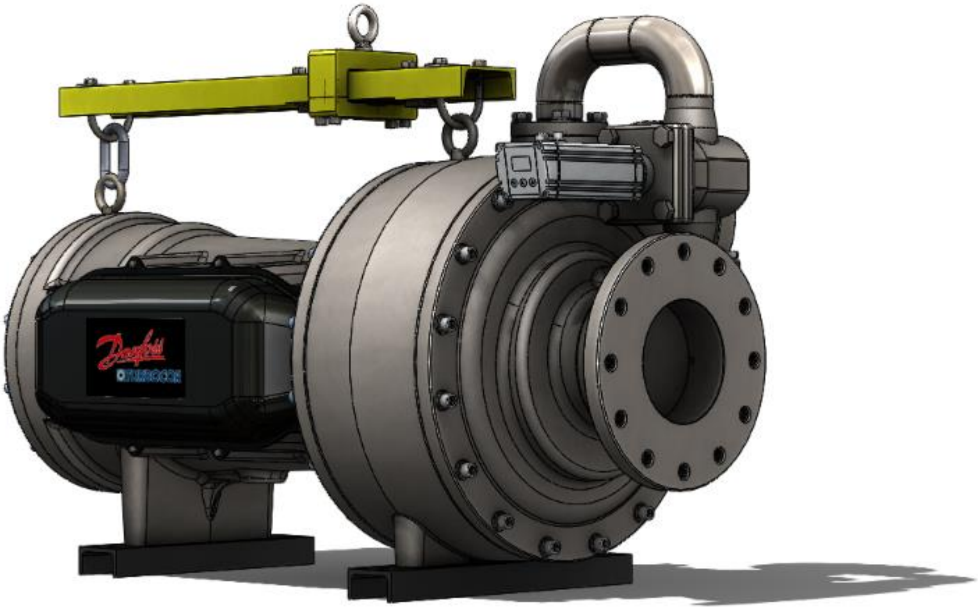

Figure 10 VTT compressor and adjustable lifting bar

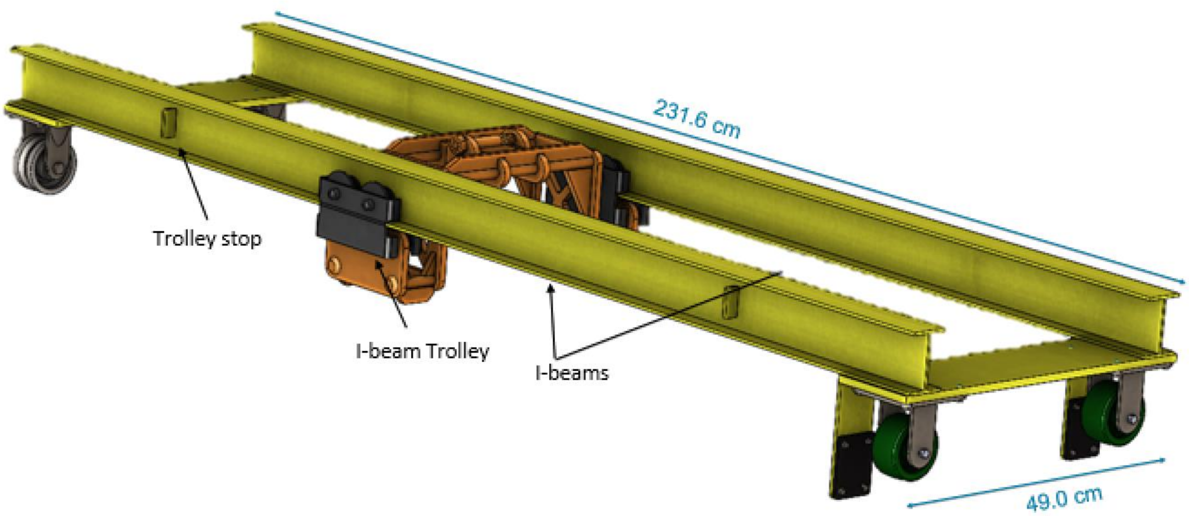

Figure 11 CAD model of gantry and trolley

IV. Load Testing

A. Prototype Testing

Team 5 was able to utilize the Structures Lab in the civil engineering department at the FAMU/FSU College of engineering in order to perform prototype testing. This lab houses an MTS actuating hammer that can apply forces up to 110 kip, in both tension and compression. The figure below shows the MTS actuator mounted on a MTS 55 kip Material Testing Frame.

Figure 12 MTS actuator in the civil engineering Structures Lab

The initial testing of the variable center of gravity lifting system took place in the strength of materials laboratory on February 12 under the supervision of Brandon Winters. Rearranging the lab took several hours to ensure that the testing closely simulated the environment in chiller 3. The gantry was set up directly under the actuator and was subjected to 2500lb force. It performed well under the 2500lb load test, experiencing roughly 1 mm of deflection which closely match the FEA simulation results of 0.5 mm and this can be seen in the figure below.

Figure 13 Gantry load testing (Experiencing 2500 lbf load)

The trolley was placed on top of the gantry and in the same fashion as gantry and was also subjected to 2500lbf. However unlike the gantry the trolley showed signs of plastic deformation undergoing roughly 8 mm of deflection. This was not expected because the initial FEA analysis displaying approximately 1 mm of deflection and was result of testing oversight. One cause was due to the fact that the trolley was placed stationary on top of the gantry instead of hanging from trolley below the I beams which caused the trolley to experience a large amount of deflection. In the Fig. 14 below the deflection experienced by the trolley can clearly be seen. Another reason the testing does not match the FEA analysis is because of the idealized simulation and limited constraints in the modeling program. Any slight change in constraints and model properties would drastically change the results or cause the simulation to fail. After presenting the results and gaining feedback from Turbocor, Team 5 decided to revise the trolley by adding supplementary gussets to the frame in efforts to reduce deflection. Additionally several new FEA simulation were performed in order to best match the results to real life application. Currently Team 5 is still in the process of performing a second round of testing to the revamped trolley with the gantry in order to gain more accurate results and also set begin initial testing on the lifting bar to complete the project.

Figure 14 Magnified View of trolley load testing (Experiencing 2500 lbf load)

B. Design for reliability

To determine how this device will perform over time, it is necessary to compare the stresses felt by the system to a fatigue curve for steels. The maximum stress that the system will feel is approximately 70 MPa. This system will not cross the endurance limit since it approaches nowhere near the stress needed to cross the endurance limit. Anything under the endurance limit has infinite cycles. Shown below is the fatigue curve of aluminum and steel.

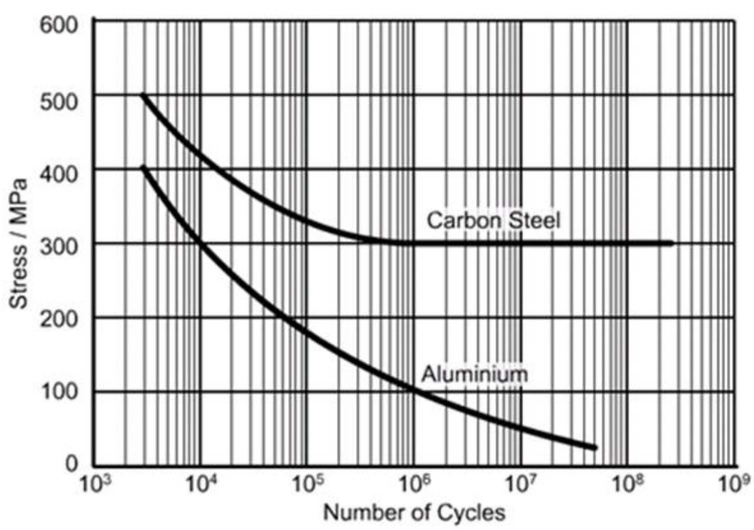

Figure 15 Fatigue Limit of Steel

The main concerns of reliability are primarily centered on the lifting bar. These modes of failure can be viewed in the FMEA table in Appendix B – FMEA/FEA. Each potential failure mode that received a 10 in severity must be brought to attention. First off, the power screw must not feel any forces in the Z component (vertical) while under load, otherwise it will bend and not be able to adjust to different lifting positions. This can happen if the delrin spacers wear out which are designed to perfectly space the lifting block from the U-channel. The way to address this issue is to periodically check the delrin spacers to see if there has been any wear. To prevent any issues with the mobility of the power screw, it must be greased often to ensure minimal friction.

The Trolley was also a reliability concern in its early stage, but added support gussets greatly augmented the structural integrity of this component. With the first round of load testing, the trolley experienced deflection which was greater than the analysis shown in FEA. To address this issue, team 5 did additional FEA with more gussets added to the trolley. FEA showed that the trolley only experienced .125mm of deflection with the new design, compared to 13mm of deflection from the original design in testing. Satisfied with these results, additional gussets were cut with the water jet and welded to the trolley. This new design proved to be much stronger than the previous rendition, and is no longer a concern of reliability. Additional FEA results can be view in Appendix B – FMEA/FEA.

All of the remaining modes of failure that received a 10 were wear to hardware. This hardware included fasteners, shackles, and rods. Each piece of hardware purchased has a load rating prior to purchase, which has been approved by Team 5. Risk mitigation still must be performed, and to prevent failure, this hardware must be inspected before each time a compressor is lifted to ensure safety to equipment and human life.

V. CONSIDERATION FOR ENVIRONMENTAL SAFETY AND ETHICS

During all stages of the development of the variable center of gravity lifting bar, safety was of the upmost concern. This includes the safety of the compressor test operators and the safety of the expensive equipment which is part of the compressor testing process. In order to mitigate the risk on the life's of these operators, safety standards must be met. These safety standards were created by the Occupational Safety & Health Administration (OSHA). OSHA entails hundreds of pages of safety standards which cover possible scenarios seen by today's employers.

For team 5's particular application of an overhead gantry system at Danfoss Turbocor, standards must be met in order to be in compliance with OSHA. These standards include in summary:

- Factory of safety of at least 1.25 on all load bearing components
- "Caution" Yellow shall be the basic color for marking physical hazards
- "Warning" orange for trolleys or other hazardous components
- Trolley stops to limit trolley movement
- Rated load shall be displayed on the gantry
- Guards for moving parts

All of these safety standards have been included in the design phase and have been installed in the completed assemblies. The final step to ensure that this project is safe was to test. Testing was the most important and most challenging phase of this project. The gantry, trolley, and lifting bar had been tested to a factor of safety of 1.25 to ensure structural integrity.

VI. PROJECT MANAGEMENT

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 will continue 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 will meet with Turbocor bi-weekly 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 did began towards the end of fall semester and ensured all parts arrived 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. 9 as a flow diagram.

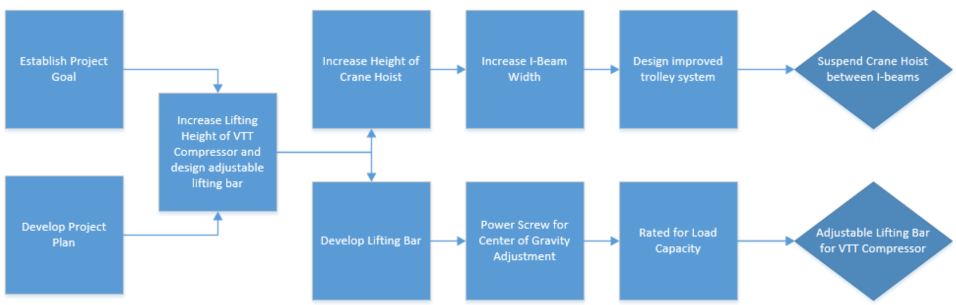

Figure 16 Flow Diagram of the design process

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 was followed as closely as possible and when scheduling changes are necessary, the project plan was updated. 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.

As Team Leader, Devin is responsible for maintaining a clear schedule and project plan, delegating responsibilities to each member and ensuring each member is held accountable for their responsibilities to the team. It will be Devin’s responsibility to make sure all team members have the knowledge and resources necessary to complete any and all tasks assigned. Devin has been the main source of contact with Turbocor. He has spent a large amount of time working on the adjustable lifting bar as this is a very difficult part to design due to its complexity. Devin has been working with the financial advisor, Luke, to make sure he has an update parts list. With this updated parts list, Luke prepare a proper purchase order.

As the Secretary, Coert has been responsible for documenting the content of each team and sponsor meeting to warrant a clear understanding amongst team members. The secretary will also be responsible for making sure that all deadlines are met for each deliverable, staff meeting, and sponsor meetings. Coert has also spend a large amount of time assisting each member with their individual tasks as they come up.

As the Lead Mechanical Engineer, Yoel will be in charge of the design, development, and implementation of the project. He will work hand and hand with the team leader and financial advisor to make sure all project specifications are met and that the project stays within budget. If any budgetary changes must be made in order for fulfillment of the project, the team leader and the financial advisor must approve these changes. Additionally, it will be the Lead M.E.'s responsibility to ask for assistance and delegate tasks to all members of Team 5 if help is needed in meeting a deadline or with design.

As the Financial Advisor, Luke will not only be responsible for ensuring the project stays within budget, but will also facilitate communication with the sponsor regarding any purchasing of material. If the financial advisor approves a budgetary change that has also been approved by the team leader, it will be his responsibility to communicate with Turbocor the need for this budgetary change. As the Webmaster, Gabriel will be responsibility for the creation and upkeep of the team's website. As project progression is made, updates will be uploaded to the website so that all aspects of the project are transparent to the sponsor and advisors. Background information about the project and each team member will be provided on the website as to allow insight on the project at hand and who is in behind finding a solution to the problem at hand.

C. Procurement

The cost of Team 5's solution is approximately $1496.85, which includes all of the materials and hardware. The lifting bar alone costs $608.61 partly due to the expensive ball screw. The gantry costs $402.09, and the large percentage of this cost was the I-beam which is a lot of steel. The trolley costs $486.15. The most expensive part of this component was the trolley hoist which mates the trolley to the gantry. Team 5 has exceeded the budget by $496.85, but Turbocor had agreed to increase the budget after a sufficient project plan had been presented. All of Team 5's financial records can be view in Appendix C – Purchase Requisitions. All of the hardware including screws, nuts, and washers were donated by Turbocor to keep the cost of the project down.

Since Turbocor had its machinists provided for Team 5, the cost has been factored into the Turbocor's financials, and not in Team 5's budget. If this project required Team 5 to source the fabrication to a different company, the cost would have been far greater. Overall, the cost of this project could be reduced in further revisions of the original design, but an effective way to determine which parts can be changed is to implement the lifting system and determine optimal design. A visual representation of the budget breakdown can be seen below in Fig. 4. Each component is composed of any store bought parts, raw material, and hardware. To keep the cost down in future renditions, reducing the amount of store bought material is essential.

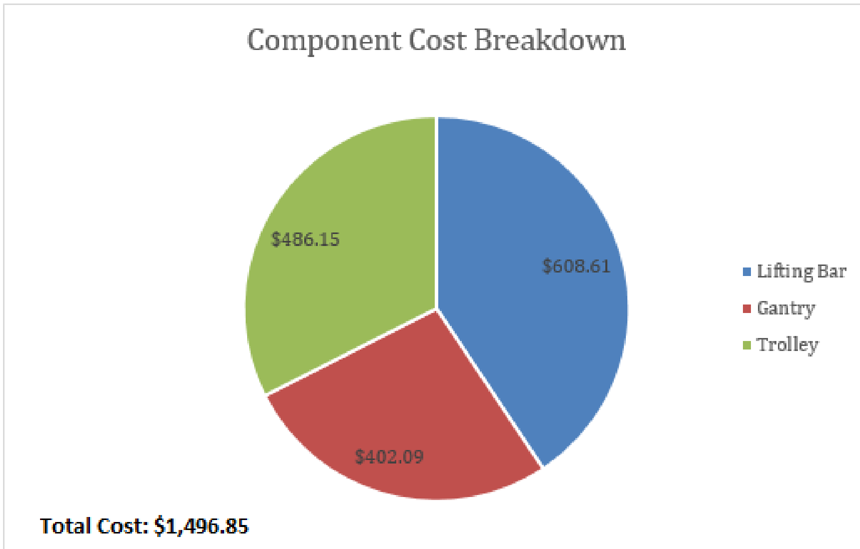

Figure 17 Cost breakdown of components

D. *Communication*

Team 5 has faced little or no challenges with communication, the issue of lack of good communication had been envisaged and team 5 drafted a routine meeting with one another which usually take place every week and a bi-weekly meeting with our sponsor Danfoss Turbocor. The team has maximize the opportunity of meeting with the team's advisor Dr. Hollis for further assistance in the design and manufacturing of the project and to make it more strong and reliable, messages and information were passed across through some social medias like; the google drive, group-me message application, calling through phone and text messaging.

VII. 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 had 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 had proposed that, in order to safely solve this issue, a new gantry system must 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. Team 5 had left fall semester with a completed design for the gantry, trolley, and lifting bar which was approved by Turbocor. With spring semester came the fabrication of each component by Turbocor as well as team 5. Following the completion of fabrication, assembly of each component began by welding of the gantry and trolley by Turbocor welders. The assembly of the lifting bar took place at the COE due to its modular design. Following completed assembly, preliminary load testing took place at the Strength of Materials laboratory at the COE. Following load testing, the test results did not match what was expected in the FEA. This being the case, team 5 simply could not get the lifting system implemented until testing was approved by Turbocor. Team 5 went back to the drawing boards to revise the design of the trolley in order to increase its structural integrity. Team 5 proposed the new trolley design and FEA results to Turbocor and gained their approval to go ahead and fabricate the new strength support gussets and have them welded to the trolley.

Team 5 is currently awaiting the second round of testing to test all three components, but due to the loss of the previous load testing supervisor Brandon Winters, the team is currently at a standstill until the new lab supervisor can learn to operate the MTS load testing unit. Team 5 has approached this situation with extreme diligence, aiding the supervisor in any way possible to speed up the process, but until the he is comfortable with loading the team's project, the project is at a standstill.

Team 5 has learned that no matter how far ahead of schedule the team may be, there will always be problems. In order to mitigate this, extra time must be assigned as "problem mitigation" phase. Also, even though the team had a limited budget, the team could have requested additional money to get testing done by a 3rd party. This would have made sure that project was properly tested with the proper equipment and a calibrated set up.

Team 5 has decided over some future recommendations for any revisions to the design. The first upgrade would be an actuated ball screw which would not require an operator to hand crank for the adjustable center of gravity. Also, a load cell attached to the eye-bolt of the lifting bar would be greatly beneficial to the operators, knowing the exact load being felt by the lifting bar. The third recommendation would be an improved trolley which would utilize a more lightweight design with an improved geometry. This would increase ensure a structurally sound design that is easier to traverse due to its lower weight.

VIII. REFERENCES

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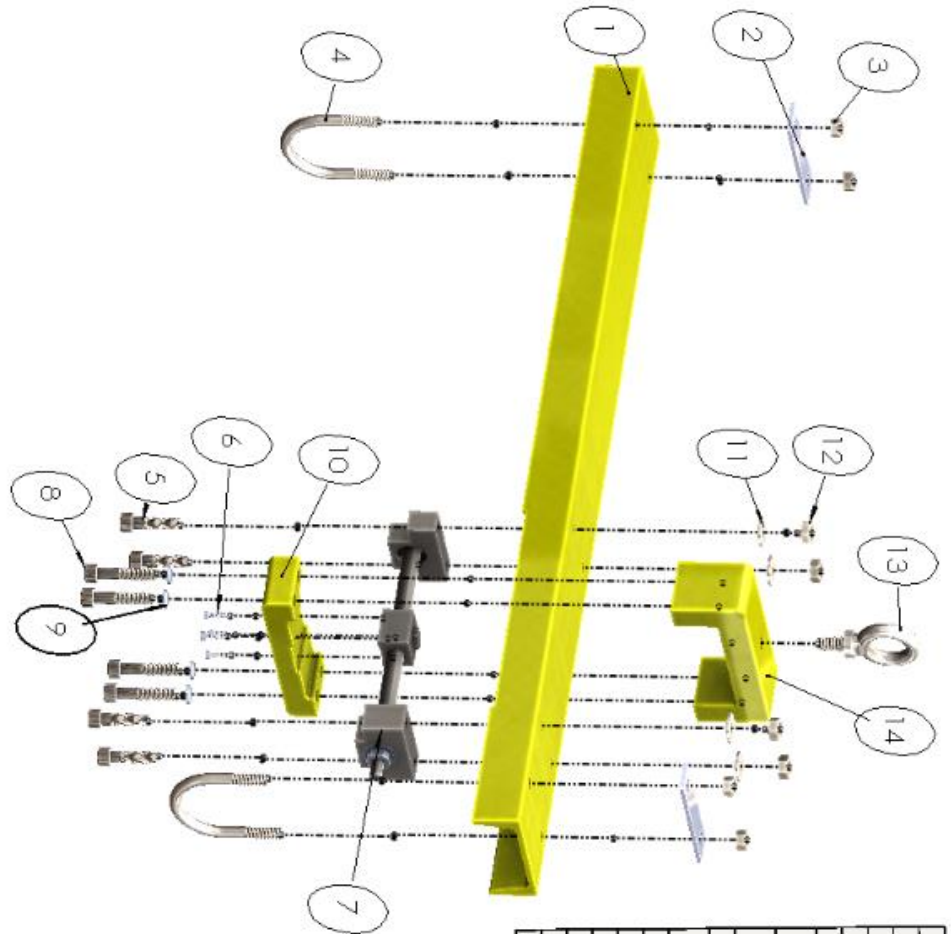
[2] Lohman, Kevin. "Project 5 - DTC Bi-directional Lifting Bar." *Www.campus.fsu.edu*. Florida State University, 31 Aug. 2014. Web. 26 Sept. 2014.

[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.

Appendix A – Exploded View Assemblies



ITEM NO.	PART NUMBER	QTY.
1	U Channel	1
2	U Bolt Saddle	2
3	3/8" Locking Nut	4
4	3/8" U-Bolt	2
5	Socket Cap Screw M8 x 1.25 x 20	4
6	Socket Cap Screw M4 x 0.7 x 10	4
7	Ball Screw Assembly	1
8	Socket Cap Screw M10 x 1.5 x 45	4
9	Locking Washer M10	4
10	Lift Block Bottom	1
11	Locking Washer M8	4
12	M8 Locking Nut	4
13	Eyebolt M12 x 1.25	1
14	Lift Block Top	1

Figure 18 - Lifting Bar Exploded View

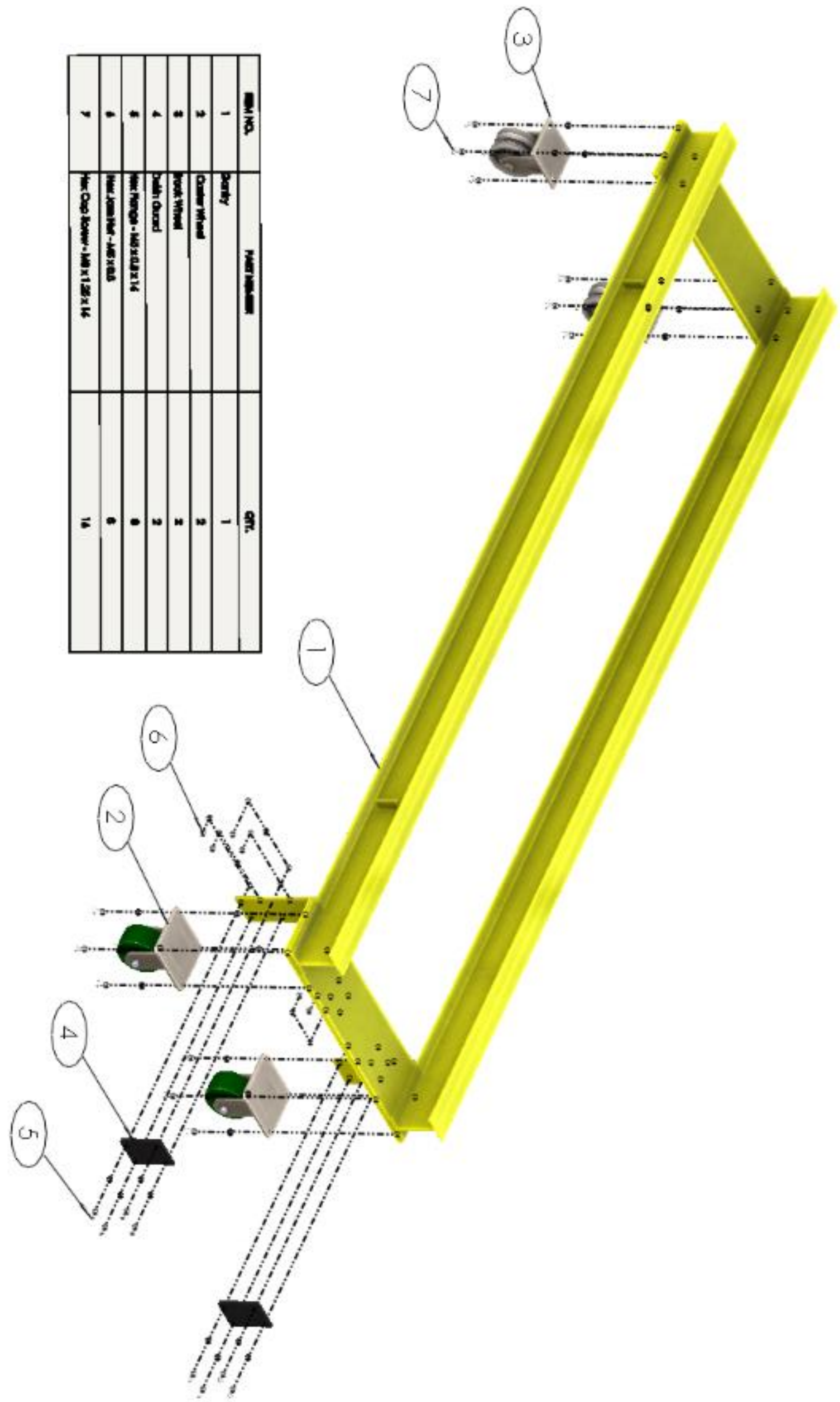


Figure 19 – Gantry Exploded View

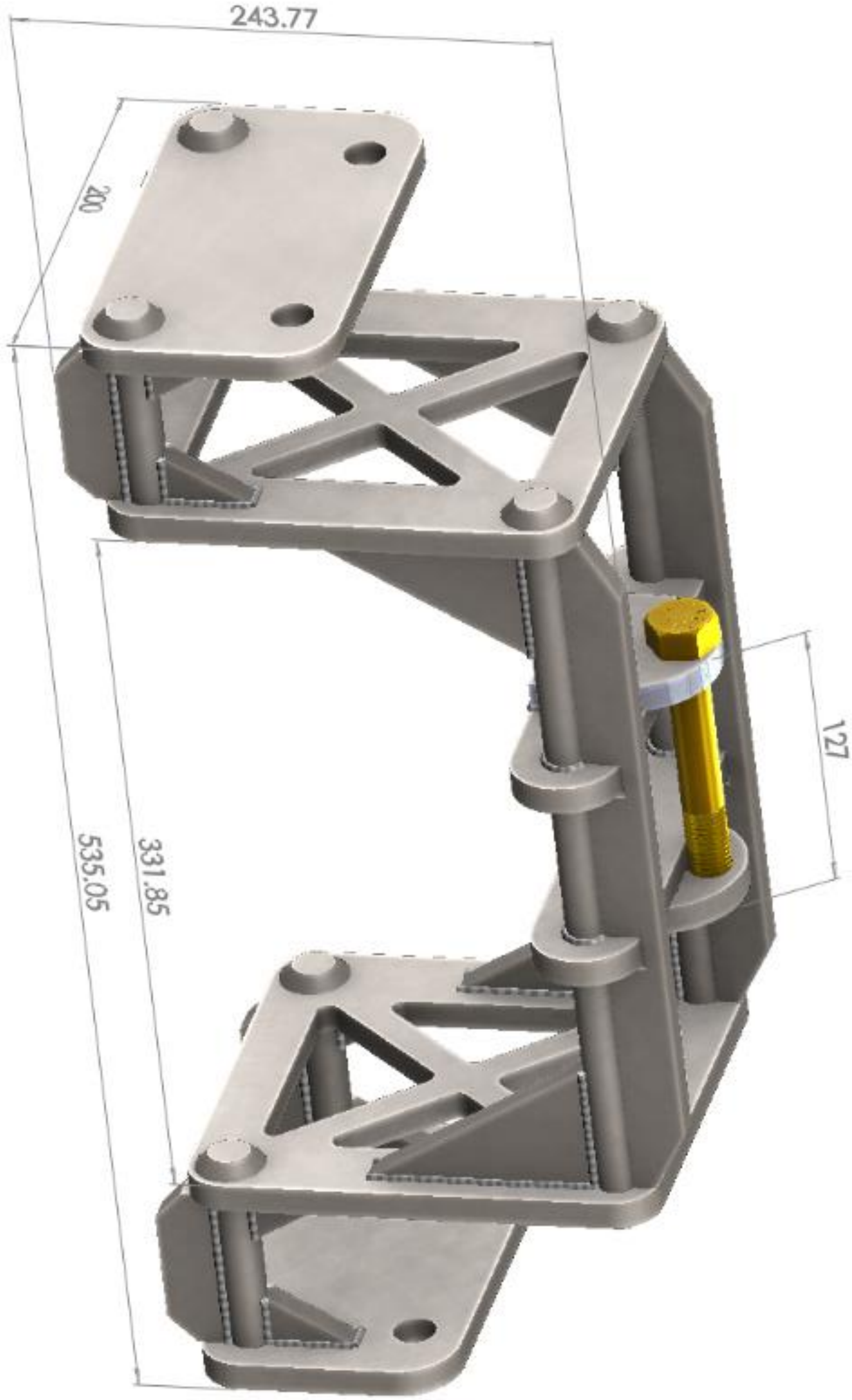


Figure 20 Assembly of Trolley

Appendix B – FMEA / FEA

Failure Modes Effects Analysis

Team #:	5
Project Title	Bi-Directional Offset Lifting Bar

Key Process Step or Input	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN	Actions Recommended	Resp.	Actions Taken
What is the Process Step or Input?	In what ways can the Process Step or Input fail?	What is the impact on the Key Output Variables once it fails (customer or internal requirements)?	How **Severe** is the effect to the customer?	What causes the Key Input to go wrong?	How **often** does cause or FM **occur**?	What are the existing **controls** and procedures that prevent either the Cause or the Failure Mode?	How well can you **detect** the Cause or the Failure Mode?		What are the actions for reducing the occurrence of the cause, or improving detection?	Who is Responsible for the recommended action?	Note the actions taken. Include dates of completion.
Loading of Lifting Bar	Deformation of Shackles or U-Bolts	Danger to equipment and operators	10	Overloading or improper use	5	Operator Manual, Hardware strength exceeds max	1	50	Check equipment for signs of wear before and after	Test-Room Operator	
	Yielding of Fasteners	Danger to equipment and operators	10	Overloading or improper use	2	Operator Manual, Hardware strength exceeds max	3	60	Check equipment for signs of wear before and after	Test-Room Operator	
	Plastic deformation of U-Channel	Danger to equipment and operators	10	Overloading or improper use	4	Operator Manual, Material strength exceeds max	1	40	Check equipment for signs of wear before and after	Test-Room Operator	
	Movement of Ball screw during lift	Danger to equipment and operators	8	Improper use, lifting at an angle	4	Operator Manual, Locking mechanism	2	64	Verify proper center of gravity before full lift	Test-Room Operator	
	Ball-Screw Binding	Unability to lift compressor safely	7	Overloading, lack of maintenance	3	Operator Manual, Lubrication	1	21	Maintain Ball screw clean and lubricated	Test-Room Operator	
	Delrin Sheave Cracked	Damage to Lifting Bar	7	Regular Use	4	Operator Manual,	2	56	Replace Sheaves as Needed	Test-Room Operator	
	Ball-Screw Set Screw Tightening	Loss of Ball Screw Adjustability	3	Improper set screw position	3	Operator Manual	1	9	Proper Ball Screw Adjustment According to user	Test-Room Operator	
	Rust	Increased maintenance downtime	2	Lack of Maintenance	1	Paint	2	4	Regular Maintenance	Test-Room Operator	
Loading of Hoist Trolley	Deformation of Rods, gussets, or structural parts	Danger to equipment and operators	10	Overloading or improper use	2	Operator Manual, design	2	40	Testing, Check equipment for signs of wear	Test-Room Operator	Added additional Gussets 3/20
	Cracked welds	Danger to equipment and operators	10	Overload or improper use	1	Stength of materials, and proper weld	4	40	Periodic inspection of lifting equipment	Test-Room Operator	
	Binding of I-Beam Trolleys	Inability to use lift compressor	7	Overloading or lack of maintenance	1	Rated for load significantly higher than recommended	1	7	Regular Maintenance as needed	Test-Room Operator	
	Hardware showing signs of wear	Danger to equipment and operators	7	Overloading	3	Rated for load significantly higher than recommended	2	42	Periodic inspection of lifting equipment	Test-Room Operator	
	Not sitting evenly between Gantry	Potential binding or collapse of trolley	10	Fastener wear, or backing out	3	Locking Fasteners, Threadlock, and Lock washers used	2	60	Periodic inspection of lifting equipment	Test-Room Operator	
Gantry	Binding of Caster Wheels	Downtime to performance maintenance	4	bearing wear	1	casters with sealed bearings	1	4	Maintenance as Needed	Test-Room Operator	
	Shifting track position	Potential derailment of gantry	6	Loose fasteners, improper use	3	V-Tracked casters, derailment guards, and locking fasteners.	2	36	Periodic inspection of lifting equipment	Test-Room Operator	
	Damage to Trolley Stop Plates	Unsafe trolley positioning	5	Improper use	2			0	Periodic inspection of lifting equipment	Test-Room Operator	
	Hardware showing signs of wear	Danger to equipment and operators	10	Overloading	1	Grade 8 fasteners	2	20	Periodic inspection of lifting equipment	Test-Room Operator	
	Deformation of I-Beams	Damage to Gantry	10	Overloading	1	Gantry strength greatly exceeds max hoist load	1	10	Periodic inspection of lifting equipment	Test-Room Operator	

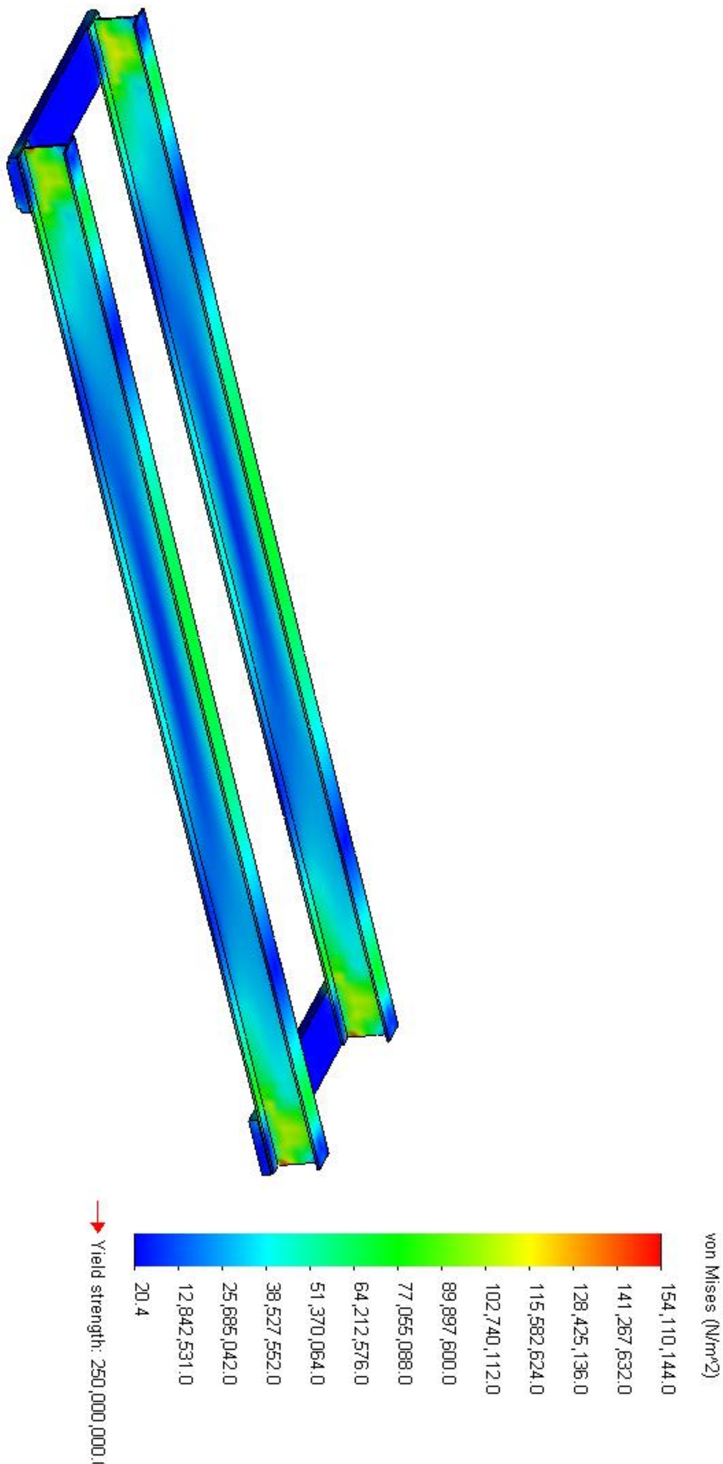


Figure 21 Gantry FEA

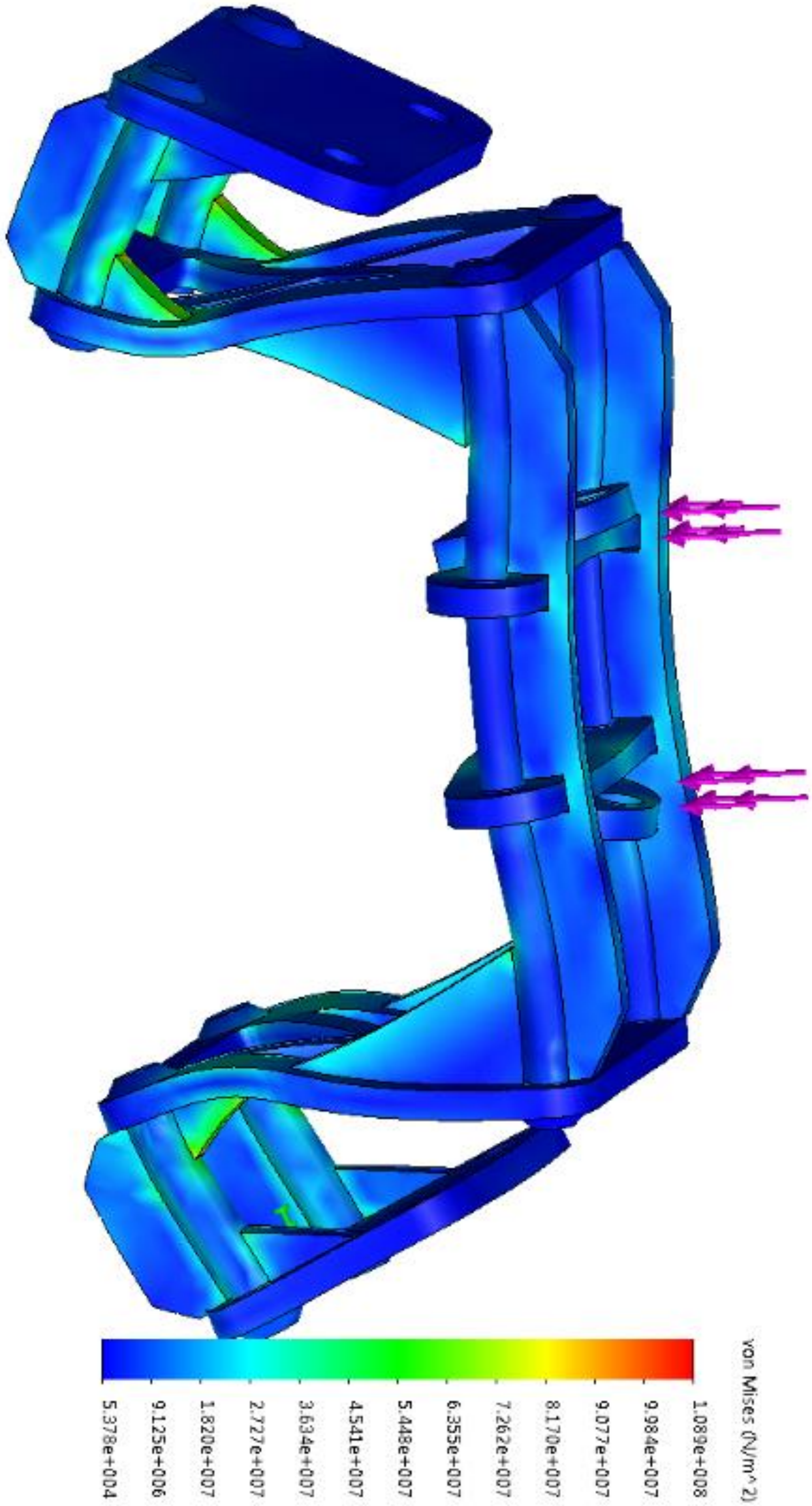


Figure 22 Trolley FEA

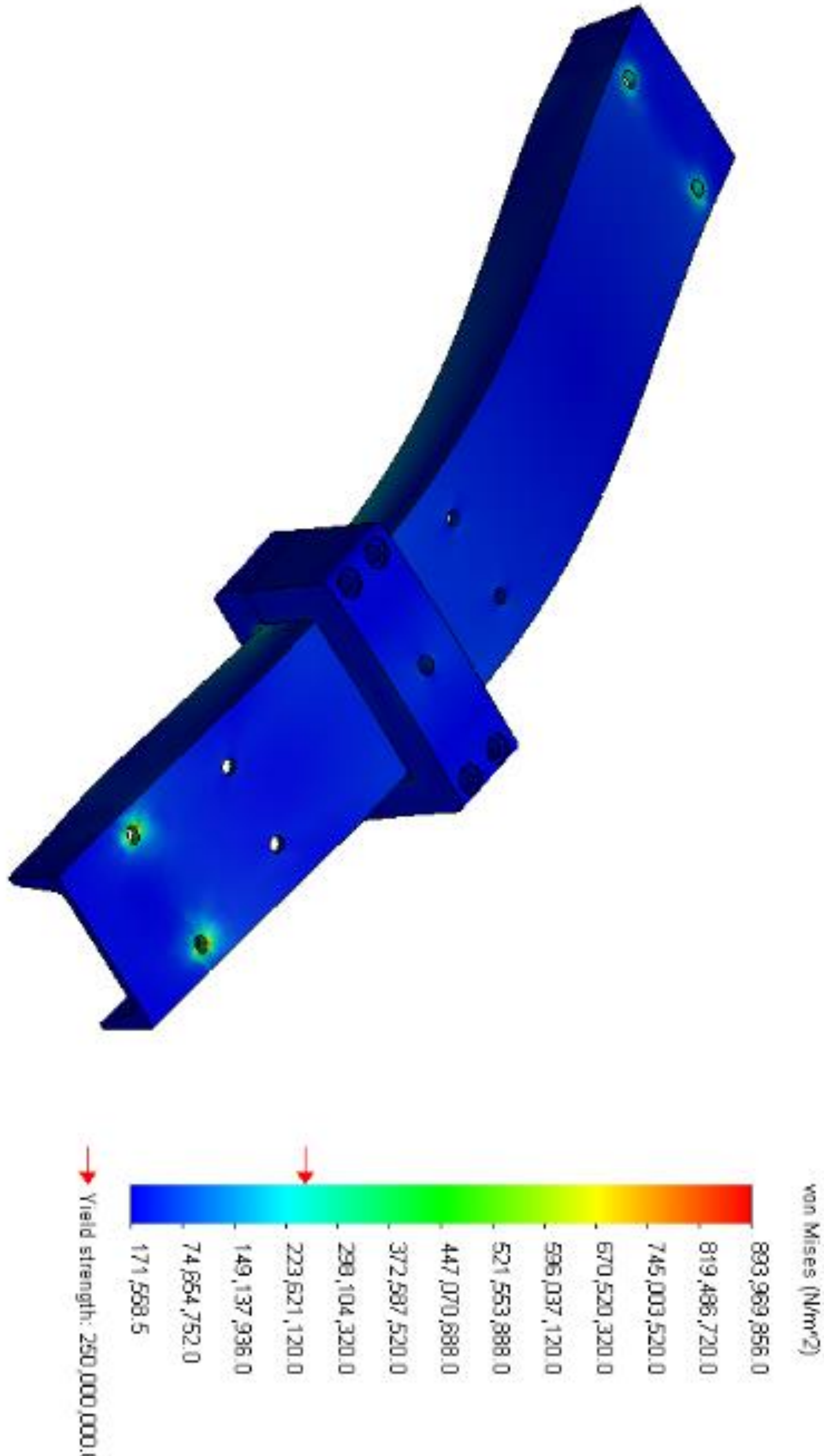


Figure 23 Lifting Bar FEA

Appendix C – Complete Parts List

Table 2 - Lifting Bar parts list

Adjustable Lifting Bar	
Component	**Qty.**
Eyebolt for lifting - M12 x 1.75, 30 mm eye	1
Lifting Block (2 Piece)	1
3/8" Zinc Chain (2 Links)	1
Block Ball Screw	1
Support Bearing - Fixed Side	1
Support Bearing - Support Side	1
Delrin spacer	2
Loctite	1
U-bolt Shim 1/4" thick	1
Steel Shackle - 3/8" x 1 7/16"	2
U-bolt Saddle 1/8" thick	2
U-Bolt - 3/8" x 16, for 2" pipe	2
M10 x 45mm Socket Cap Screw	4
M10 Lock Washers	4
U-bolt Nuts 3/8"-16	4
M4 x 10 mm Socket Cap Screw	4
M8 x 20 mm Socket Cap Screw	4
M8 Lock Washer	4
M8 Hex Nut	4

Table 3 - Gantry Parts List

Gantry	
Component	**Qty.**
I Beam 4" x 3" x 8'	2
Steel Gantry Caster Plate	2
Guard Delrin	2
4" Track Wheels	2
4" Caster Wheels	2
M4 x 15mm Pan-head Screw Length	8
M4 Nuts	8
M8 x 15mm Socket Cap Screw	16
M8 Nut	16
M8 Lock washer	16

Table 4 - Trolley Parts list

Trolley System	
Component	**Qty.**
Grade 9, 3/4" x 5" bolt	1
3/4" Nut	1
Trolley Plate	2
Round Bar - 19.05 x 369.95	2
I-Beam Trolley	2
Connecting Support	2
Vertical Support	2
Strength Gusset	2
Bolt Support	2
Bottom Gusset	4
Large Gusset	4
Round Bar - 19.05 x 152.4	4
Small Gusset	8

Appendix D – Purchase Requisitions

Table 5 - Component Bill of Materials

Adjustable Lifting Bar					
Component	**Part #**	**Vendor**	**Cost**	**Qty.**	**Total**
Eyebolt for lifting - M12 x 1.75, 30 mm eye	3040T15	McMaster-Carr	$6.63	1	$6.63
Steel Shackle - 3/8" x 1 7/16"	3560T47	McMaster-Carr	11.14	2	$22.28
U-Bolt - 3/8" x 16, for 2" pipe	3043T41	McMaster-Carr	6.33	2	$12.66
4" x 8" x 2" Steel Block (4"x4"X12")block	N/A	Speedy Metals	103	1	$103.00
3/8" Chain (1')		McMaster-Carr	10.64	1	$10.64
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 Sheet, 2" x 12" x 1/8"	8662K13	McMaster-Carr	4.2	1	$4.20
U-channel C4x5.4 (roughly 31 inches)	N/A	Speedy Metals		1	$25.55
Total Cost					$608.61
Trolley System					
Component	**Part #**	**Vendor**	**Cost**	**Qty.**	**Total**
1/2" x 24 " x 24 " Steel Plate	P112	Metals Depot	110.24	1	$110.24
3/4"-10 Hex Nuts (25ct.)	90499A837	McMaster-Carr	9.82	1	$9.82
3/4" x 6' 1018 Round Bar	R134	Metals Depot	20.22	1	$20.22
Grade 9, 3/4" x 5" bolt	90201A660	McMaster-Carr	11.25	1	$11.25
Grade 9, 3/4" x 6" bolt	90201A667	McMaster-Carr	14.28	1	$14.28
Hoist Trolley	3267T62	McMaster-Carr	160.17	2	$320.34
Total Cost					$486.15
Gantry System					
Component	**Part #**	**Vendor**	**Cost**	**Qty.**	**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" Caster 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 Sheet, 3" x 12" x 3/8"	8662K35	McMaster-Carr	13.83	1	$13.83
Total Cost					$402.09
		Total Cost			**$1,496.85**

PURCHASE ORDER REQUISITION

Vendor: Trident Company
108 Fairbanks Ave, Thomasville, GA 31792

Contact: (229) 225_9965

DATE: 8-Dec-14

DATE REQUIRED:

CAPITAL EXPENDITURE (please tick):

CURRENCY: USD

NOTE: THIS IS NOT A PURCHASE ORDER AND CANNOT BE ISSUED TO SUPPLIER

TURBOCOR P/N	DESCRIPTION	VENDOR P/N	QTY	UNIT PRICE	TOTAL PRICE	PROJECT NUMBER	ACCOUNT NUMBER
	I Beam, 4" x 2.663" x 0.193" x 96"	N/A	2	$ 66.80	$ 133.60		

FREIGHT: A) PREPAID (included)
B) PREPAID & CHARGE
C) COLLECT
D) FIXED AMOUNT amount

TOTAL $ 133.60

Special instructions:

Prepared by: KEVIN LOHMAN (Print name)

Approved by: (Manager)

Approved by: (Director)

PUR-00007F01

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Danfoss TURBOCOR

PURCHASE ORDER REQUISITION

Vendor: McMaster-Carr

Contact:

DATE:

DATE REQUIRED:

CAPITAL EXPENDITURE (please tick):

CURRENCY: **USD**

NOTE: THIS IS NOT A PURCHASE ORDER AND CANNOT BE ISSUED TO SUPPLIER

TURBOCOR P/N	DESCRIPTION	VENDOR P/N	QTY	UNIT PRICE	TOTAL PRICE	PROJECT NUMBER	ACCOUNT NUMBER
	3/4" Grade 9 Hex Bolt Overall Lg. 6"	90201A667	1	$ 14.28	$ 14.28		

FREIGHT: A) PREPAID (included)
B) PREPAID & CHARGE
C) COLLECT
D) FIXED AMOUNT — amount

TOTAL $ 14.28

Special instructions:

Prepared by: KEVIN LOHMAN (Print name)

Approved by: (Manager)

Approved by: (Director)

PUR-00007F01

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Danfoss TURBOCOR

PURCHASE ORDER REQUISITION

Vendor: Speedy Metals

Contact: 866-938-6061

DATE: 8-Dec-14

DATE REQUIRED:

CAPITAL EXPENDITURE (please tick):

CURRENCY: USD

NOTE: THIS IS NOT A PURCHASE ORDER AND CANNOT BE ISSUED TO SUPPLIER

TURBOCOR P/N	DESCRIPTION	VENDOR P/N	QTY	UNIT PRICE	TOTAL PRICE	PROJECT NUMBER	ACCOUNT NUMBER
	4" {A} Sq. A-36 Hot Rolled Steel- By the Inch		1	83.52	$ 83.52		
	Overall Length: 8"	SKU: hs4					
	Price Per inch: $10.44						
	Channel, 5.4 lb/ft A-36 Hot Rolled Steel		1	25.55	$ 25.55		
	4" x 1.584" x 0.184"	SKU: hc4x5.4-36					
	Overall Length: 36"						
	A-36 Hot Rolled Steel Plate		1	$ 53.69	$ 53.69		
	1/2" Thickness	SKU: hp.5-12x24					
	12" x 24" Dimensions						

FREIGHT: A) PREPAID (included)
B) PREPAID & CHARGE
C) COLLECT
D) FIXED AMOUNT — amount

TOTAL $ 162.76

Special instructions:

Prepared by: KEVIN LOHMAN (Print name)

Approved by: (Manager)

Approved by: (Director)

PUR-00007F01

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PURCHASE ORDER REQUISITION

Vendor: Misumi

Contact: (847) 843-9105

DATE:

DATE REQUIRED: 8-Dec-14

CAPITAL EXPENDITURE (please tick):

CURRENCY: USD

NOTE: THIS IS NOT A PURCHASE ORDER AND CANNOT BE ISSUED TO SUPPLIER

TURBOCOR P/N	DESCRIPTION	VENDOR P/N	QTY	UNIT PRICE	TOTAL PRICE	PROJECT NUMBER	ACCOUNT NUMBER
	Block Ball Screw	BSBR1505-250	1	245.92	$ 245.92		
	Support Bearing - Fixed Side	BSWE12	1	87.14	$ 87.14		
	Support Bearing - Support Side	BTN12	1	90.59	$ 90.59		

FREIGHT: A) PREPAID (included)
B) PREPAID & CHARGE
C) COLLECT
D) FIXED AMOUNT — amount

TOTAL $ 423.65

Special instructions:

Prepared by: KEVIN LOHMAN (Print name)

Approved by: (Manager)

Approved by: (Director)

PUR-00007F01

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PURCHASE ORDER REQUISITION

Vendor: Metals Depot
Corporate Office & Warehouse

4200 Revilo Road, Winchester, KY 40391 USA
1-859-745-2650 Fax 1-859-745-0887

Contact: 1-859-745-2650

DATE:

DATE REQUIRED:

CAPITAL EXPENDITURE (please tick):

CURRENCY: USD

NOTE: THIS IS NOT A PURCHASE ORDER AND CANNOT BE ISSUED TO SUPPLIER

TURBOCOR P/N	DESCRIPTION	VENDOR P/N	QTY	UNIT PRICE	TOTAL PRICE	PROJECT NUMBER	ACCOUNT NUMBER
	Low Carbon Steel Plate, 1/2" x 24 " x 24"	P112	1	110.24	$ 110.24		
	1018 Steel Round bar, 3/4" x 72"	R234	1	20.22	$ 20.22		
	Low Carbon Steel Plate, 1/4" x 12" x 12"	P114	1	18.01	$ 18.01		

FREIGHT: A) PREPAID (included)
B) PREPAID & CHARGE
C) COLLECT
D) FIXED AMOUNT — amount

TOTAL $ 148.47

Special instructions:

Prepared by: KEVIN LOHMAN (Print name)

Approved by: (Manager)

Approved by: (Director)

PUR-00007F01

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PURCHASE ORDER REQUISITION

Vendor: Mc Master Carr
6100 Fulton Inddustrial Blvd. SW
Atlanta, GA 30336-2853

Contact: (404) 346-7000

DATE: 8-Dec-14

DATE REQUIRED:

CAPITAL EXPENDITURE (please tick):

CURRENCY: USD

NOTE: THIS IS NOT A PURCHASE ORDER AND CANNOT BE ISSUED TO SUPPLIER

TURBOCOR P/N	DESCRIPTION	VENDOR P/N	QTY	UNIT PRICE	TOTAL PRICE	PROJECT NUMBER	ACCOUNT NUMBER
	Eye Bolt, M12x1.75, 30 mm eye	3040T15	1	$ 6.63	$ 6.63		
	Steel Shackle, 7/16" x 3/4"x 1/2"x1 1/2"	3560T47	2	$ 11.14	$ 22.28		
	U-Bolt Pipe, 3/8" x 16, for 2" Pipe	3043T41	2	$ 6.33	$ 12.66		
	Delrin Black, 1/8" x 2" x 12"	8662K13	1	$ 4.20	$ 4.20		
	Grade 9 Hex Bolt, 3/4"-10 x 5"	90201A660	1	$ 11.25	$ 11.25		
	Trolley 1100 lb capacity	3267T62	2	$ 160.17	$ 320.34		
	4" Caster Wheels	8745T89	2	$ 31.99	$ 63.98		
	4" Track Wheels	2453T1	2	$ 26.63	$ 53.26		
	Delrin Black, 3/8" x 3" x 12"	8662K35	1	$ 13.83	$ 13.83		
	3/4"-10 Hex Nuts (Qty 25)	90499A837	1	$ 9.82	$ 9.82		
	Grade 100 Chain - 0.83" x 24"	3410T62	1	$ 10.64	$ 10.64		

FREIGHT: A) PREPAID (included)
B) PREPAID & CHARGE
C) COLLECT
D) FIXED AMOUNT amount

TOTAL $ 528.89

Special instructions:

Prepared by: KEVIN LOHMAN (Print name)

Approved by: (Manager)

Approved by: (Director)

PUR-00007F01

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IX. APPENDIX E - DRAWINGS

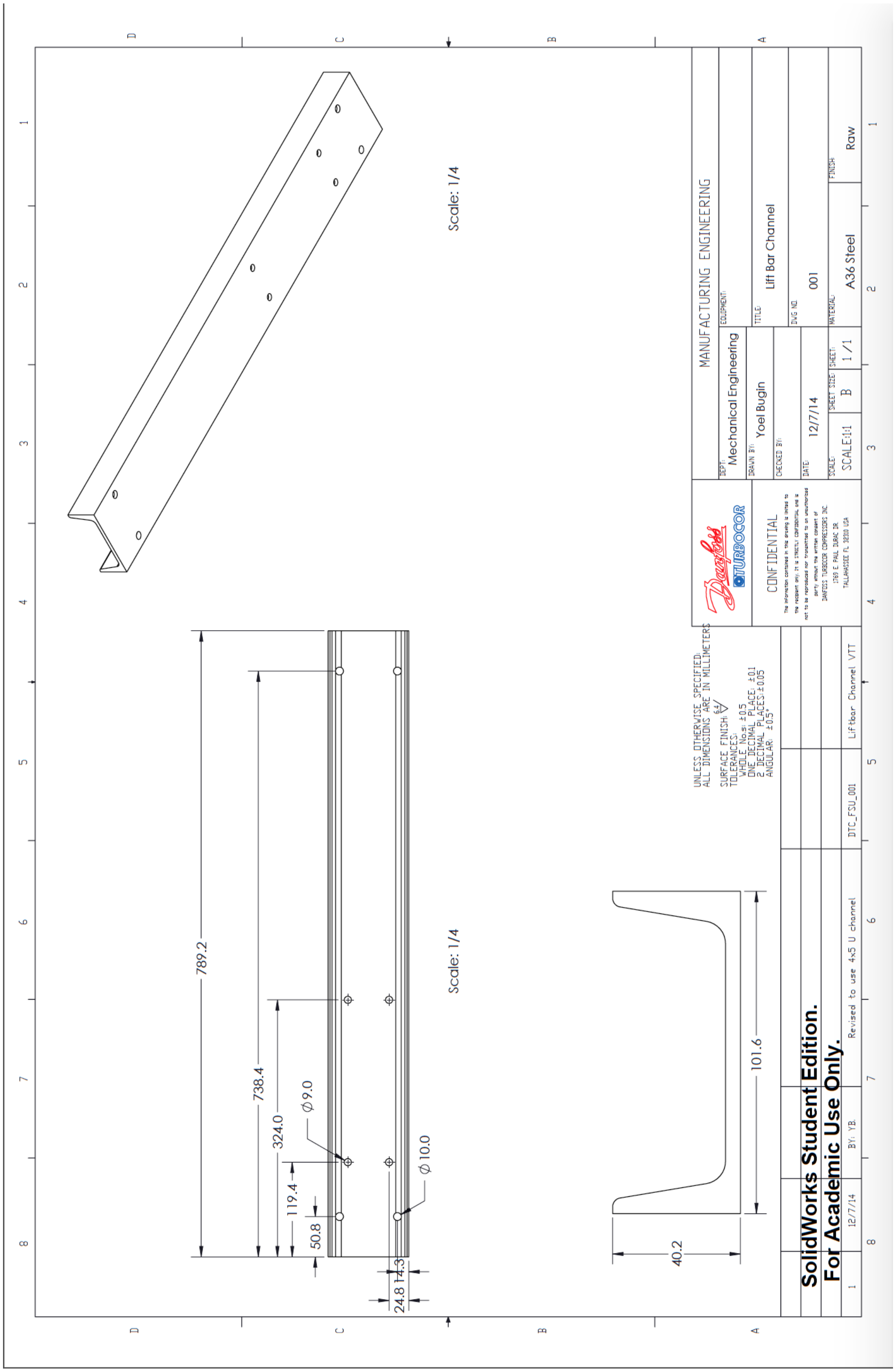

Figure 24 Drawing of C-Channel

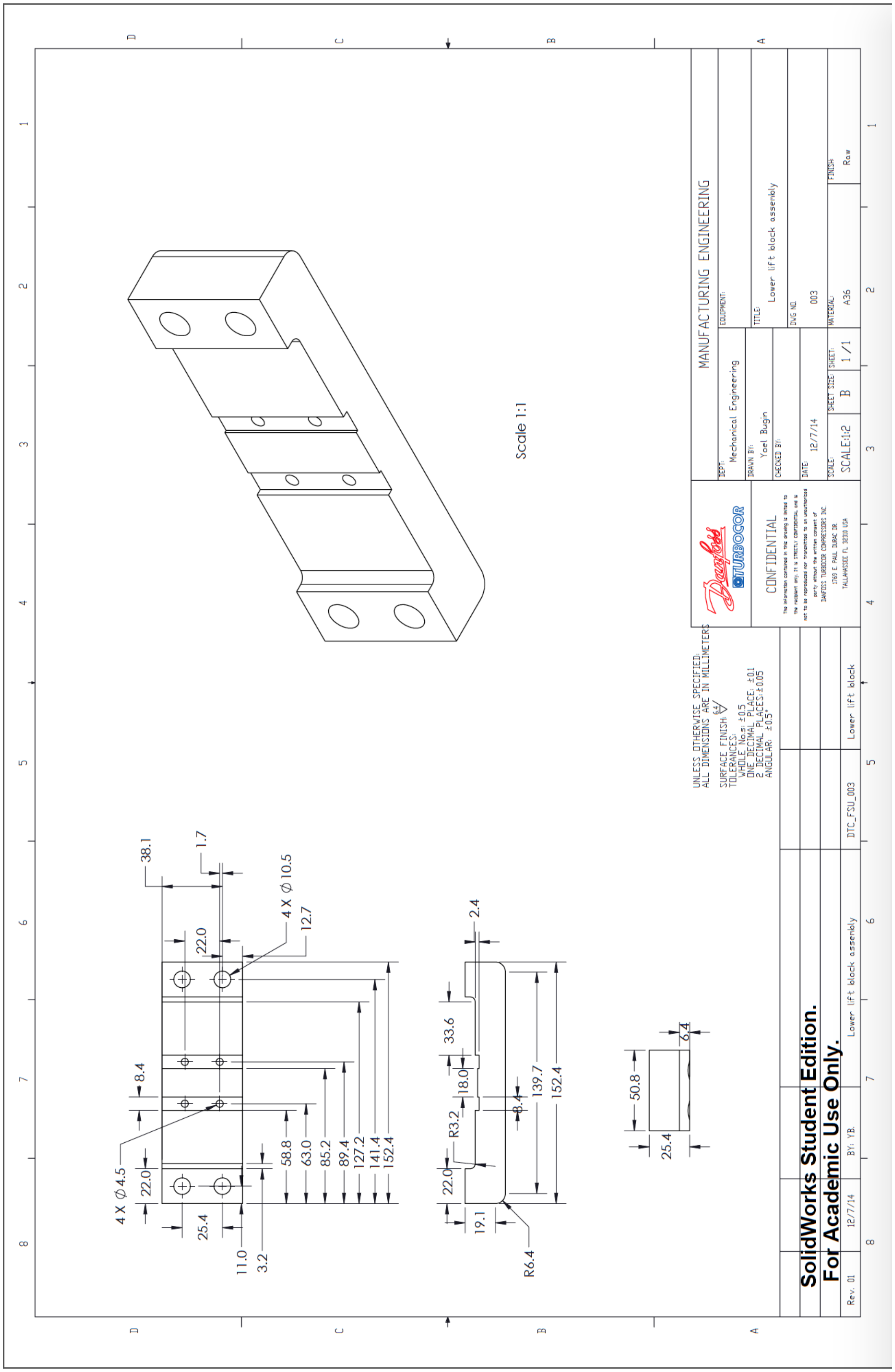

Figure 25 Drawing of Lifting Point Adjustment Block (1)

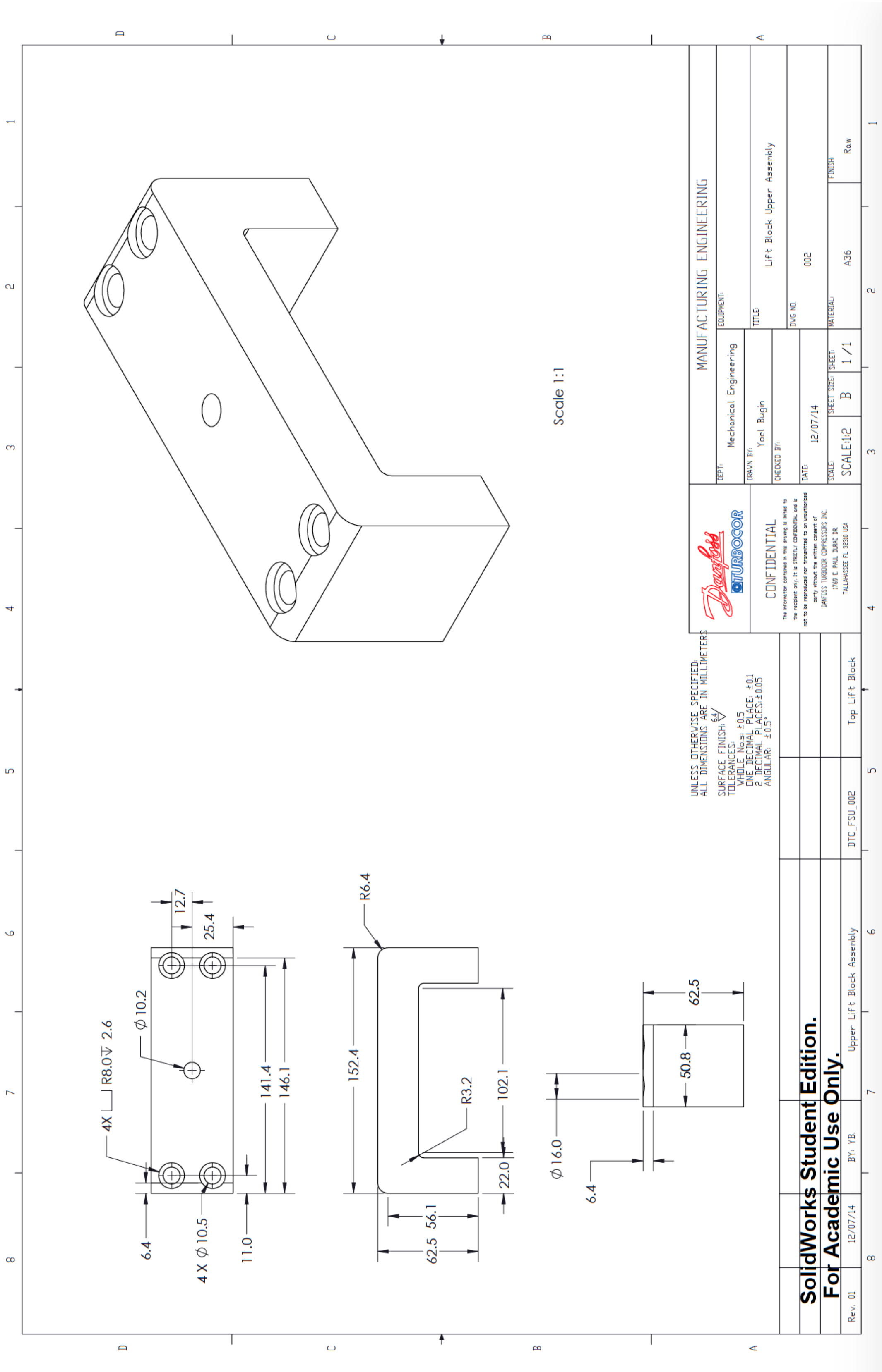

Figure 26 Drawing of Lifting Point Adjustment Block (2)

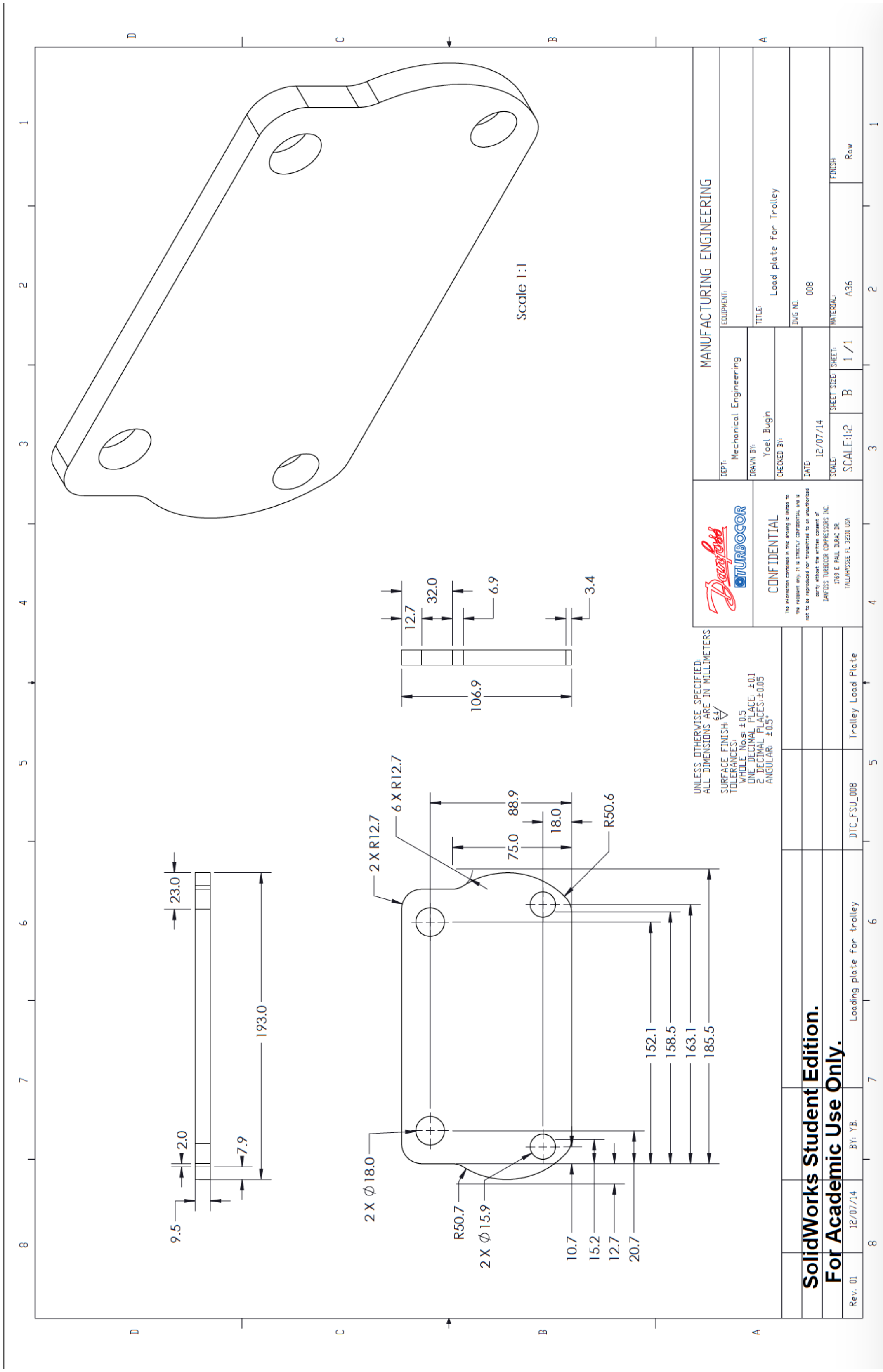

Figure 27 Trolley Load Plate

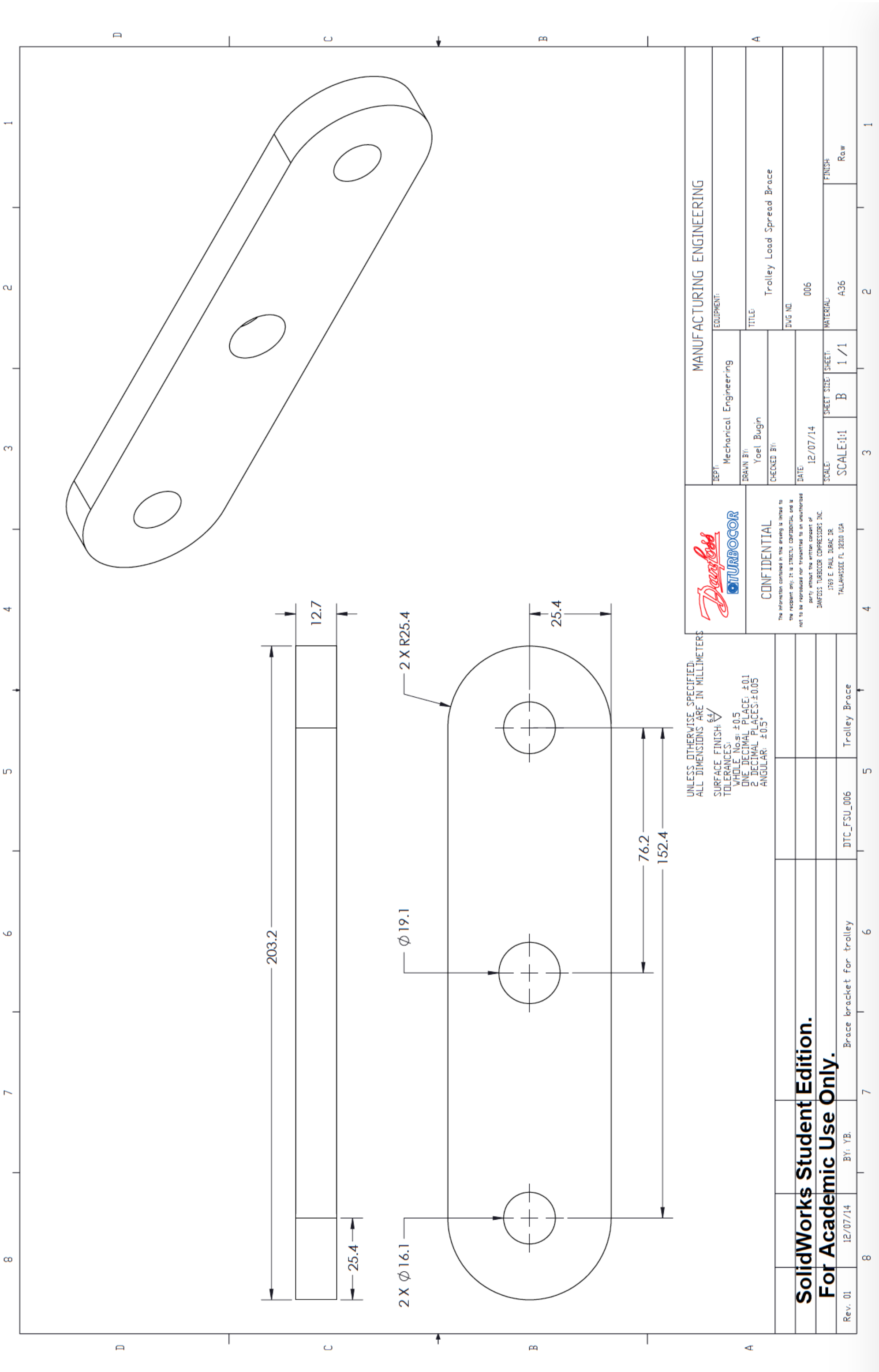

Figure 28 Trolley Support Brace

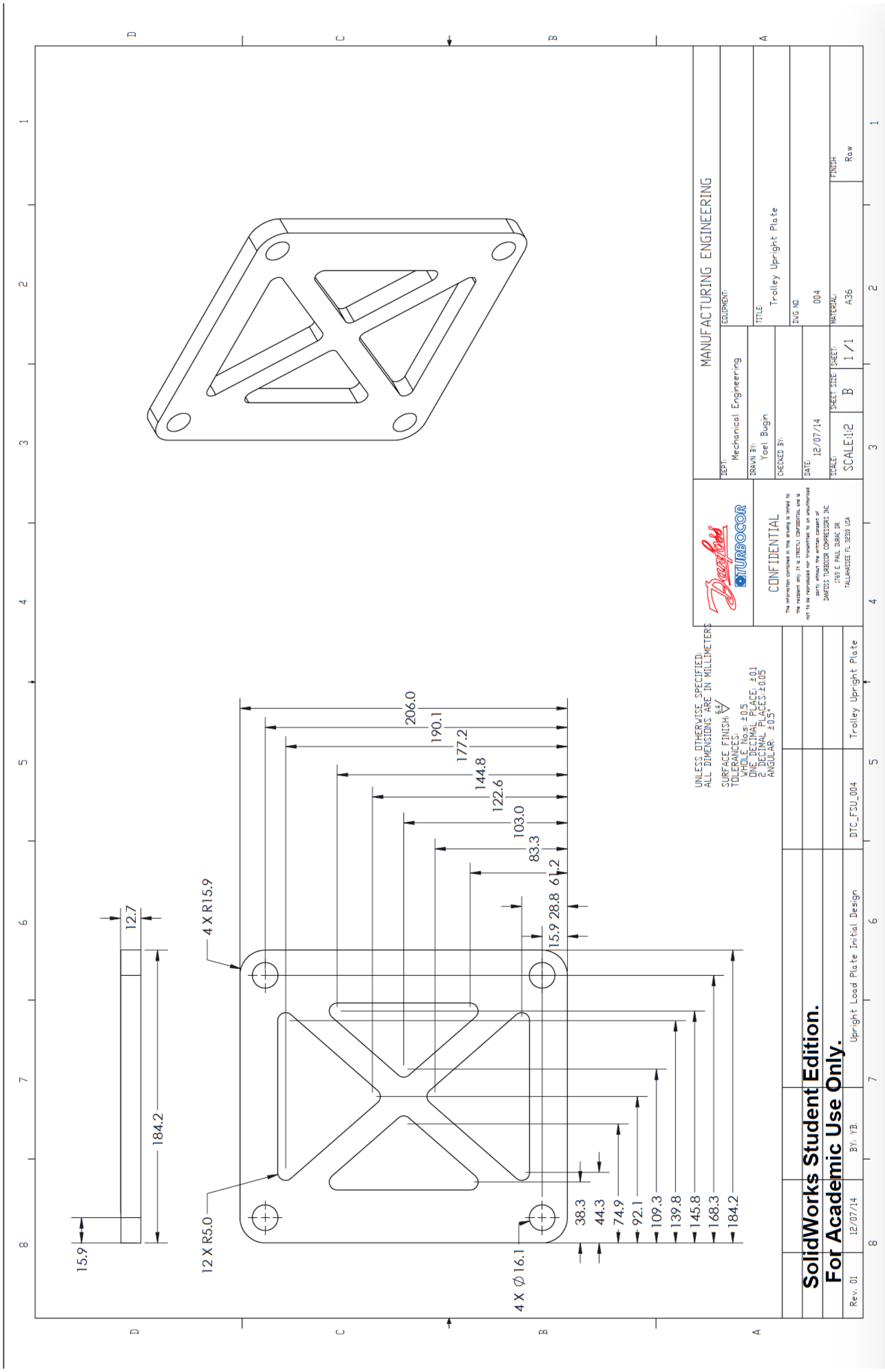

Figure 29 Trolley Vertical Load Support