Part Handling and Processing of the 68K Blade

Final Design Report

EIN 4890 – Senior Design – Fall 2011 Deliverable

Team # 5

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Executive Summary

TECT Power produces a range of components for clients including G.E., Pratt and Whitney, and Boeing. This project primarily focuses on 68K blades used in jets and some locomotive engines. Each blade requires a meticulous multi-stage process in order to be useable in their various applications. This project will focus on the ergonomic improvement and mechanical design for the processing and handling of 68K turbine blades. Prior to broaching, the blades weigh approximately 45 lbs and current handling methods require manual lifting to and from containers as well as milling machines. These methods lend themselves to a high risk of personal injury.

The goal of this project is to develop a mechanism that is able to lift, carry and assist in loading the blades onto the first machine in the broaching area. Also, there is a need to redesign the manner in which these blades are received and oriented in their storage containers to better suit the proposed lifting procedure. The decision matrix is used to determine the most feasible design to accomplish the project goals. Material selection is based on the analysis conducted on stress, cost and material properties. The goal is to achieve the best material properties under the financial constraints. These process improvements will provide greater safety of the operators, preventing cost due to work-related injury. If the project is unsuccessful TECT Power could face significant costs in the form of downtime and disposal of scrap material.

Introduction

Turbine Engine and Components Technology (TECT) Power is a manufacturing company that produces products such as: airfoil blades, airfoil vanes, diffusers, impellers, as well as a myriad of other components. TECT has requested a modification to their current manufacturing methods. The goal of this project is ergonomic improvement and mechanical design for the processing and handling of 68K turbine blades. The blades weigh approximately 45 lbs prior to broaching and current handling methods require manual lifting to and from containers as well as milling machines. These methods lend themselves to a high risk of personal injury.

Project Overview

The goal of this project is to develop a unique solution for the receiving and transportation of 68k blades as they move through the manufacturing line. The 68K blades can be difficult to handle, weighing approximately 45 lbs, and the incorporation of bulky lifting mechanisms decreases the overall production efficiency. This project incorporates both the redesign of receiving methods in order to create a more efficient process as well as the design and fabrication of a new mechanism able to safely handle the blades through the multi-step manufacturing process. The receiving, storage, and broaching processes are the main concern for the scope of this project.

Figure 1 - Turbine Assembly[1]

Team Organization

The team is comprised of five members, each of which was assigned a job title for the 68K blade handling process. Jason Newton is assigned the role of team leader who is responsible for assigning tasks, maintaining group collaboration, and ensuring all deadlines are met. Reginald Scott is assigned as team liaison who and is responsible for communicating the groups requirements to the TECT Power sponsors. The team liaison is also required to keep the advisors and sponsors well informed of the status of the project. Nadia Siddiqui is assigned the role of team organizer, who is responsible for coordinating meetings, keeping a meeting log, and maintaining all backup documents. Michael Brantley was assigned to be the team treasurer and is responsible for maintaining the budget, logging all financial transactions, and placing orders of materials. Ryan Ferm holds the role of team webmaster. The webmaster is responsible for developing and maintaining the project website with team information as well as frequent status updates on the project. A hierarchal diagram of the roles of each member and the primary contacts can be seen in Figure 2 below.

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[1] Courtesy of TECT Power

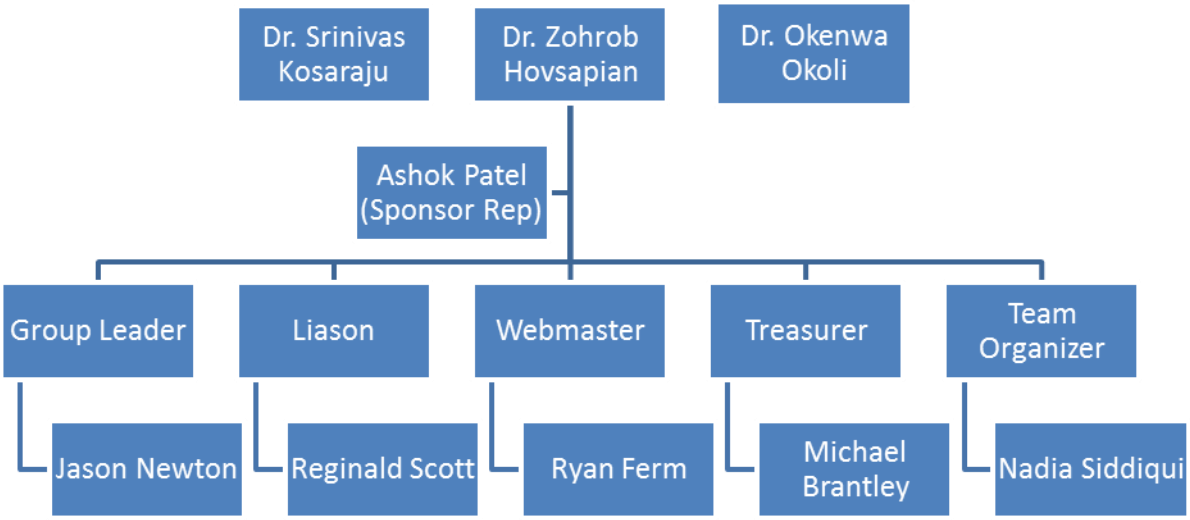


Figure 2 - Organizational Team Chart

Project Schedule

A project schedule was generated to assist in maintain the appropriate project deadlines. This can be found in Appendix B.

Product Specification

Our task is to develop a new procedure for the receiving and transportation of these blades as they move through the manufacturing line. The blades travel through a multi-step process. This process is discussed in further detail below.

Receiving

The current receiving methods are comprised as a shipment of blades arriving in the form of a crate filled with 5 -8 forgings. These parts are not organized in a defined manner and are frequently entangled with adjacent forgings. The dimensions of the crate are approximately 3x3x3 foot crate. These crates must be moved from the receiving center of the plant to the storage center where it will be held until the broaching process. Figure 2 below depicts the layout relative processing locations within the plant. In the storage facility, the crates are placed at ground level onto individual pallets. This is shown in Figure 3.

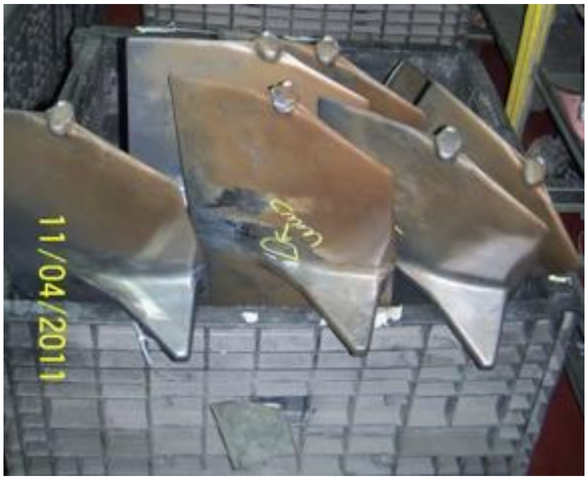


Figure 3 - Current Forging Shipping Methods

Processing

After the blades are received, they are relocated to the storage area of the factory. See Figure 4 for a depiction of the current plant layout. The transition from receiving to storage takes place in the same container. This area holds various types of blades until processing and is located adjacent to the broaching section. The blades are stored in a manner that limits access. A blade handling mechanism would need to approach the containers, remove a single blade, and return to the milling location without hindrance from other stored forgings. To solve this problem, the storage must be reorganized to allow blade access without encountering obstacles. In addition to their storing location, the blades should be stored in a way that would eliminate any physical damage.

Constraints

The redesign of this process as well as the design of a mechanical handling mechanism must adhere to the following constraints set forth by the company:

The Mechanical Design Must:

- Carry a minimum of 45lb
- Be able to extend the blade between 3-5 feet
- The device cannot exceed allowable path dimensions

The Process Redesign Must:

- Maintain or improve efficiency
- Not be operator exclusive
- Reduce time spent between machining

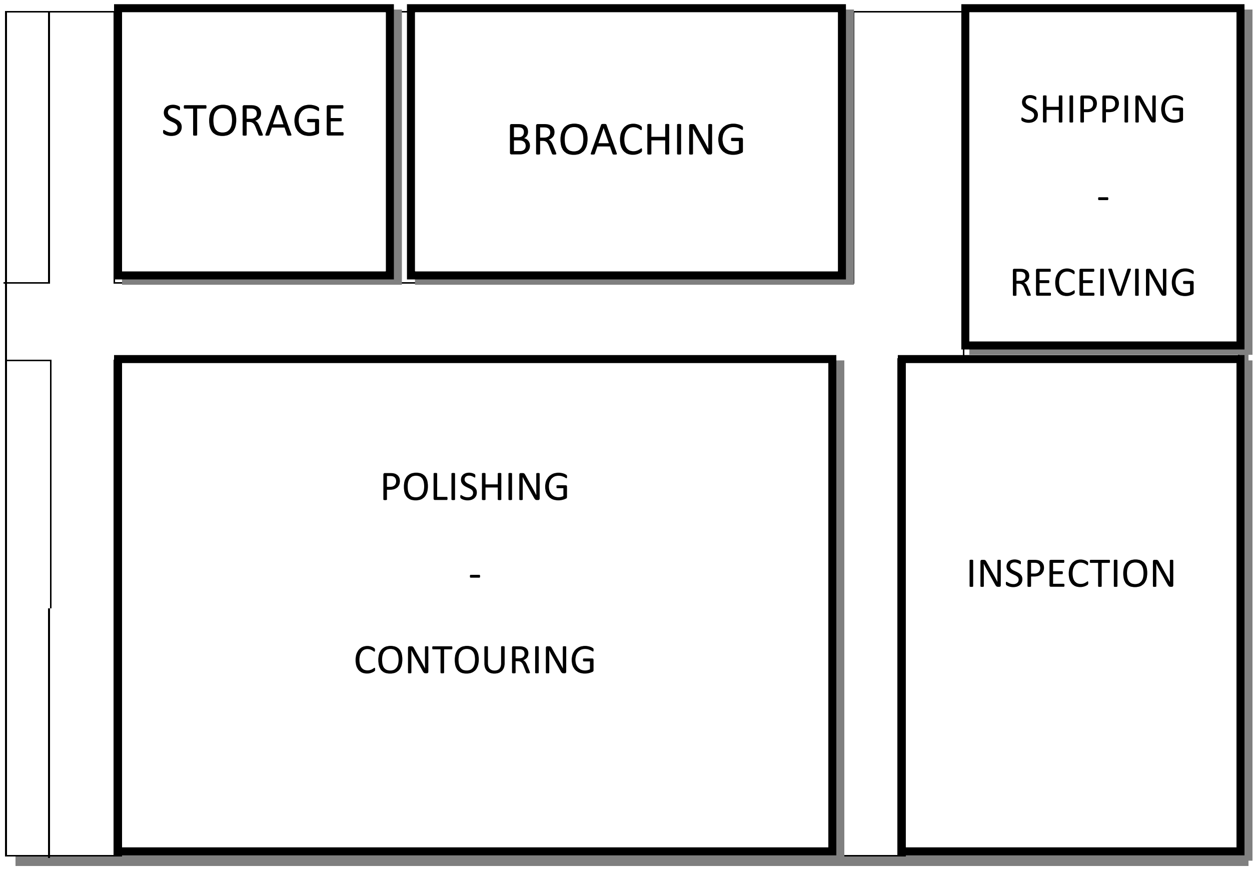


Figure 4 - East Plant Layout

Handling

The opening of the crate requires the blades to be manually lifted to a minimum height of 30 inches in order to retrieve the part. Once lifted, the forging is placed on one of two types of cart. One version holds the blades in a horizontal fashion, with 4-5 shelves at varying heights, each holding a single blade. The second style of cart orients the blades vertically in sectioned holders. 4-5 blades can be held in this manner. The depiction of the cart styles are seen below in Figures 5 and 6**.** Both types of cart require the operator to bend when retrieving the blade and reorient it for attachment to a milling machine. Each milling machine is surrounded by an oil bed protruding approximately 8 inches off of the ground. This bed poses a challenge for direct interaction between the blade carrying device and the mounting fixtures of the mill.

Figure 5 - Vertical Cart Represention

Figure 6 - Horizontal Cart Representation

Concept Design

The following section contains the ideas developed from brainstorming. They are separated into three defined categories.

1. Mechanism Design
2. Container Design
3. Storage Design

All designs are evaluated using a decision matrix found on **page XX.**

Mechanism Design 1- Cart in Cart

The first design for the mechanical carrying device is the combination of subsequent carts to achieve the desired degrees of freedom. The cart, seen in Figure **XXa** would be comprised of a larger, outer cart with a smaller inner cart locked inside. This inner cart would be able to vary its height in order to easily load forgings onto the platform without requiring manual lifting (See Figure **XXb**). Once the forging has been secured onto the platform, the cart can be rolled up to the oil bed and locked into place. The inner cart can then roll directly onto the oil bed and hold the blade adjacent to the milling fixture for mounting; this is depicted in Figure **XXc**. The other benefit of this design is a hinging platform seen in Figure **XXd** that presents the blade in a position for vertical mounting milling attachments.

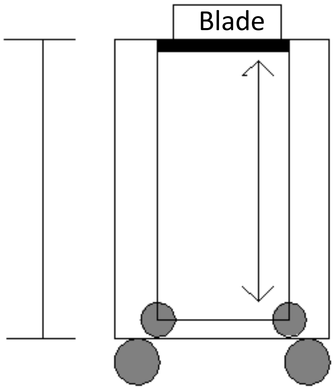


Figure 7a – Overall cart design

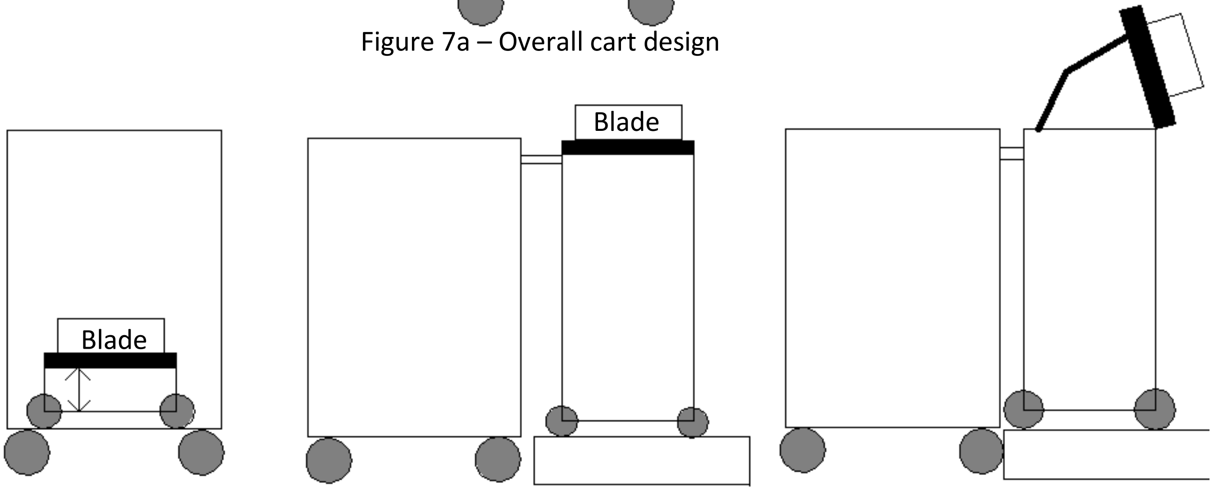


Figure 7b – Variable Height

Figure 7c – Inner cart matches oil bed height

Figure 7d – Tilting Upper Platform

Figure 7 - Cart-in-Cart Capabilities

Mechanism Design 2 – Conveyor System

The second concept involves the development of an overhead conveyor system that extends from the storage location throughout the broaching process. Figure 8 depicts the general path taken by the conveyor. The storage location would act as the initial loading point, where a forging will be loaded onto a platform capable of being lowered to a workable height during loading and raised for locomotion. The container holding each blade will be stopped at each required milling location and lowered for attachment. Upon completion of milling, the blade can be placed back onto a cart and sent to the next location. This method will reduce the amount of traffic in walkways and assist in loading onto each machine. The process is also depicted from a side view in Figure 9**.** The problems associated with this design are the cost to implement such a fixture as well as the results of a failure. Since the device is suspended overhead, a certain level of risk is prominent when considering a failure resulting in a falling forging. Also, if one cart were to lose mobility, the entire manufacturing line would be hindered until that one component was repaired or removed.

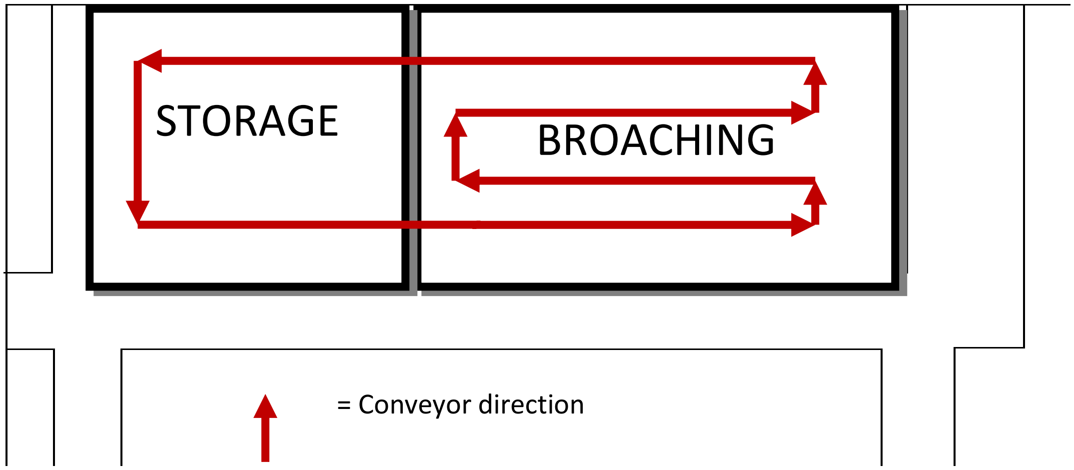


Figure 8 - Conveyor Path

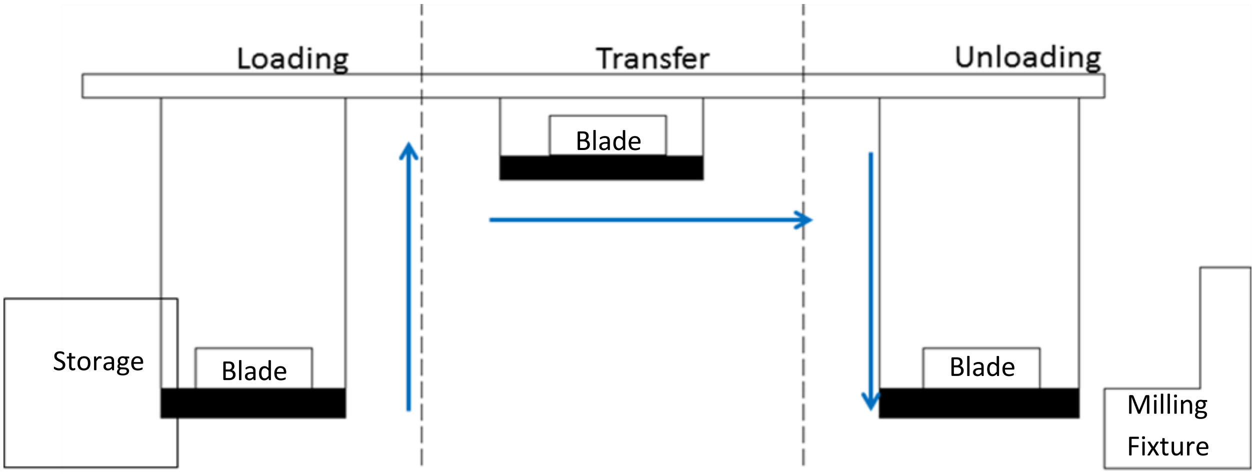


Figure 9 - Conveyor Methods

Mechanism Design 3 – Vehicle Mounted Lift

Another concept was the modification to current small scale industrial vehicles. A hoist mechanism attached to the rear of a highly mobile vehicle could provide a versatile tool capable of carrying multiple blades for milling. Figure XX demonstrates a rough conceptualization of what the methodology of this vehicle. The hoise on the rear of the vehicle could be formed from two independent winches or a single “y” shaped crane. The single mechanism would add the capability of a full 360^o rotation of the lift. More benefits to this system include the amount of blades held for processing. Since the lift mechanism would not be constrained to a single “cart”, the bed of the vehicle could be modified to hold an entire crate of forgings. This would reduce the processing time required by limiting trips from broaching to storage. The downside of this design involves the size constraints of the plant. The broaching section is very restrictive in its free space between machines and a vehicle may hinder movement to other sections of broaching.

Figure 10 - Vehicle Lift Concept

Mechanism Design 4 – Barrel Cart

The final mechanical design utilizes a rotational shelf system to remove the need for a variable height platform. The device will be a large cylinder, the diameter of which will encompass the lowest height required for blade loading and the highest height required for milling attachment. The barrel can be designed in a way to hold multiple blades inside its architecture. When approaching a milling fixture, each section of the barrel can be extended outward on a sliding mechanism to place the blade in an ideal location for attachment. Figure 11 depicts the rotational bin and its sliding shelf mechanism. This design allows for the storage and processing of numerous blades without having to return to the original blade storage location.

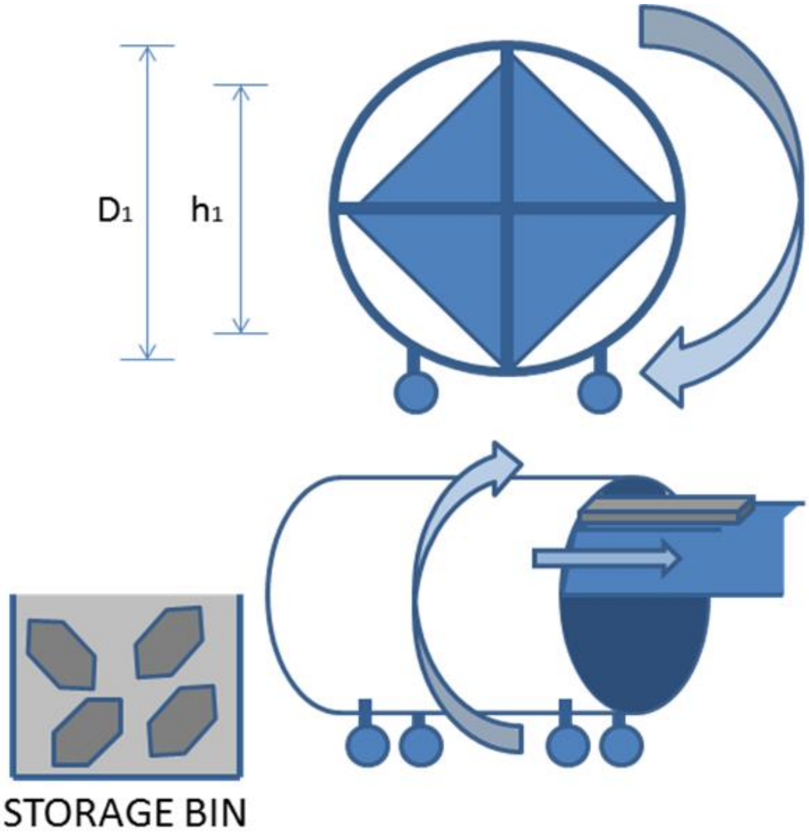


Figure 11 - Barrel Concept

Container Design 1 – Horizontally Sectioned

One method for designing the container would be to have the blades laid down horizontally and separated from the other blades via walls. Figure 12 represents the holding pattern of the container. This design allows for each blade to be accessed individually without experiencing problems with tangling. In order to remove manual lifting, each blade would have to be removed laterally from the front of the container and slid directly onto a platform capable of making the transition from the storage height to the milling attachment height.

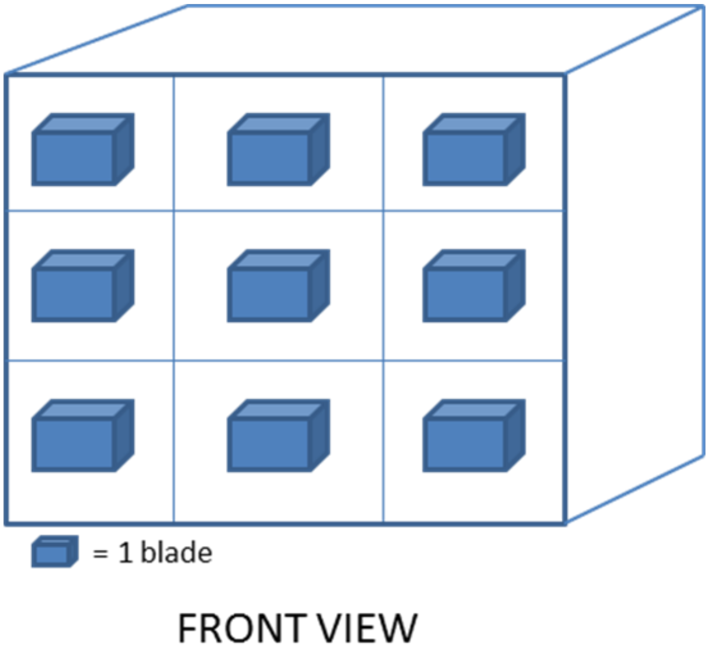


Figure 12 - Crate Concept Horizontally Sectioned

Container Design 2 – Vertically Sectioned

Depicted in Figure 13, the second container design utilizes a vertical orientation for the placement of the blades. Each blade will be separated by a rigid wall, effectively creating multiple “aisles” of forgings. If tangling occurs, each part could be separated further through the use of multiple removable walls placed between the forgings. This would result in every blade being isolated from the adjacent components. This design allows for full access to the length of the blade, utilizing either an upward or outward force for removal.

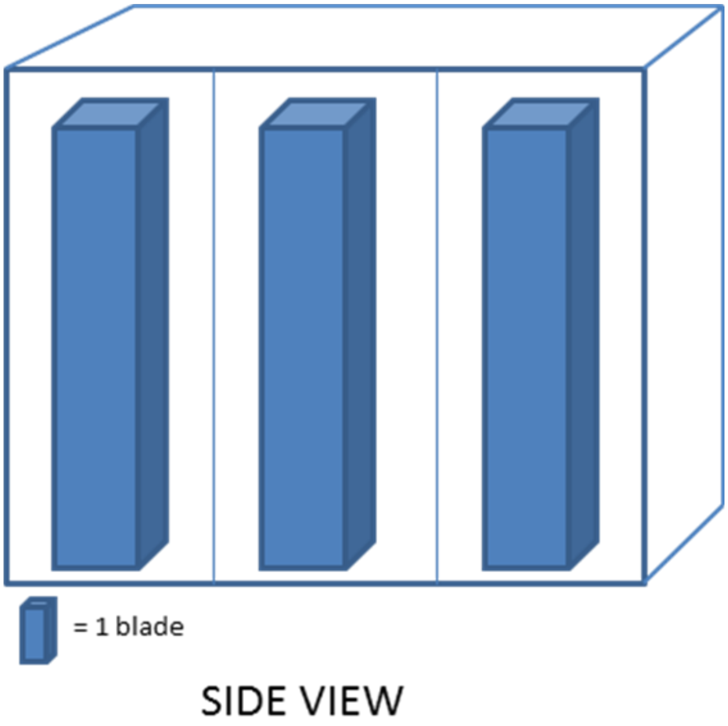


Figure 13 - Crate Concept Vertically Sectioned

Container Design 3 – Angled

The angled design allows for a more open architecture and therefore a wider range of options when attempting to remove the blade from the bin. A representation of this concept can be seen in Figure 14. The blade will be placed onto a rigid shelf, mounted (depicted as a red block) and wedged against the far lower corner. In order to prevent movement of the blade, packing straps or lightweight packing material could be used during shipping. While this method might limit the number of blades able to fit per container, it allows for a variety of retrieval methods.

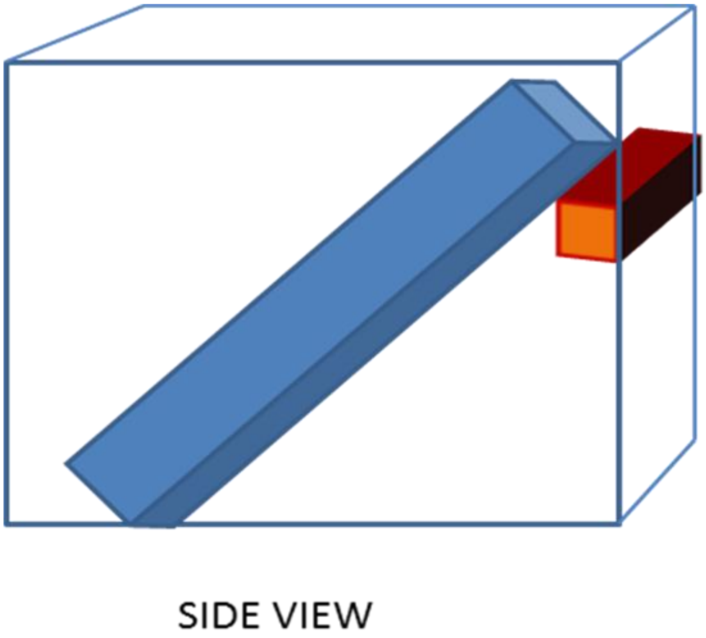


Figure 14 - Crate Concept Angled

Container Design 4 – Horizontally with vertical retrieval

The last concept involves the placement of the blades horizontally on the container floor separated by walls. The variation between this design and design 1 occurs in the retrieval methods. Design one relied on a sliding motion to remove the blades from a hole on the side of the container. This method allows for the removal of the forgings from the top of the container as is represented in Figure 15**.**

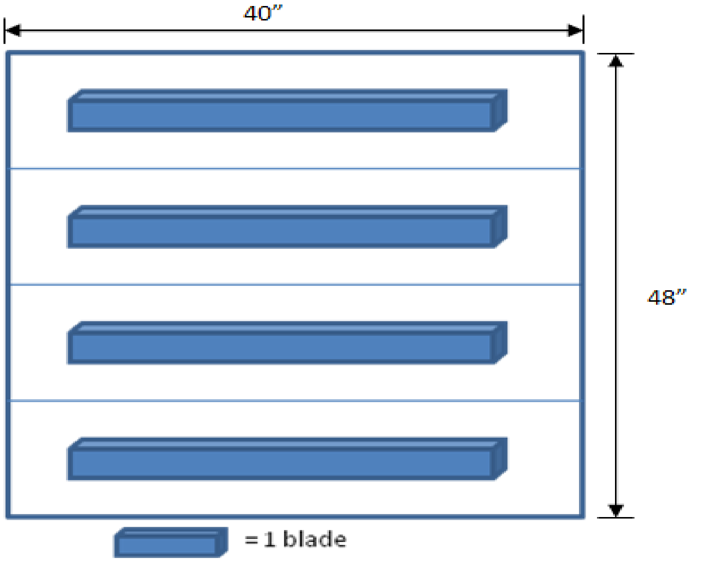


Figure 15 - Crate Concept Vertical Retrieval

TOP VIEW

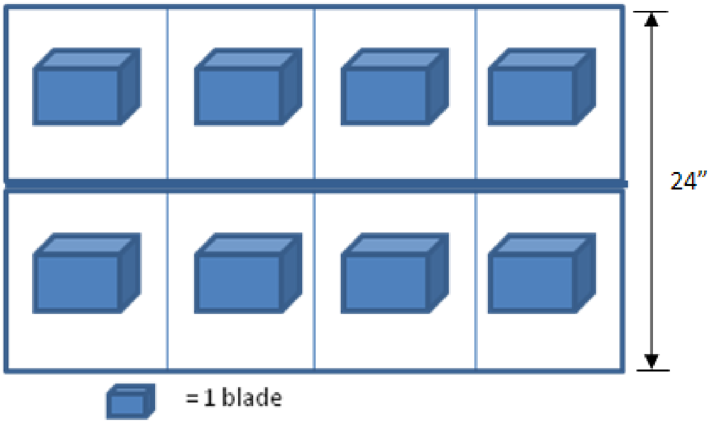


Figure 16 - Crate Concept with Vertical Retrieval Side view

SIDE VIEW

Storage Design

The current storage design has the forging containers place on the floor in semi-organized areas. The new design for the storage location would be to use clearly defined sections for each blade type as well as the implementation of elevated rolling tables. The rolling tables, depicted in Figure 17**,** would allow for blades to be at a more manageable height allowing the mechanism design to have a smaller required height variation. When blades are received, a forklift could place the container directly onto the table and an employee could easily walk the container to the back of the rollers, allowing for more incoming crates. As the blades are processed and the containers empty, the empty crates could be discarded and a new, full container could be rolled to the front of the line. Figure 18 depicts some of the various factors for purchasing the roller table.

Figure 17 - Roller Table

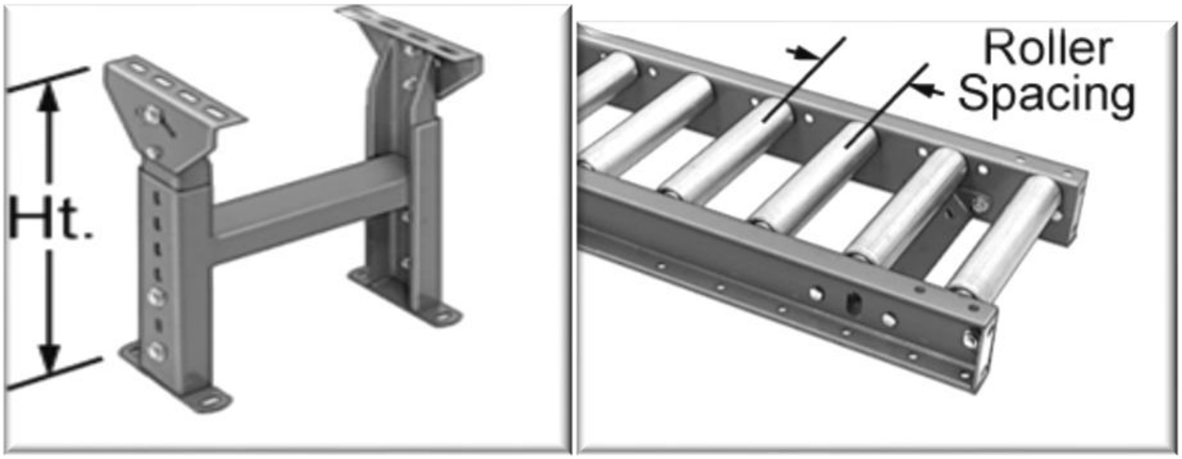


Figure 18 -Roller Table Factors

Decision Matrix

When beginning to set up the decision matrix, the factors must first be defined and justified. The most obvious criteria was cost, since the project is heavily restricted by a predetermined budget. Another factor to be considered is the ergonomic improvement from implementing each design. This was measured through the use of RULA worksheets. The RULA scores are just as important as the cost because if the design does not provide the worker with a simpler operation than the project goals were not met. Also, a certain degree of mobility is required for the designs to be used in the broaching area. The restrictive aspect of the broaching area is the narrow aisles. So to measure mobility, the width of the designs was used to predict mobility within these aisles. Then a durability and maintenance rating was applied to the designs based on how accessible the mechanism would be to an operator. For example, the L-cart is a very open design so the maintenance person would have to difficult seeing and repairing the defect; whereas the conveyor system, being suspended high in the air, makes maintenance and repair difficult.

Table 1 - Decision Matrix Factors

Mechanism	**Cost ($)**	**Width (inches)**	**RULA**
Barrel	1200	44	3
L-Cart	1860	60	3
Conveyor	11000	N/A	7
Vehicle	13899	45	3
Cart-in-Cart		44	7

The first design to be removed from consideration was the cart-in-cart design. This was due to its poor rating on the RULA scale. As mentioned previously, if the design does not address the ergonomic concerns, it will not be implemented. The next designs to be eliminated were the vehicle and conveyor ideas. These concepts were quickly dismissed based simply on the fact their projected costs near tripled the set budget.

Each factor was translated into a number on a scale of 1-10. The criterion for this translation has been explained below.

RULA

- 8-10: Score between a 1-3 on the RULA scale
- 4-7: Score between a 4-5 on the RULA scale
- 1-3: Score between a 6-7 on the RULA scale

Cost

- 8-10: Cost fit under budget with extra spending available
- 4-7: Cost fits closely to allowed budget
- 1-3: Cost exceeds budget

Maneuverability

- 8-10: Design is fits inside aisles easily and can change directions without difficulty
- 4-7: Design is wide but can still effectively move through aisles
- 1-3: Design doesn't fit in broaching area

Durability/Maintenance

- 8-10: Design is easily accessible with no obstruction when attempting repair; passes stress analysis
- 4-7: Moderately accessible to maintenance personnel; passes stress analysis
- 1-3: Repair/maintenance is difficult to perform, design is in difficult position i.e. elevated position, panel must be removed; Fails stress analysis

Table 2 - Decision Matrix

Factors	**Weight**	**Cart-in-Cart**	**Conveyor**	**Vehicle**	**Barrel**	**L-Cart**
RULA	0.45	2.5	7.8	9.6	8.9	8.2
Cost	0.25	8.6	1.6	2	7.76	7
Maneuverability	0.15	8.6	9	1	7.8	6.4
Durability/Maintenance	0.15	7.8	4	8	8.2	7.9
TOTAL (max 10)	1					

Designs

Container Decision

Since the nature of this project is to change the process to eliminate manual lifting, manipulating the receiving methods and storage area is essential. The storage area dimensions in the facility are 20ft by 30ft of which 4ft by 8ft are reserved for the 68k blades. Three things will be considered when changing the storage area: the container the blades arrive in, where and how there are stored, and how they will be removed from the storage area to the broaching area.

The blades currently arrive in a container with 8-12 blades in a vertical position. This is hazardous to the operator because they become nested making it difficult to disentangle and remove them from the crate due to the shape and weight of the blade. Adding to the physical stress of the job, operators find it difficult to grasp and hold the blade while wearing protective gloves. To improve this process, the blades will arrive in a horizontal container with two rows of four blades laying flat. Each blade is 11in wide, 37in long and 13in tall so the entire container will be 24in tall, 48in long and 40in wide. This design is depicted in Figures 19 and 20. Additionally, the blades will be accessible from all sides of the container to account for different positions of the cart that will retrieve it.

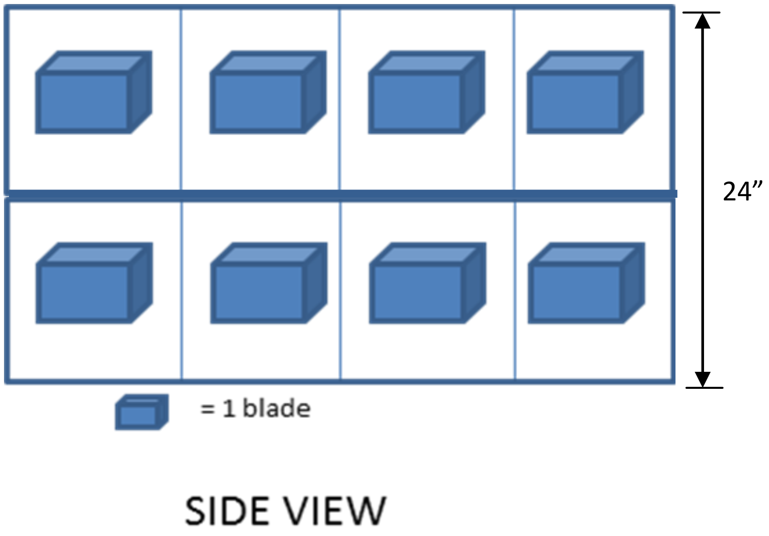


Figure 19 - Final Container Design

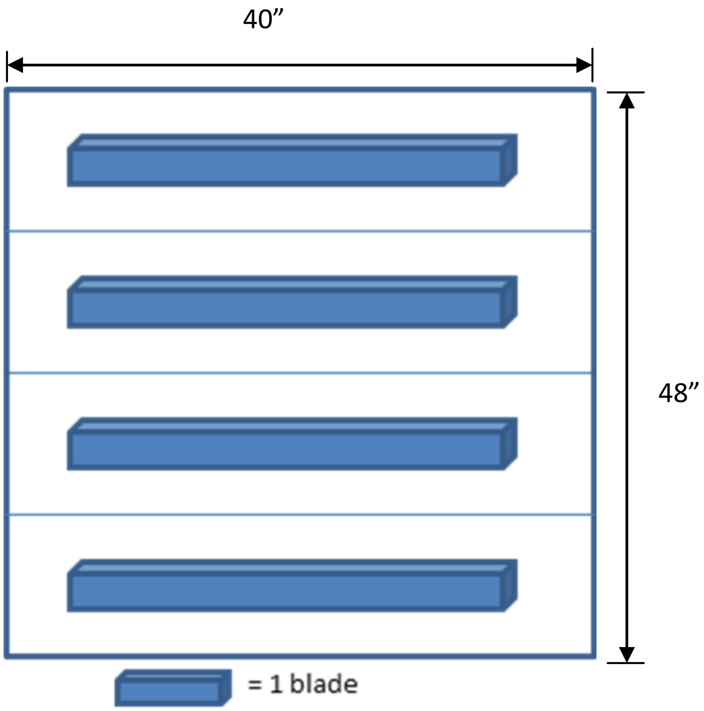
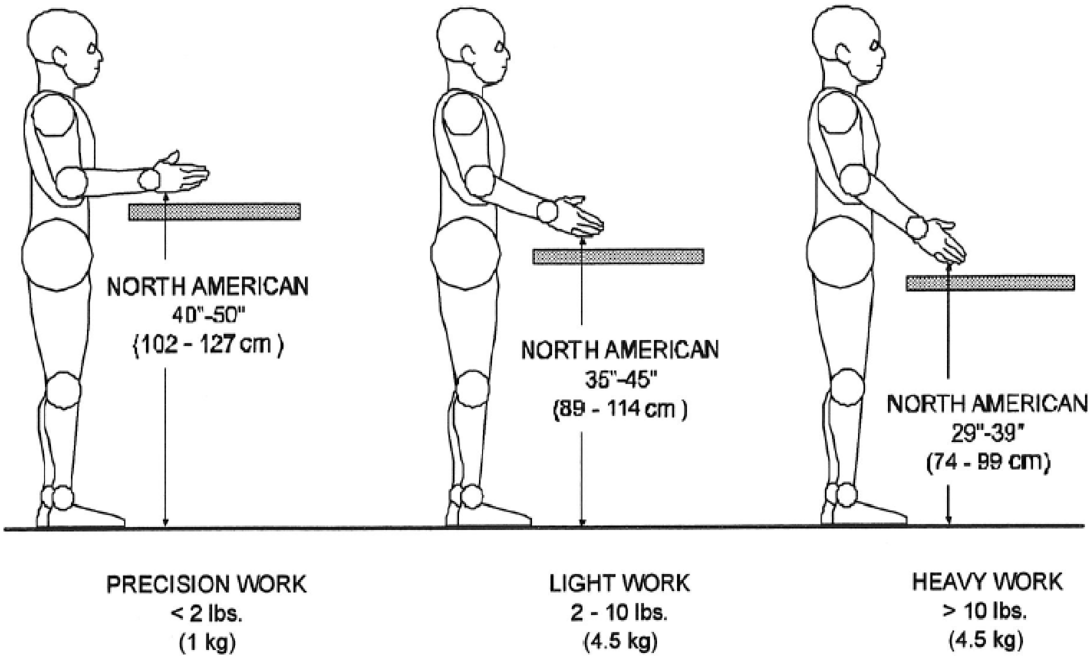


Figure 20 - Final Container Design

TOP VIEW

Concurrently, this improved container will be sitting on an elevated roller table. By bringing the blades to an acceptable work height, they become more manageable by reducing the need to lift. According to anthropometric data, see Figure 21, the height for a standing work station with heavy lifting should be between 29in-39in for North America. This height of the table will take into account the height of the container so that the workstation will still be in the ideal range. It will be 24in-28in tall, 36in-49in wide and 10 ft long.

The height of the roller table will correspond to the barrel cart, which will retrieve the blades. From the ground, the center of the barrel will be 34in tall and will correspond to the center of the container. By bringing the barrel cart next to the roller table and aligning it with a blade in the container, the operator only has to slide the blade into a compartment in the barrel cart.



Standing Workstation Guidelines (Adapted from Pheasant, 1988)

Figure 21 - Optimal Height Range[2]

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[2] Courtesy of Work Design: Occupational Ergonomics

Design: L Cart

Due to the removal of the Cart-in-Cart design, the L-Cart was developed as a replacement. Figure 22 depicts a cad model rendering of this mechanism.

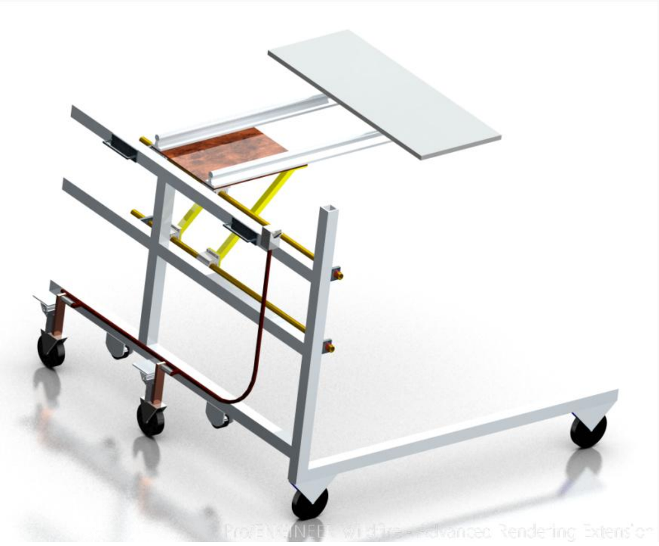


Figure 22 - L-Cart Design

The overall goal of this design is to provide bi-axial position control of a platform capable of supporting a 68K blade forging. The design of the system is L shaped to due to the constraints set forth by the geometry of the milling machine and oil bed.   It will be primarily stationary next to the first milling machine in the broaching area of the plant.

Structure

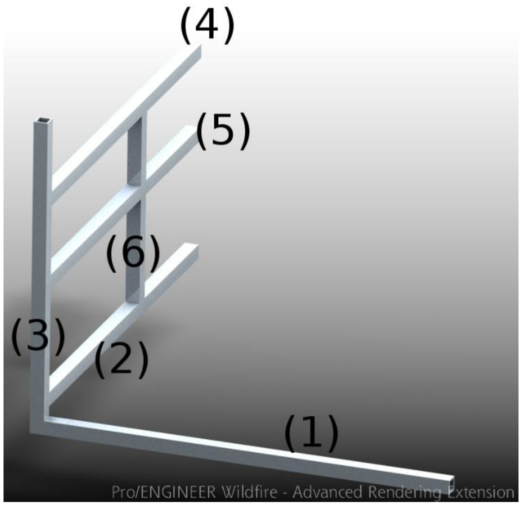


Figure 23 - L-Cart Frame Description

The frame consists of two leg beams held perpendicular to each other, forming a L shape. The lower leg and upper legs are notated in Figure 23 at (1) and (2), respectively. Each leg measures an approximate 58 inches long. The two legs of the system are welded to the primary vertical support bar, (3), which extends 45 inches above the lower leg. The section of the vertical support beam protruding from the top of the design allows the operator an extra contact point in addition to the handles seen on the upper rail in Figure 22. When having to maneuver the cart, this sections provides taller users with a more comfortable hand position. The section of the frame that will be supporting bearings are noted as (4) and (5). Since these two beams will be acting as the primary attachment for the sliding mechanism, extra support was desire to prevent a high degree of cantilever on the structure. The support is shown as part (6).

Relocation

The mechanism will utilize caster wheels in order to allow the operator to move the cart to a desired location. This mechanism will utilize two distinct types of wheels for operation, fixed casters and hinging casters. Both the fixed casters and the hinging casters exhibit a full 360° of rotation, but the difference is found at the mountin plate. The fixed casters are rigidly mounted to the frame. The hinging casters are able to rotate the entire wheel 90° from its original vertical position. The Hinging casters will be located on the upper leg, part (1) in Figure 24. The placement of these casters is to allow the mechanism to overcome the height of the oil bed. Once the cart has been pushed adjacent to the oil bed, the operator can activate a lever to a cable pull system which will remove the locking pin depicted as part (3) in Figure 24. The device can then be pushed forward and wheels will bend upward. Once on the oil bed, smaller fixed casters, part (2) in the figure, support the weight of the cart as it is navigated closer toward the milling fixture. See Figure 25 for a visual representation of this.

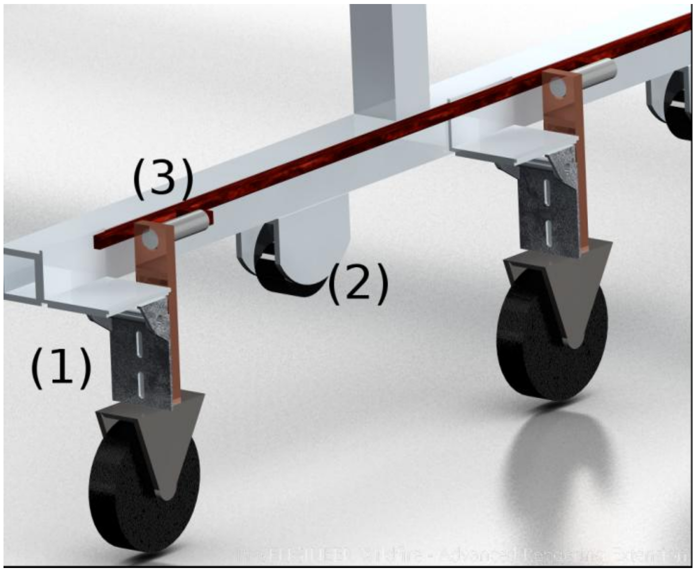


Figure 24 - L-Cart Wheel Descriptions

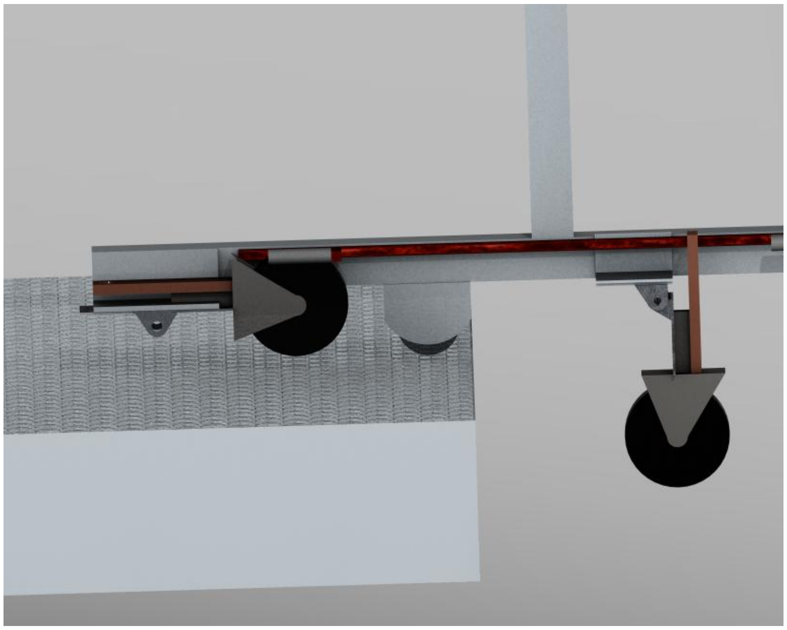


Figure 25 - L-Cart While on Oil Bed

Axis Control

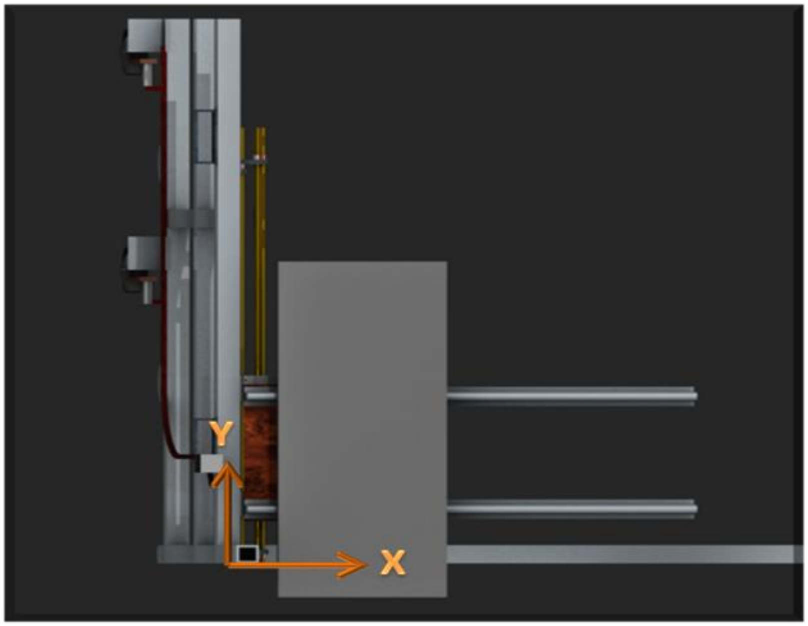


Figure 26 - L-Cart Axis Control Description

The two degrees of freedom demonstrated by the blade platform will be implemented by using multiple sets of linear pillow block bearings. There will be two types of pillow block bearings used in this mechanism. The first type is a closed bearing and the second type is an open bearing. These are shown in Figure 27. The benefits of using these bearings are their minimal maintenance requirements. They are sealed to prevent contaminants from hindering bearing motion and forms of them can also be purchased which never require lubrication. Two sets of closed bearings, part (2) in **Figure view2**, will be mounted onto horizontal rods to provide motion in the Y direction as depicted in **Figure verticalview**. The rods are shown as parts (1) in **Figure x**. Rod mounts will be placed near the vertical supports of the frame to prevent excessive deflection.

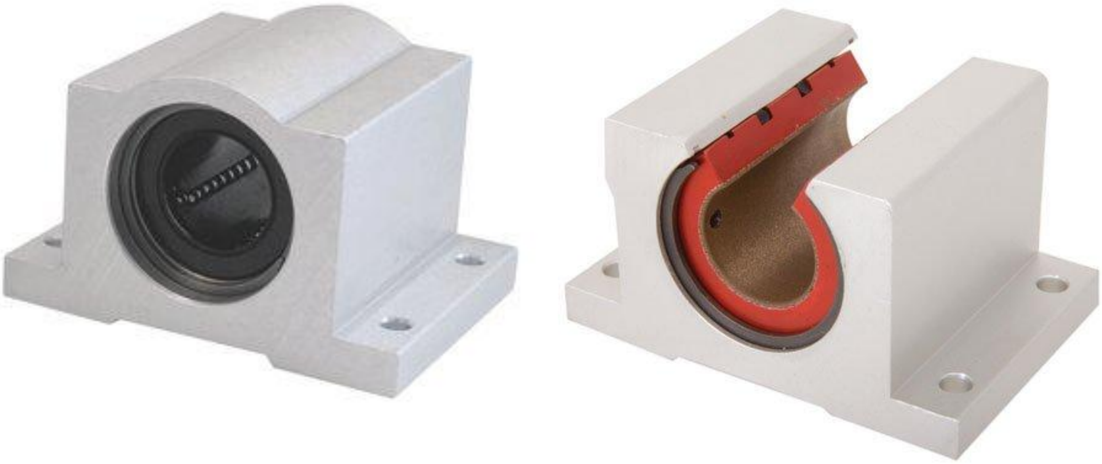


Figure 27 - Closed Pillow Block Linear Bearing (Left) and Open Pillow Block Linear Bearing (Right)

The closed pillow block bearings are shown in Figures 28 and 29 as part (2). There are 4 closed bearings in total, 2 per rod. The lower rod's bearings act as a support for the cantilevered portion of the upper platforms. They connect to the angled beams, parts (3), which are then attached to a platform containing the linear guide support rails, parts (4). The final component of the system is the blade platform which is labeled part (6). This is the portion of the mechanism that will hold the blade while the operator is moving the platform toward the broaching machine. High strength industrial Velcro straps have been thought of as a containment mechanism to prevent blade slippage.

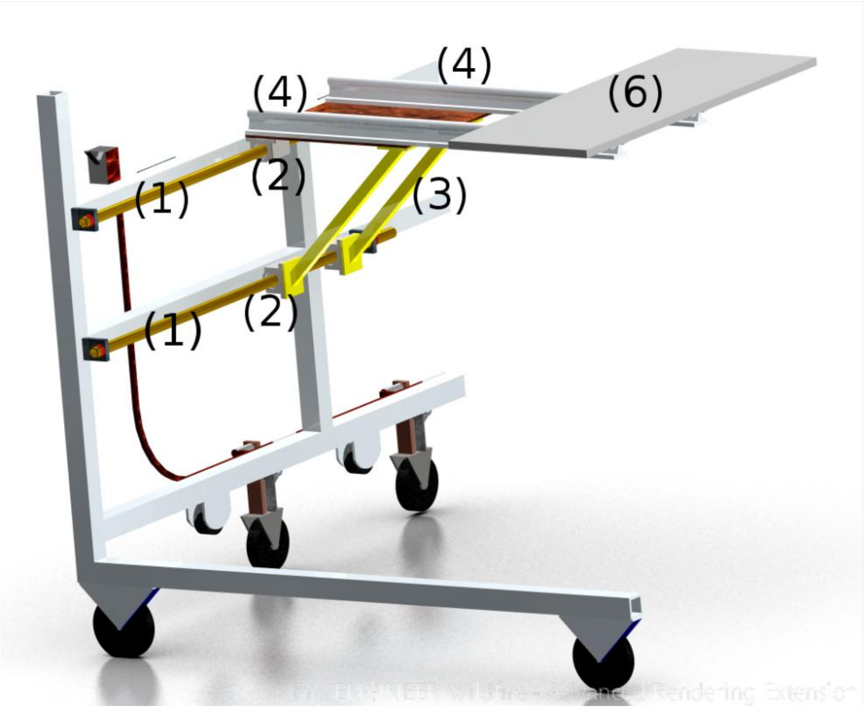


Figure 28 - L-Cart Part Description

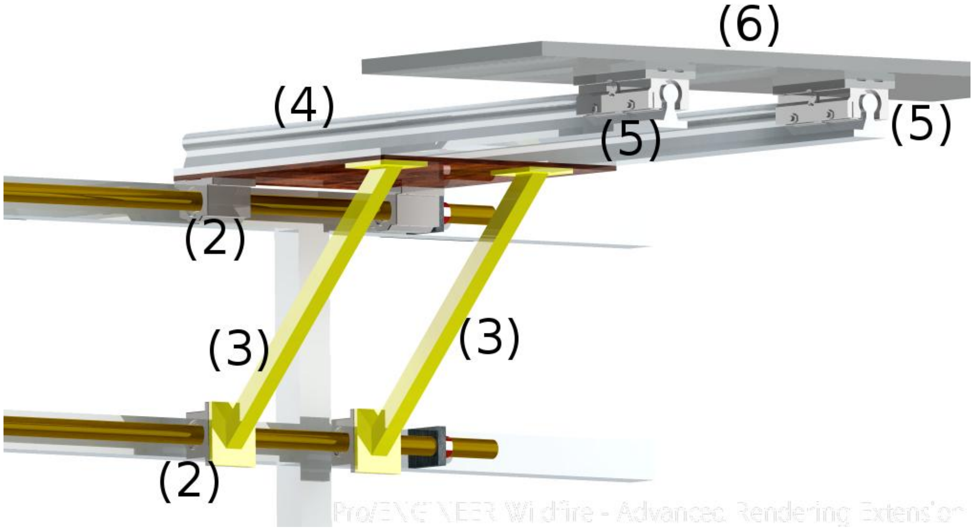


Figure 29 - L-Cart Part Description Side View

Design: Barrel Cart

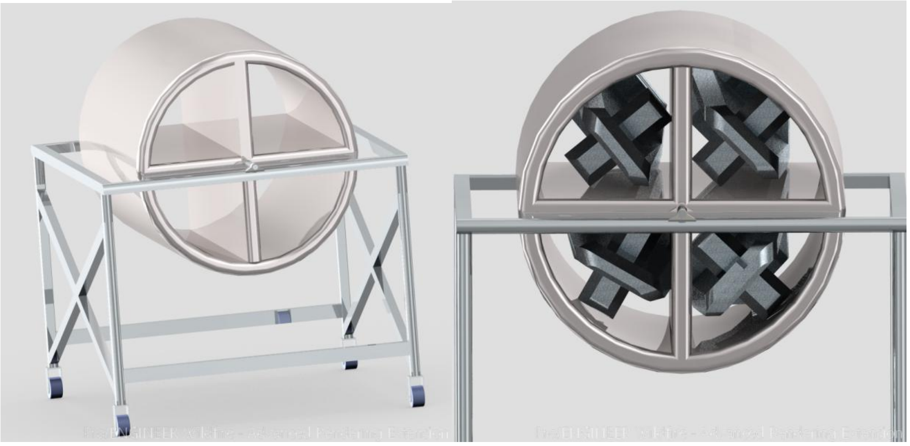


Figure 30 - Barrel Design

Structure

The barrel is a relatively simple design designed for the containment and relocation of forgings. The empty and filled states of the design are depicted in Figure 30. The actual rotating portion of the design will be constructed from three sections of tubing bent into a circular design. This will form the skeleton of the barrel. The sections will then be welded onto a sheet of metal which can be wrapped around to add an outer surface. Cross pieces will then be added within the barrel to create a rigid surface on which the blades could be held. The inner surfaces will be coated with a polymer coat to prevent both corrosion of the cart and metal on metal contact of the cart and forging. Straps will be fixed onto the inner portion surfaces of each compartment. These will serve to hold the blade in place while traveling. An example of this locking pin is shown in Figure 31.

Figure 31 -Locking Pin[3]

Operation

The Barrel Cart was built to be a compact storage container for the holding and relocation of the blade forgings. In storage, the operator will be able to slide the blades into the mechanism from an elevated table and rotate the mechanism to allow for an empty section of the cart to be loaded. The height of the barrel is optimized to match the required height of the L-Cart as well as provide a reasonable working height for the operator. Once full, the blades can be locked into place using straps attached to the inner surfaces of the barrel. This loading process is depicted in Figure 32.

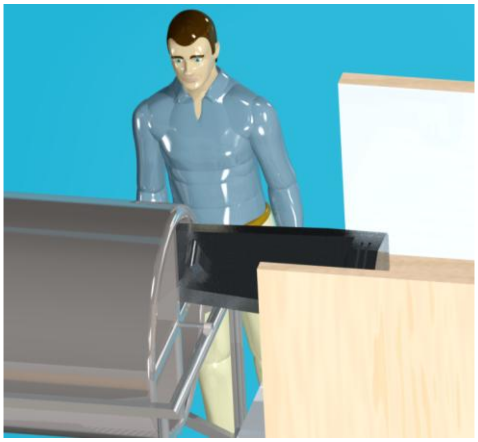


Figure 32 - Barrel Loading with Working Height Reference

The operator can then transfer the cart from the storage area over to the broaching area where the L-Cart will established. The blades could then be slid out of the barrel and onto the L-Cart as seen in Figure 33 below.

---

[3] Courtesy of Race Ready Products

Figure 33 - Barrel Cart Interface with L-Cart

Analysis

Stress Analysis – L-Cart

The majority of the analysis on the L-Cart was performed in PTC's Pro Engineer Mechanica. The design was implemented in the program as a structure, using finite element analysis as the methodology. The structure was broken up into four separate areas of analysis as depicted in Figure 30.

1. Frame
2. Bearing Rods
3. Angled Supports
4. Lateral Bearing Guides

Figure 34 - L-Cart Analysis Locations

Each of these components was exposed to 150lbf using a “worst case scenario” loading. More specifically, the loads were placed in positions to create maximum moments onto the system and, when applicable, point loads were used rather than a distributed load over the surface area. The results of the analysis can be found in Table 3 below.

In order to determine an approximate displacement of the part, materials were assigned based off the level of stress endured by the part. The images depicting stress concentrations and displacement magnitudes of taken from the analysis can be found in Appendix A. The displacements were scaled in order to better depict the methods in which deflection occurred.

Table 3 - L-Cart Stress and Displacement Results

Component	Maximum Stress (ksi)	Maximum Displacement (in)
Frame	3	$4*10^{-4}$
Bearing Rods	17.2	$9.5*10^{-2}$
Angled Support	2	$2.75*10^{-2}$
Lateral Bearing Guides	0.978	$2.14*10^{-2}$

Stability Analysis – L-Cart

In order to ensure tipping does not occur on the L-Cart, a stability analysis was performed using the support polygon method. This method involved the examination of the ground contact points and establishment of the stable regions. The stable region is bounded by a polygon that is created using all ground contacts as corners of the shape; this is depicted by the shaded area in Figure 31.

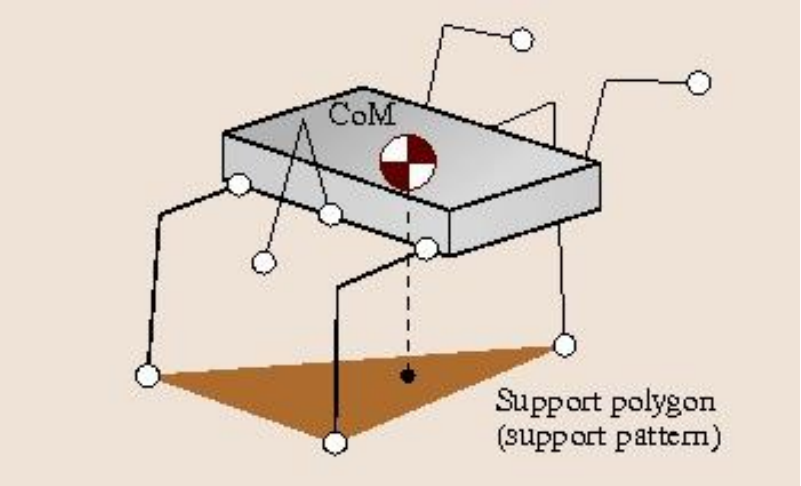


Figure 35 - Polygon of Support Depiction

The stability is determined by the center of mass of the system. As long as the projection of the center of mass towards the ground remains within the boundaries of the polygon, the system is stable. The analysis on our system, performed with 100lbf being loaded onto the platform when it is extended to its farthest position from the joint of the two legs, initially proved that an instability was occurring. Calculations showed that the stable region could encompass this position with a 7 inch increase in both leg lengths. The legs of our mechanism were extended by an additional 12 inches to account for a buffer zone of safety. The figure depicting the center of mass location as calculated can be seen in Figure 32 below. In this figure, the vertical and horizontal boxes represent the legs of the system and the line forming the hypotenuse of the triangle is the bounding stability line.

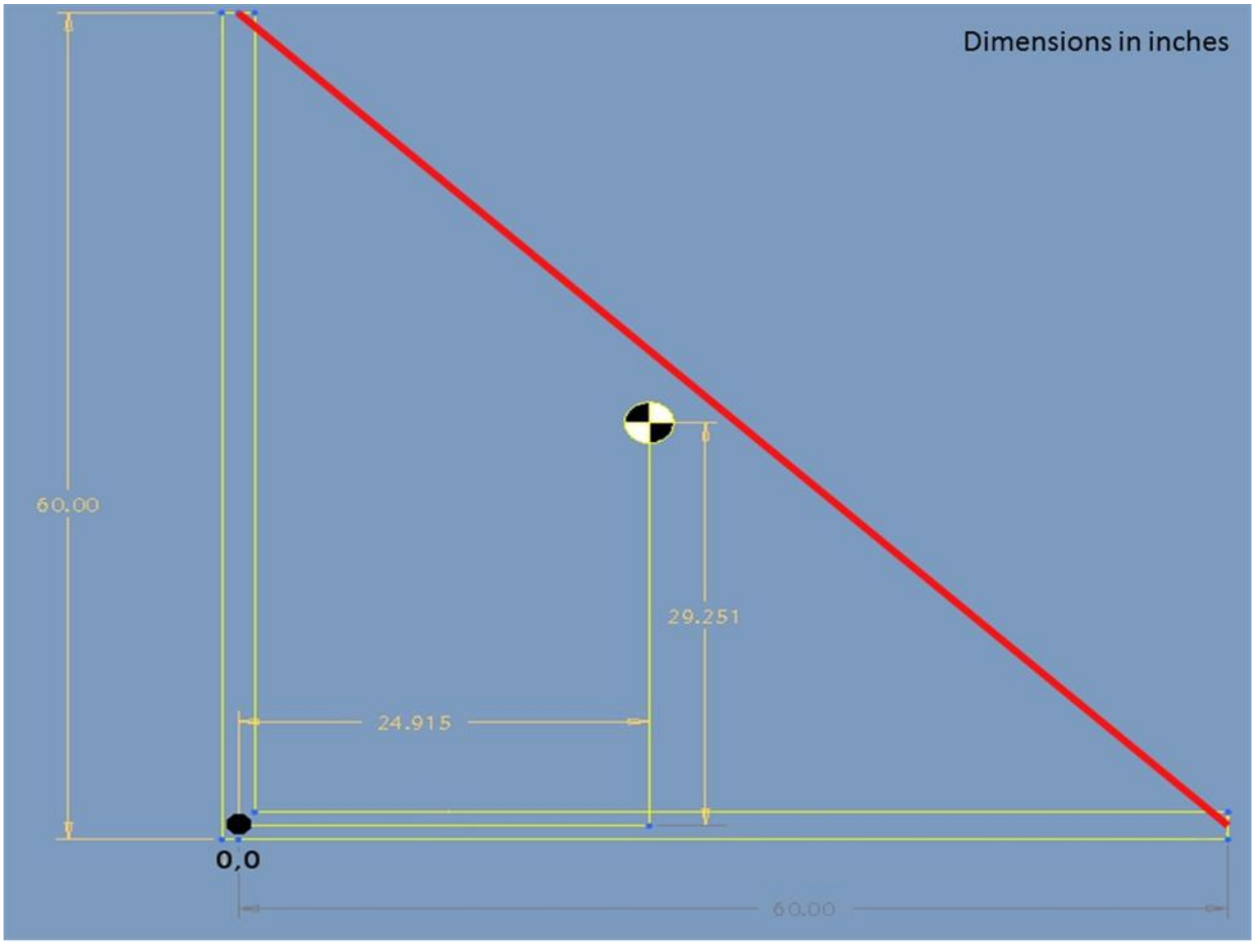


Figure 36 -Stability Analysis Result

This analysis shows that the system is stable when in the most the greatest overturning moment is being generated. However, this analysis is not all inclusive and does not represent the dynamic effects of momentum on the system. In order to prevent accidental tipping during unforeseen circumstances, a redesign is currently in progress to establish a mounting system which could fix the mechanism to the milling machine, preventing any loss of stability.

Barrel Cart Analysis

The Barrel Cart is primarily comprised of 3 components.

1. Frame
2. Bearing Rod
3. Barrel

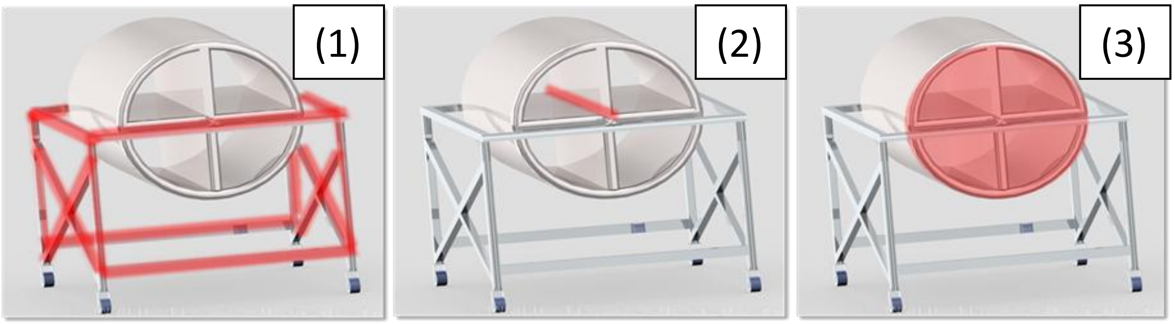


Figure 37 - Barrel Cart Analysis Locations

The components depicted in Figure 37 were the ones chosen to focus on during the Pro Engineer Mechanica analysis. The wheels were neglected during the analysis because the dynamic load ratings on the caster wheels were much greater than the loads that were actually applied to the barrel system. A load of 500lbf was estimated as the analysis parameter. In locations that could result in catastrophic failure, such as the bearing rod, the load was applied as a point force rather than a distributed load. For the barrel analysis, the load was distributed over the inner surfaces of the barrel to simulate the weight of the blades acting throughout the system. In order to determine the approximate displacements of the mechanism, a material was selected for each component based on the stress results and its properties were applied to the analysis. Table 4 below depicts the values obtained through the calculations.

Table 4 - Barrel Cart Stress and Displacement Results

Component	**Stress (ksi)**	**Displacement (in)**
Frame	4.58	$3.12*10^{-2}$
Bearing Rod	19.27	0.150
Barrel Surface	$1.4*10^{-2}$	$7.5*10^{-5}$

Free body diagrams

Every time the human body moves there are forces that act upon it. While designing a task it is best to minimize these forces, especially those pertaining to certain trouble areas known for causing work-related musculoskeletal disorders (WMSD). In the case of examining a person reaching down to pick up a 68k turbine forging, the forces are dangerously high in the lower back. When the worker bends forward to grasp the forging, their back muscles are excessively strained in order for the worker to keep their balance. The combination of the mechanical stress caused by lifting a heavy forging and the forces exerted by the muscles of the erector spinae produces a potentially harmful environment for the workers' lower back. The specific force of concern is the resulting reaction force in the axial and shear planes of the vertebrae. These forces can result in the fracture of vertebral bones and/or injury of intervertebral discs. Excessive shear forces can even result in the dislocation of adjacent vertebral bones and as well as damage to the surrounding intervertebral discs.

After evaluating the free-body diagram, of the worker performing the task of extracting a 68k forging from a storage container, it is found out that the axial force(Ra) acting upon the workers' back is 2849.77 N. This force is much too high and much too dangerous for the worker to perform during every shift. If this force is not reduced soon, the worker performing this task may not be able to perform it for a long period of time.

A free body diagram depicting the forces on the worker can be seen in Figure 38. The forces W1 and W2 represent, among other things, the weight of particular body segments. These weights are calculated through the use of anthropometric data (from some article reference) which give the segmented weight as a percentage of the total body weight. For instance, W1 is the weight of the thorax and abdomen. According to the anthropometric data, that portion of the body weighs approximately 36% of the total body weight. W2 includes the weight of the head, neck and both arms in addition to the weight of the forging. That weight is approximately 18% of the total body weight. Along with the weights, there are some angles that are taken into account when calculating force exerted on the lower back. The angle that the waist bends is critical; moreover, the angle of the force exerted by the back muscles supporting the spine is equally detrimental. In the case of the 68k process, the bending angle at the waist is approximately 45 degrees. Improving this angle is imperative because the higher the degree of the angle, the greater the strain is on the back. The force of the muscles stabilizing the spine, and the reaction shear and axial forces are found using the segmented weights previously mentioned. If the reaction forces are high, the operator is at great risk for WMSD.

$\mathbf{W_1}$ = weight of thorax & abdomen taken from the midline of the body

$\mathbf{W_2}$ = weight of neck, arms, and the weight of the blade

$\boldsymbol{\alpha} = 13^0$, angle of the back muscles

$\boldsymbol{\theta} = 45^0$, angle of bend at the waist

F = Force of the back muscles stabilizing the spine

Rs = 66.08 N

Ra = 2849.77 N

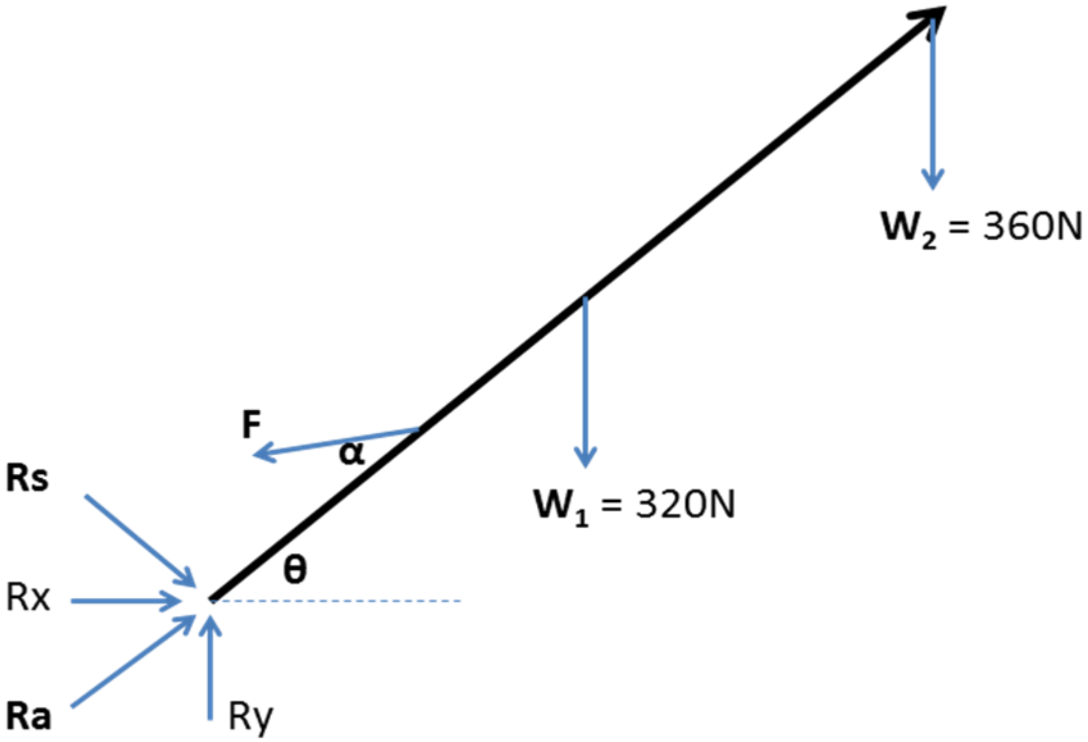


Figure 38 - Force FBD in Worker

<u>ARENA</u>

Arena is a simulation program used to demonstrate and measure a particular process or system. Correctly utilizing the program's various functions, a working model can emulate the behaviors of a real-world situation. The key to successfully measuring a system is to set up an accurate baseline model, a model that flows and bottlenecks in the same respective areas. The 68k process model depicts the actions performed from retrieval of six forgings through the first machine in the broaching area. The purpose of this model is to ensure no productive is lost due to implementing the new set of procedures as well as identifying opportunities for improvement. The model is shown below in Figure 39.

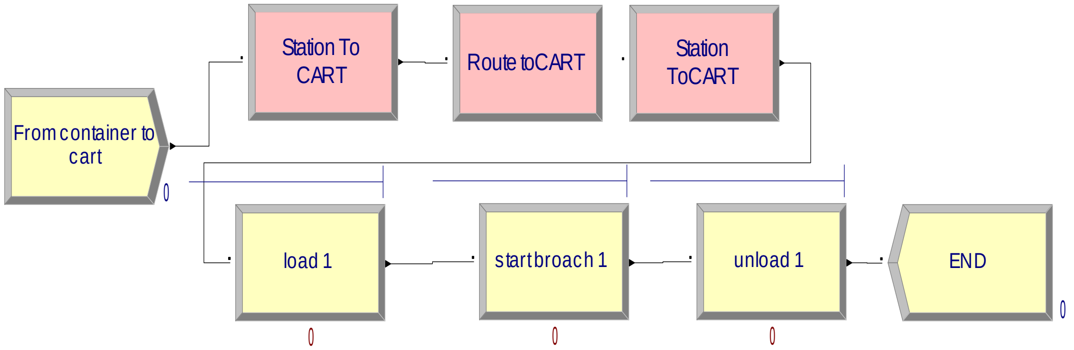


Figure 39 - 68K Process ARENA Model

Analyzing the model depicting the 68k blade process shows that the longest wait times are attributed to the queue of the first broaching machine. Since these can only negligibly be reduced, the focus is placed on the retrieval of the forging from their storage containers. The barrel mechanism is designed to aid the operator in extracting a forging from the container. Not only will the new procedures provide a safer alternative to the existing process, but potentially improve the efficiency of forging retrieval. Arena is the tool used to accomplish this measurement of the different processes.

NIOSH

The NIOSH lifting equation which stands for National Institute of Occupational Safety and Health, is an equation used for finding the recommend weight limit for a process. The equation uses several different factors which yield a recommended weight limit for the object to be in that analyzed process. The equation takes into account the origin and destination of the object; the origin being where the object is lifted and the destination being where the blade is placed. After analyzing the process the recommended weight limit became 13.38 lbs and 16.31 lbs respectively for the origin and destination compared to the actual weight of the blade, 45lbs. Once the recommended weight limit is found, the lifting index can be calculated. The lifting index is a scale which takes in to account the weight of the actual object and what is recommended by the equation. With both factors being known, the lifting index can be calculated. The higher of the two must be considered for further analysis in order to compensate for the worst case scenario. The lifting index for the origin became 3.36 and the destination lifting index is 2.76; therefore 3.36 is compared to a scale. If the lifting index is below 1, then there is low risk for the operator, if the lifting index is between 1 and 3 there is some risk and should be looked at for redesign. The worst case scenario is if the lifting index is greater than 3, which means there is risk to most individuals and should be redesigned as soon as possible. Knowing the calculated lifting index for both the origin and destination, the lifting index shows that the process should be analyzed and redesigned as soon as possible. Knowing the different factors for the recommended weight limit, many measurements and weights can be changed so the operators are less prone to injury. The load should be brought closer to the body to lower the strain on the operator's back and body. Raising the origin of the object could help eliminate the bending and lifting of the blade. The NIOSH has given a better understanding that the operator is at risk and the process should be looked at further and redesigned very soon.

Multi-Task

The purpose of the NIOSH lifting equation is to rank the alternatives, not give absolute risks. Single tasks provide a recommended weight limit; composite lifting index accounts for incremental changes from one task to another. The multi-task assessment is more accurate than a simple single-task evaluation and is compared to the same scale as the single task. Currently, eight blades are lifted in this process. To account for the additional lifting involved, the multi-task lifting index is calculated. The resulting index, 3.73, indicates a negative effect after lifting additional blades of the same weight. Evidently, this index illustrates a greater need for change than the single task lifting equation. The theoretical, proposed method will decrease the index drastically in both single and multi-task equations. The removal of lifting in the process will prevent the operator from fatiguing.

Material Selection

The constraints, for material selection purposes are specific to some component of interest. When examining the linear guide rails, for example, the main constraint is to withstand a minimum force without yielding. Other constraints pertain to the parameters. The main objectives that also served for the entire mechanism are to minimize the mass and cost of the material. In Table 5 it is seen how these objectives are solved for and a 'Material Index' is derived. A material index is a tool used to identify all possible material classes that fit the objective. These classes consist of foams, natural materials, ceramics, polymers and elastomers, and metals. Due to size, elasticity, and durability purposes, this mechanism was constrained solely to the class of metals. As illustrated in Table 6, the top 4 subclasses were then evaluated and compared based upon yield strength, density, and cost per kilogram. The zinc alloy subclass was the 1st to be eliminated due to high cost and the lack of strength to compensate for this cost. Next, due to availability, the high carbon steel was eliminated due to availability issues. Thus the remaining subclasses were aluminum alloys and low carbon steels. After research on various individual properties, the final selection of materials consisted of aluminum 6061 T6, 1566 steel, and 4140 multipurpose steel. Comparing the materials, steel proved to be very strong and durable but expensive. Aluminum 6061 T6 is light and cheap, but also has relatively medium strength. In the midst of the stress analysis, another factor arose. Aluminum 6061 T6 is a case hardened metal. When this grade metal is welded, it is returned to its annealed state, aluminum 6061 O. This is depicted in Table 7. This change in grade will force the overall strength of the metal to decrease by around 80%. Because of this issue, all relating parameters were optimized to efficient standards.

Table 5 - Material Equations

Equation	Description
$m = LA\rho$	Objective Function
$F_f = \frac{CZ_p\sigma_y}{L}$	Failure Force (cantilevered beam)
$A = \pi r^2$	Area
$Z_p = \frac{\pi r^3}{3}$	
$m = L\pi r^2\rho$	
$r = (\frac{m}{L\pi\rho})^{\frac{1}{2}}$	
$F_f = \frac{C\pi r^3\sigma_y}{3L}$	
$F_f = \frac{C\pi\sigma_y(\frac{m}{L\pi\rho})^{\frac{3}{2}}}{3L}$	
$M = \frac{(\sigma_y)^{\frac{2}{3}}}{\rho}$	Standard material index equation (cantilevered Beam)
$m^{\frac{3}{2}} = \frac{3LF_f(L\pi\rho)^{\frac{3}{2}}}{C\pi\sigma_y}$	
$m = C^{-\frac{2}{3}} * (3F_f)^{\frac{2}{3}} L^{\frac{5}{3}} \pi^{\frac{1}{3}} * \frac{\rho}{(\sigma_y)^{\frac{2}{3}}}$	Altered mass eqn. – relates in Material index
$m = \frac{1}{C} * (3F_f)^{\frac{2}{3}} L^{\frac{5}{3}} \pi^{\frac{1}{3}} * \frac{1}{M}$	
$M = \frac{(3F_f)^{\frac{2}{3}} L^{\frac{5}{3}} \pi^{\frac{1}{3}}}{m\,C^{\frac{2}{3}}}$	Final Material Index Equation – used to find top 4 subclasses ***Maximize Material index to maximize objective >> Minimize Mass

Table 6 - Initial List of Potential Materials

Material	**Strength σ_f (MPa)**	**Density ρ (Mg/m^3)**	**Cost C_m ($/kg)**
Al Alloys	30 -500	2.5 – 2.9	1.5 – 1.7
Low Carbon Steels	400 – 1100	7.8 – 7.9	0.81 – 0.89
Zinc Alloys	80 – 450	4.95 – 7.0	1.2 – 1.3
High Carbon Steel	400 – 1155	7.8 – 7.9	0.72 – 0.80

Table 7 - Property Variation of Aluminum Due to Welding

Materials	**Aluminum 6061 T6**	**Aluminum 6061 O**
Ultimate Tensile Strength (UTS)	42,000 psi (300 MPa)	18,000 psi (125 MPa)
Yield Strength (σ_y)	35,000 psi (241 MPa)	8,000 psi (55 MPa)
Notes:	*Welding induced strength loss *Loss of strength of 50 – 80%	

Table 8 - Aluminum and Steel Comparison

Materials	**Steel (Multi-Purppose 4140)**	**Aluminum 6061 T6**
Tensile yield strength	417.1 MPa	276 MPa
Modulus of elasticity	190 – 210 GPa	70 – 80 GPa
Pros	Very high strength	Light weight, cheap
Cons	Heavy & expensive	Medium

Cost Analysis

Cost analysis is a systematic tool for calculating the costs and advantages for a project when taking into account the different materials that could possibly be used along with the corresponding measurements for the part. The sizes of materials can vary depending on the material used and the amount of pressure applied to the part. A cost analysis can balance out the mechanical requirements with financial constraints. The main reason for doing a cost analysis is to see what material should be used for the project because of its feasibility. When comparing the materials, there should be a ranking system to show which material is better to use compared to the others, along with benefits for each material. This should give a better understanding of the materials that should be chosen depending on the benefits and cost that are within the budget. The objective of a cost analysis is to receive the maximum benefits while staying within the financial constraints.

The materials being analyzed for design cost are aluminum 6061 and multi-purpose steel 4041.

Table 9 - Steel vs. Aluminum Cost Analysis

Materials	**Steel (Multi-Purpose)**	**Aluminum 6061**	**Combination**
Total Material Cost	$ 3276.86	$ 1420.91	$ 1860

4041 steel and 6061 aluminum have similar properties. 4041 steel is very tough with a high strength rating, and is also very easy to weld. 6061 aluminum has medium to high strength and is very easy to machine. 4041 Steel has a higher tensile yield strength and modulus of elasticity than 6061 aluminum but is more expensive. An approximate cost for the all steel L-Cart would be $ 3276.86 compared to an all aluminum cart that costs about $ 1420.91. There is a large cost difference between these two models. 6061 Aluminum is the most feasible material for the majority of the L-Cart. The combination of 6061 aluminum and 4041 steel will give the cart the necessary properties to withstand the pressures of the process. The majority of the L-Cart will be aluminum except for the parts which endure the highest level of stress. The steel is required for critical stress level parts because steel is the stronger material.

Bill of Materials

The bill of materials included is a list of the materials required for the product being manufactured. The list in Table 9 shows an approximate list of parts and the cost for strictly the L-Cart due to unexpected financial constraints. Further investigation into concept designs will be needed over the following weeks. Upon reaching a final design, a new bill of materials will be generated.

Table 10 - L-Cart Bill of Materials

Material	Length (inches)	Width	Height	Wall Thickness	Size	Quantity	Price	Part Number	Cost
Aluminum square tube	21.833	2	2	0.25	6ft	6	89.54	6546K271	537.24
Steel tubing					6ft	2	52.11	89955K89	104.22
Bearings closed						4	72.53	9338T4	290.12
Bearings open						2	89.93	9338T17	179.86
Linear guide						2	213.85	59585K85	427.70
Stock steel						1	28.25	6554K311	28.25
Aluminum lower platform	24	24		0.19		1	107.34	89015K33	107.34
Aluminum angled support	1	1		0.125		1	25.04	6546K11	25.04
Angled support flat platform	12	24		0.19		1	58.60	89015K32	58.60
Bearings						2	50.57	6359K37	101.14
Total Price ($)									**1860**

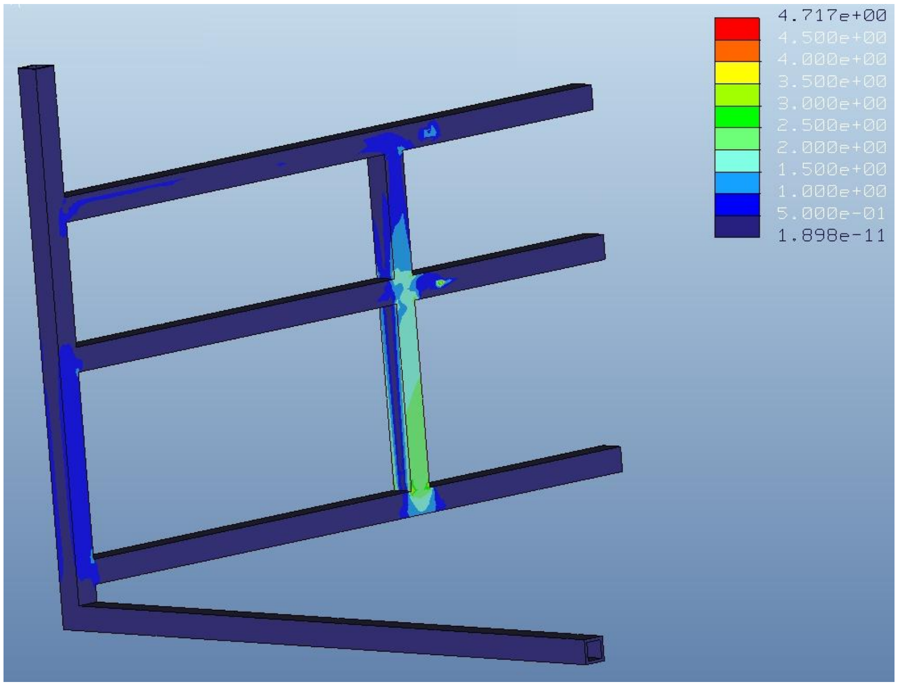
Summary

The problem presented by the customer, TECT Power, was analyzed and quantitative requirements were derived from their requests. After thoroughly defining the voice of the customer, observations were made and measurements were taken to set up a baseline for improvement. These measurements include: Time studies an Arena simulation, the Rapid Upper Limb Assessments (RULA), the NIOSH composite lifting index, free-body diagram input into Arena simulation. The time studies were conducted to obtain accurate information on the behavior of the current process and they were also input into the program Arena to better understand the flow and areas of process improvement. The RULA evaluations were used to determine the level of risk involved in the current process. It was also used as a factor for the decision matrix safety portion. The lifting index is inclusive of single as well as multi task procedures. They rank which alternative job is best. From our lifting index it was concluded that both single and multi task jobs were harmful to the operator because they scored above three. The free-body diagram identified the amount of pressure placed on the base of the spine. This area is critical because it may cause work-related musculoskeletal disorders. To prevent injury, multiple design concepts were generated and through the use of a decision matrix, the most feasible designs were chosen. A finite element analysis was performed on both the L-Cart and the Barrel Cart designs in order to determine which types of materials should be chosen and the structural stability of the presented designs. It was determined that the majority of the cart frames could be constructed of Aluminum 6061, while areas containing a higher stress concentration will be manufactured from 4140 or 1566 steel. The combination of both cart designs would virtually eliminate lifting from the current process implemented at TECT Power. By implementing the new designs into the process the force on the lower spine will decrease allowing for less potential of injury. The loading portion of the process will be the focus as it yields the greatest opportunity of improvement. However, due to unforeseen financial problems, the given budget is half of the originally plan. With this variation in product constraints, the system will have to be redesigned to match the new budget.

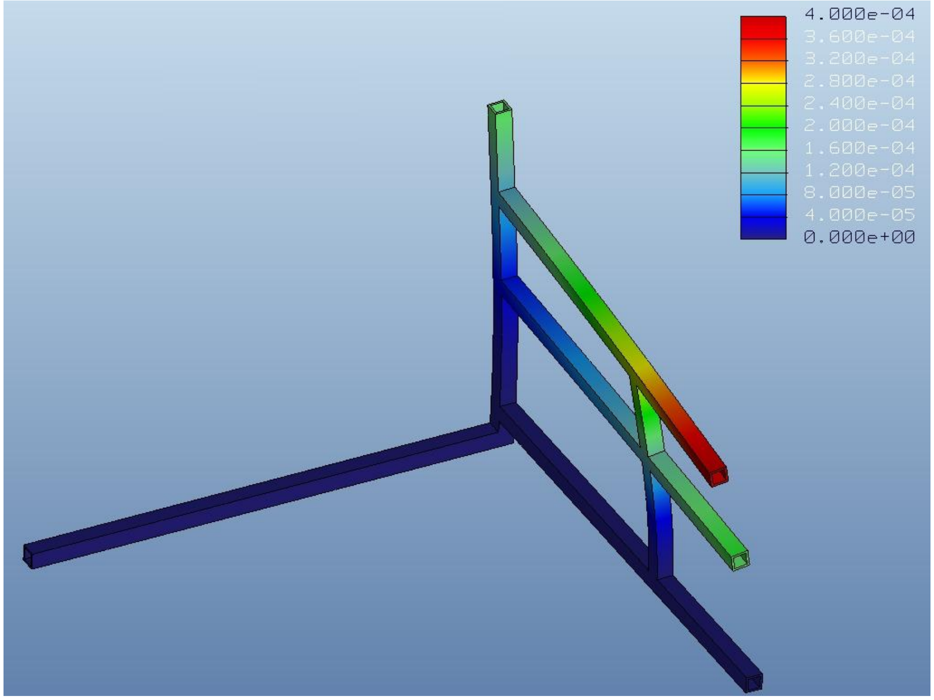
Appendix A: Stress and Displacement Images

L-Cart – FEA Images

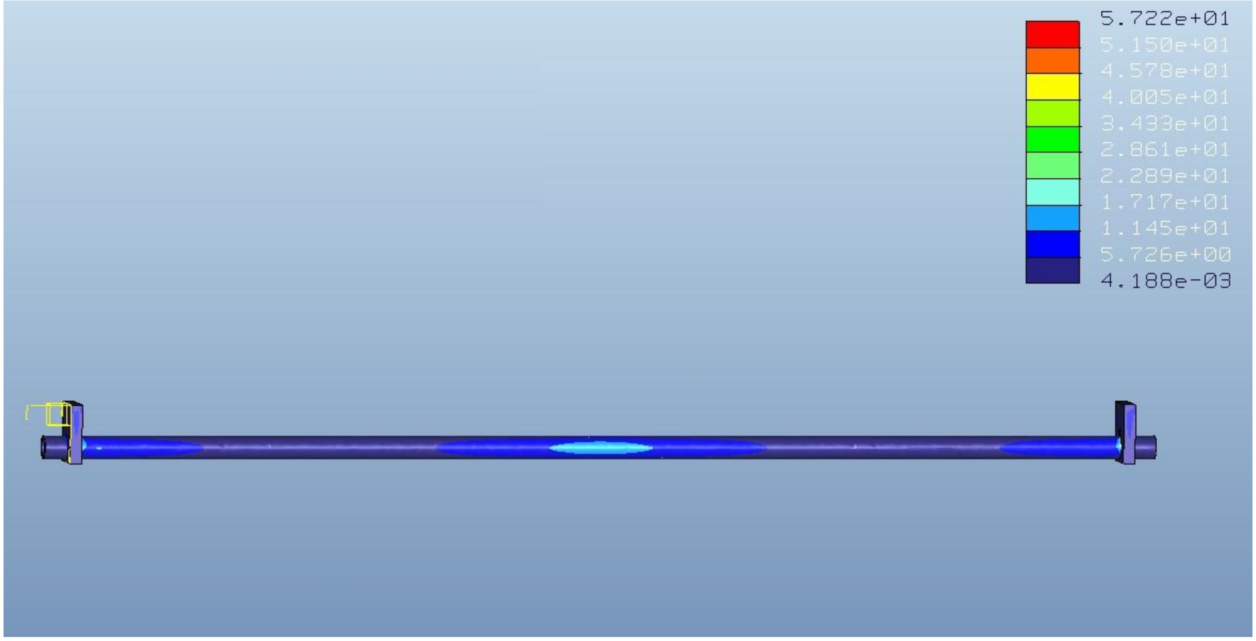
Frame – Stress (ksi)



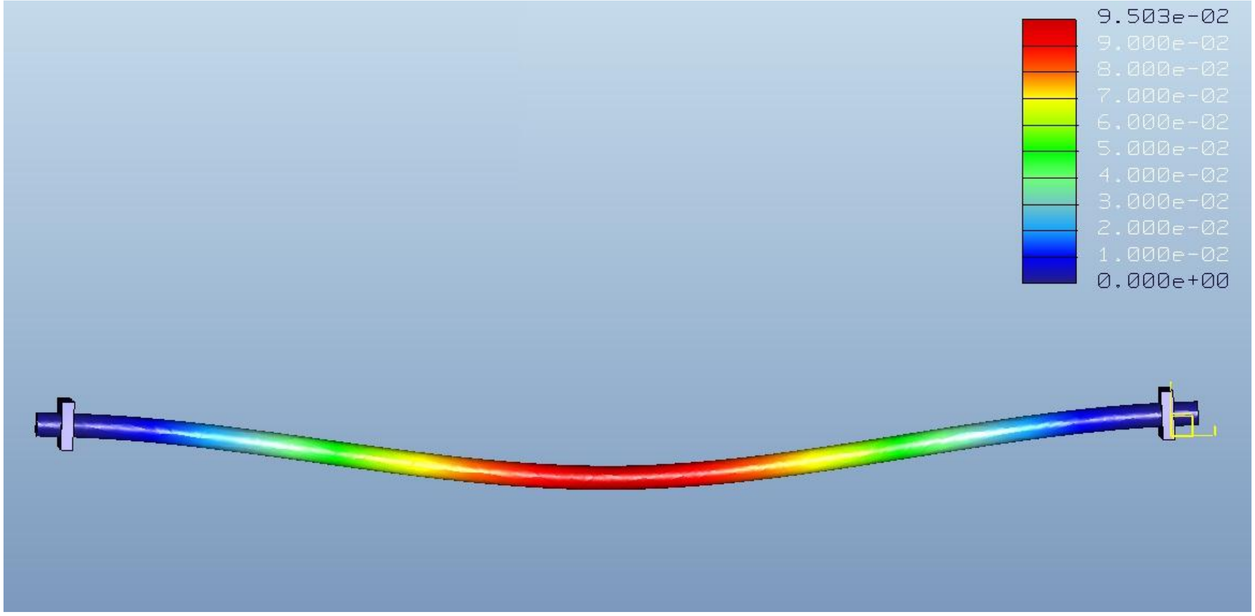
Frame –Displacement (in)



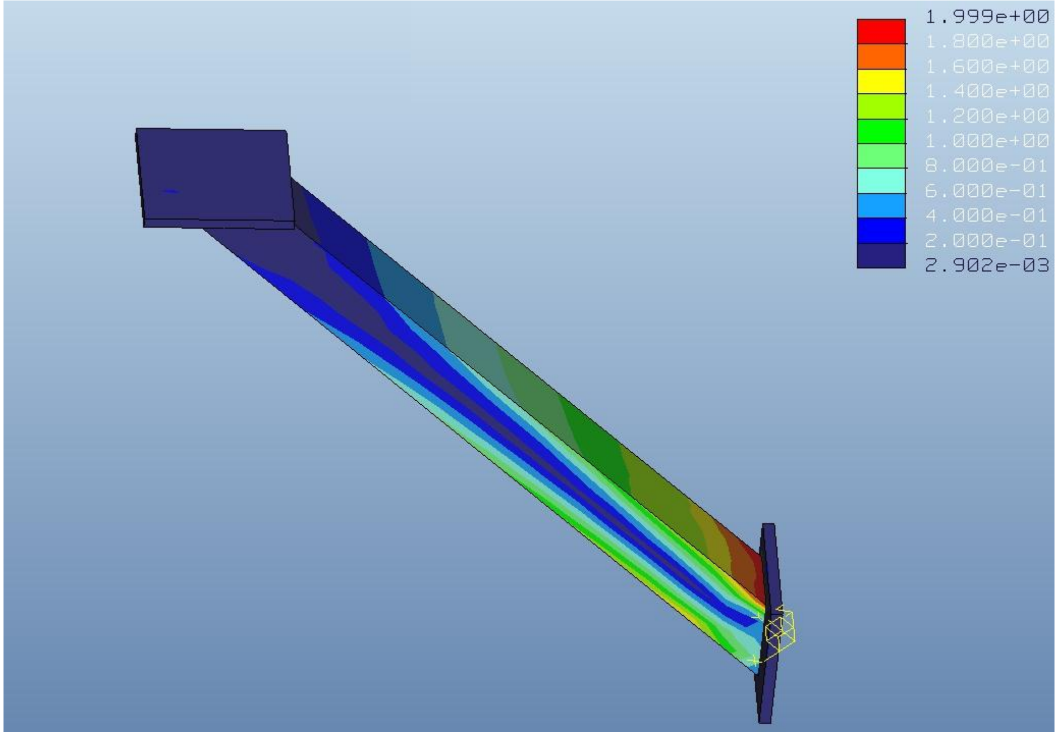
Bearing Rods – Stress (ksi)



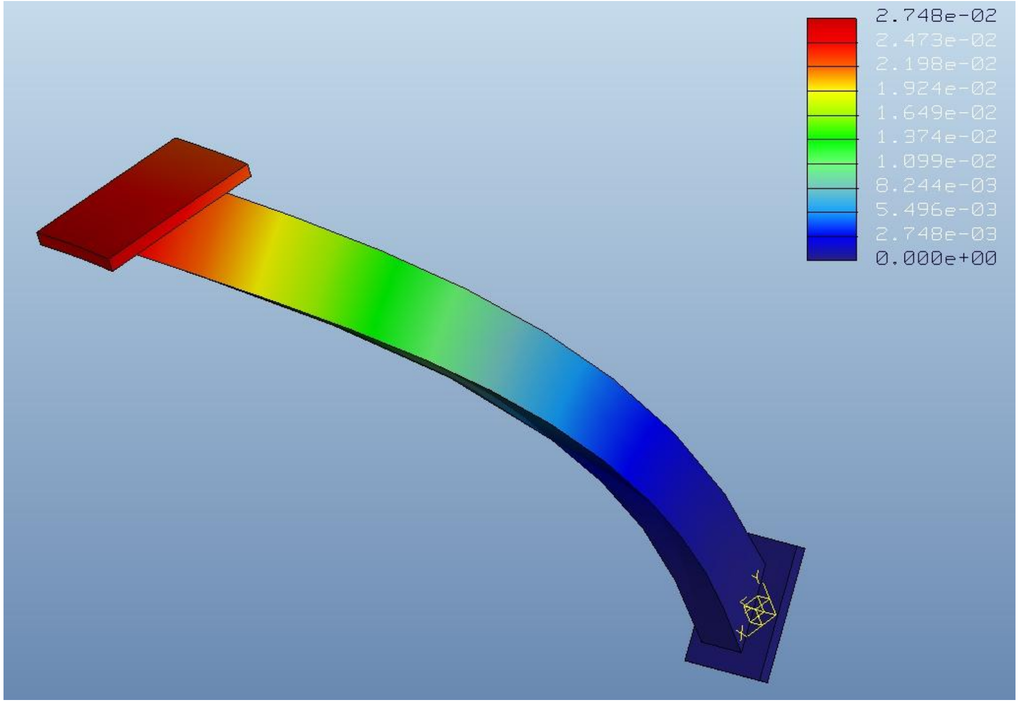
Bearing Rods – Displacement (in)



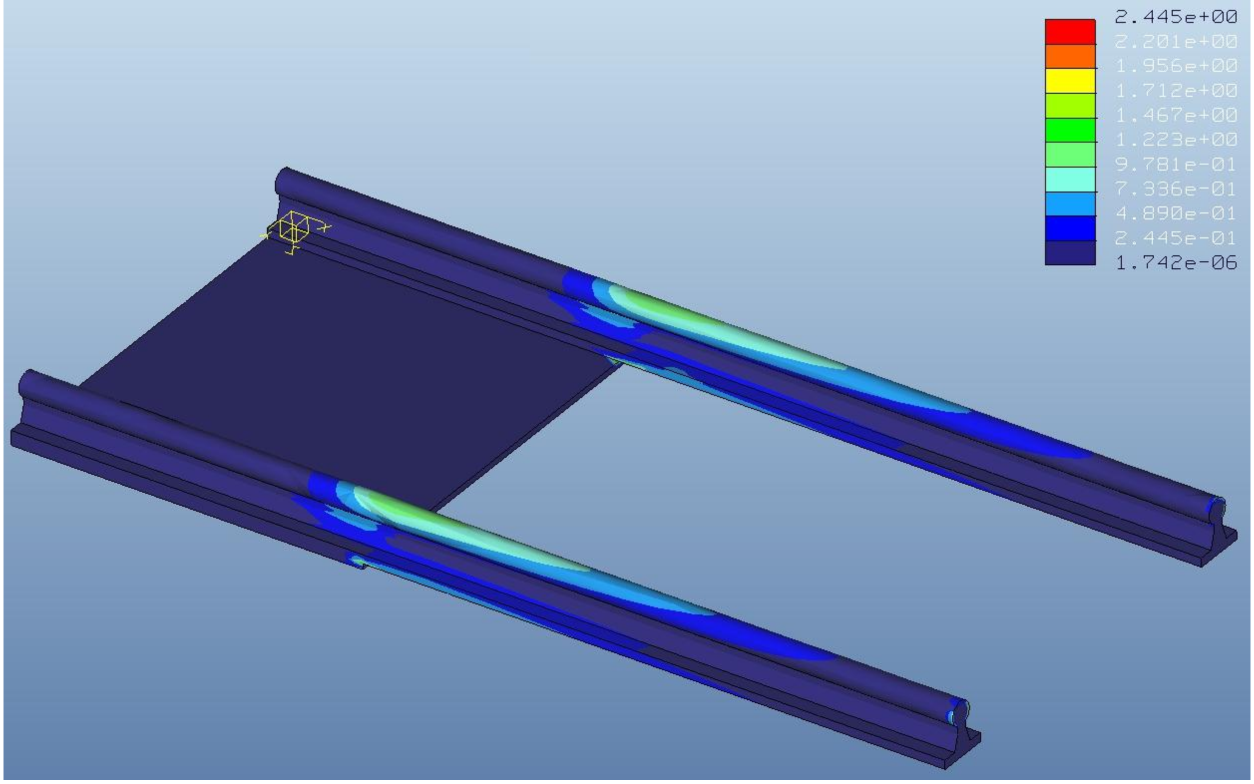
Angled Supports – Stress (ksi)



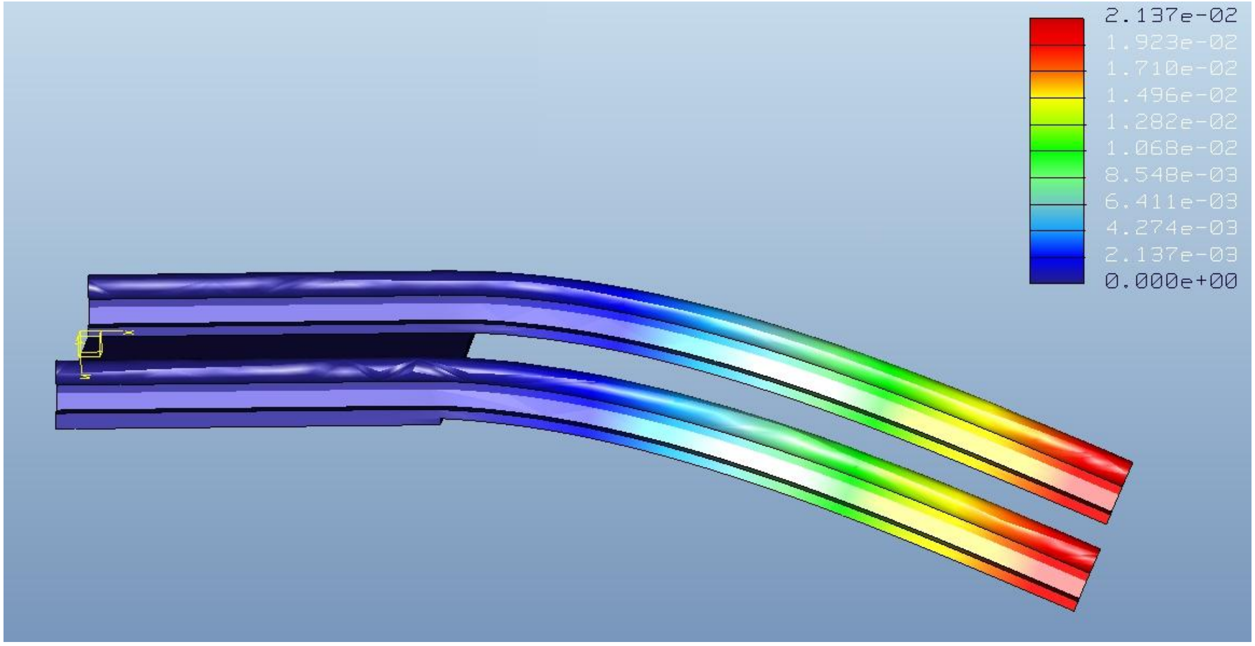
Angled Supports – Displacement (in)



Lateral Bearing Guides – Stress (ksi)

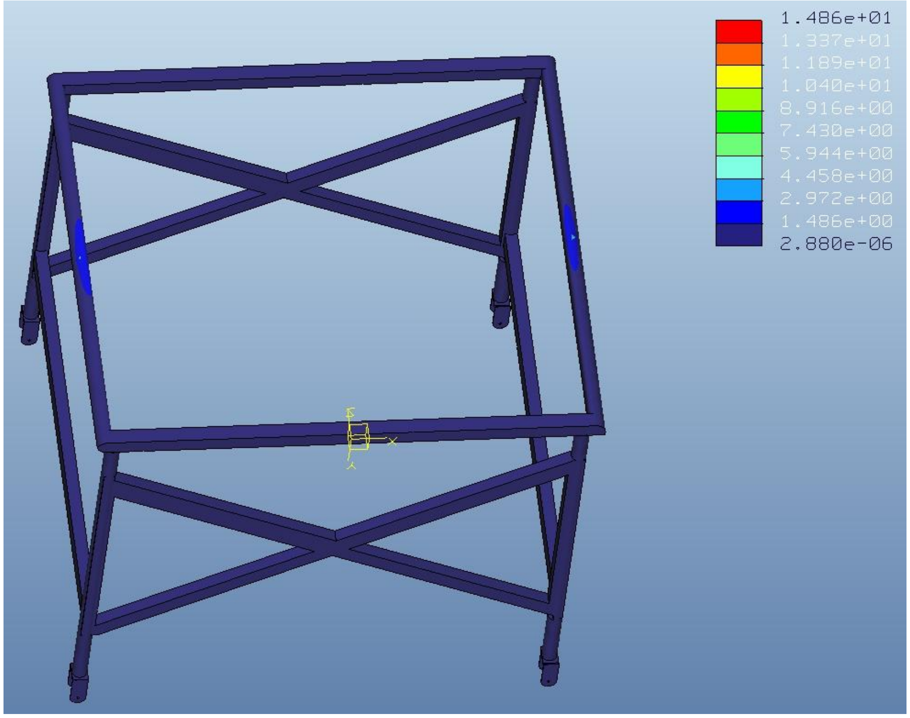


Lateral Bearing Guides –Displacement (in)

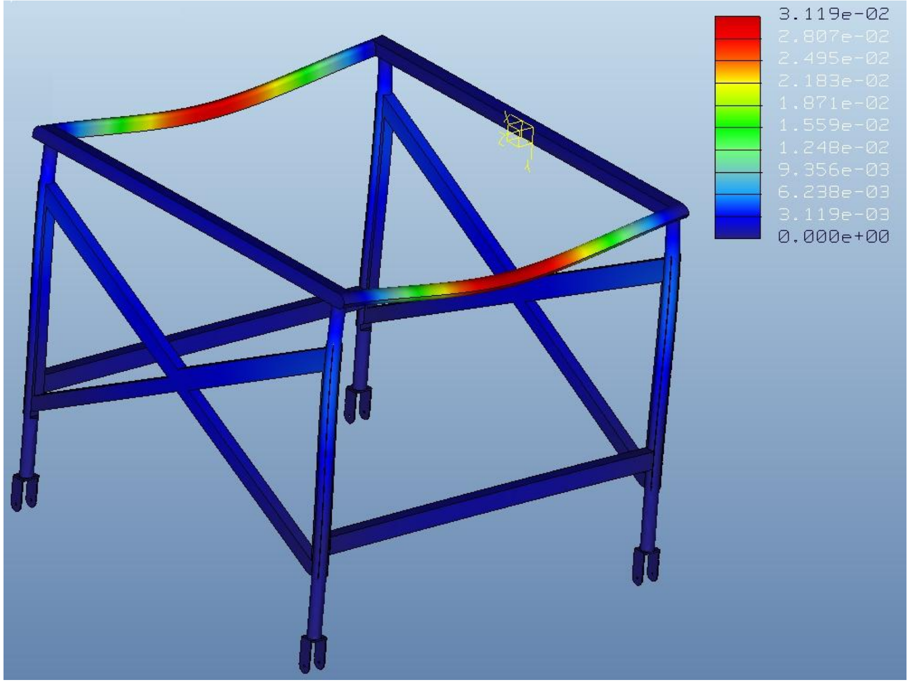


Barrel Cart – FEA Images

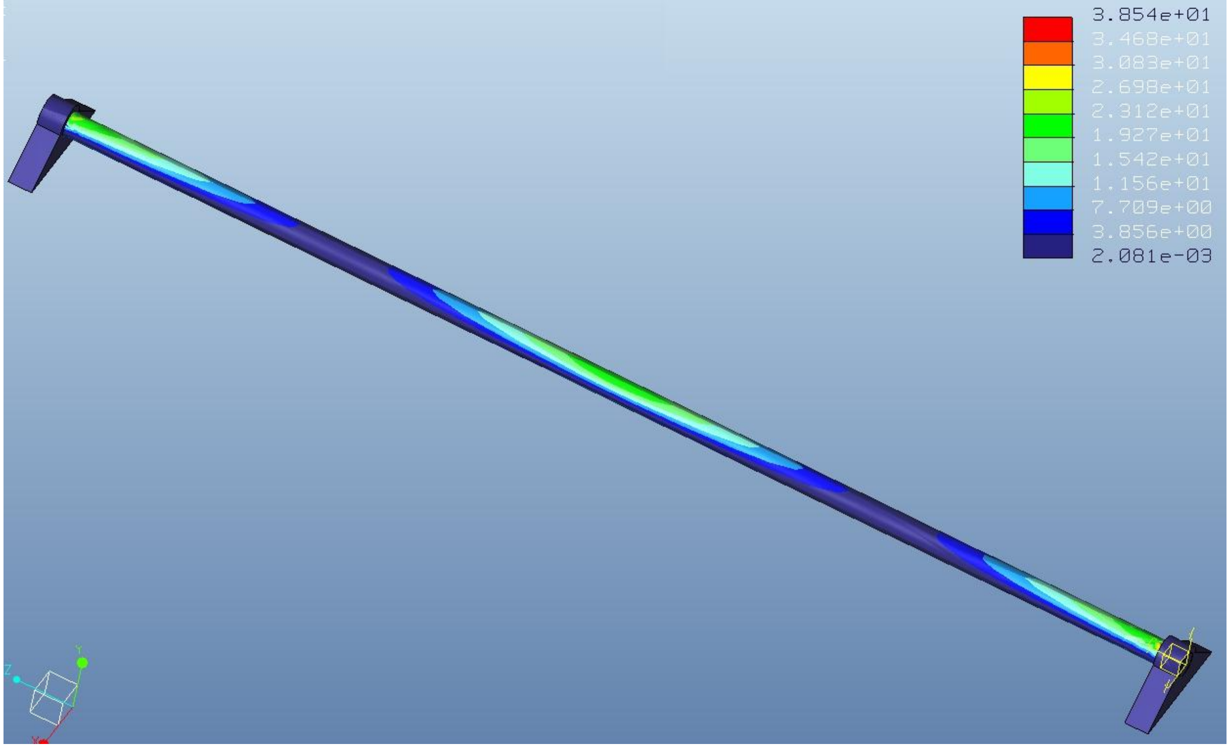
Frame - Stress (ksi)



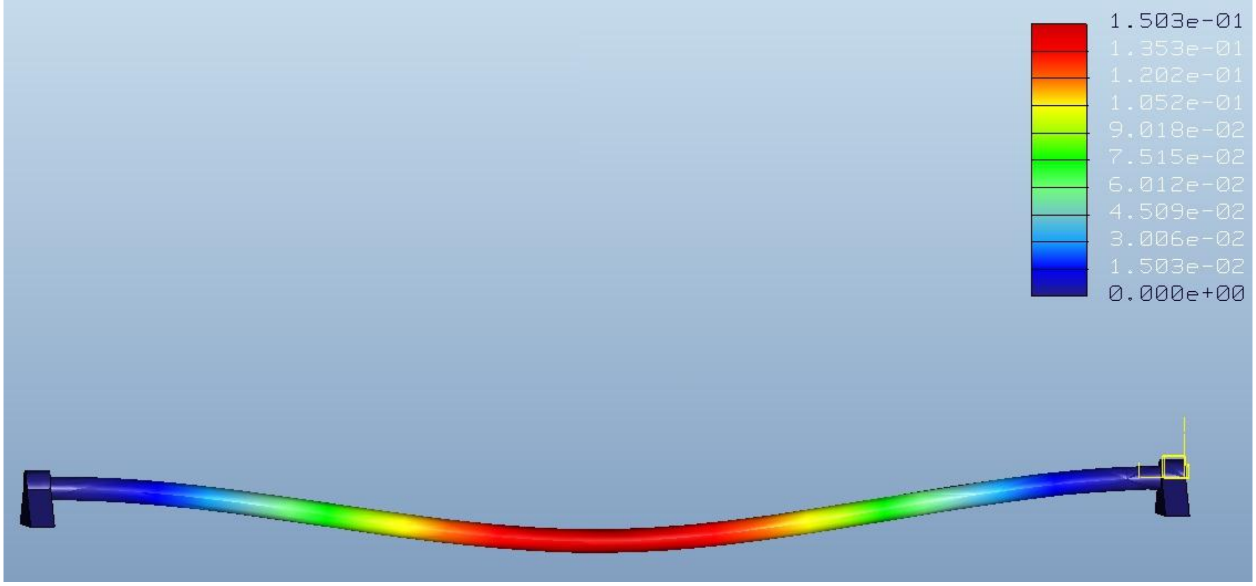
Frame - Displacement (in)



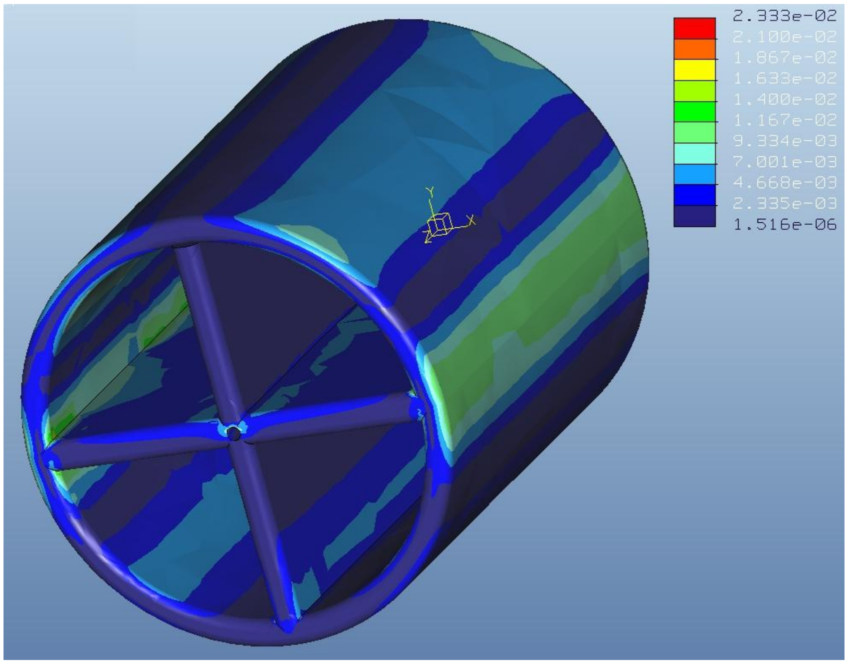
Bearing Rod – Stress (ksi)



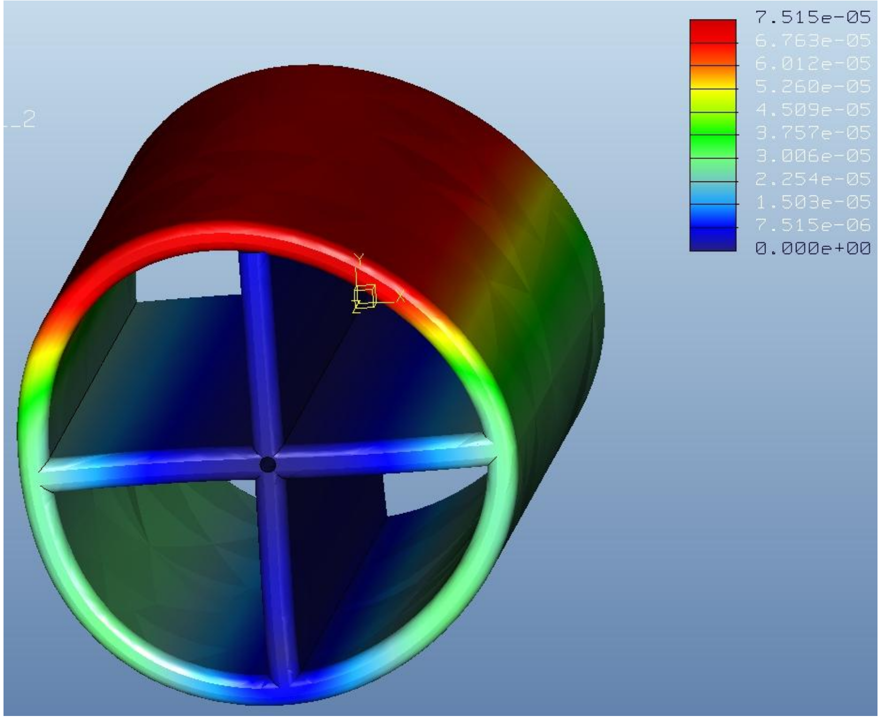
Bearing Rod – Displacement (in)



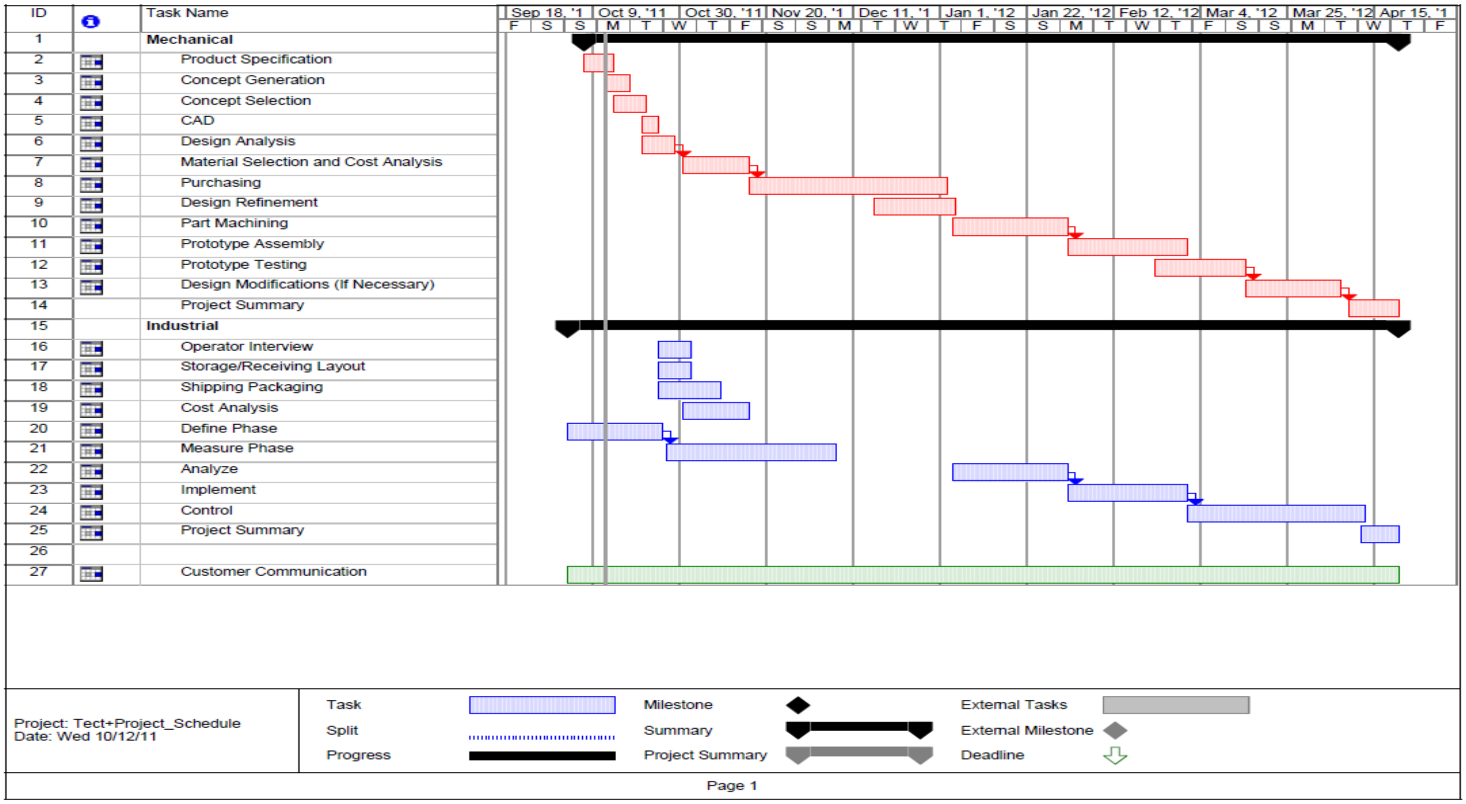
Barrel Surface – Stress (ksi)



Barrel Surface – Displacement (in)



Appendix B: Project Schedule



ID	Task Name
1	**Mechanical**
2	Product Specification
3	Concept Generation
4	Concept Selection
5	CAD
6	Design Analysis
7	Material Selection and Cost Analysis
8	Purchasing
9	Design Refinement
10	Part Machining
11	Prototype Assembly
12	Prototype Testing
13	Design Modifications (If Necessary)
14	Project Summary
15	**Industrial**
16	Operator Interview
17	Storage/Receiving Layout
18	Shipping Packaging
19	Cost Analysis
20	Define Phase
21	Measure Phase
22	Analyze
23	Implement
24	Control
25	Project Summary
26	
27	Customer Communication

Project: Tect+Project_Schedule
Date: Wed 10/12/11

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Special Thanks

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