MECH 4860

PT6 Gas Generator Case Stand

Team 3 - Final Report

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Dear Dr. Labossiere,

Enclosed is our conceptual design report entitled *PT6 Gas Generator Case Stand*. We have prepared this report for our sponsors at StandardAero as well as our reviewers at the University of Manitoba. The date of submission of this report is Wednesday, November 30th, 2011.

StandardAero has proposed this project to us and has supplied us with all of the necessary requirements and constraints needed to design a nickel plating stand. Our team feels that we are fully capable of assessing the problem and designing practical solutions that will meet all of the compulsory requirements of our client. The purpose of this report is to evaluate our initial conceptual designs and also to refine our overall designs to meet the requirements and specifications provided by our client.

This report will begin with an overall introduction followed by the problem statement and the background of the problem. We will then present our project objectives, target specifications, and our various search results. We will also include our initial concept generation, analysis and selection of designs, screening and scoring process, and our project organization. Lastly, our references will be included in the final section of the report. This report has been prepared by Adam Soliman, Erwing Salinas, Hao Xu, and Ye Qing Wang of the University of Manitoba.

While writing this report, we have received a tremendous amount of support from our sponsors at StandardAero, Travis Guenther and Andrea Harrison. We have also worked closely with Norma Godavari and Aidan Elizabeth Topping from the University of Manitoba Engineering Library. Last, but certainly not least, we have gained a vast amount of knowledge and guidance from our faculty advisor Dr. Meera Singh, course instructor Dr. Paul Labossiere, and teaching assistant Curtis Carrick. We would like to share our appreciation with all of the aforementioned individuals. Please feel free to contact any of the group members through the University of Manitoba with any comments or concerns regarding this report.

Sincerely,

Adam Soliman	Erwing Salinas	Hao Xu	Ye Qing Wang

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1. Executive Summary

This report contains a complete solution to the problem experienced by our client, StandardAero, while performing repairs in their facilities. StandardAero performs a nickel plating repair on the PT6 gas generator case. The setup for this repair is not ideal for safety and operational reasons. The technician performing the repair currently experiences difficulties while performing the repair due to the height of the cart supporting the components necessary to execute the plating repair. Additionally, the current cart does not meet the storage requirement within StandardAero facilities and is incapable of remaining stable when subjected to rotational loads commonly induced by the plating process.

In this report we include the detailed process of generating an optimal solution beginning with an analysis of the problem background, followed by the search techniques, concept generation, loading analyses, building components, possible commercially available alternatives, and a final optimal design. In addition, we include all costs and specifications of each purchased component selected for the final proposed design. Most importantly, we analyzed both static and dynamic loading conditions by hand and also numerically using advanced software to ensure that our results were accurate. A CAD model assembly has been created after selecting the best suitable material and geometry to help perform the analysis and calculations. Finite element analysis was employed to analyze and simulate both the static and dynamic loading cases.

We determined that the static stress distributed equally on the four legs will be 94.3 psi and that the deflection created by the rotating dynamic load will be a maximum of 0.0424 inches. The yield strength of the steel made to construct the cart is 34 Ksi, which is far removed from the axial load described above, ensuring that the cart will not fail under axial loads present during the nickel plating repair. The dimensions and materials of the stand's components are shown in Table XVII, and result in a total cost of $719.74 before taxes and shipping costs.

2. Introduction

StandardAero is currently using a generic cart as a repairing stand to perform a nickel plating repair on the PT6 engine's gas generator case. Since the cart is not specifically designed for this process, there are some issues with its operating conditions that affect the safety, mobility, and storability of the plating equipment. Our team is required to design a customized repairing stand that will meet all of the requirements of the nickel plating process.

2.1 Problem Statement and Background

In order to fully understand the problem that the client is experiencing, we must first understand the background behind the plating process. Figure 1 below shows the entire setup currently being used by StandardAero.

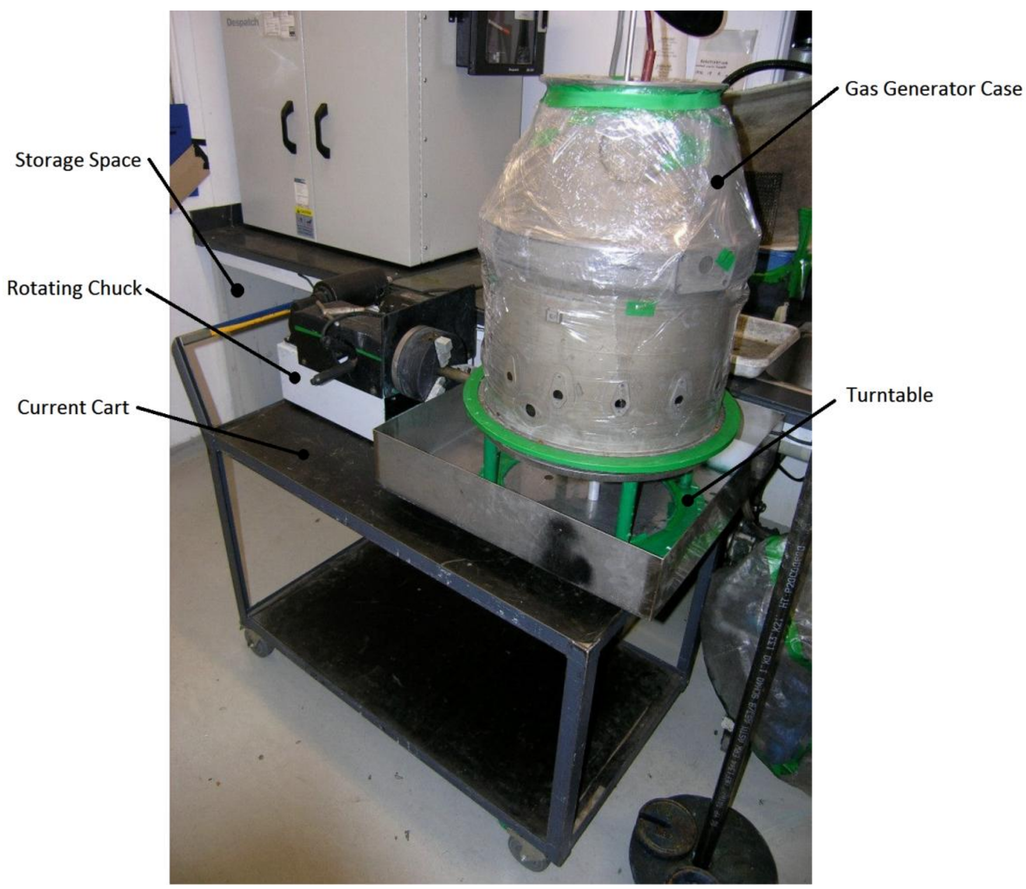

Figure 1. Current Plating Setup [1].

The full setup includes four main components – the stand, the rotating chuck, the turntable, and gas generator case as shown in Figure 1. To begin the plating process, a manual operator first puts both the rotating chuck and the turntable on the cart. Then, he places the gas generator case on the turntable and turns on the rotating chuck. The rotation from the chuck is translated through a driveshaft to a bevel gear underneath the turntable and thus, the turntable and gas generator case both rotate in unison. The bevel gear under the turntable has a 3:1 gear reduction, and in order to spin the gas generator case at the required 80 RPM for the plating process, the rotating chuck must rotate at 240 RPM. Predictably, the rotational inertia from these parts is transferred to the cart, and since the cart is not designed for this type of loading, it becomes very unstable. This is not only an issue of safety, but also may cause an issue with the quality and consistency of the plating repair process.

The main structure of current cart is made of mild steel and the top face of the cart is made of wood. There is also a thick rubber isolation ply on top of the wood to help dampen the vibration from the rotating turntable and gas generator case. The cart has two swivel wheels and two fixed wheels, neither of which are equipped with a brake function.

While the plating process is being performed, the operator must be able to observe the surface being plated in order to measure the thickness of the plating solution. With the height of the current cart, the operator needs to use a steeping stand to be able to see this surface. Not only does the stepping stand inconvenience the operator, but if he were to lose his balance while the gas generator case was rotating at 80 RPM, he could very seriously injure himself. To continue the use of the current stand is a recognized safety risk and safety is always the first priority in any professional industry.

Another problem with the current setup is that the cart is being temporarily borrowed from another department in the StandardAero facility. While the plating process is taking place, the other department is missing one of their carts and causes an inconvenience and prevents them from moving parts as quickly as they need to.

The final major concern with the current cart is the amount of area it takes up in the plating room. Since space in the plating room is very limited, a large cart sitting in the workspace is not ideal when the plating process is not taking place. The current cart takes up approximately half of the floor space in the room and makes maneuvering equipment difficult. It would be ideal if we could take advantage of the storage space seen under the counter in Figure 1 to store our stand when not in use.

Overall, the cart is not designed to support the nickel plating repair process and fails to meet the safety, operational, and dimensional requirements of the process.

2.2 Objectives

The objective of this project is to design a customized stand to support the nickel plating process with no safety concerns, minimum size, high mobility, and high stability for StandardAero. The following requirements will be integrated into our final design.

- Safety of both the operator and the work piece
- Stability to support the weight of the work piece and plating equipment
- Rigidity to absorb the vibration induced due to the plating process
- Mobility/maneuverability to allow for easy movement as needed
- Setup and storage simplicity to minimize set-up and operating time

2.3 Target Specifications

After meeting with our client, our target specifications were very well defined and have been listed below.

1) The new design must fit into a storage space of 26” wide x 32”high x 33”deep.

3) The design must support both the chuck and turntable when operating.

4) The stand must be mobile enough for one operator to be able to store it.

5) The turntable must have a minimum drainage height of 18”.

6) The stand must be able to hold the repair equipment and work piece together.

7) The stand must be mobile for set up and storage, but stationary when in use.

8) The design must be optimized to minimize vibrations.

These specifications have been quantified and arranged in Table I below.

Table I. DEISGN SPECIFICATIONS

Specification	Metric	Description
Length (Storage)	Min: 24” Max: 32”	Storage space is 32” deep Turntable is 24” x 24”
Length (Plating Process)	50”	Support the chuck and fixture
Width	Min: 24” Max: 26”	Turntable is 24” x 24” Storage space is 26” wide
Height	19”	<18” is too low for the drainage system >20” is too high for the operator
Load Capacity	> 150lb	Total weight is ~150lb
Mobility	High	Easy to set up, store, and move the stand
Stability	High	Stationary in plating process
Vibration	Minimum	Minimize the vibrations

Our sponsors have also included that they have an approximate budget of $1500.00 for the materials and construction of this stand. Our team has designed our stand to be constructed of materials only costing half of this amount.

3. Search Techniques

Since we are designing a unique part, we must first understand what materials are available for construction, what standards and codes we must meet in our design, and also if there are any patents we should be aware of while selecting our components. Sections 2.1 through 2.5 of this report cover this information in detail.

3.1 Internal Searches

In the early stages of our project, our searching method consisted of contacting our sponsors via telephone and email and meeting them to obtain specific information pertaining to the project. Our sponsors were able to provide us with general details of the problem while performing the repair on the gas generator case. We have been informed that the current cart being used to perform the repair does not meet ideal functionality, commodity, safety, or storage requirements. In order to organize our search for solutions to this problem, we assigned each team member a specific task with a precise deadline in order to keep the schedule moving forward. We felt that our efforts would be maximized if we could each focus on one of four major sections:

- Stand material (plates and legs)
- Folding extension (hinge or brackets)
- Wheels
- Commercially available alternatives

Our team also brainstormed for ideas and combined our general knowledge of practical applications to filter our searches to be as specific as possible. A number of ideas also came from our team meetings with our sponsors, as well as a very informative conversation we had with the operator of the nickel plating equipment. Given the design dimensions described in the target specifications section, we had to narrow down our search to meet various constraints such as vibration dampening, size, storability, and cost. Additionally, we needed to ensure that our stand was manufacturable using commercially available products.

3.2 External Searches

To conduct our external searches, we utilized the internet as the primary search engine since we were able to obtain a wide variety of information from a large number of sources in a relatively short amount of time. In order to find the best results, an extensive search was done among a wide range of suppliers. To ensure we receive quality products with reliable properties, an external search was performed by contacting McMaster-Carr [2] and Hardware Source [3] individually via e-mail. We researched which components were currently available from these suppliers and contacted them for drawings and tables outlining the respective specifications of the parts we were interested in. By using all of the supplied data to perform the required stress analysis, we predicted all possible modes of failure for our stand design. While performing our external searches, we always took into consideration the ease of repair of components, standardized tools for repairing parts if needed, and kept in mind that fewer parts and easier accessibility will help us keep the build and maintenance costs to a minimum. The drawings and specifications of the parts considered for our design are shown in the results section below.

3.3 Standards and Codes

In order to ensure the safety of our client, we have strictly followed the American Society of Mechanical Engineers (ASME) standards for all material, parts, and any components of our design [4]. Furthermore, the components of our stand are all standardized for optimal performance and ease of testing. It is also important to mention that the required operation license of the design will have to be obtained by our sponsor once the design is completed. In the selection of the material that will constitute the body of our stand, we will use standard mild steel. All dimensioning and tolerances of design drawings and prototypes will follow ASME requirements. This means that the design requirements and dynamics of any potential part features such pins, slots, surfaces, brackets, or holes will all be dimensioned with the appropriate tolerances and annotations as per ASME standards. In section 5 of this report, tables provided by the licensed suppliers that display features of their products are shown. These are the exact products that have been considered to be used as part of our stand. The codes for identification purposes of these parts are also attached to their corresponding descriptions. Finally, when selecting the material that will be used in the construction of our stand, some codes may apply to the American Society for Testing and Materials, such as the parts from McMaster-Carr, and these parts will be appropriately tested prior to use on any production parts.

3.4 Patents

In the case of designing a completely new concept, the necessary procedures to obtain a patent will be performed. At this point, the only possible existing patents are the ones belonging to the companies we will be purchasing our components from. The patents of most of our potential parts belong to worldwide known parts sources – McMaster-Carr and Hardware Source. We have contacted McMaster-Carr and Hardware Source to inquire about a need to archive any patents for the parts to be purchased and are awaiting their reply.

4. Concept Generation

In order to generate the maximum number of conceptual ideas, our team decided to start with a very basic structure before brainstorming for specific details. We wanted to start with a simple design initially in order to keep our design unconstrained and also to prevent us from excluding any ideas that may have been overlooked otherwise. This method allowed us to start our design process with a clean slate and even ideas that may have seemed unsuitable or were in need of further development prior to implementation were recorded for future reference. The basic structure we started with is shown below with dimensions in Figure 2.

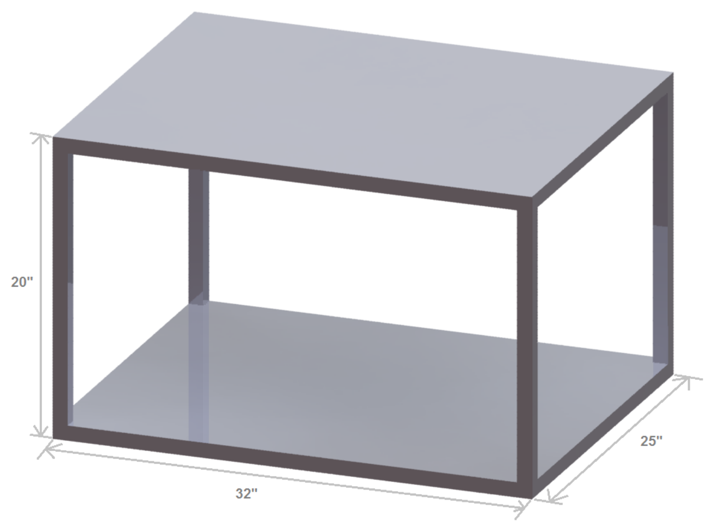

Figure 2. Primary Stand Design.

We began with a 1” square geometry for the legs and a plate thickness of 0.5” as preliminary values. In the analysis of our final design, we will optimize the size and shape of the legs to improve the overall design function. One of the first ideas our group produced was a cross-bracing system to add rigidity to the overall structure in order to help resist vibrating due to the revolving motion of the gas generator case. Figure 3 shows our initial bracing design.

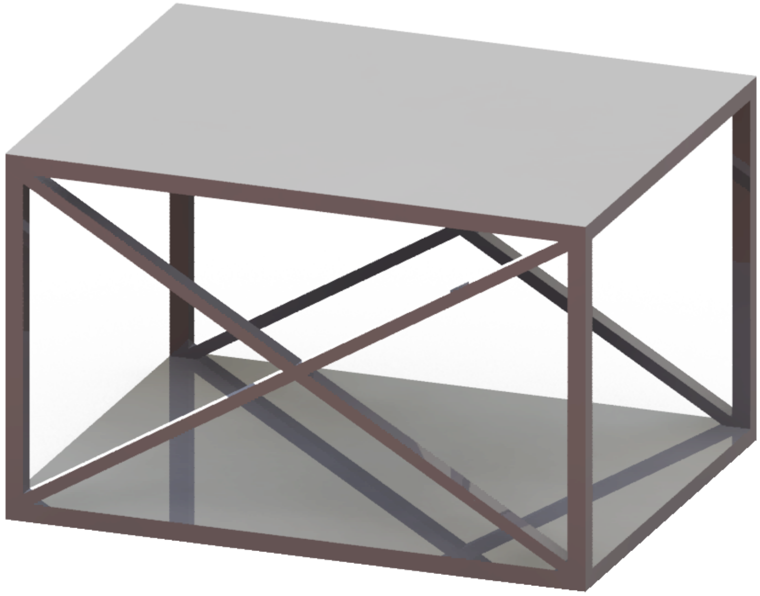

Figure 3. Initial Bracing Design.

The cross braces, similar to the four main legs, have a square 1” cross section and are to be optimized in the analysis of the overall structure.

The next idea our team generated was a solution for the mobility of the stand. The current cart has two wheels that can only roll in one direction and this setup makes the cart very difficult to maneuver in the small plating room. Our solution to this problem is four free-swiveling casters. These casters are able to rotate in all directions and provide very little rolling resistance to the stand. We feel that these casters will be more than sufficient in moving the stand in and out of its storage space. Figure 4 shows our first caster design.

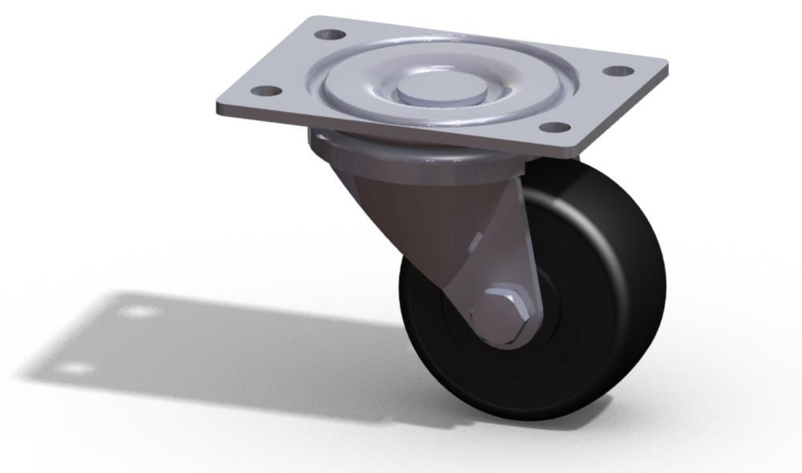

Figure 4. Initial Caster Design.

The initial caster is designed to bolt to the bottom of the stand, but this may be changed if our client feels otherwise. Additional, we will add a prevision to these casters to include a brake function in order to hold the stand in place while the plating process is taking place. Subsequently, after the caster design idea was presented, we began brainstorming ideas for a solution to meet the 50" length requirement to be used while the gas generator case is being plated. We knew that some sort of sliding or collapsible extension would be ideal and our first design used a simple hinge mounted on the bottom face of the upper surface of the cart. Figure 5 displays the general idea behind the simply hinged connection.

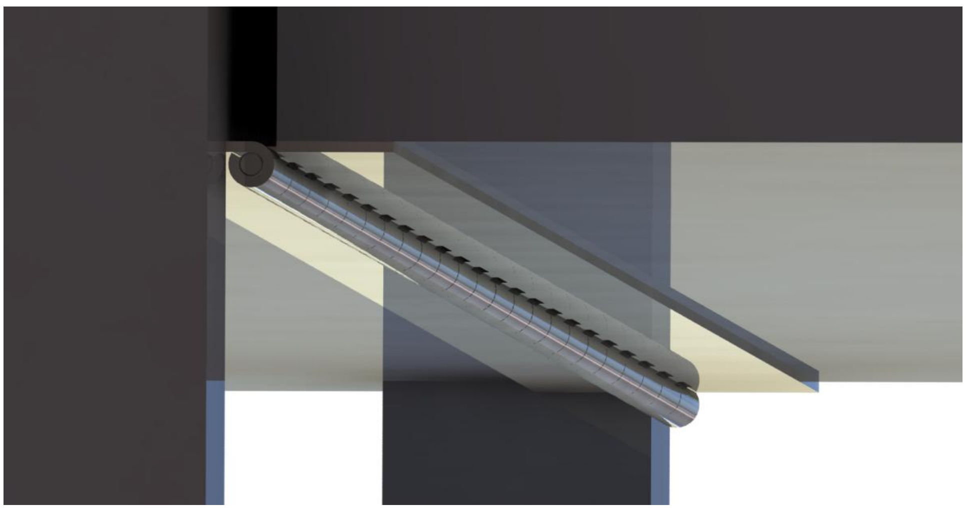

Figure 5. Hinged Extension.

The main issue with the hinged design shown above is that the hinge does not provide any support to the extension while in the upright position without the addition of some sort of bracing to either the existing stand structure or the floor beneath the extension. Upon further consideration, the floor in the plating room is not perfectly level due to an intentional slope for drainage purposes and for this reason, we will avoid the use of support from the floor. After researching solutions to this issue, our team learned that there are two different types of brackets that will meet all of our requirements: sliding and folding brackets. Sliding brackets, as anticipated, utilize a slider to guide the support surface through its intended range of motion. The folding bracket option is pinned in the middle of the support and is designed to be collapsible upon itself, similar to a common folding table leg. These two designs are shown below in Figure and Figure 7.

Figure 6. Sliding Bracket [5].

Figure 7. Folding Bracket [6].

It is important to note for our project that both of these bracket designs allow the extension to travel between a 0^{o} and 90^{o} range and are lockable at both extremes. This is crucial to our design, as the rotating chuck will be sitting on top of the extended portion of the stand.

5. Analysis and Selection

In our analysis of the gas generator case stand, we have performed hand calculations and also used finite element analysis to investigate the stresses found in the structure. By performing these analyses, we have determined that our design meets all of the specified requirements provided by our client. We primarily performed these analyses in order to determine if we needed to make certain geometries larger to stiffen up the structure, or we could decrease the size of certain sections to save weight.

5.1 Axial Analysis

Throughout our analysis, we have assumed that our material is standard carbon steel with an elastic modulus of 200 GPa and a density of 0.284 lb/in^3. We started our analysis with a very basic hand calculation for the axial stress in the steel legs (Eq. 1). In order to determine the approximate force carried by each leg, we assumed the following conservative values.

$$Force = \frac{\text{Weight of top plate } + (\text{Weight of plating equipment and work piece})}{4 \text{ Legs}} \quad \text{(Eq. 1)}$$

$$Force \quad F \quad = 94.3 \text{ lbs}$$

$$\sigma = \frac{Force}{Area}$$

$$\sigma \quad = 94.3 \text{ psi}$$

Since the yield stress of steel is on the order of 34 ksi, we can state with confidence that our stand will not fail due to pure axial stress. In fact, since this value is so much below the yield stress, our team felt it was necessary to optimize the leg geometry to save some weight. After researching commercially available geometries, we decided to use an L-shaped bar for the four legs with the dimensions shown below in Figure 8.

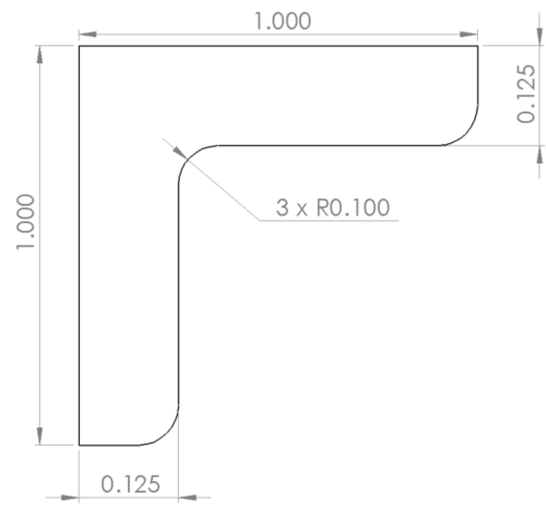

Figure 6. Leg Geometry (Not To Scale).

The axial stress through the new cross-sectional geometry was found to be 402.3 psi by using Equation 1 once more. This magnitude is still significantly below our yield stress, but we feel that this geometry is as small as we would like to use in order to preserve the structures equivalent rigidity. These hand calculations are useful for determining the pure axial stress in the legs, but in order to achieve a clear image of how the stress is distributed throughout the structure and to observe any stress concentrations, we also performed a finite element analysis using the SolidWorks software. The mesh used to generate these results was as fine as

SolidWorks would allow and comprised of over 85,000 nodes. This mesh can be seen in detail in Appendix A. The FEA results of the overall structure and the legs are shown in Figure 9 and Figure 10 respectively.

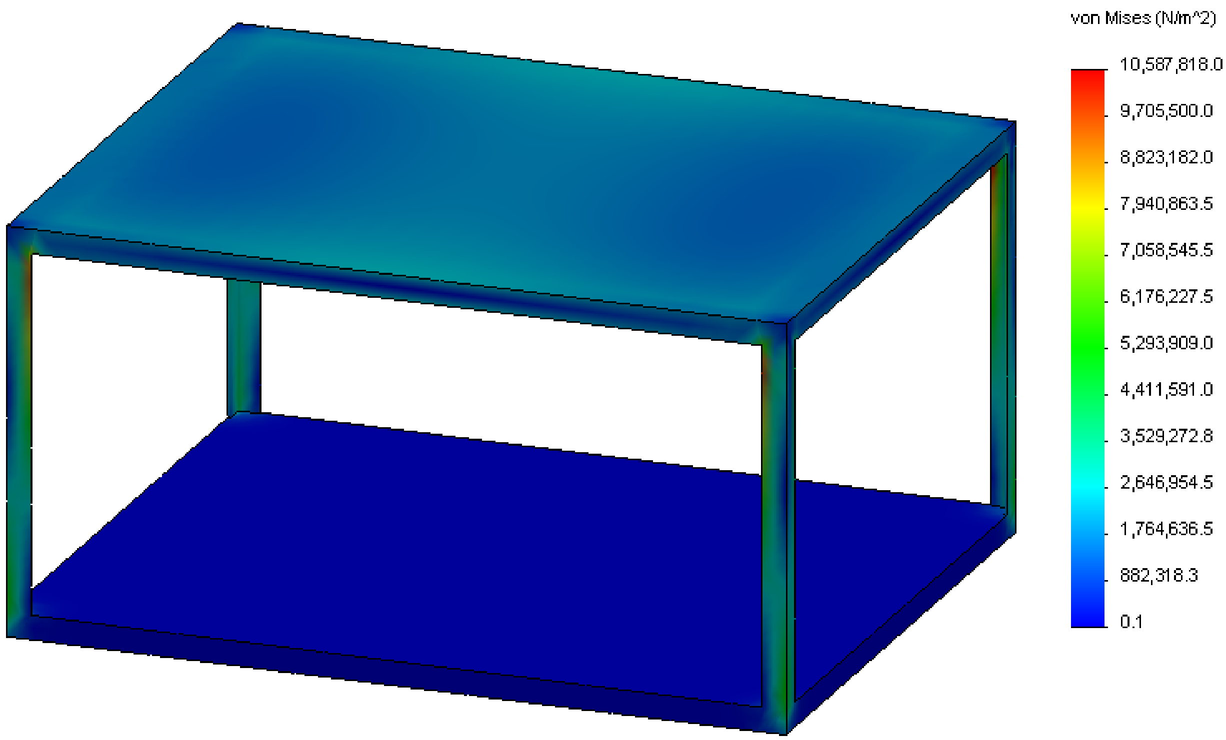

Figure 7. Axial FEA Results (Overall).

It is important to note that for all finite element analysis presented in this report, we have run numerous iterations at various mesh resolutions and have observed the convergence of our results.

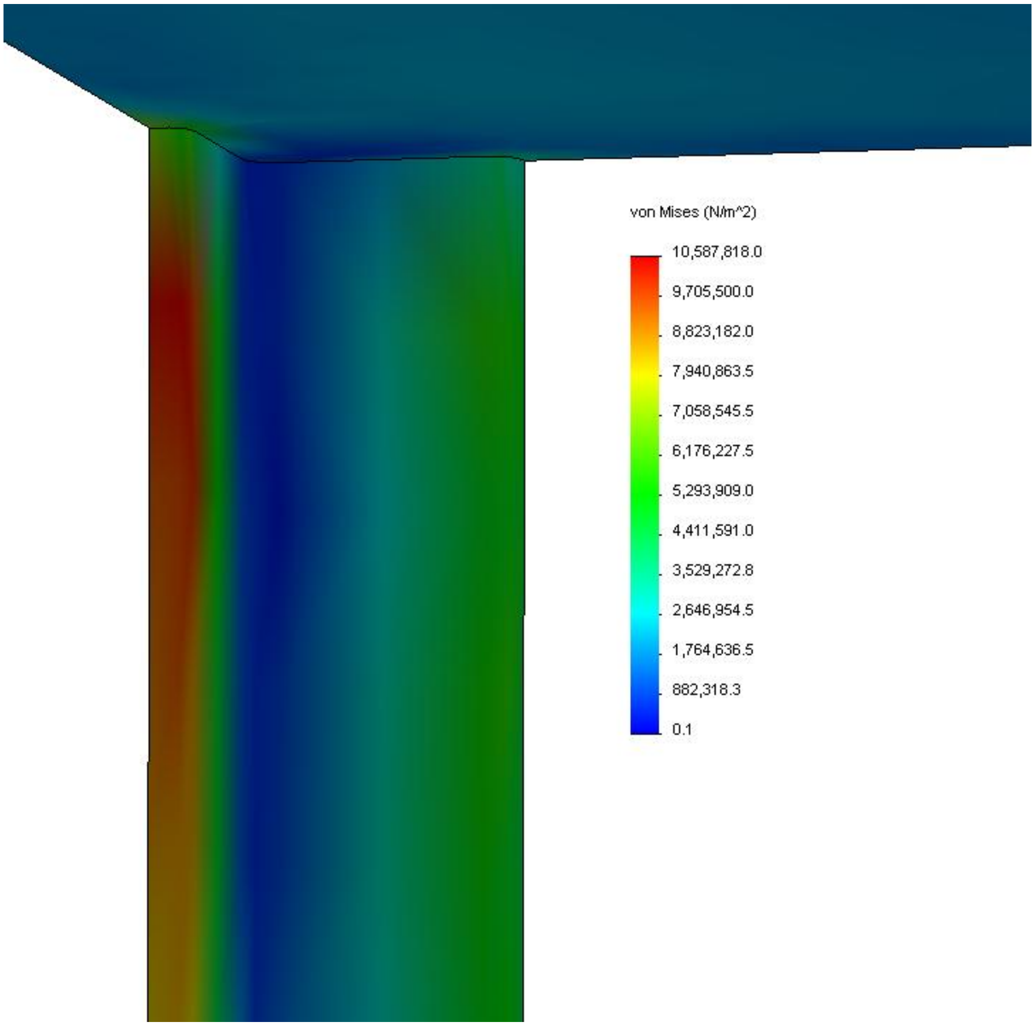

Figure 8. Axial FEA Results (Leg).

As can be seen in Figure 9, the cross braces were not considered in this evaluation and the compressive forces applied did not warrant any additional rigidity. We found from the FEA that our hand calculations were accurate, and also that the stress concentrations at the upper corners were only on the order of 1,535 psi which is significantly below the yield stress. Additionally, the weld radius will cut this stress concentration down when the actual stand is being manufactured. We are now confident that we have fully evaluated the vertical axial loading of the stand and will begin to assess the vibratory motion due to the revolving gas generator case.

5.2 Rotational Analysis

To accurately perform this analysis, we will use a dynamic loading study, again in the SolidWorks software. This type of study allows us to inflict a variable force on the structure. The one assumption we must make prior to conducting this investigation is how much lateral force the gas generator case is transferring to the structure. The gas generator case is approximately 50 pounds and is designed to be fairly consistently balanced about its central axis. To be conservative, we will assume that all of the mass of the gas generator case is located at one point on the maximum radius of the cylindrical shape. In reality, the maximum amount of off-balance mass is probably closer to five or ten pounds but since we have no way of quantifying this value, we have chosen to be conservative with our approximations and well assume the mass to be perfectly off-balance. Since the maximum radius of the gas generator case is 12” and the weight is approximately 50 pounds, the maximum torque applied to the table due to the rotating gas generator case is as follows:

$$Torque\ \ T\ \ = Force\ x\ Distance \qquad \text{(Eq. 2)}$$

$$Torque\ \ T\ \ = 50\ ft \cdot lbs$$

We assumed that the bottom of the table was perfectly fixed to the ground and that the torque was creating a pure bending force on each of the legs. First, we needed to find the centroid of the L-shaped cross section. To solve for the centroid, we first utilized the multi-section method which splits the cross section into separate pieces. The centroids of these smaller sections are recorded and connected with a line. This process is repeated once again using different sections and there the two connecting lines intersect is the centroid of the whole L-shaped section. This process has been confirmed by the traditional method and is shown in Figure 11.

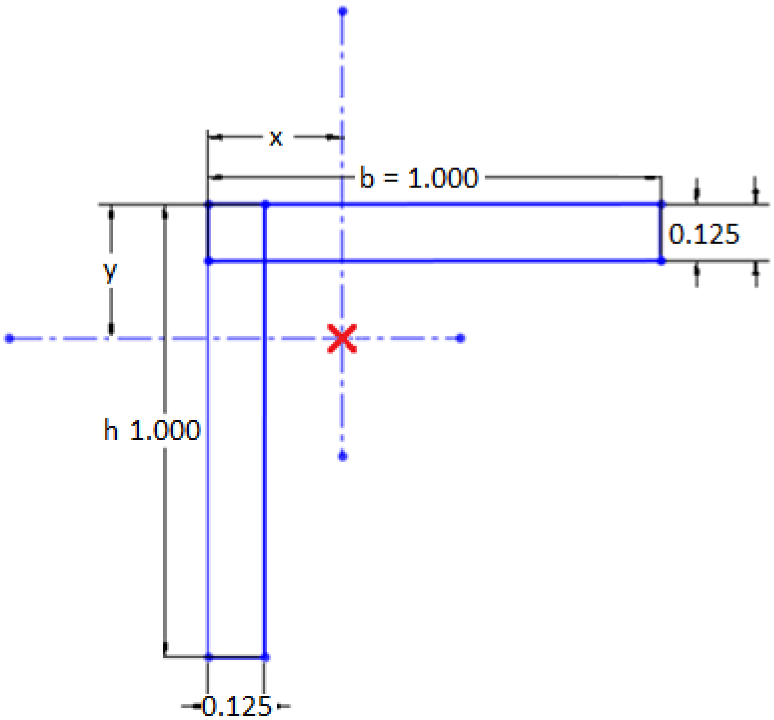

Figure 9. Centroid of the L-Shaped Section.

Now that we had solved for the centroid of the section, we could now apply a force to the leg as it if were a cantilever beam. The following calculations (Eq. 3 through Eq. 7) were performed to solve for the deflection of the individual legs. Figure 12 shows our deflection approximation schematic.

$$x = \frac{(b^2 + \ \ h - t \ \ t)}{2(b + h - t)} = 0.2958\ in \qquad \text{(Eq. 3)}$$

$$y = \frac{h^2 + \ \ b - t \ \ t}{2 \ \ b + h - t} = \ 0.2958\ in \qquad \text{(Eq. 4)}$$

Moment of inertia:

$$I_{xx} = \frac{1}{3} * \ \ t \ \ h - y \ \ ^3 + (by^3) - \ \ b - t \ \ \ y - t \ \ ^3 \qquad \text{(Eq. 5)}$$

$$I_{xx} = 0.0217\ in^4$$

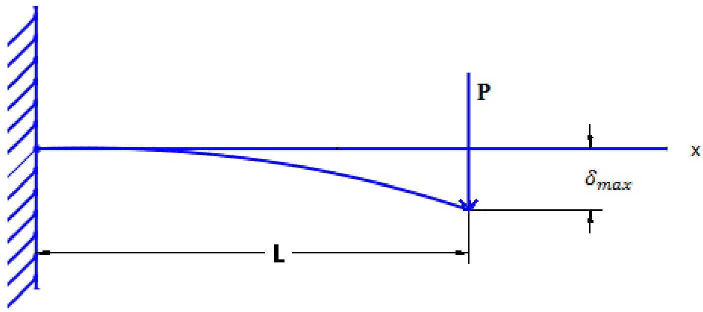

Figure 10. Cantilever Beam Approximation.

In order to be additionally conservative, we applied a factor of safety of 2 and applied a 25 pound force to each leg instead of the 12.5 pound maximum force that the legs may be subjected to during use.

$$Y = \frac{Px^2}{6EI}(3l - x) \qquad \text{(Eq. 6)}$$

$$\delta_{max} = \frac{Pl^3}{3EI} = \frac{25 * 14.75^3}{3 * (2.9 * 10^7) * 0.0217} = 0.0424\ in \qquad \text{(Eq. 7)}$$

In order to verify these hand calculations, we have used an alternate method shown in detail in Appendix B. Furthermore, we have also performed a finite element analysis as if the leg were a cantilever beam with an end load of 25 pounds. The mesh for this analysis was as fine as SolidWorks would allow and included over 98,000 nodes. The results are shown in Figure 13.

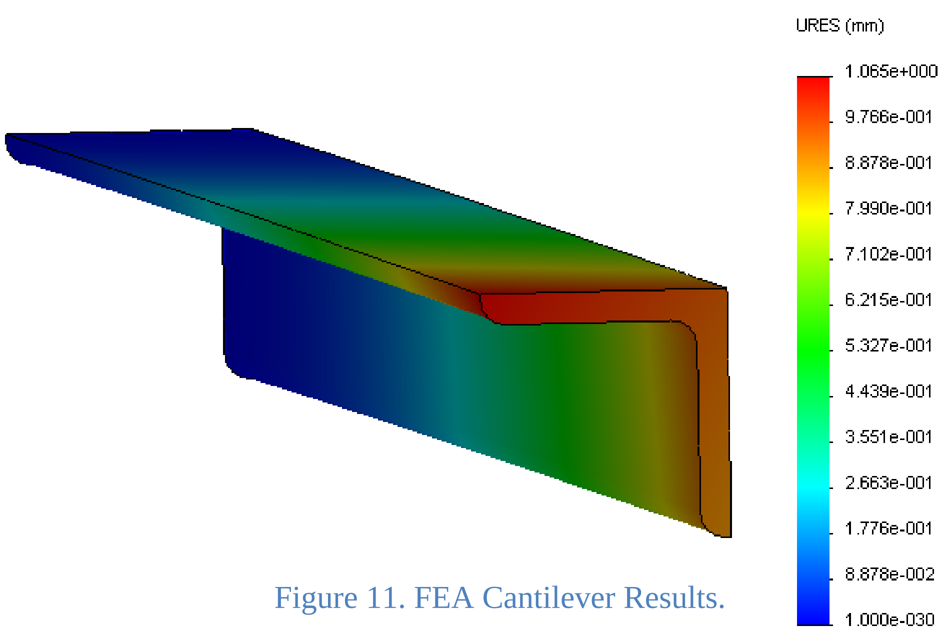

Figure 11. FEA Cantilever Results.

From the above two analyses, we have obtained a maximum deflection from our hand calculations of 0.0424" and a maximum deflection from our FEA investigation of 0.0419". These two values differ by only 1.2% and thus, we are confident that we have successfully solved for the total deflection in the legs of our stand due to the vibratory motion of the gas generator case. Furthermore, we feel that a deflection of 0.04" is acceptable for the application with the assumptions we have made.

The one drawback of performing the previous cantilever analyses is that we are unsure about the behaviour of the rest of the structure under these conditions. We felt that it was also necessary to perform a full-scale analysis on the structure to better understand the stress distribution throughout the stand. To do this, we applied a torque to the top plate of the stand and fixed the bottom plate in order to observe the displacement due to the vibratory motion. As mentioned previously, when our team is forced to make an approximation, we generally err on the side of caution. In this case, we applied a 100 ft·lbs torque to the top of the structure to further ensure our factor of safety. The FEA results are shown in Figure 14.

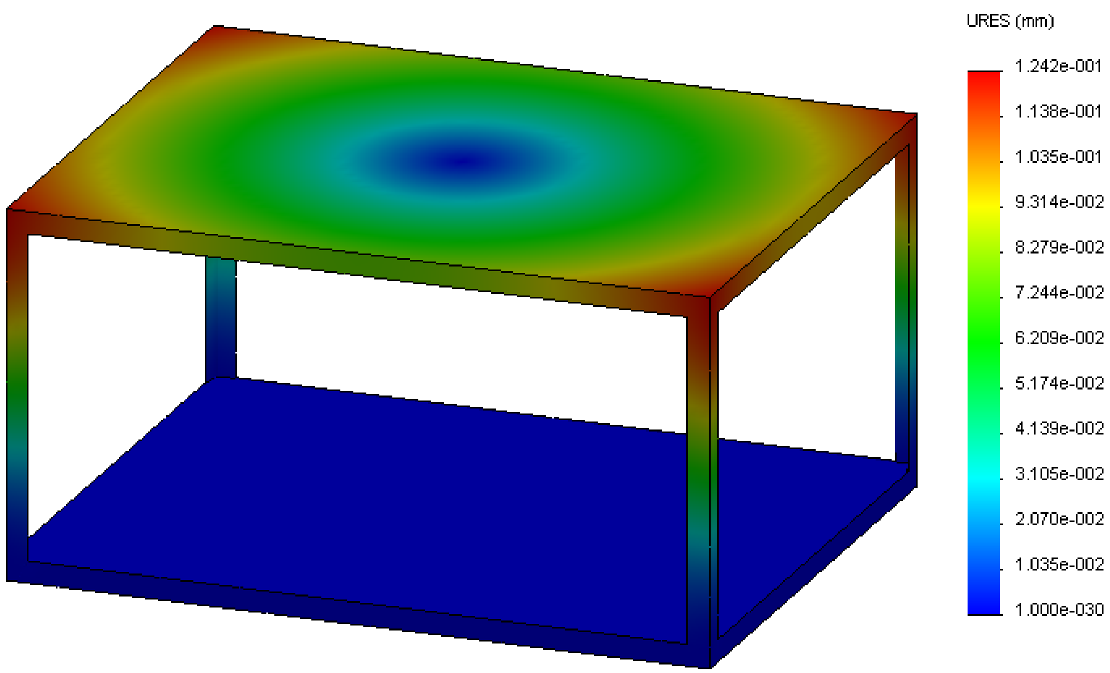

Figure 12. Rotational FEA Results.

Similar to the axial compression FEA, the rotational evaluation was also performed without the cross braces in place and we found that the structure performed suitably without them present. We have decided to disregard the cross braces from this point forward. Also similar to the compressive FEA result, we are again seeing the highest stress and deflection at the top attachment interface between the legs and the top surface. The maximum deflection in this area is on the order of 0.005”, which is acceptable for our application. The reason why this value is less than our simple cantilever analysis is due to the additional stiffening of the overall structure due to the top plate. The 0.005” value is more of a realistic value and better represents what we will observe once the stand has been constructed. Now that we have mathematically validated our stand design, we can choose exactly which components to construct it with and compare it to and other commercially available options.

6. Components

As mentioned previously, our team divided up the search categories into stand material, folding extension, wheels, and commercially available alternatives. In order to help narrow down our search results, we only looked for parts that would meet our target specifications and ensured that each section would be compatible with the others.

To start off our search, we began by determining the base material for the top and bottom plates as well as the legs. We decided as a team that our primary structure should consist of low-carbon steel for ease of use and manufacturability and also because this material is the material StandardAero currently uses for all of the stands in their facilities.

6.1 Legs

After some preliminary analysis, our team decided that the geometry of the legs will consist of L-shaped lengths as is discussed in section 4 of this report. We chose McMaster-Carr as our supplier for these legs (code #9017K44) [7]. The raw material is available in 6’ lengths and cost $13.44 each. We intend these legs to be welded to the top and bottom plates in order to ensure a solid connection. All specifications can be seen in Table II.

Table II. LOW-CARBON STEEL LEG SPECIFICATIONS [7]

Material	General-Purpose Low-Carbon Steel
Finish/Coating	Unpolished (Mill)
Shape	90° Angles
Thickness	1/4"
Thickness Tolerance	±0.015"
Leg Length	1"
Leg Length Tolerance	±1/16"
Length	6'
Yield Strength	36,000 psi
ASTM Specification	ASTM A36

6.2 Top and Bottom Plates

When it came to the top and bottom faces of our stand, we choose to use 1018 carbon steel alloy due to the forces being applied directly to the top face. In order to obtain an accurate price, we contacted McMaster-Carr directly for a quote based on the nominal dimensions of 25" by 32". The price that McMaster-Carr provided us with for a 0.5" thick piece is approximately $220.00. See Table III below for the exact specifications of these plates.

Table III. TOP AND BOTTOM PLATE SPECIFICATIONS [8]

Specification	Metric
Alloy/Type	1018
Material	General-Purpose Low-Carbon Steel
Finish/Coating	Unpolished (Mill)
Thickness	0.5"
Thickness Tolerance	-0.008"
Tolerance	Standard
Hardness	Rockwell B72-B86
Maximum Attainable Hardness	Rockwell C60-C62

Yield Strength	45,000 to 55,000 psi
ASTM Specification	ASTM A108

6.3 Extension Brackets

When selecting a suitable bracket, we have chosen to stick with our material choice of low-carbon steel in case StandardAero chooses to weld the brackets to the legs. Conversely, the brackets can also be screwed or bolted to the stand legs if the operator prefers.

The rotating chuck weighs approximately 75 lbs and to be safe, we will only examine hinges that are capable of supporting at least 150 lbs to give ourselves a comfortable factor of safety of 2. The total length of the extension must be 18” in order to provide us with a total working area of 50” as outlined in Table I. The width will be 25” and have a thickness of 1” in order to be consistent with the top and bottom plates of the stand. The final set of hinges selected will be attached to the bottom of the folding extension and also to each of the legs on one end of the cart as shown in Figure. Overall, the design parameters include size, load capacity, set-up, cost, functionality, and safety. The main constraints of the brackets are outlined in Table IV.

Table IV. BRACKET SPECIFICATIONS

Specification	Metric	Description
Horizontal Length	Max: 18”	Must not protrude from under extension
Vertical Length	Max: 14.75”	Must not be longer than the stand legs
Load Capacity	> 150lb	Total weight is ~150lb
Locking	Required	Must be lockable in the upright position

Additionally, we have kept in mind the ease of set up, use, and repair when selecting a set of brackets. It is important to note whether or not a bracket has previsions for bolts or screws or if it is intended to be welded to a metal structure. Also, although cost isn’t necessarily our first priority, we should keep in mind that we do realistically have a budget for this project and that the price should be reasonable.

After an extensive search on the internet, the supplier who best met our needs was Hardware Source [3]. This supplier specializes in hinges and is well known throughout North America. The options that will be compared are outlined below in more detail.

6.3.1 Bracket Option 1

The first bracket we considered is comprised of powder coated steel. The zinc plated locking mechanism of this particular hinge consists of a lever which is positioned inside the hinge and allows the hinge to drop down against the legs when resting. All mounting screws or bolts must be purchased separately. When the shelf is folded down in the vertical position, the gap between the bottom of the shelf and the legs it is attached to will be approximately 1” [9]. This bracket is shown in Figure 13.

Figure 13. 701200 Powder Coated Steel Bracket [9].

Some key features of this bracket are shown below in Table V.

Table V. 701200 BRACKET SPECIFICATIONS [9]

Specification	Metric
Locking angle	90°, 80°, 70°
Locking Mechanism	Latch leveler
Maximum Load (2 hinges)	750 lbs
Length (Horizontal Piece)	11-3/4”

Width (Horizontal Piece)	1-3/16”
Thickness	7/8”
Length (Vertical Piece)	7-7/8”
Width (Vertical Piece)	3/4”
Material	Powder coated steel
Recommended Attachment	#10 round head screws (8)
Price (Pair)	$41.94

6.3.2 Bracket Option 2

The second bracket we have considered features a double-folding mechanism that allows for easy movement and smooth operation. Unlike the first bracket presented, all screws are included with the brackets in this case. If the need presents itself, StandardAero can also use nuts and bolts or weld this bracket to the leg of the stand depending on the preference of the technician building the stand. Similar to the previous bracket, the gap between the top surface of the stand and the extension will be approximately 1”when the extension is folded in the vertical position [10]. Figure 16 shows this bracket in both open and partially closed positions.

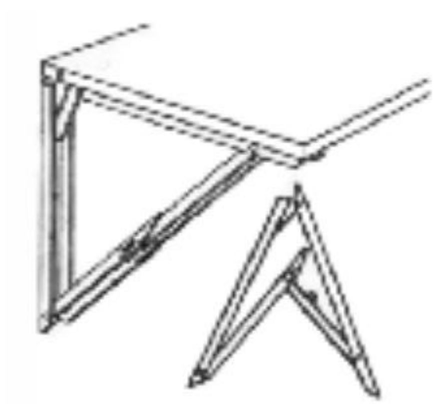

Figure 14. 218706 Double-Folding Bracket [10].

Table VI shows the key features of this particular hinge.

Table VI. 218706 BRACKET SPECIFICATIONS [10]

Specification	Metric
Locking angle	90°
Locking Mechanism	Diagonal Support latch
Maximum Load (2 hinges)	200 lbs
Length (Horizontal Piece)	23-3/4”
Length (Vertical Piece)	21"
Width	Not specified
Recommended Attachment	Screws (size is not specified)
Price (Pair)	$47.97

6.3.3 Bracket Option 3

The third and final bracket we have considered for our design is SKU 897225 [11]. The functionality of this hinge is similar to the first bracket shown in Figure 13 in that it utilizes a locking slider mechanism to adjust the angle of the bracket. Figure 15 shows an example of the bracket in question.

Figure 15. 897225 Locking Slider Stainless Steel Bracket [11].

Since this bracket is made of stainless steel, it cannot be welded to the stand, but there are provisions for either screws or bolts for fastening. Table VII below displays the key features of this bracket.

Table VII. 897225 BRACKET SPECIFICATIONS [11]

Specification	Metric
Locking angle	90°
Locking Mechanism	Pressure Leveler Latch
Maximum Load (2 hinges)	500 lbs
Length (Horizontal Piece)	12"
Width (Horizontal Piece)	7/8"
Thickness	1/16"
Length (Vertical Piece)	6.5"
Width (Vertical Piece)	7/8"
Recommended Attachment	#10 pan head screws (12)
Material	304 Stainless Steel
Price (Pair)	$66.00

6.3.4 Bracket Selection

In order to quantify exactly how much each of these brackets meets our design requirements, we have made Table VIII. This table compares the different brackets side-by-side and ranks them in different categories relevant to the application.

Table VIII. BRACKET COMPARISON

SKU#	Size	Load Capacity	Set Up	Cost	Safety	Functionality	Score
701200	4	4	5	5	5	5	**28**
218706	4	3	5	4	5	5	**26**
897225	5	1	5	2	5	5	**23**

From this table, we can conclude that the most suitable candidate for our application is Item 701200 from Hardware Source [3].

6.4 Casters

As mentioned previously in section 3 of this report, we will be including casters in our design in order to allow it to be moved around the plating room easily. The casters we have chosen are mounted to the bottom of the cart and have been specifically rated to support the weight of work piece, equipment, and the stand itself.

Generally, there are four different mounting types shown in Figure 18. These types use different mounting methods as outlined in the figure. Since we have designed the bottom of out stand to be flat and have L-shaped legs, the stem and socket mounting types are not feasible for integration into our design without alteration.

[redacted]

Figure 16. Caster Mounting Types [12].

Even though the purpose of casters to our design is to increase the mobility of the stand, we must also ensure that we have a way of stabilizing the stand while the plating process is going on. In other words, the casters must have some sort of locking mechanism. The three commonly found locking types are shown below in Figure 19.

[redacted]

Figure 17. Caster Braking Types [12].

To find the casters best suited for our application, we must compare the available options based on criteria related to our target specifications. Criteria such as load capacity, stability, mobility, size, chemical resistance, and cost are all considered in this section. In total, we considered four different casters to be included in our design and they are listed below along with their manufacturer's specifications.

6.4.1 Caster Criteria

Load capacity is the most important factor that needs to be considered while choosing which casters to use. The casters must be able to carry the weight of the work piece, the repair equipment, and the stand body itself. The weight of work piece and repair equipment is 150 lb and the weight of cart is 295 lb as shown in section 6. One important issue is that the load is not always distributed equally among the four casters. There may be times when the majority of the load is applied to only three of the four casters and our design must support this loading condition. That being said, the minimum load capacity of each caster must be (150 lbs + 295 lbs) / 3 = 150 lbs.

To increase damping and reduce noise, a simple rule of thumb is followed in the world of casters: Use soft wheels on hard floors and use hard wheels on soft floors [13]. Since the weight of load is relatively light, the noise induced by the stand will be very minimal and we can choose any wheel hardness we desire.

Surface pressure would be a significant issue for some applications. For example, a wooden floor could be damaged due to high surface pressure and the wheels chosen would need to reflect the amount of pressure the floor is capable of supporting. In our case, the floor in the plating room is made of concrete and therefore, surface pressure is definitely not an issue.

Temperature and chemical resistance generally should not be a problem in our application, but since the stand will be used for a nickel plating process there is a small chance that the plating solution could spill on to the cart. The two major nickel plating solutions being used are combinations of nickel sulphate and nickel chloride between 30^{o}C and 70^{o}C [14]. This range of temperature is not a problem for the casters, and all rubber, polyamide, and polyurethane wheels are resistant to the two nickel solutions [14].

6.4.2 Mighty-Lite Casters

The first set of casters we considered comes from the Mighty-Lite line of casters available from McMaster-Carr [12]. Figure 20 shows an example of these casters and Table **IX** shows the manufacturer's specifications.

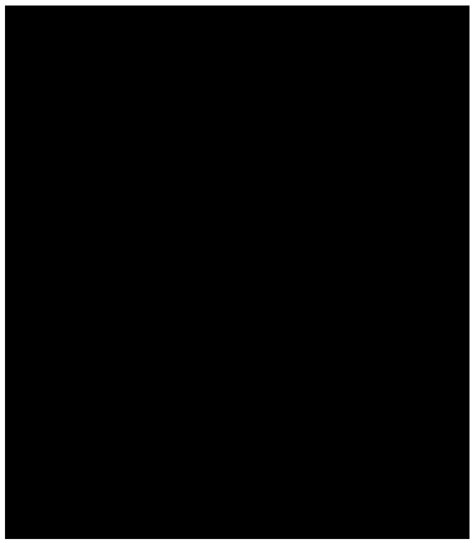

Figure 18. Mighty-Lite Caster [12].

Table IX. MIGHTY-LITE CASTER SPECIFICATIONS [12]

Specification	Metric
Capacity	125 - 175 lbs.
Mounting Type	Plate
Caster Type	Swivel with Brake
Wheel Material	Rubber
Wheel Diameter	4"
Wheel Width	15/16"
Mount Height	4-3/4"
Plate Length x Width	3-3/4" x 2-1/2"
Plate Thickness	1/8"
Bolt Size	5/16"
Number of Bolt Holes	4
Frame Material Type	Steel
Frame Construction	Cold Formed
Frame Finish/Coating	Zinc Plated
Swivel Construction	Rivet Kingpin
Wheel Bearing Type	Plain

Swivel Bearings	Double Ball
Wheel Bearings Material	Self-lubricating Bronze
Brake Style	Side Wheel Brake
Price (Each)	$11.12

6.4.3 Cart-Smart Junior Casters

The next set of casters we have considered for our design comes from the Cart-Smart Junior Casters line of McMaster-Carr [15]. Figure 21 shows an example of these casters and Table X shows the manufacturer's specifications.

Figure 19. Cart-Smart Junior Caster [15].

Table X. CART-SMART JUNIOR CASTER SPECIFICATIONS [15]

Specification	Metric
Capacity	90 - 175 lbs.
Mounting Type	Plate
Caster Type	Swivel with Brake
Wheel Material	Plastic
Wheel Diameter	2"

Wheel Width	1"
Mount Height	2-1/2"
Plate Length x Width	2-9/16" x 1-7/8"
Plate Thickness	1/16"
Center-to-Center	15/16" x 2-1/8"
Bolt Size	1/4"
Number of Bolt Holes	4
Frame Material Type	Steel
Frame Construction	Cold Formed
Frame Finish/Coating	Zinc Plated
Swivel Construction	Rivet Kingpin
Swivel Bearings	Single Ball
Brake Style	Side Wheel Brake
Price (Each)	$4.10

6.4.4 Cart-King Casters

The third caster we have considered for our design comes from Mc-Master Carr's Cart-King line of casters [16]. Figure 22 shows an example of these casters and

Table **XI** lists the manufacturer's specifications.

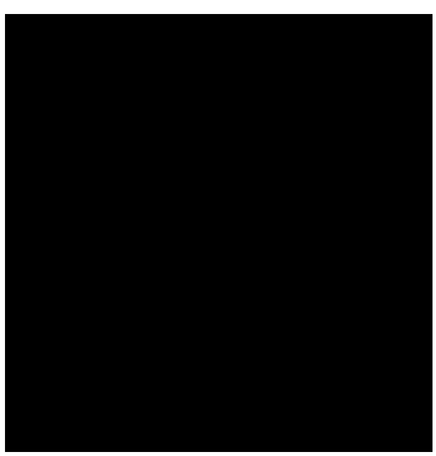

Figure 20. Cart-King Caster [16].

Table XI. CART-KING CASTER SPECIFICATIONS [16]

Specification	Metric
Capacity	200 lbs.
Mounting Type	Plate
Caster Type	Swivel with Brake and Lock
Wheel Material	Polyurethane
Wheel Diameter	3-1/2"
Wheel Width	1-1/8"
Mount Height	4-3/4"
Plate Length x Width	3-3/4" x 2-1/2"
Plate Thickness	1/8"
Center-to-Center	1-3/4" x 3"
Bolt Size	5/16"
Number of Bolt Holes	4
Frame Material Type	Steel
Frame Construction	Cold Formed and Heat Treated
Frame Finish/Coating	Zinc Plated
Wheel Bearing Type	Plain
Swivel Bearings	Double Ball
Wheel Bearings Material	Acetal
Brake Style	Face Wheel Brake
Price (Each)	$28.59

6.4.5 Cushion-Center Casters

The fourth and final caster we are considering for our design comes from the Cushion-Center caster line manufactured by McMaster-Carr. Figure 23 shows an example of these casters and Table **XII** outlines the manufacturer's specifications.

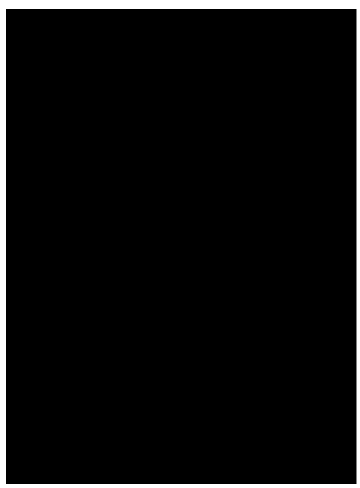

Figure 21. Cushion-Center Caster [17].

Table XII. CUSHION-CENTER CASTER SPECIFICATIONS [17]

Specification	Metric
Capacity	440 lbs.
Mounting Type	Plate
Caster Type	Swivel with Brake and Lock

Wheel Material	Plastic
Wheel Diameter	4"
Wheel Width	1-3/8"
Mount Height	5-1/8"
Plate Length x Width	3-15/16" x 3-3/8"
Plate Thickness	1/8"
Bolt Size	5/16"
Number of Bolt Holes	4
Frame Material Type	Steel
Frame Construction	Cold Formed
Frame Finish/Coating	Zinc Plated
Wheel Bearing Type	Maintenance-Free Precision Ball
Swivel Bearings	Double Ball
Brake Style	Face Wheel Brake
Price (Each)	$28.87

6.4.6 Caster Selection

Similar to the brackets in section 5.3, we must compare the presented casters side-by-side in order to rank them and see which caster best meets all of our requirements outlined in section 1.3 of this report. Table XIII shows our comparison scoring process.

Table XIII. CASTER COMPARISON

Option	Capacity	Safety	Stability	Mobility	Size	Chemical Resistance	Cost	Score
1	3	4	4	3	3	4	4	**25**
2	3	4	4	3	5	4	5	**28**
3	4	5	5	5	4	5	3	**31**
4	5	5	5	3	3	3	3	**27**

According to Table XIII, the casters that best meet our requirements are option 3, Mc-Master Carr's Cart-King casters [16].

7. Commercially Available Options

When designing a component such as the stand we have created, it is important to also look to the suppliers for any currently available alternatives to the final proposed design. In order to support our stand design in selecting plate types, leg geometries, and material choices, we have analyzed a number of different commercially available carts in their construction parameters. Design factors such as price and additional features from these existing commercial products have added a new dynamic to our stand design. We must be able to make our design meet the specified requirements at a lower cost than any of these presented carts.

7.1 Cart Option 1

The first cart our team considered is shown in Figure 24. This cart includes a foot-operated height adjustment and is available through McMaster-Carr for $643.33.

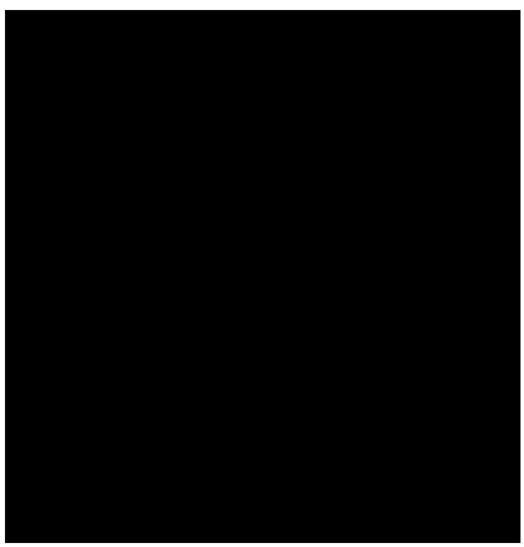

Figure 22. Foot Operated Mobile Lift Table [18].

As shown in Figure 24, there is a handle mounted directly to the base of the cart to aide in maneuvering the cart. This handle is covered with a treated rubber sleeve to improve the ergonomics of the cart and also to help isolate the operator's hands from any translated vibrations. There is also a smaller handle mounted to the base of the frame to actuate a locking leg which is used to keep the cart stationary when needed. This is a necessary feature for our stand design because we need the cart to be perfectly still while the plating process is taking place. The pedal at the bottom face of the cart is used to pump the hydraulic cylinder in order to adjust the height of the table. Table XIV shows the manufacturer's specifications for this cart.

Table XIV CART 1 SPECIFICATIONS [18]

Specification	Metric
Load Capacity	330 lbs
Length	27.5"
Width	17.75"
Height	Min: 8.375" Max: 28.375"
Elevation Per Stroke	1.3125"
Handle Height	31.3125"
Wheel Diameter	4"
Price	$643.33

One of the main problems with this cart design is that it will require more maintenance than the stand we have designed. The hydraulic cylinder will need to be maintained and there are a lot more failure modes associated with a cart of this type. Also, judging by the sizes of material used and the complexity of the design, it is anticipated that this cart will also be very heavy. Furthermore, for the intents of our project, the adjustable height range we can use is only about 2" and for this reason, we do not necessarily have a need for an adjustable height feature. Lastly, the width of 17.75" will mean that the turntable fixture will overhang 6.25" off the edge of the stand and the length of 27.5" is not long enough to support the rotating chuck needed to for nickel plating repair process.

7.2 Cart Option 2

The second cart we considered for comparison is again offered by McMaster-Carr [2] and is primarily made of type 430 stainless steel. Contradictory to the first cart shown in section 6.1, this cart does not have an adjustable height feature as this attribute is simply not needed for our purposes. The cart is shown in Figure 25 and the manufacturer's specifications are listed in Table XV.

Figure 23. Stainless Steel Cart [19].

Table XV. CART 2 SPECIFICATIONS [19]

Specification	Metric
Top Load Capacity	650 lbs
Shelf Load Capacity	325 lbs
Length	24"
Width	20"
Height	21.1875"
Price	$586.39

Unlike the previous cart, this cart has locking wheels instead of a locking leg in order to keep it stationary during use. Overall, this is a very simple cart which will reduce the maintenance and upkeep costs. The benefit of having the cart made of stainless steel is that it will not corrode or rust with use and it is also very chemically resistant. Similar to our designed stand, this cart has a storage space on the bottom plate and also uses L-shaped legs to support the top plate. The main problem with this cart is that the wheels are made of hard plastic and will not offer any vibration isolation while rubber wheels will help damped this effect. Also, the width of the cart is only 20” and we would like to have at least 24” in order to avoid any overhang of the turntable fixture. The length of this cart is only 24” and we need approximately 50” to support the rotating chuck during the plating process so this cart will not work for our purpose.

[redacted]

7.3 Cart Option 3

The third and final cart our team has considered is perhaps the most similar to our final design. This cart features L-shaped steel legs, a dual shelved main design, and plate-mounted casters. Figure 26 shows the cart offered by ULine [20].

Figure 24. ULine Welded Steel Cart [20].

This cart features a completely welded structure in order to avoid the use of any bolts or screws. Also, the two shelves have small lips on them in order to avoid small objects from falling off of the cart. The main drawback of this cart is that there is no way of securing or locking the cart to prevent it from rolling around when the plating process is occurring. Also, the total height of the cart is 35” which is too high for the operator to easily see the plating surface of the gas generator case. Furthermore, the width of 18” is also not desirable since the turntable fixture is 24” x 24”. Table XVI. CART 3 SPECIFICATIONS **[20]**

shows the manufacturer’s specification for this cart.

Table XVI. CART 3 SPECIFICATIONS [20]

Specification	Metric
Top Load Capacity	1,200 lbs
Length	30”
Width	18”
Height	35”
Weight	71 lbs
Price	$252

Our team has not been able to find a cart that had a built-in extension in order to allow it to fit into our storage space. Also, we were not able to find any carts with nominal dimensions near 24” x 50” capable of supporting both the turntable fixture as well as the rotating chuck. Overall, no carts we found met all of our design requirements and thus, our customized design is the only stand available that will meet the needs of our client.

8. Final Design

To summarize, our final design will be composed of the components listed in

Table **XVII**.

Table XVII. FINAL STAND CONFIGURATION [7][8][9][16]

Component		Dimensions	Material	Cost
Top and Bottom Plates		25” x 32” x 0.5”	1018 Carbon Steel	$440.00
Extension		25” x 18” x 0.5”	1018 Carbon Steel	$110
Legs		1” x 1/8” L-Shaped	Low-Carbon Steel	$13.44
Hinges		11-3/4” x 7-7/8”	Powder Coated Steel	$41.94
Casters	Frame	3-3/4” x 2-1/2” x 1/8”	Cold Formed and Heat Treated	$114.36
	Wheel	4”	Polyurethane	

This configuration results in a total cost of $719.74 before any taxes, shipping fees, or applicable discounts. The stand has been rendered and is shown in Figures 27, 28, and 29.

Figure 28. Final Design - Brackets Folded.

Figure 29. Final Design - Bracket Detail.

Major overall dimensions are shown in Appendix C. Additionally, since StandardAero already has a thick piece of rubber on their current cart, they have the option available to transfer this rubber ply to our new stand design in order to help isolate the vibrational motion induced on the stand. This decision will be made at the discretion of the operator of the nickel plating repair process.

As has been explained in this report, our team has met all of our client's specifications and have custom designed a stand to be used for the nickel plating repair of the PT6 engine's gas generator case. Our final stand design has the necessary dimensions to both be useful during the plating process and also while being stored. This characteristic is due to the collapsible hinge which saves space and also allows the extension to be locked in the upright position. The stand is more than capable of supporting the axial and rotational loads induced by the plating equipment and will remain stable under all circumstances with an appropriate factor of safety. We hope that StandardAero is able to include this equipment in their facility and that it can support their nickel plating repair process for years to come.

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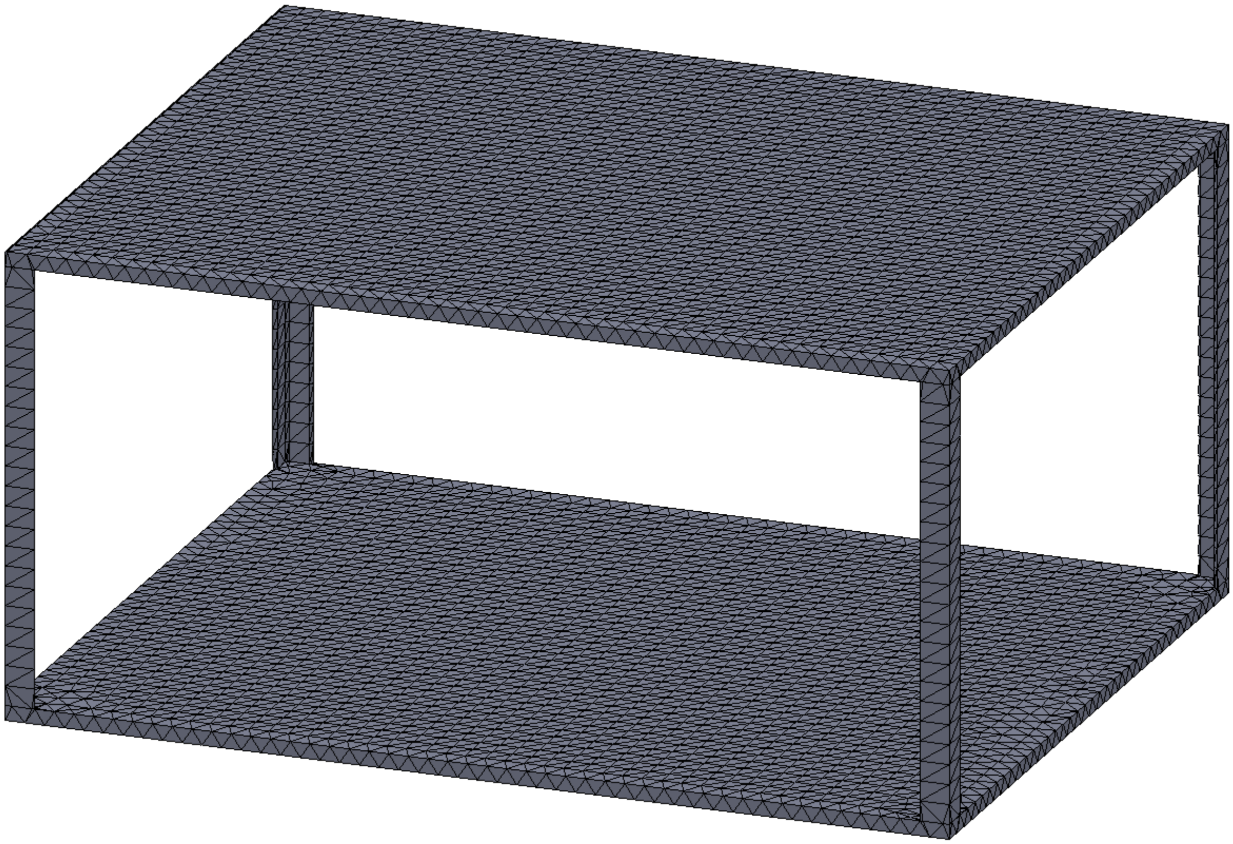
Appendix A



Our fine mesh (85,728 nodes) used in our finite element analyses.

Appendix B

In order to perform our secondary method of hand calculations, we must first solve for the equivalent stiffness of one single leg by using Equation 8.

$$K_{equivalent} = \frac{3EI}{L^3} \quad \text{(Eq. 8)}$$

$$K_{equivalent} = \frac{3 * \ 2.9 * 10^7 psi \ * (0.0217\ in^4)}{14.75\ in^3}$$

$$K_{equivalent} = 588.31\ psi$$

Now that the stiffness has been found, we can solve for the deflection by using Equation 9.

$$Force\ \ F \ = K_{equivalent} * Deflection\ (\delta_{max}) \quad \text{(Eq. 9)}$$

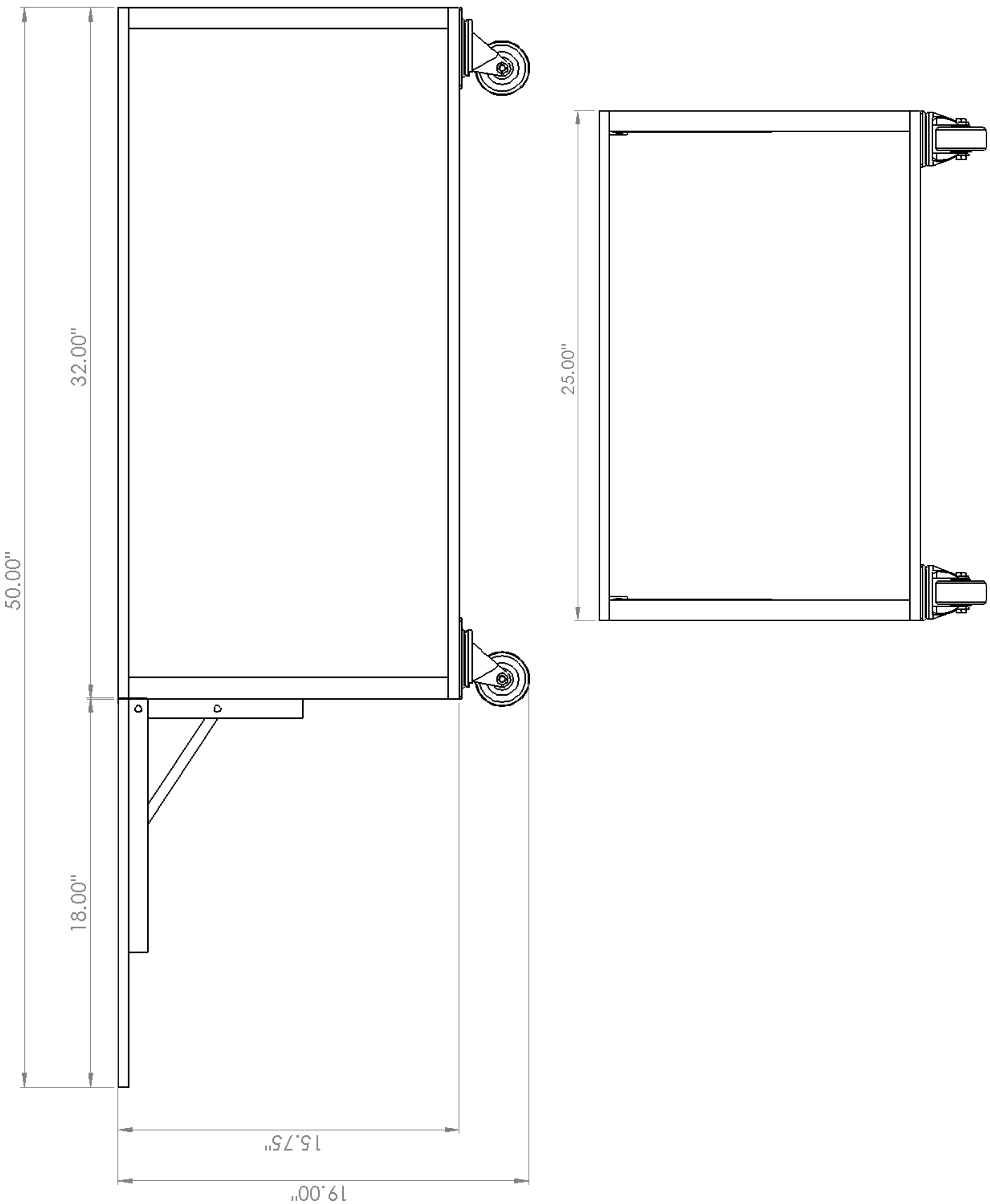
$$Deflection\ \ \delta_{max} \ = \frac{Force\ \ F}{K_{equivalent}}$$

$$Deflection\ \ \delta_{max} \ = \frac{25\ lbs}{588.31\ psi}$$

$$Deflection\ \ \delta_{max} \ = 0.0425"$$

This deflection value agreess with our other two methods of analysis.

Appendix C



Appendix D

Gantt Chart

		Task Name	Duration	Start	Finish
1	✓	**Team Establishing**	**1 day**	**Tue 13/09/11**	**Tue 13/09/11**
2	✓	Learn Project Assignment	1 day	Tue 13/09/11	Tue 13/09/11
3	✓	Meet team & faculty advisor	1 day	Tue 13/09/11	Tue 13/09/11
4					
5		**Learning Project**	**9 days**	**Wed 14/09/11**	**Thu 22/09/11**
6	✓	Meet With Sponsor #1	1 day	Wed 14/09/11	Wed 14/09/11
7	✓	Define Problems	1 day	Wed 14/09/11	Wed 14/09/11
8	✓	Determine Wants & Needs	1 day	Wed 14/09/11	Wed 14/09/11
9	✓	Obtain General Project Specfication	1 day	Wed 14/09/11	Wed 14/09/11
10	✓	Set Project Time Line	6 days	Thu 15/09/11	Tue 20/09/11
11	✓	Meet With Sponsor #2(on site)	1 day	Thu 22/09/11	Thu 22/09/11
12					
13		**Project Design**	**68 days**	**Thu 22/09/11**	**Mon 28/11/11**
14	✓	Take Measurement & picture	1 day	Thu 22/09/11	Thu 22/09/11
15	✓	Project Definition Preparation	13 days	Thu 22/09/11	Tue 04/10/11
16	✓	Research Material Available	5 days	Fri 23/09/11	Tue 27/09/11
17	✓	Brainstorming	5 days	Fri 23/09/11	Tue 27/09/11
18	✓	Gather Information & sources	33 days	Thu 27/10/11	Mon 28/11/11
19	✓	Write & Edit Report	63 days	Tue 27/09/11	Mon 28/11/11
20	✓	Conceptual Design	8 days	Fri 28/10/11	Fri 04/11/11
21	✓	Off the Shelf Option	8 days	Sat 29/10/11	Sat 05/11/11
22	✓	Design Refinement	13 days	Thu 06/10/11	Tue 18/10/11
23	✓	Feasibility Fetures	13 days	Thu 06/10/11	Tue 18/10/11
24	✓	Testing	6 days	Thu 13/10/11	Tue 18/10/11
25	✓	Validation of Design	15 days	Thu 13/10/11	Thu 27/10/11
26	✓	Added features	15 days	Thu 13/10/11	Thu 27/10/11
27	✓	Consult Client	3 days	Tue 25/10/11	Thu 27/10/11
28	✓	General Decision	1 day	Thu 27/10/11	Thu 27/10/11
29					
30		**Report & Presentation**	**41 days**	**Thu 27/10/11**	**Tue 06/12/11**
31	✓	Presentation Preparation	41 days	Thu 27/10/11	Tue 06/12/11
32	✓	Presentation Practice	15 days	Tue 22/11/11	Tue 06/12/11
33	✓	Finalize Report	8 days	Mon 28/11/11	Mon 05/12/11
34	✓	Make Poster	5 days	Tue 29/11/11	Sat 03/12/11
35					
36		**Important Due Dates**	**63 days?**	**Tue 04/10/11**	**Tue 06/12/11**
37	✓	Important Due Dates	0 days?	Tue 04/10/11	Tue 04/10/11
38	✓	Phase 1 Oral Report	0 days	Tue 04/10/11	Tue 04/10/11
39	✓	Hand in Draft #1	0 days	Thu 27/10/11	Thu 27/10/11
40	✓	Hand in Draft #2	0 days	Fri 18/11/11	Fri 18/11/11
41	✓	Draft Evaluation	0 days	Tue 29/11/11	Tue 29/11/11
42	✓	Hand in Final Report	0 days	Mon 05/12/11	Mon 05/12/11
43	✓	Presentation	0 days	Tue 06/12/11	Tue 06/12/11