The Design of a Robust, Reconfigurable Racking (R3) System for Vehicle Body Panel Transport and Assembly

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ABSTRACT

Part specific racks are a major source of transportation and storage costs and are responsible for nearly 10% of all part defects during automobile production. Racks are used to transport parts from metal-stamping locations to final assembly facilities. Currently, the racks are designed for a specific part from a specific model and do not accommodate for similar parts of other models. As a result, each rack must be reconfigured for every new or updated model. The goal of this project is to design a Robust, Reconfigurable Racking (R3) System that can be used for a specific part family of all different models and years.

INTRODUCTION

Part racking systems currently create a major challenge for automobile manufacturers. In addition to the nearly 10% of part defects attributed to poorly designed racking systems, most racks are not reusable after a model change or easily reconfigurable. Hence, for each new make and model of automobile designed, a new rack must be created or timely and costly modifications must be made to the existing racks. The introduction of an R3 System for vehicle assembly would be extremely valuable to the automotive industry.

Dr. Gap-Yong Kim from the Mechanical Engineering Department at the University of Michigan is currently engaged in a project with DaimlerChrysler. They have requested his assistance in designing a new racking system that would meet their 4R Strategy: Reduce, Reuse, Recycle, and Re-Invent. Their hope is that the racks will be designed, constructed, and ready for installation and implementation in their manufacturing facilities by July 30th, 2007 for their Summer Shutdown. To assist in this process DaimlerChrysler has also hired Ghafari, a consulting and manufacturing firm, to generate concept ideas for several different rack systems and produce prototypes of selected concepts.

Dr. Kim has requested the assistance of a team of student engineers from ME 450 to fulfill the obligations set forth by DaimlerChrysler. He would like the team to come up with new and innovative design concepts that may not otherwise be explored by the time and cost constrained DaimlerChrysler design team. The student team will need to select a part family, such as doors or hoods, and produce approximately 5 design concepts, from which the team will select the best design and build a functioning prototype.

INFORMATION SEARCH

In-house racking mechanisms are devices used in assembly plants in all sectors of industry. These devices are used for transportation of parts from one step of vehicle assembly to another. In the automotive industry different racking devices are used to store different vehicle components, which results in a unique rack for each component from every vehicle make and model. The purpose of the racks is to allow ease of access and to ensure that parts are not damaged during transport from the first manufacturing step to the last.

DaimlerChrysler has identified these individual, unique racks as a source of major costs and problems in their manufacturing process. DaimlerChrysler has been brainstorming and developing ideas that would allow for the recyclability, reconfigurability and reusability of their existing racks to minimize the cost to prepare the assembly line for each make and model.

It is reasonable to assume that one rack could be designed to fit many variations within a part family. Drawings provided by DaimlerChrysler (see Figure A) show that the envelope of each hood changes only slightly from year to year and model to model. This means that only slight adjustments would be needed to fit a large percentage of the parts. Since this is a long standing trend, it is a reasonable assumption that this concept will continue and a reconfigurable rack designed now will likely fit the majority of the parts designed in the coming years.

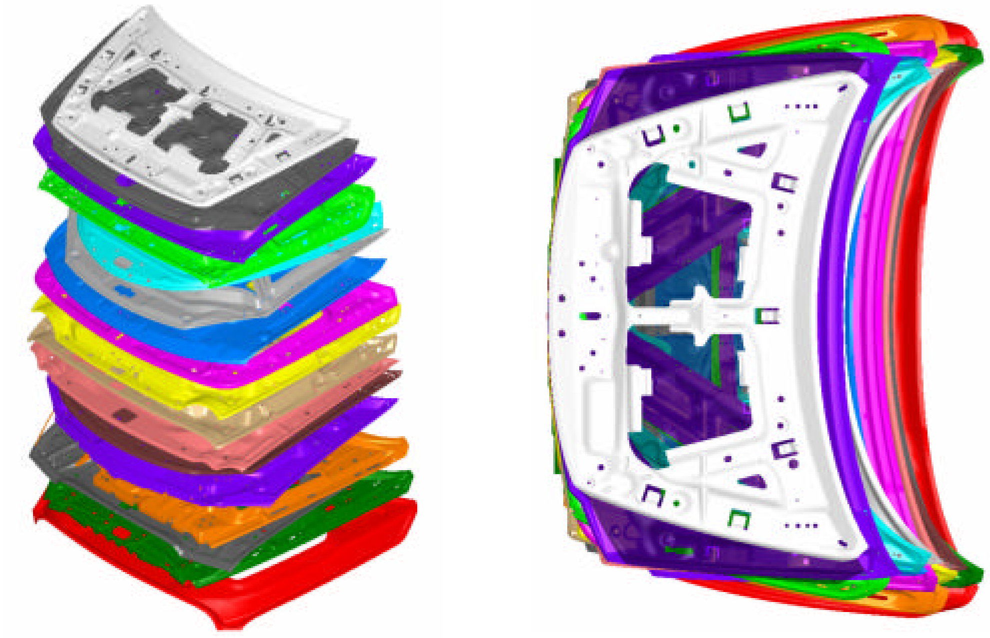


Figure A: These hood drawings show that the design trend allows for the hood to typically fit within a specified envelope, proving the feasibility of this design project.

After a visit to the DaimlerChrysler assembly facility in Windsor, Ontario, and a meeting with rack engineers from DaimlerChrysler and representatives from Ghafari, the student design team was able to define the problem. The following design challenges and requirements were presented by Ghafari and supported by DaimlerChrysler. This input was used by the student team to construct the customer requirements and design specifications:

- Racks must be compatible with the different robotic loading and unloading systems at the various DaimlerChrysler facilities.
- Racks must be configured such that manual and robotic interface is feasible.
- Racks must meet ergonomic guidelines for one and two person loading/unloading.
- Racks must be light weight yet durable for fork lift handling.

- Racks must be designed with impacts in mind, such as forces encountered through truck and rail transport.
- Racks must meet tolerance requirements even after years of use or rack must be designed such that slight rack deformation does not affect performance.
- Rack must be simple.

The manufacturing engineers at DaimlerChrysler have identified two possible paths for the new racking techniques that are being considered, smart racks and dumb racks. One example of a prototype dumb rack involves a design where the peripheral panels on the existing racks would be replaced with panels that allow for adjustable, sliding dunnage bars. However, this would take a large amount of time to implement and require significant down time for the entire assembly line, perhaps beyond the planned shutdown time. Figures B and C show examples of these ideas as demonstrated by DaimlerChrysler.

Figure B: Current reconfigurable racking ideas as demonstrated by DaimlerChrysler (prototypes, not yet used in production) – This design features adjustable dunnage bars by slots.

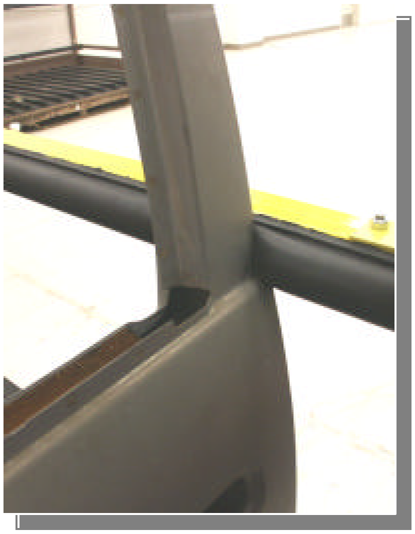


Figure C: Current reconfigurable racking ideas as demonstrated by DaimlerChrysler (prototypes, not yet used in production) – This design features a form fitting "Gumby dunnage" which temporarily molds to the shape of the part contained by the rack.

DaimlerChrysler's example of a smart rack incorporates the use of fully automated racking mechanisms. These racks would be connected to computers that would have access to all of the designs, allowing them to adjust their actuators in order to fit any family of parts. This system would have a cycle time of approximately 30 seconds, which is less than the time required to acquire parts from the point of delivery and store them in the racking system. However, this system is currently priced at $1.1 million and is therefore not feasible.

The rack designs currently proposed by Ghafari focus mostly of the dumb rack concept. Engineers at both Ghafari and DaimlerChrysler feel that the design of a reconfigurable, recyclable and reusable dumb rack is more robust and flexible. Therefore, our designs will stem from ideas on dumb racks, in addition to the other customer requirements defined by DaimlerChrysler and Ghafari.

CUSTOMER REQUIREMENTS AND ENGINEERING SPECIFICATIONS

To create innovative rack design concepts, several factors must be taken into consideration. Most importantly the design must meet the needs and requirements of the customer. To do so the engineering specifications must be weighed against the customer requirements. A Quality Functional Deployment (QFD) chart was utilized for this purpose.

CUSTOMER REQUIREMENTS

Based on information from Dr. Kim and the engineers at DaimlerChrysler and Ghafari, the most prominent customer requirements included that the rack be reconfigurable, reusable, and have consistent part placement. These requirements are necessary because the racks must be versatile enough to accommodate both manual and robotic loading and unloading. At the same time, the racks need to be easily reconfigured for parts of differing size and shape within a family. While loading, a panel should consistently fit into the same location within the rack. Racks are often moved by forklift and the tolerances on the frame and other components must last for the lifetime of the rack. At the end of the life of the rack, it is important that the materials can be either recycled or reused. In addition, the racks will be transported by rail or truck from the stamping plant to the assembly plant, and must firmly secure the parts to minimize damage. The cost of the racks is important, otherwise the benefits will go unrealized.

The customer requirements that were defined include:

- Recyclable
- Reconfigurable
- User-Friendly
- Economic
- Reusable
- Securely Holds Part
- Protective of Part
- Accurate and Consistent Part Placement
- Integrate with Manual and Automated Systems
- Durable

ENGINEERING SPECIFICATIONS

To create innovative rack design concepts, several customer requirements must be considered. Although the engineering specifications may appear similar to the DaimlerChrysler and Ghafari specifications detailed above, the student team chose to focus on a more global approach that is not company-specific. The student team also has the unique opportunity to look farther ahead into the future and is not constrained by the short-term goals of DaimlerChrysler's project.

One of the most important characteristics of a well-designed rack is a simple design. A simple design is easy to manufacture, is lightweight, takes less time to reconfigure, and will often cost less. A rack should be light weight so it is easy to move within a factory, costs less to transport, and requires less material. When a rack needs to be configured, it is desirable to have a quick reconfiguration time to save on additional labor expenses. The section of the rack in contact with the parts must be properly toleranced and can have a form-fitting material to hold the panels in place. Strong materials should be used to ensure that the rack is durable. A major concern of the UAW workers at the DaimlerChrysler Windsor Assembly Plant was the degradation of the moving joints. For older racks, the workers would sometimes have to use a hammer to release the securing pin on the dunnage bar.

When creating a rack, it is most cost-effective to use standard material and hardware that is common and easy to obtain in the market. Furthermore, in order to have an effective design, it has to be user-friendly. Therefore, the number of steps for an operator to access the parts should be minimized. Since each company has already invested in their current racking system, it would be impractical to completely scrap the current system. To accommodate this, the final design must be compatible with the system that is already in place while simultaneously showing the need for improvement.

One of the most important aspects of a reconfigurable rack is the lifetime. In order to recover the value of the initial investment, the racks must be designed to last for multiple model changeovers. Finally, allowing the weight of a part to secure itself simplifies the rack by reducing the number of components. At the same time this makes it safer because the part will be less likely to fall out.

The engineering specifications that were chosen include:

- Simple Design
- Light Weight
- Toleranced to Parts / Form Fitting Material
- Short Time to Reconfigure
- Secure Joints / Points of Movement
- Strong Material
- Standard / Common Materials
- Standard / Common Hardware
- Steps for User to Access Parts
- Compatible with Existing Systems
- Lifetime
- Weight of Part Secures Itself

BENCHMARKING

To make improvements, one must know how current racks perform. The racks that were benchmarked include a current rack from DaimlerChrysler, a prototype rack from DaimlerChrysler, and sketches of concept racks from Ghafari. Values have been assigned to these benchmarks to create a base-level performance that our design must exceed to be feasible.

QUALITY FUNCTIONAL DEPLOYMENT CHART (QFD)

A QFD chart was used to determine the most important engineering specifications, and can be found in Appendix A. To use this tool the customer requirements are listed in the left column while possible engineering specifications are listed with their weighted importance along the top. In the relationship matrix, a nine is entered to signify strong correlation between the requirements and specifications and a zero means no relation. From this, a total importance is derived for each engineering specification. This will allow us to better focus on the important aspects of the design.

The most important aspects of the reconfigurable rack design are standard hardware, utilizing the part’s weight to secure the part, and being compatible with existing systems. We have used these ideas throughout our concept design and selection process. One example of addressing standard hardware and compatibility with existing systems is to use a frame similar to that which is currently used. The design should also allow a part to sit in the rack in a stable position so it won’t easily fall out.

Some less important aspects include a light weight design and a quick reconfiguration time. The weight is not as significant because the racks are transported by semi-trucks and fork lifts; both of these forms of transportation are able to accommodate heavy loads. The major cost savings should come from the ability to reuse the racks. The reconfiguration time should be a secondary concern, as long as it provides an advantage over the current racks.

Along the top of the diagram is a relation of the engineering specifications to each other, with either a positive, negative, or no correlation. This section weighs the importance of trade-offs made when choosing a final design, and indicates which specifications can be more easily completed together.

While comparing these specifications, we found that a simple design is most correlated to the other specifications. A more simple design will decrease cost by minimizing material, lowering the complexity of manufacturing, and a shortening the reconfiguration time. The only specification with a negative correlation to more than one other specification was light weight. A lighter weight would interfere with a strong material and the cost, as well as the lifetime and durability of the rack.

CONCEPT GENERATION

To begin brainstorming and generating design concepts, one must first identify the basic function of the rack: to transport hoods inside and between plants by truck, rail, forklift, or robot. In addition, a new rack needs to act as a means of transport, a facility for storage, a secure part holder, a damage reducer, and a money saver. Using a Function Analysis System Technique (FAST) Diagram, the functions mentioned above are organized in the basic and secondary functions of the rack, the design requirements for enabling the secondary functions, and solutions to those design problems (see Appendix E).

Furthermore, the use of a morphological chart allows the team to elaborate on the rack’s functions, and organize concept ideas for how the rack should perform its functions (see Appendix F). The specific functions of the new rack are to be a part holder, a damage reducer, to fit the entire part family, serve as a means of transport, and provide a means of storage.

PART HOLDER

The most significant role of the rack is to function as a part holder; therefore, most of the design concepts involve different means of holding the part. Table 1 shows a list of the design concepts and the corresponding appendices that show design ideas incorporating that concept.

Table 1: List of Part Holder Design Concepts

PART HOLDER DESIGN CONCEPT	CORRESPONDING APPENDICES
Adjustable/Moveable Clamps	G, H, I
Grooves	L, T
Rollers	R, V
Dunnage Bars	J, P, U, V
Hairbrush Design	M, R
Meat Hooks	Q
Hangers	G, Q
Cables	S
Suction Cups	J, S
Inflatable Cushions	S
Sleeves	O, W

One innovative design concept for a part holder is the Magical Sleeve Machine (see Appendix W). This design uses a metal exterior frame filled with a foam cushion material. The foam has several slots, each of which is dimensioned to fit all hoods based on an “envelope” created from the dimensions of the largest hood. Though appropriate foam may not be available, the concept is ideal because it reduces the need for reconfiguration.

DAMAGE REDUCUCER

A new rack must also reduce the number of part defects caused by transportation or the racks themselves, which is a large problem with the existing racks. The concepts generated that aimed to reduce damage include memory foam fixtures (see Appendices O, R, T, V, W), rubber fittings (see Appendices L, M, U, W), and an increase in the number of points of contact (see Appendices G, H, M, Q, R, S, U, W).

The Concept Collaborator (see Appendix R) would be ideal for reducing damage simply by increasing the number of points of contact on a hood. Two rubber rollers supporting the bottom of the hood, fitted foam clamps on the back side of the hood, a dunnage bar on the front side of the hood, and hairbrush style prongs holding the top of the hood in place would provide a very secure fit for hoods.

FIT ENTIRE FAMILY

To accommodate all the parts from a given part family (i.e. hoods), a grid system to support adjustable clamps (see Appendix H), various mobile clamps (see Appendices G, H, I, J, L, P, T), sleeves (see Appendices O, W), shape changing racks (see Appendices K, X), and a hairbrush design were all considered (see Appendix M).

The Shape Shifter (see Appendix X) can fit all hoods by adjusting its exterior frame size. The Shape Shifter functions with a stationary back edge, where the arc of the hood comes into contact, and has an adjustable “leg” at each end of the back edge. The legs can pivot inward for smaller hoods and outward for larger hoods.

MEANS OF TRANSPORT

To ensure the rack would be suitable as a means of transport, forklift fittings (see Appendix U), trailer size, and stacking capability were considered (see Appendices L, N, U). One can safely assume that all the racks will be moved either by forklift or robot and it is important to consider the corresponding fixtures. The Hoodlum Roller (see Appendix U) uses the four exterior corner beams of the rack to extend beneath the bottom edge of the rack so that there is room for a formed metal bracket to create slots for a forklift.

MEANS OF STORAGE

Because the racks will need to be stored in the warehouse during the time between their arrival and placement on the production line, adjustable space consumption (see Appendices K, X), additional fixtures to hold more parts (see Appendices H, L, Q, S), and stackable racks (see Appendix L, N, U) were also taken into consideration as design concepts.

Since the racks will most likely be stacked on each other during transit and storage, male/female connectors could be used to align the stacks. Appendix L shows a design with four knobs protruding from each corner that was considered for the top surface of the rack. The rack also has corresponding indentations on the bottom surface at each corner to fit the knobs from the top of another rack. This enables the racks to be stacked by holding the top rack in place.

CONCEPT EVALUATION AND SELECTION

Through brainstorming and concept generations, over 15 partial and comprehensive racking mechanism concepts were produced. In order to minimize the amount of concepts, one must group the designs together based on similar concepts as well as based on similar mechanisms.

The concepts included sliding cubical frames with vertical load, part holders, damage reducers, fitting the entire family of parts, transportability, storage and stacking. These all had fairly similar mechanisms in terms of some sort of a dunnage bar, a rear support column as well as some sort of a clamping mechanism. The primary resource for selecting the number of concepts was based on the advice of Dr. Gap-Yong Kim, as well as the representatives of DaimlerChrysler and Ghafari.

Furthermore, through our meetings with Dr. Gap-Yong Kim, as well as corporate references such as DaimlerChrysler and Ghafari, the customer requirements were ranked and placed appropriately (see Appendix A). Considering these requirements and with the aid of a Pugh Chart, seven designs satisfied all of the concepts and displayed a good summary of all the mechanisms that would be feasible. Before beginning the Pugh Chart, it was important that the basic constraints be prioritized. This would envelope the idea of being easily mass manufactured, easy to use and having between three and four contact points in order to secure the hood into place.

The seven designs that we were able to narrow it down to were the following:

1. The Meat Hooks (Appendix Q)
2. The Trojan Rack (Appendix S)
3. The Clamp Master 2007 (Appendix T)
4. The Hoodlum Roller (Appendix U)
5. The Shape Shifter (Appendix X)
6. The Feasible Design (Appendix Y)
7. The Hanger Rack (Appendix G)

The Meat Hooks represented the idea of using hooks that would compensate for movement by tensioning the part in mid air. However, this idea failed to be recyclable, reusable, protect the part, or be durable, primarily because the parts had to be fixed and there was a lack of guidance in the mechanism which could possibly lead to part defects.

The Trojan Rack represented a very unique idea in terms of having an inflatable balloon that would encompass parts that were being pressed into the rear support by the dunnage bar. However, the feasibility of this project was very unlikely as its durability is questionable. Considering the balloons could fail due to the sharp sheet metal or wear and tear, the subsequent loss of one of the three points of contact would be very easy.

The Clamp Master brought to the surface a very secure way of fastening the hood without damaging the component at the points of contact. This concept maintained three points of contact and utilized foam and a sliding-over-lapping plates to hold the hoods with equal spacing in between. However, the complexity as well as the lack of recyclability of this design was the reason why it was not chosen.

The Hoodlum Roller represented a unique method of supporting the hood in the vertical direction. This design utilized the inner side of the crescent shaped hood to have a guidance system by using the weight of the component secure itself. Thus making sure that the part is not damaged. However, the lack of user-friendliness of the rollers as well as the inability to be economical was crucial in this design not being chosen.

The Shape Shifter incorporated an idea similar to a compact disc changer and was the only design where the hoods were horizontally loaded. Even though there were guidance mechanisms to make sure that the hoods would stay horizontal at all times during transport, the load on two of the four contact points was far too great to incorporate a rotation around a single column. Furthermore, many companies try to avoid horizontal loading primarily because of the moment generated by gravity on the hood making loading and unloading very difficult.

The Feasible Design managed to satisfy a lot of criteria by having a guidance mechanism with more than three points of contact, ensuring the placement of the hoods and reducing the possibility of parts sliding out in any direction. However, it did not use its own weight to hold itself in place which is why it was not chosen.

Through use of a Pugh Chart and consideration of the designs previously mentioned, one final design, The Coat Hanger Rack (see Appendix G), was selected. However, there was room for improvement of this design. This involved replacing complex mechanisms with simpler ones, increasing part contact points, and using a collaboration of ideas from all of the previous designs. The detailed explanation can be seen in the next section as well as the computer aided drawing of the Coat Hanger Rack.

Table 2: Pugh Chart

	Weight	Sketch "G"	Sketch "Q"	Sketch "S"	Sketch "T"	Sketch "U"	Sketch "X"	Sketch "Y
recyclable	7	+	0	0	+	0	0	0
reconfigurable	10	+	+	+	0	+	+	+
user-friendly	9	+	+	0	0	0	-	0
economic	8	+	+	0	0	-	+	0
reusable	10	+	0	+	+	+	+	-
won't damage part / securely holds part	9	0	-	+	+	+	0	+
protective of part	8	+	0	-	+	0	+	+
accurate and consistent part placement	10	+	-	0	0	+	+	0
integrate with manual & automated systems	8	0	-	-	0	0	-	+
durable	8	0	0	0	-	0	-	+
total "+"		7	3	3	4	4	5	5
total "-"		0	3	2	1	1	3	1
total		7	0	1	3	3	2	4

SELECTED CONCEPTS

The two selected concepts considered for the final design were the Coat Hanger Rack and the Feasible Design. The Hanger Rack would suspend the part from the top and have bars to secure the parts on each side. The Feasible Design would have an adjustable swing-arm to accommodate different size panels and a ratcheting bar to hold them in. Both would use an outer frame identical to those used in production today (96.5” (l) x 71” (w) x 68” (h)).

HANGER RACK

This rack can be seen in Appendix D, Figure C. Across the top center it has a curtain-rod style apparatus where part hangers are installed. Using this method the parts are held into the rack by their own weight. These part hangers are interchangeable for different part families, such as doors or hoods. This requires each part family to have similar grab points, an idea currently being pursued by DaimlerChrysler. The width of the hangers in contact with the rod could be sized to accommodate the depth of whichever part is in the rack, and will keep them properly aligned during loading. The two side contact bars use memory foam which conforms to the contour of the edge of any part. These bars would be universal to all parts. A pin-fitting is used on the ends to secure them in place, allowing for easy removal. The mounting points for these bars will be adjustable plates, which will allow the bars to move inward and outward as well as up and down. At the bottom of the rack, there will be a divot the size of the bar, which when removed will easily be placed out of harm's way.

FEASIBLE DESIGN

This rack can be seen in Appendix D, Figure D. The bottom and rear bars have slots in them for proper alignment of the parts while loading. These bars are bolted in and can be adjusted to accommodate any part family, such as hoods or doors. The top swing-arm will come down on top of the parts to adjust for variation in size within a part family. This swing arm will consist of a hinge joint at one end, and a milled semi-circle guide for a pin on the other end. There will be a locking mechanism to secure the swing-arm when it is in the correct position. The bar across the front will have a click-in mechanism with a pin release, and will be the final securing point for the parts. On the front bar, there will be "memory foam" to securely hold the part in place. This bar can be stored in a groove in the base of the rack. A major benefit of this design is that there are no moving parts which extend outside the original rack frame. Also, the front bar will be low enough that an operator of any size or height would be able to handle it.

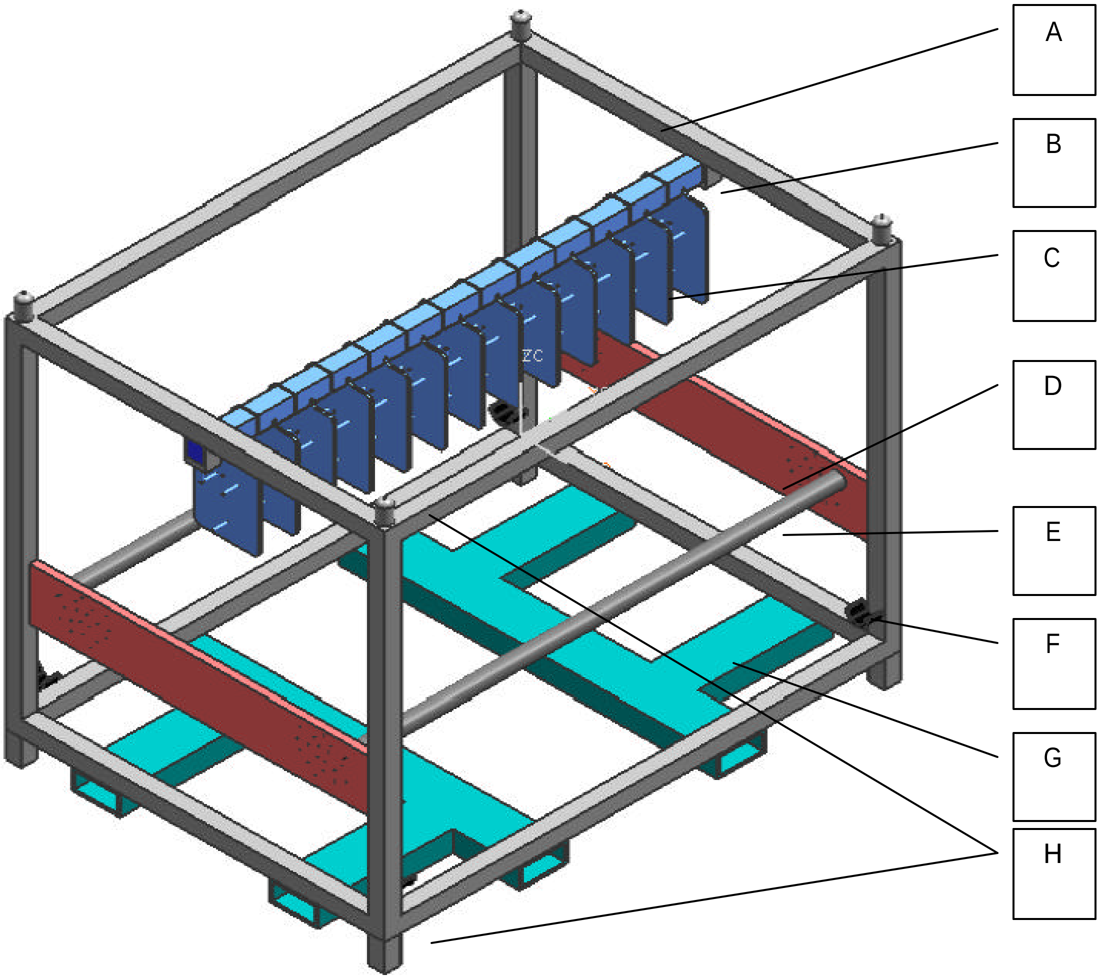
MATERIALS COST

To gain a rough estimate of a prototype design, materials were priced per the McMaster-Carr website [5]. The frame for a full-sized rack alone would require nearly 80 feet of three inch by three inch square tubing (Part number 6527K33 in [5]). This material's cost would be $7.50 per foot, for a total cost of over $600. Also, the maximum length of this tubing from McMaster-Carr is six feet. The maximum length of a bar in the current racks is over eight feet, which would require additional welding or an alternate supplier. Hence, to stay within budget constraints and meet project deadlines, a scale model will be produced.

Other materials common to both designs include a two feet by two feet steel plate, with a cost of $128 (part number 4459T23 in [5]). Also, a one foot by one foot steel plate has a cost of $35 (part number 4459T21 in [5]).

FINAL DESIGN

The concept chosen for the prototype was the Coat Hanger Rack because it most closely matched the design constraints. The final design was slightly modified based on the needs identified in the engineering analysis. All of the final design components are identified in Figure I and the labels correlate to the Final Design Bill of Materials in Table 3.



Final Design Bill of Materials

Label	Quantity	Component Name	Material	Description
A	1	Rack cage	Square steel bar	Fit to standard factory dimensions
B	1	Hanger bar	Square steel bar	Solid steel bar; can be removed from assy
C	13 (min)	Hanger	Steel plate, sleeve and hooks	Adjustable sleeve width for different parts
D	2	Side panel	Steel plate	Various holes to be drilled for dunnage bar
E	2	Dunnage bar	Steel bar with foam overlay	Spring pin assy in ends for removal
F	4	Dunnage bar cradle	Steel tube	"Storage" of bar during rack use
G	1	Forklift tray	Steel sheet	Fit to standard forklift dimensions
H	4	Stacking pins and ends	Steel tube and stock	Female and male ends for secure stacking

Figure I: Final Design components

The most innovative and non-standard component of the design is the hanger, which is drawn with full details and dimensions and included in Appendix AE.

ENGINEERING ANALYSIS

Quantitative and qualitative engineering analysis methods were used to ensure the validity and robustness of the hanger rack design. Because automotive racks built with similar structures and dimensions are already in use and have been proven over time to function properly, the engineering analysis focused on the innovative features of the hanging rack design. For example, instead of analyzing whether or not racks will buckle when they are stacked, which has already been time-tested and proven unlikely, the analysis focused on whether the hanger and rod will fail under the stresses generated from supporting the heaviest available hood.

QUANTITATIVE ANALYSIS

The quantitative analysis focuses on the innovative, untested hanger rod system and the hangers that will slide on the rod. The aim of the analysis is to approximate deformations and test for yield under the most strenuous conditions the racks may encounter.

Hanger rod analysis The most conservative analysis for the hanger rod includes analyzing the heaviest available hood and using the smallest dimension for the depth of a hood. This ensures that the greatest number of hoods will hang from the rod and that the hoods are the heaviest possible weight, making it the most strenuous scenario the hanger rod would encounter.

The heaviest hood weighs 182 N (41 lbs) and the maximum thickness on the thinnest hood is 0.058 m (see Appendix Z). The hanger rod and hangers will be made of steel with a maximum density of 7830 kg/m3, minimum modulus of elasticity of 190 GPa, and minimum yield stress of 200 MPa (30 ksi) [1]. To maintain a conservative analysis the material properties used were the weakest values quoted for steel. The hanger rod will be made of hollow, square 3” stock with a 1/8” wall thickness and an overall length of 96.5”. This is the standard size of stock used by DaimlerChrysler for the frames of their current racks.

The hanger will consist of a steel sleeve and a plate with three hooks on it (see Figure D). The sleeve will be hollow, square 3¼” stock with a 1/8” wall thickness. For analysis, the plate was approximated as a 12” x 16” x 0.25” plate. The total weight of each hanger is 60.4 N (13.6 lbs) (see Appendix AA for all calculations).

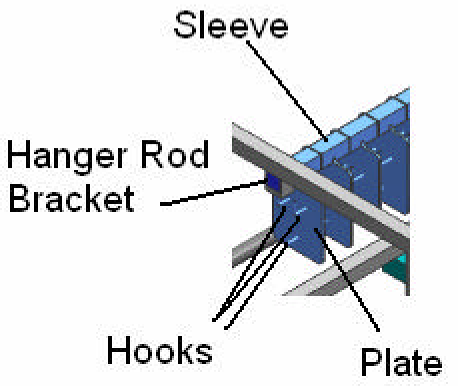


Figure D: Hangers on hanger rod for rack. Hanger consists of sleeve, plate, and 3 hooks. Hangers fit over 3" square stock hanging rod.

If each hanger requires a 0.058 m sleeve, the maximum depth of the smallest hood, no more than 42 hangers can fit on the rod. Given the known weight of the hood and by approximating the weight of the hanger, a rod with 42 hangers and hoods would need to support 10,360 N. Because there are 42 hangers distributed evenly across the rod, the load can be approximated as uniformly distributed, with a weight distribution of 4,250 N/m. With these values and approximations, the maximum deflection in the rod occurring at the center is less than 1.25 cm. This maximum deflection should not interfere with the design tolerances, so long as it does not lead to yielding in the hanger rod.

To determine whether the hanger rod would yield, it was noted that the maximum stress in the rod would be the normal stress in the cross section at the center of the rod, where maximum deflection occurs. Furthermore, the maximum stress would occur at the outer edge of the rod where either tension or compression is maximized. With the uniform weight distribution approximation, the largest normal stress encountered is 146 MPa, which is less than 75% of the smallest yield stress of steel, 200 MPa. Yield and deformation should not be a problem for the hanger rod.

Hanger Analysis Two different analyses were performed at the major stress concentrations on the hanger to assure that it will correctly work for its intended purpose. The first analysis addresses the joint between the plate of the hanger and the sleeve. At this point, the material will experience a normal, downward force from gravity, as well as a moment due to a center of gravity not directly positioned under the joint and longitudinal accelerations during transport. The second engineering analysis accounts for the shearing force on the hanger hooks. This force will result from the weight of the suspended hoods. See appendices AB and AC for dimensioned drawings and calculations. The analysis was done using the heaviest hood weight, or approximately 182 N (41 lbs), and approximating the hanger weight as 60.4 N (13.6 lbs).

Sleeve and plate joint analysis The first stress component considered was the normal force created by the weight of the largest hood and the weight of the plate, equal to 54 pounds, between the plate and the sleeve. This force is equally distributed over the weld and acts in the downward direction. The second component contributing to the stress at this joint results from the moment created by the off-center hood and acceleration during shipping, equal to 164 lb-ft. This was calculated by using a conservative estimate of the maximum displacement of the hood's center of mass from the lateral centerline of the hanger, determined as the maximum width of any available hood. This moment, coupled with the acceleration due to gravity, leads to a moment of 21 lb-ft. The acceleration during shipping also contributes to the maximum moment, which would be experienced during emergency braking maneuvers. To approximate this figure, a simulation was run in the program CarSim [12] with maximum braking of a large SUV giving 26 ft/s^2. To include a safety factor and simplify calculations, 32 ft/s^2 will instead be used. Coupling this acceleration with the mass and vertical offset of the hood center of mass and plate center of mass gives a moment of 143 lb-ft from braking.

When manufacturing these plates, the weld must be sufficient to hold without breaking. This would consist of a 3.25" long weld on both sides of the plate to connect it to the sleeve. The thickness of the plate is 0.25". The weld would have to withstand a 54 pound normal force as well as a moment of 173 lb-ft with a centerline parallel to the weld. See appendix AC for calculations.

Hook and plate joint analysis The force considered between the plate and the hook is created by the weight of hood. As it hangs the hood will create a shear force between the hooks and the plate. As a conservative estimate the weight of the largest hood was used. The hooks have a 0.5" diameter. Assuming that this force was distributed over the cross-sectional area of one of the top two hooks, there would be a shear stress of 208 psi. Using Mohr's Circle [7], shear stress is proportional to normal stress. As noted in the Hanger Rod Analysis section above, the minimum yield stress of steel is 30 ksi [1]. The stresses seen due to shear force will be much lower than the force applied by a single hood to one of the hangers, proving a safe design.

QUALITATIVE ANALYSIS

The qualitative analysis included Design For Manufacturing and Assembly (DFMA) and Failure Mode and Effect Analysis (FMEA).

Design For Manufacturing and Assembly (DFMA) The DFMA analysis of the design includes concepts and ideas on how to manufacture and assemble the rack easily. During the course of designing the rack, several design ideas were brainstormed and discussed by the team. Many of the ideas were rejected or modified because they were too difficult to manufacture or assemble. The DFMA analysis presents some of these ideas and solutions to potential design problems. Five guidelines were selected and a different design concept was analyzed for each guideline [3, 4, 5].

Design parts with symmetry One of the concerns about part symmetry from the original rack design focused on the hangers. In order to cut down on manufacturing costs by reducing the amount of machining required and to reduce the overall complexity of the part, the hangers were modified from their original design to the present design (see Figure E).

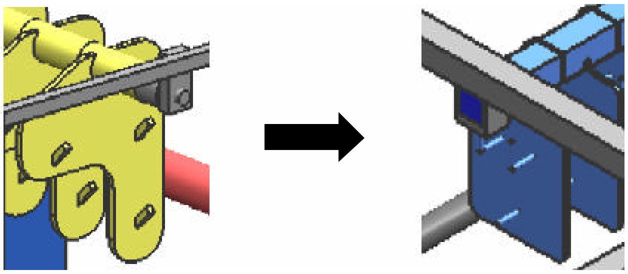


Figure E: Original L-shaped hanger plate modified into new square hanger plate to introduce symmetry and simplify the design.

The primary modification was making the hanger plate square instead of the original L-shape design. In addition, the bottom hook was moved to the center of the plate, increasing symmetry, balance, and stability. These adjustments should make the part cheaper and easier to manufacture, assemble, and use.

Simplify the design and reduce the number of parts Reducing the number of parts is the easiest way to simplify a design, reduce product cost, lower manufacturing difficulty, and avoid additional assembly. One of the proposed methods for reducing the number of parts is in the hanger rod mounting brackets. Originally, it was proposed that the bracket be welded to an additional steel plate that is mounted on two steel bars (see Figure F). This requires the material addition of a plate and a support bar, as well as significant additional welding for assembly. To simplify the design, a modified bracket was proposed. The new bracket will be made of the same square stock as the hanger sleeves, and hence the material will already be available because it is already in use. It will be welded to the bottom of the support bar that is already mounted to the rack as part of the frame instead of requiring an additional bar and plate.

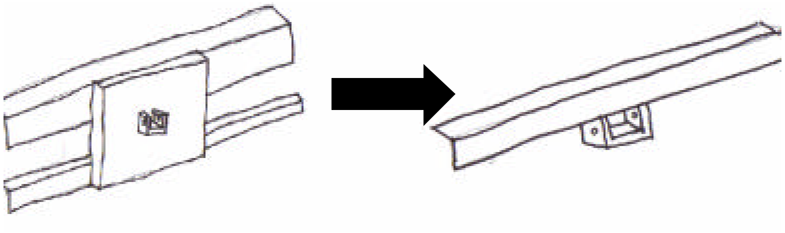


Figure F: Original support bracket modified into new support bracket to reduce number of parts and simplify the design.

Standardize and use common parts and materials In order to minimize the use of exotic or unique components in the rack, several commonly used and widely available materials were selected for the design. Among these materials was hollow, square 3” steel stock used to produce the frame of the rack. This is a standard size and should be available through many material suppliers. Furthermore, using 3” square stock throughout the frame will reduce the number of different parts required for manufacturing. Using standard 3” stock instead of an obscure size stock will make the rack cheaper and easier to manufacture and assemble.

Design for easy fabrication, processing, and assembly There are several ways by to make the rack easier to fabricate, process, or assemble. One way is to simplify the dunnage bar mounting system. Rather than having two mounting plates, as in the old design, a single mounting plate was preferred (see Figure G). The single, larger part should be easier to handle, making the rack easier to assemble. Furthermore, fewer plates require less manufacturing, so the overall fabrication should be easier. The larger plates also allow for reconfiguration.

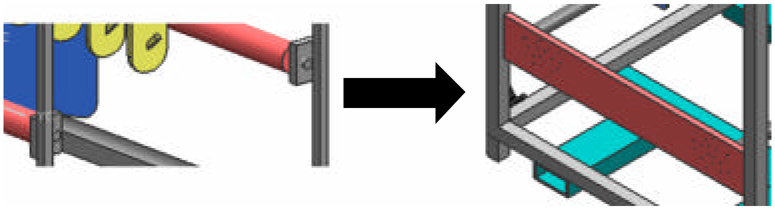


Figure G: Old dunnage bar mounting system modified into new system in order to make fabrication, processing, and assembly easier. New system has one plate that spans across the frame instead of two separate plates.

Design for fixturing One of the major functions of the rack is to serve as a means of transport for hoods between cities, from building to building, or within plants. They will travel by rail, truck, and forklift. Accordingly, the racks will be loaded and unloaded from different storage containers and locations constantly throughout their use. Hence, fixturing that accommodates forklifts and automated machinery is necessary for the racks. Previous racks incorporate a plate along the bottom, or floor, of the rack and have formed plates to act as guides for the forks on forklifts (see Figure H). The new rack will eliminate the need for a base plate by using hollow steel stock in a cross pattern along the bottom of the rack.

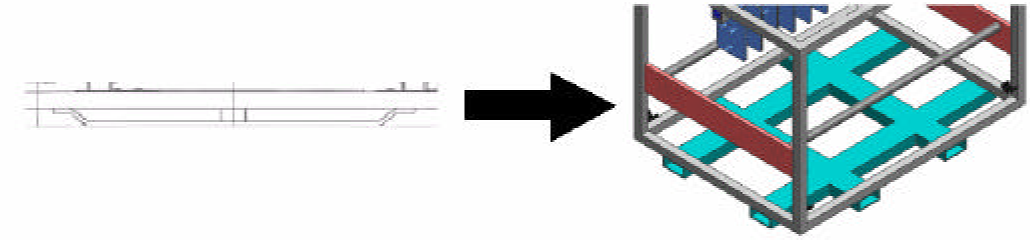


Figure H: Bottom fixturing modified to reduce weight and material requirements while still providing adequate access for forklift and potential automation of manufacturing process.

Failure Mode and Effect Analysis (FMEA) A FMEA chart was created to analyze the different possible failure modes of the design. For each part, a list of potential failure modes was created. Each mode was assigned a severity (S), occurrence (O), and detection (D) rating. The Risk Priority Number (RPN) was calculated by multiplying these ratings. From this RPN, one can determine the optimal modifications to a specific part to decrease part failures.

As can be seen in Appendix AD, a majority of the failure modes with large RPN's were due to a frame that becomes bent out of shape through repeated use. Most notably, the single biggest

RPN comes from seizure of the pins on the dunnage bar. As the frame becomes progressively more bent, these pins will not line up correctly. This will make it harder to use the pins and may result in expenditure of excess time and money. The second largest RPN comes from deformation of the frame, which creates alignment problems with all of the removable parts. In addition to the dunnage bars, the pins that hold the hanger bar in place will be affected. Other large problem areas include wear on the mounting hooks on the hanger, the dunnage bar itself becoming damaged, and the hanger bar becoming unequally loaded.

Many steps were recommended to reduce the RPN. With the changes, new S-O-D metrics were used to create new risk priority numbers. The failure mode with the most reduced RPN number is the frame being bent out of shape, which would be a result of stiffening the frame. Reducing this failure mode will also help to reduce other failure modes. The second-most reduced RPN is associated with the pins on the dunnage bar, which is also the result of a stiffer frame.

PROTOTYPE

The prototype presented at the Design Expo will be an approximate 1:3 scale model. This decision was made from a feasibility stand point as the model will need to fit through standard doorways, hall ways and be lifted by as few team members as possible. Using a standard doorway as the limiting factor, the scale was calculated to be 1:3 and this will provide the details needed to convey the design concept without making the model too difficult to deal with on a daily basis.

The relative dimensions will be the same in the prototype design as the prototype will simply undergo a linear scaling and the same final components will be portrayed. For these reasons, the final prototype bill of materials and the full assembly drawing as portrayed in Figure I and Table 3 are also valid for the final prototype design. Again, the major design component is the hanger and the drawing in Appendix AE is still accurate, however the dimensions are given at the full size as opposed to the 1:3 scale.

The only changes that might be made to either of these models will be dependent on any possible unforeseen errors or problems that may arise in manufacturing.

MANUFACTURING AND TESTING PLAN

Since the resources available at the University were sufficient to manufacture a scaled prototype, outsourcing any aspect of the hanger design was not necessary.

PROTOTYPE PLAN

To produce the prototype, the materials as seen in Appendix AF were purchased. The parts required to make the prototype were easily acquired through local material supply shops.

The frame consists of two square side brackets and four horizontal square tubes made of 1” x 1” steel tubing. The angle between the top bar and the uprights is 90°. However in order for there to be no open ends, the joints have to be cut at a 45° angle allowing for a smooth and strong weld.

The hanger rod shall also be made of 1” x 1” steel square tubing and will slide into support collars that are welded onto the frame. For the prototype, the support piece will be made out of steel square tubing with a slightly larger diameter than the 1” x 1” tubing. This will restrict rotational motion between the slot and the hanger rod. The translational motion shall be limited by pins securing the hanger rod to the collars.

The hanger plate will be made out of ¼” thick steel and will be welded to a sleeve as displayed in Figure 1. The three hooks will also be welded to provide three points of contact, reinforcing the notion of stability.

The fork-lift sleeves will allow the operator to access the frame from any of the four sides, furthermore welding the sleeves to the frame will provide the extra stability required. The fork-lift sleeves consist of four rectangular tubes that run across the frame along the bottom of the frame. These tubes also ensure that the automotive components will not get scratched by the forks.

The reconfigurable holes will be drilled on 7 gauge steel plates. These holes will be symmetrical on each side so the dunnage bar is able to compensate for changes in breadth of the automotive component. This will be done using a mill to decrease the tolerance on each plate.

The dunnage bar requires two circular PVC rods. To make the pin mechanism, this rod will have a horizontal slot milled for the release and a cavity for the spring and pin will be created using the lathe. The purpose of the horizontal slot is for a thumb-release to be inserted into the pin for actuation in releasing the dunnage bar from the plate. Finally, a layer of foam will be applied to the dunnage bar so it can apply pressure on the automotive parts to restrict any possible movement during transportation.

MASS PRODUCTION PROCESS

The first stage of the manufacturing process is to cut all the pieces to appropriate dimensions, seen in the Bill of Materials (BOM) Appendix AF. This means all the components of the frame, hanger rod, hanger plate, fork-lift, reconfigurable holes and the dunnage bar will be separated and ready for assembly.

The tools required to fabricate and assemble the reconfigurable racking mechanism are the lathe, weld, mill, drill, and saw. The mass manufacturing process can be simplified into three stages: creating the frame, the hanger and the dunnage.

The first stage is to construct the frame, starting with the square on either end. After the square ends are welded, the bars that run the length of the rack will be welded to the squares to form a rectangular cube. The square brackets are welded first as the tolerance of these welds determines the precision of all the other parts on the frame. After the frame has been constructed, the next step is to attach the plates where the reconfigurable holes will be located. These plates will be drilled into the frame after the holes have been milled into the plate, so that we minimize the deformation of the bar caused by the excessive heat transfer during welding. The last step is to weld the forklift tubing to the bottom of the frames so it can be transported around the factory. These tubes have to be welded to be sturdy enough to withstand the necessary loading.

The second stage is to construct the hanger. This starts by welding support pieces for the hanger rod, which will secure the rod with two pins. The next step is to weld three hooks to the 1/4" steel plate. This needs to be done before welding the plate to the sleeve so that there is no deformation between the sleeve and the plate. The last step is to weld the plate to the center of the sleeve perpendicular to the hanger rod, once completed these can be slid onto the hanger bar.

The third stage is to construct the dunnage bar. This requires a fairly large mill and lathe as the dunnage bar will be approximately six feet long. The bar needs to be milled so that there can be a slot for the retracting pin. After the pins have been made, one needs to apply a layer of glue to adhere the layer of foam to the dunnage bar.

There are no significant modifications in the manufacturing of the prototype compared to the mass manufacturing plan apart from the scale of the prototype is 1:3 of the real size of the racking mechanism. Furthermore the material used for the dunnage bar will not be PVC for the actual racking mechanism as this is far too weak of a material for the size.

This concept is simpler than the previous designs. This is seen by the reduced number of components, also implying that our design weighs less than the other racking concepts that we eliminated. The material for the forklift tubes and frame are similar to materials used in current designs, which further suggests that its durability is of industry standards. The points of movement are restricted by the two dunnage bars, the three hooks and the square sleeve. Unfortunately this means that this design is not compatible with how the automotive parts are manufactured and stored in the assembly plant. Nonetheless it is part of the idea ‘thinkpack’ which suggests that while designing components that one should simultaneously think about packaging.

All the parts are either easily found at any metals factory or are already being used in current racking devices. The steps required for accessing the parts are the same as before, therefore it is just as efficient in an assembly line situation. The hanger design allows the parts to hang by the force of its own weight, as is visible from the design. In order to manufacture this in a lean manner one must ensure that the procedures being used are inexpensive. Furthermore, all expensive procedures should be minimized. For example, the welding is minimized to only the frame, the support piece for the hanger rod and the fork-lift guides. As mentioned all the parts are easily accessible from any metals supplier which means that the parts are relatively inexpensive.

TESTING

Durability is an important aspect of manufacturing racks and therefore this design must be robust enough to handle different activities. The prototype was tested for failure via the two major functions it would see in use – travel in a truck and loading / unloading of the parts.

For travel durability testing the rack was placed, unsecured, in the rear of a truck and driven at various speeds for several hours. The rack did not vibrate excessively and all components were in satisfactory condition after the testing. The rack also stayed in place and didn't lean in such a way that the hoods would have fallen off of the rack.

To test the loading and unloading of the rack, scale hoods were cut from sheet metal and loaded and unloaded from the hangers. The hanger pegs and all affected components were effective during this function of the rack. While more testing may be needed for a full scale model of the rack and hood, the hanger is the only new, untested component of our design and could be tested very easily. The overall rack structure is the same as the current model and therefore has been tested by use and time.

Other components of the rack are the same or very similar to the racks currently used in production. As these components have been tested by time and full use, it was not important that those attributes of the prototype rack be tested. These attributes include the shear and bending of the overall rack cage, the effectiveness and durability of the forklift sleeves and the stacking and un-stacking of loaded and empty racks.

FUTURE IMPROVEMENTS

As detailed in the sections above, the strengths of our design are ease in reconfiguration, increased reusability, and promoted recylability. The major shortcoming of our design is the method to implement this concept into the current system. Since this is a proof-of-concept project, we examined how this idea would work in a general sense. However, to apply our design within a manufacturing setting, a design standard would need to be created regarding placement of "grab points" for either hanging the part or robotically handling it.

The strength and geometry of the hanging holes is one item of concern. Because we had very little knowledge about the forces experienced during shipping or the shape of the robotic gripper, we could not accurately design the attachment points. These attachment points must be strong enough to handle the forces during shipping and by robotic transport within the factory. On this same topic, the hanger hooks would need to be designed accordingly.

Another iteration on this design must be made to accommodate robotic loading and unloading of the parts. Currently, the theoretical grab points used for hanging the parts are also considered as the robotic handling points. To address this, perhaps the hanger plates could be detachable and removed by the robot. Another idea would be to design the plate so it can allow the robotic arm to approach from beneath the hanger and lift the plate off. One additional idea that may improve accessibility would be to have a vertical plate in which the hanger rod ends could be inserted. This would create a stiffer frame, a more durable connection from the rack to the parts, and more adjustability.

Use of memory foam surrounding the dunnage bars is suggested. This would allow accommodation of many different parts. Since the dunnage bars can be detached from the system and may somehow become misplaced and/or damaged, this should be taken into account during design. Also, ergonomic issues from bending over to set down and lift the dunnage bar should be eliminated. In addition, one should consider that there is nothing stopping these racks from being shipped without either dunnage bar, and proper precautions should be taken place so this will not happen. Regarding the side plates with holes, one must ensure that the dunnage bars would be placed correctly. A suggested solution would entail color-coordination by painting a ring color around the proper hole that matches the hanger. Different colors could be used for different hoods.

Finally, this concept may be applied to panels other than hoods. With the proper effort, it may be possible to design hangers for doors, fenders, or other metal stampings. For some stampings that are currently stacked on top of each other rather than secured individually in racks, such as relatively-flat roof panels, the hanger concept would not be an improvement. However, for any panel that requires individual isolation, the hanger design could greatly improve flexibility of manufacturing.

PROJECT PLAN

To complete the project objectives, many subsequent tasks were completed (see the Gantt chart in Appendix B for more detail). At least one team member was responsible for the completion of every task, and worked with other team members to complete it. The project began with background research on automotive racking systems and meetings with the project sponsor, Dr. Gap-Yong Kim, to become acquainted with the project definition.

Through a visit to DaimlerChrysler Headquarters in Livonia, MI, the team became familiar with the existing manufacturing racks as well as some of the prototypes that DaimlerChrysler is considering as temporary replacements. A visit to an assembly plant in Windsor, Canada allowed the team to observe problems with the existing racks first hand. Furthermore, this opportunity was used to talk with assembly line workers about the most significant problems faced during a regular working day.

A creative process of concept generation was used after a sincere understanding of the problem was acquired. From the generated concepts, technical input from Dr. Kim and DaimlerChrysler employees was requested on the feasibility of each idea. It was at this meeting where additional input from Ghafari, one of the engineering firms that DaimlerChrysler had hired to help solve the problem, was obtained. Through this meeting and the information obtained, it was easy to select a final design idea.

In order to assure the satisfaction of the engineering specifications for the rack, quantitative and qualitative engineering analysis was performed. The quantitative analysis focused on the newer design features, including the hanger rod, hangers, and hooks while the qualitative analysis included DFMA and FMEA.

The prototype satisfying the sponsor's criteria and constraints is completed. Due to the large size of the rack system and material cost constraints, creating a scale model focusing on modeling the design concept was best. A 1:3 scale factor was selected so that standard material sizes would be available. The bill of materials was completed and the materials required for prototype construction were obtained. The steel bar stock for the frame and hanger sleeves, steel plates for the hangers and dunnage bar holders, and PVC piping for the dunnage bars were purchased. All other materials were obtained in-house and all manufacturing took place in-house at the University of Michigan Mechanical Engineering Machine Shop.

Each team member obtained welding training to build the rack. All construction was completed, the prototype was tested and painted, and a presentation produced in preparation for the Design Expo. The project is complete and has been submitted to Dr. Kim for his final approval.

CONCLUSIONS

After many meetings with the project sponsor, DaimlerChrysler, and Ghafari, several concept ides were generated for the Robust, Reconfigurable Racking system (see Appendices D, G-Y). With the aid of a QFD Diagram (see Appendix A), design requirements and features of the rack were identified and weighted based on importance. A FAST Diagram (see Appendix E) was used to further analyze the rack's functions, and a Morphological Chart (see Appendix F) was used to organize the concept ideas by function. A Pugh Chart (see Table 2 on p.14) was used to analyze several final design concepts and rank them based on the design requirement criteria. The highest ranking design concept was the Hanger Rack (see Appendix G) and this was the design idea selected for prototyping.

A preliminary CAD model of the final design is shown in Appendix D, Figure C. With the aid of quantitative and qualitative engineering analysis, several modifications to the design were made. The quantitative analysis focused on the newer and innovative design features of the Hanger Rack that have never been previously manufactured or tested. The conservative, worst-case-scenario analysis results show that material deformation and yield will not be a problem (see Appendix AA for calculations). Hence, the rack design is robust and will withstand the loading encountered during use. Detailed qualitative analysis including Design For

Manufacturing and Assembly and Failure Mode Engineering Analysis (see Appendix AD) identifies several design modifications and potential failure modes. A CAD model of the finalized design is shown in Appendix AE.

A manufacturing and test plan was created, a bill of materials generated, and parts purchased. Production of the prototype is completed, and has been presented at the University of Michigan end-of-semester Design Expo.

ACKNOWLEDGEMENTS

We would like to extend a special thank you because this project would not be possible without the support of the following people:

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Suman Das, Associate Professor, Mechanical Engineering
Bob Coury, Senior Engineering Technician, Mech Eng & Applied Mech Dept
Marvin Cressy, Senior Engineering Technician, Mech Engr Dept
Steve Emanuel, Research Laboratory Specialist

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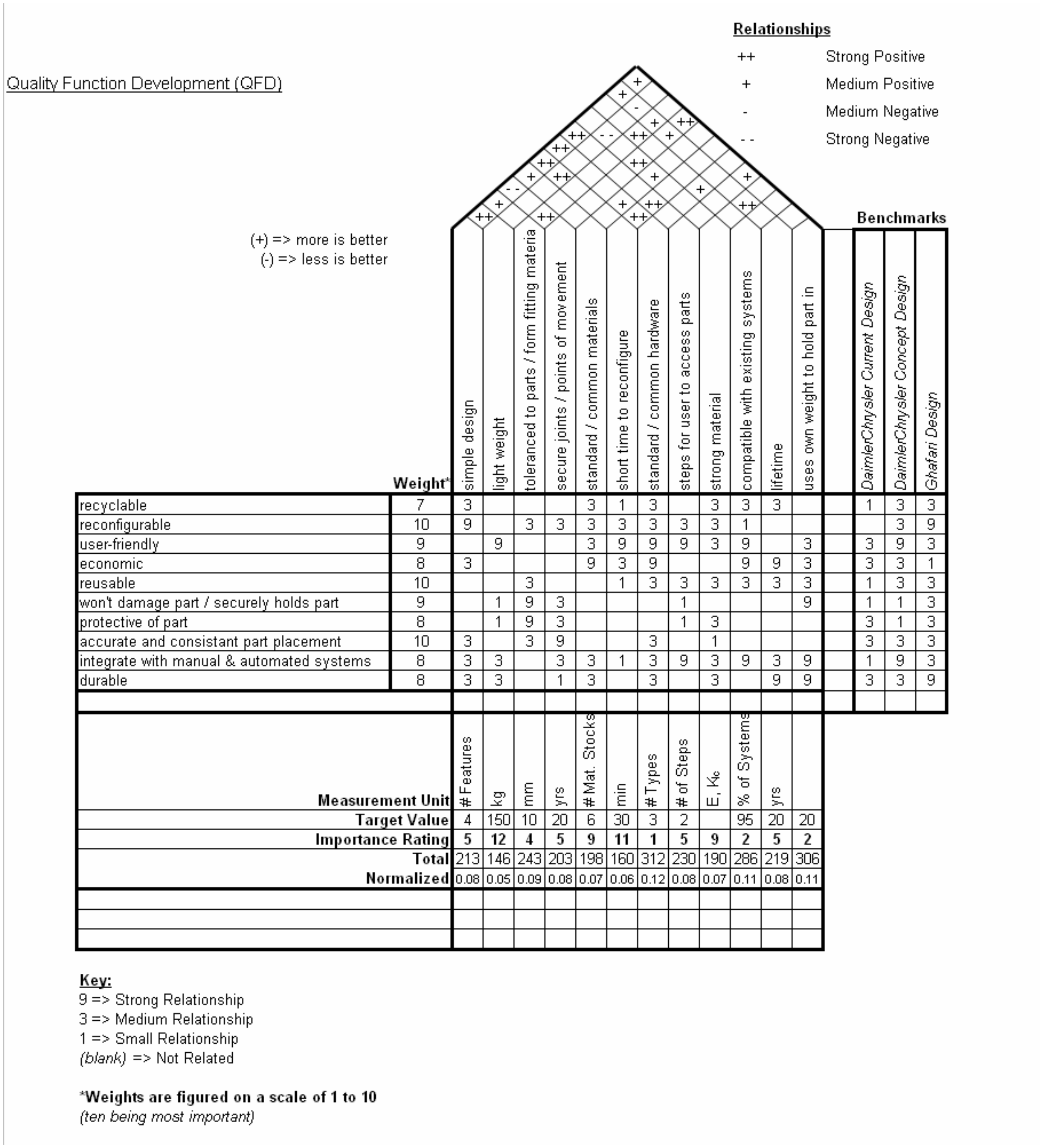
APPENDIX A: QFD DIAGRAM



Quality Function Development (QFD)

Relationships

++	Strong Positive
+	Medium Positive
-	Medium Negative
- -	Strong Negative

(+) => more is better
(-) => less is better

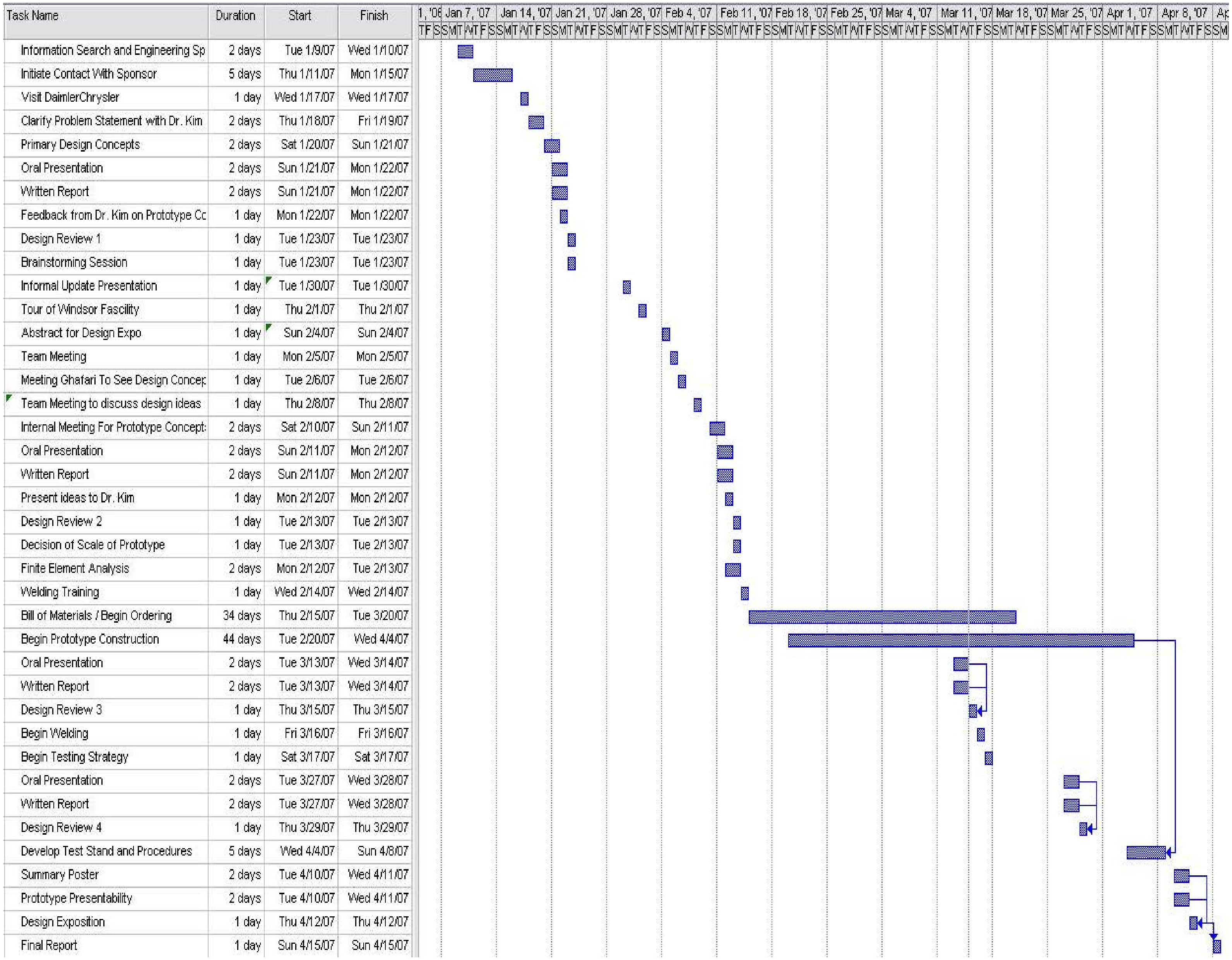
	Weight*	simple design	light weight	toleranced to parts / form fitting materia	secure joints / points of movement	standard / common materials	short time to reconfigure	standard / common hardware	steps for user to access parts	strong material	compatible with existing systems	lifetime	uses own weight to hold part in		*DaimlerChrysler Current Design*	*DaimlerChrysler Concept Design*	*Ghafari Design*
recyclable	7	3				3	1	3		3	3	3			1	3	3
reconfigurable	10	9		3	3	3	3	3	3	3	1					3	9
user-friendly	9		9			3	9	9	9	3	9		3		3	9	3
economic	8	3				9	3	9			9	9	3		3	3	1
reusable	10			3			1	3	3	3	3	3	3		1	3	3
won't damage part / securely holds part	9		1	9	3				1				9		1	1	3
protective of part	8		1	9	3				1	3					3	1	3
accurate and consistant part placement	10	3		3	9			3		1					3	3	3
integrate with manual & automated systems	8	3	3		3	3	1	3	9	3	9	3	9		1	9	3
durable	8	3	3		1	3		3		3		9	9		3	3	9
Measurement Unit		# Features	kg	mm	yrs	# Mat. Stocks	min	# Types	# of Steps	E, K_c	% of Systems	yrs					
Target Value		4	150	10	20	6	30	3	2		95	20	20				
Importance Rating		**5**	**12**	**4**	**5**	**9**	**11**	**1**	**5**	**9**	**2**	**5**	**2**				
Total		213	146	243	203	198	160	312	230	190	286	219	306				
Normalized		0.08	0.05	0.09	0.08	0.07	0.06	0.12	0.08	0.07	0.11	0.08	0.11				

Benchmarks

Key:
9 => Strong Relationship
3 => Medium Relationship
1 => Small Relationship
(blank) => Not Related

***Weights are figured on a scale of 1 to 10**
(ten being most important)

APPENDIX B: GANTT CHART



Task Name	Duration	Start	Finish
Information Search and Engineering Sp	2 days	Tue 1/9/07	Wed 1/10/07
Initiate Contact With Sponsor	5 days	Thu 1/11/07	Mon 1/15/07
Visit DaimlerChrysler	1 day	Wed 1/17/07	Wed 1/17/07
Clarify Problem Statement with Dr. Kim	2 days	Thu 1/18/07	Fri 1/19/07
Primary Design Concepts	2 days	Sat 1/20/07	Sun 1/21/07
Oral Presentation	2 days	Sun 1/21/07	Mon 1/22/07
Written Report	2 days	Sun 1/21/07	Mon 1/22/07
Feedback from Dr. Kim on Prototype Cc	1 day	Mon 1/22/07	Mon 1/22/07
Design Review 1	1 day	Tue 1/23/07	Tue 1/23/07
Brainstorming Session	1 day	Tue 1/23/07	Tue 1/23/07
Informal Update Presentation	1 day	Tue 1/30/07	Tue 1/30/07
Tour of Windsor Fascility	1 day	Thu 2/1/07	Thu 2/1/07
Abstract for Design Expo	1 day	Sun 2/4/07	Sun 2/4/07
Team Meeting	1 day	Mon 2/5/07	Mon 2/5/07
Meeting Ghafari To See Design Concep	1 day	Tue 2/6/07	Tue 2/6/07
Team Meeting to discuss design ideas	1 day	Thu 2/8/07	Thu 2/8/07
Internal Meeting For Prototype Concept	2 days	Sat 2/10/07	Sun 2/11/07
Oral Presentation	2 days	Sun 2/11/07	Mon 2/12/07
Written Report	2 days	Sun 2/11/07	Mon 2/12/07
Present ideas to Dr. Kim	1 day	Mon 2/12/07	Mon 2/12/07
Design Review 2	1 day	Tue 2/13/07	Tue 2/13/07
Decision of Scale of Prototype	1 day	Tue 2/13/07	Tue 2/13/07
Finite Element Analysis	2 days	Mon 2/12/07	Tue 2/13/07
Welding Training	1 day	Wed 2/14/07	Wed 2/14/07
Bill of Materials / Begin Ordering	34 days	Thu 2/15/07	Tue 3/20/07
Begin Prototype Construction	44 days	Tue 2/20/07	Wed 4/4/07
Oral Presentation	2 days	Tue 3/13/07	Wed 3/14/07
Written Report	2 days	Tue 3/13/07	Wed 3/14/07
Design Review 3	1 day	Thu 3/15/07	Thu 3/15/07
Begin Welding	1 day	Fri 3/16/07	Fri 3/16/07
Begin Testing Strategy	1 day	Sat 3/17/07	Sat 3/17/07
Oral Presentation	2 days	Tue 3/27/07	Wed 3/28/07
Written Report	2 days	Tue 3/27/07	Wed 3/28/07
Design Review 4	1 day	Thu 3/29/07	Thu 3/29/07
Develop Test Stand and Procedures	5 days	Wed 4/4/07	Sun 4/8/07
Summary Poster	2 days	Tue 4/10/07	Wed 4/11/07
Prototype Presentability	2 days	Tue 4/10/07	Wed 4/11/07
Design Exposition	1 day	Thu 4/12/07	Thu 4/12/07
Final Report	1 day	Sun 4/15/07	Sun 4/15/07

APPENDIX C: GROUP BIOS

MICKEY BOHN

Mickey is originally from Charlevoix, MI. He graduated from Culver Military Academy in Culver, IN in 2003. During his youth, he enjoyed playing with Legos, K-Nex, Lincoln Logs, Tinker Toys, and performance remote control cars. He also played with the traditional GI Joe's and Ninja Turtles, but building things with toys was a lot more fun for him. During his high school years, he loved his math courses and was encouraged to try out engineering in college. He has had internships with GE Consumer and Industrial and Caterpillar Inc., and has spent a week at a case study sponsored by Shell. This summer he will be working for Shell as an Exploration and Production Engineer. After graduation, he is considering careers in teaching, consulting, and entrepreneurship. He currently wonders how he might apply his degree in Mechanical Engineering to his future career.

PRATEEK CHOURDIA

Prateek was born in Nagaur, Rajesthan in the Republic of India. Through the course of his primary and secondary education he has been able to experience the cultures and customs of Bangkok, Singapore and Hong Kong S.A.R. the latter being the place of his residence. Having lived in South East Asia a sense of competitiveness as well being accustomed to adaptability has become innate. His passion to figure out how things worked stemmed from his ability to break objects easily during his childhood. Coming to the University of Michigan only solidified his desire to become a part of the Automotive Industry through a Bachelors of Science in Mechanical Engineering. Prateek is currently unemployed and is a junior at the University and is seeking an internship at Lotus Engineering here in Ann Arbor.

DAVID CLARK

Dave was raised in the small town of Blissfield, MI. He graduated from Blissfield High School in 2003. His grandfather was an engineer, and worked at Ford Motor Company for a while. A toy truck which David had received from his grandfather for Christmas one year perhaps sparked his interest in automobiles. Dave would routinely take apart the plastic nuts and bolts which held the truck together, and then promptly reassemble every last piece. Excelling at math and science in high school, Dave naturally applied to the best engineering college in the state of Michigan. Not to be foolish he also considered another top-notch university in the state, but fortunately he made the better decision. While at college, he has worked at the North Campus Recreation Building for four years. He has also held two summer internship positions at Tenneco Automotive in Monroe, MI. Dave has always shown a great curiosity and interest with regard to how mechanisms function, and enjoys reading articles on www.howstuffworks.com. Now that he has a real car, he loves to tinker with that instead of his old toy. Dave has actively participated in the professional/events branch of the U-M Chapter of the Society of Automotive Engineers, and hopes to become more involved in the Formula SAE project team next school year. He will soon be applying to the Mechanical Engineering SGUS program, where he plans to obtain a coursework Master's Degree in one additional year of schooling. After this, Dave plans to follow his dreams and enter the automotive industry, either in a business or an engineering position.

GABRIELLA HARRISON

Gabriella was born in South Bend, IN and has spent her entire life living in the Midwest. As the daughter of two engineers, she started taking things – including her father's dirt bike– apart at an early age. Many of her first steps were taken in the family garage to "help" bring tools and parts to her father. Gabriella attended an accelerated math and science center program at a local university as a part of her high school curriculum which included a senior project where she cloned her own DNA. She always knew she would be a Wolverine and after graduating high school she packed her things for Ann Arbor. She has interned throughout her college years at Robert Bosch Corporation in South Bend, IN working on passenger car and medium / heavy truck braking systems. Gabriella has been actively involved on campus with marching band, an executive position of the U-M Chapter of the Society of Automotive Engineers and a group leader position on the U-M Formula SAE M*Racing* team. Her professional career will begin this July with International Truck and Engine Corporation as a member of the Operations Management Development Program after she graduates this April with a Bachelor's Degree in Mechanical Engineering.

APPENDIX D: SELECTED CONCEPTS CAD DRAWINGS

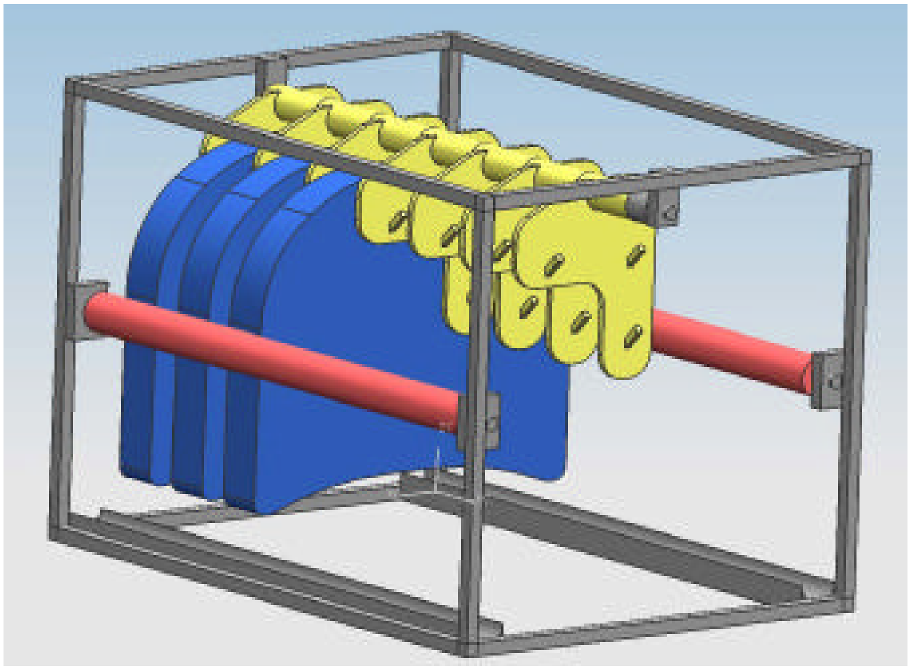


Figure C: Hanging Design Concept

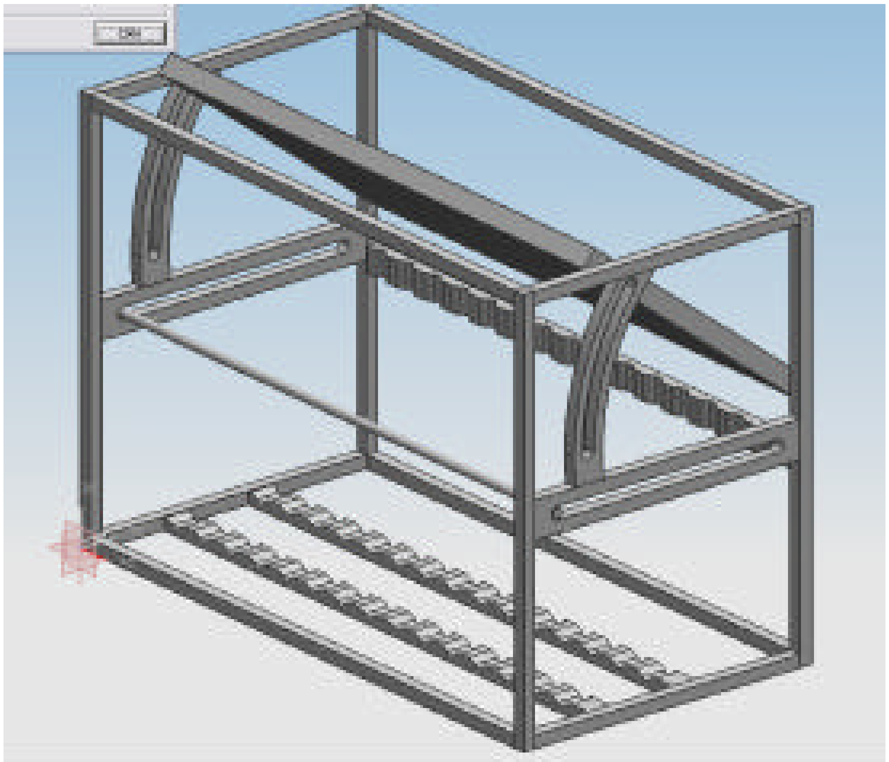
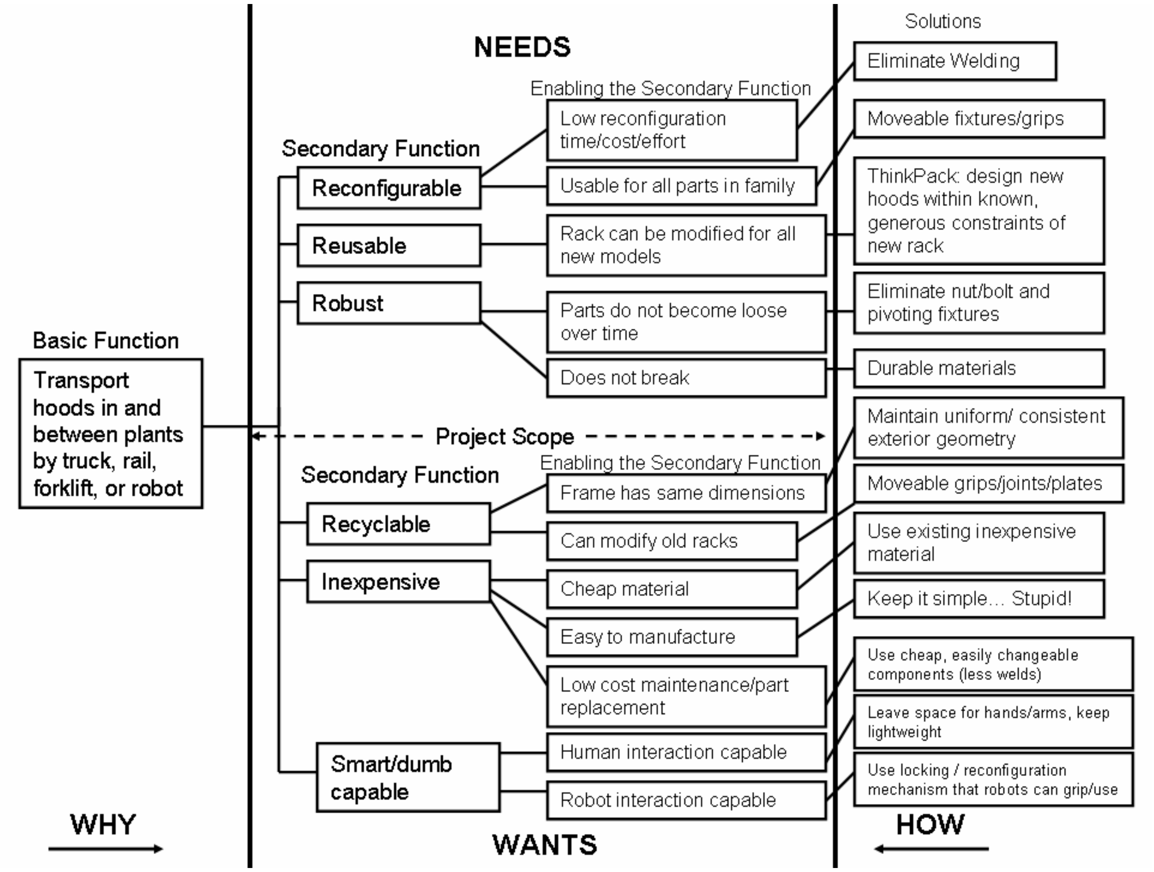


Figure D: Feasible Rack Design Concept

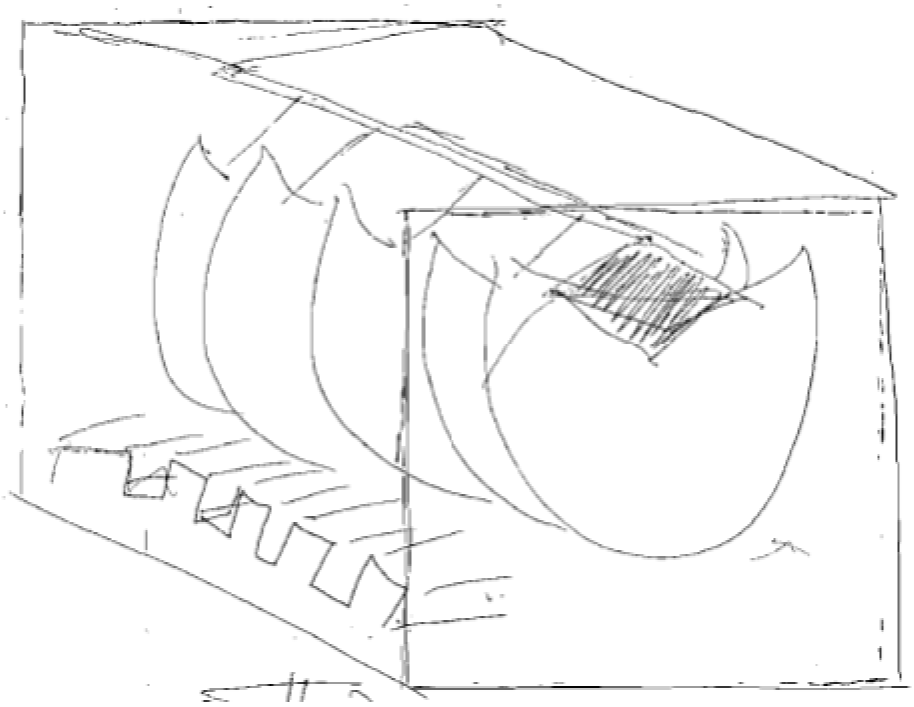
APPENDIX E: FAST DIAGRAM



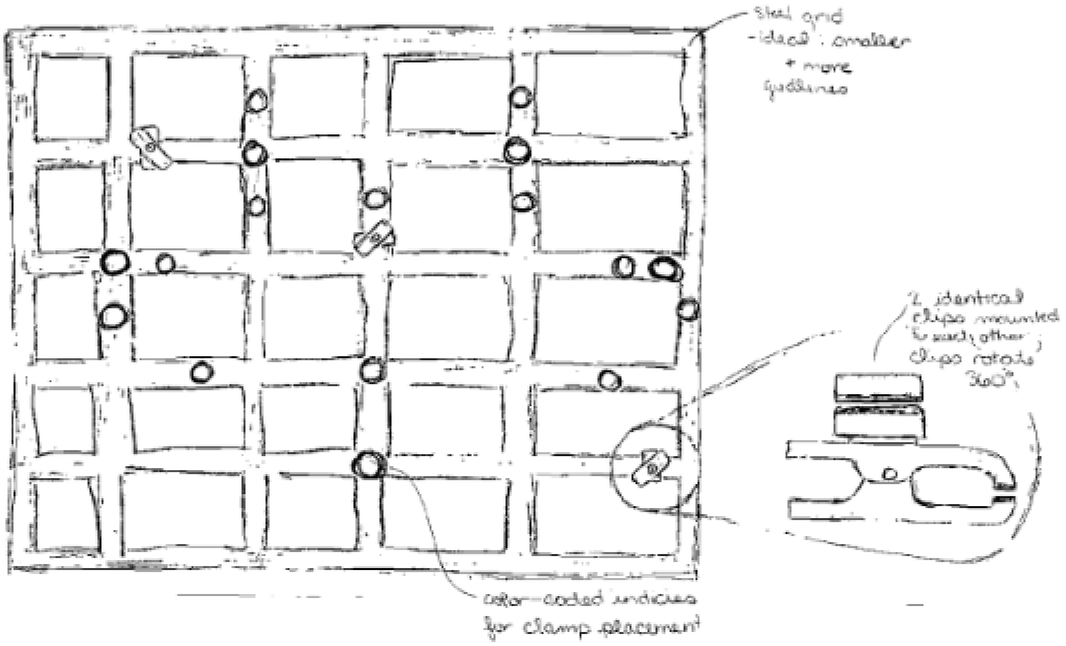
APPENDIX F: MORPHOLOGICAL CHART

FUNCTION	CONCEPTS					
Part Holder	Adjustable Clamps	Grooves	Rollers	Dunnage Bars	Hairbrush	Sleeves
	Hooks	Hangers	Cables	Suction Cups	Inflatable Cushions	
Damage Reducer	Memory Foam	Rubber Fittings	Lots of Contact Points			
Fit Entire Family	Grid System	Movable Clamps	Sleeves	Shape Changer		
Means of Transport	Forklift Fittings	Fits in Trailer	Stackable			
Means of Storage	Stackable	Adjustable Space Consumption	Add Fixtures for More Parts			

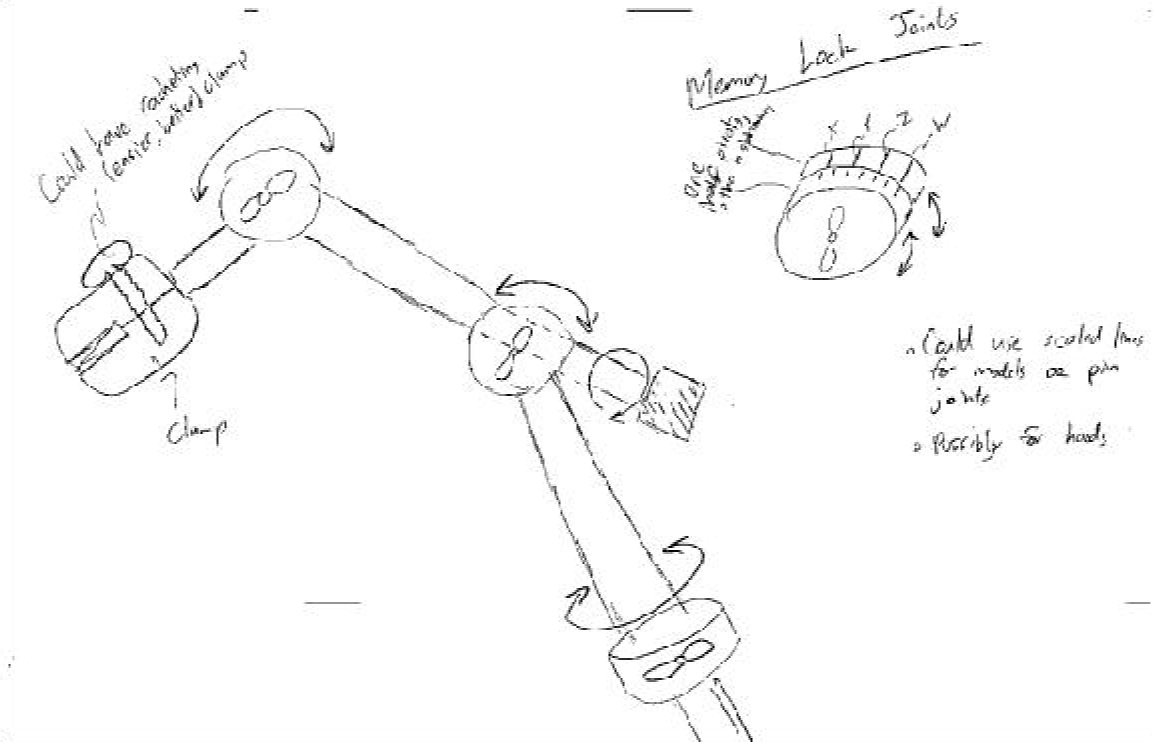
APPENDIX G: THE COAT HANGER RACK



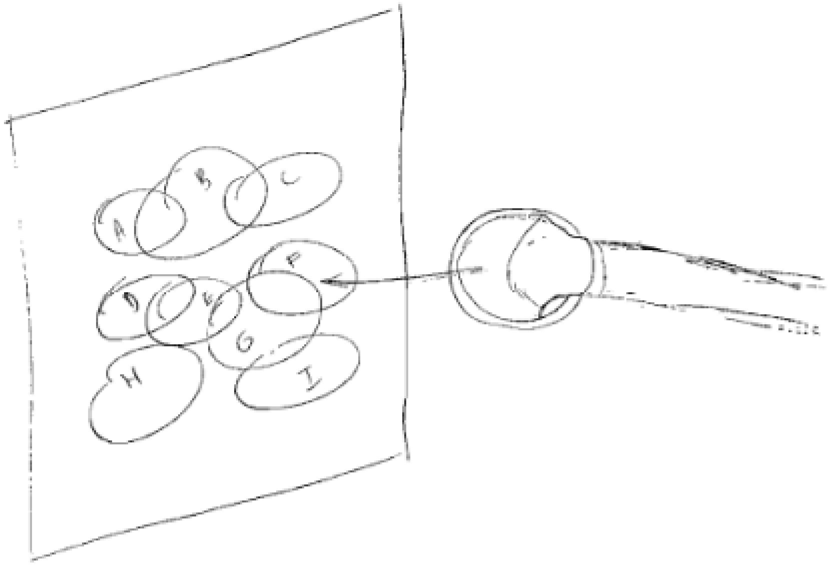
APPENDIX H: CLAMPS ON GRID SYSTEM



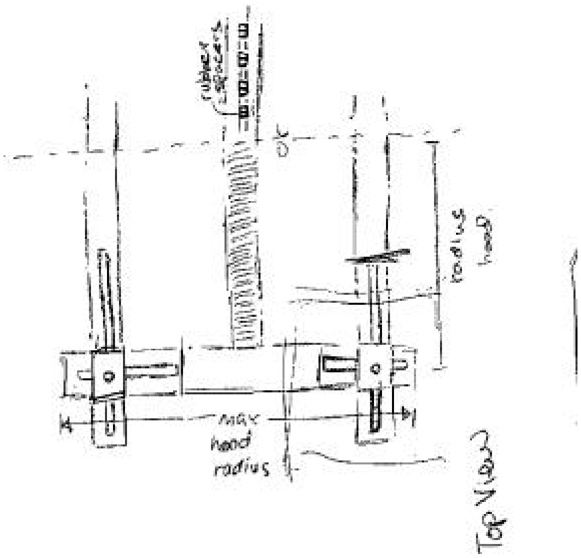
APPENDIX I: ADJUSTABLE “BOOM” ARM



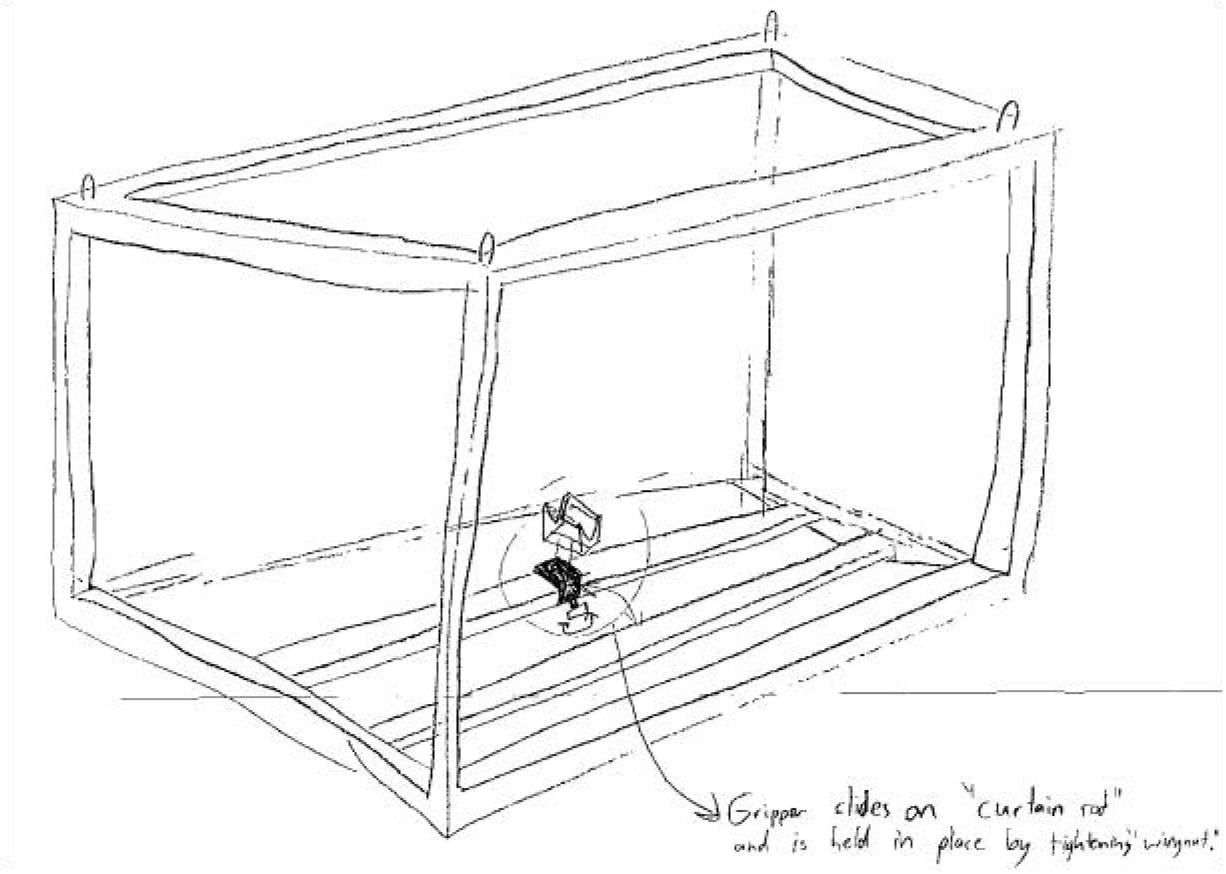
APPENDIX J: SUCTION CUP ON STATIONARY PLATE



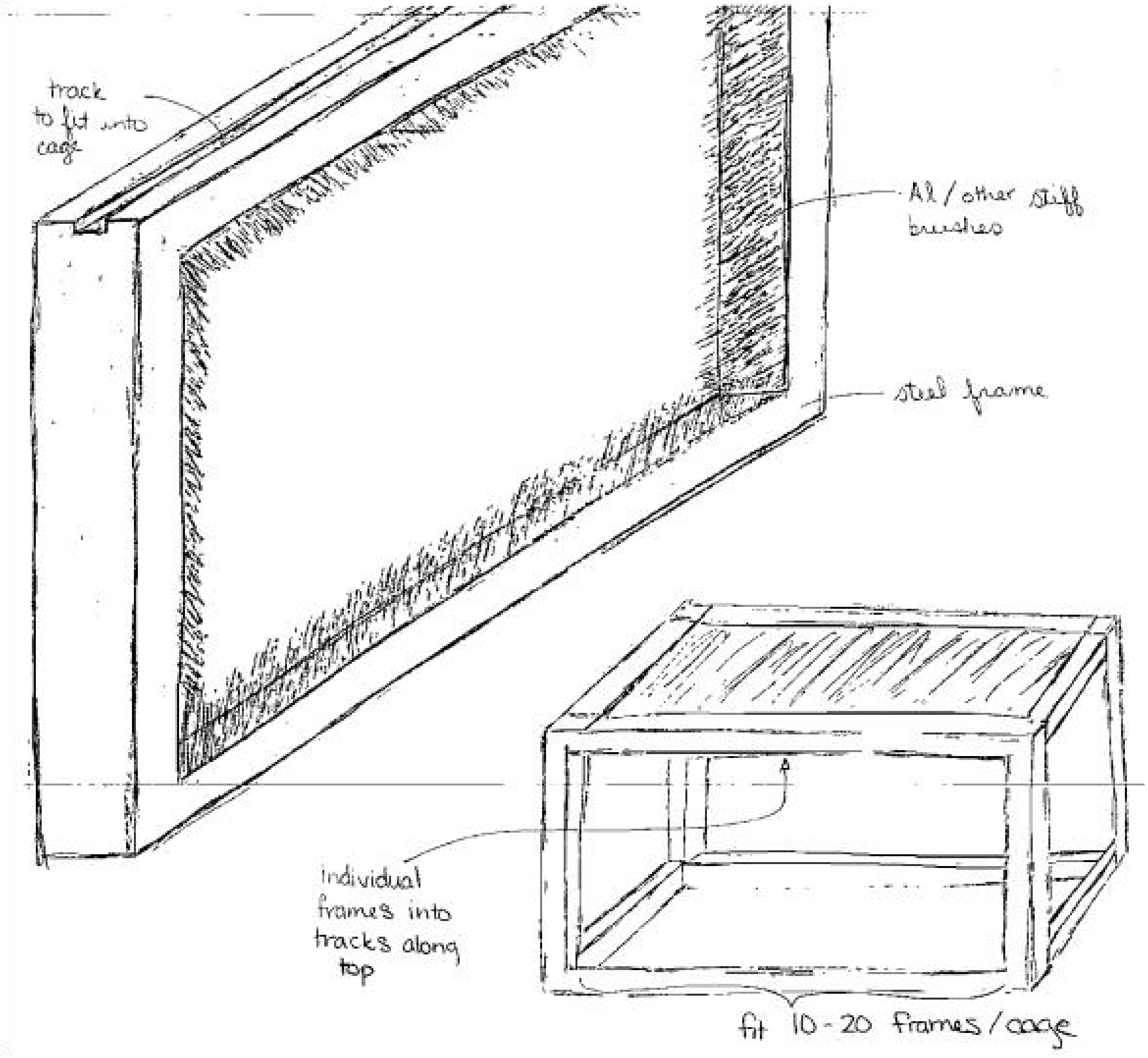
APPENDIX K: RESIZABLE RACK



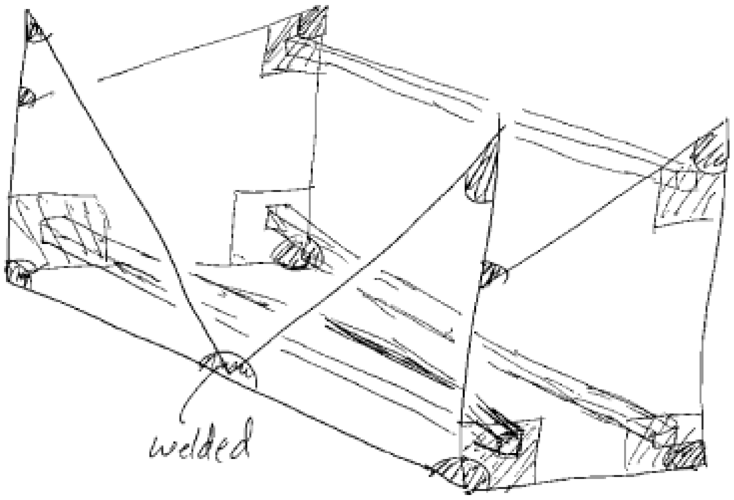
APPENDIX L: GROOVED SUPPORT ON “CURTAIN ROD”



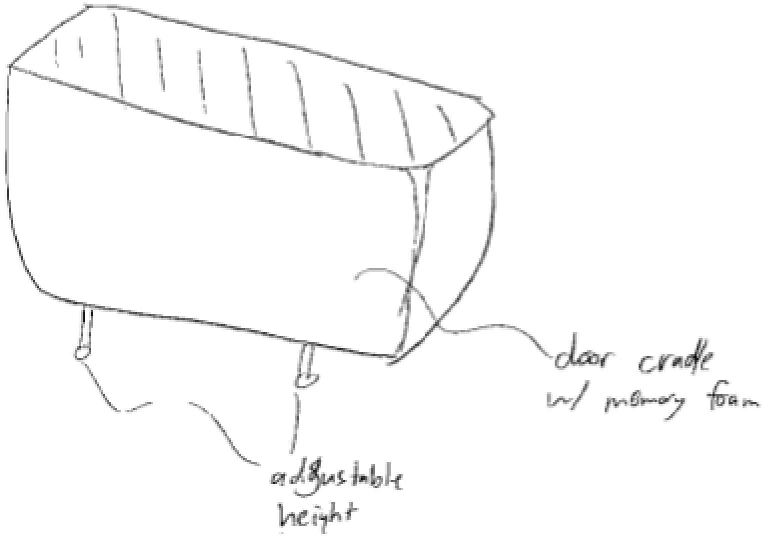
APPENDIX M: "HAIRBRUSH" GRIPPING



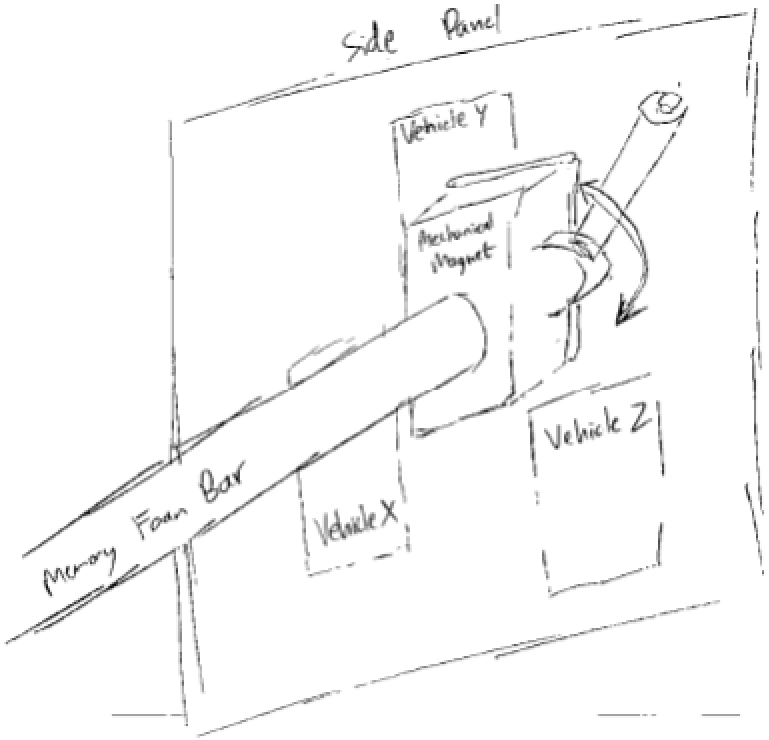
APPENDIX N: TRIANGLE STYLE MATERIAL CUT-OUT



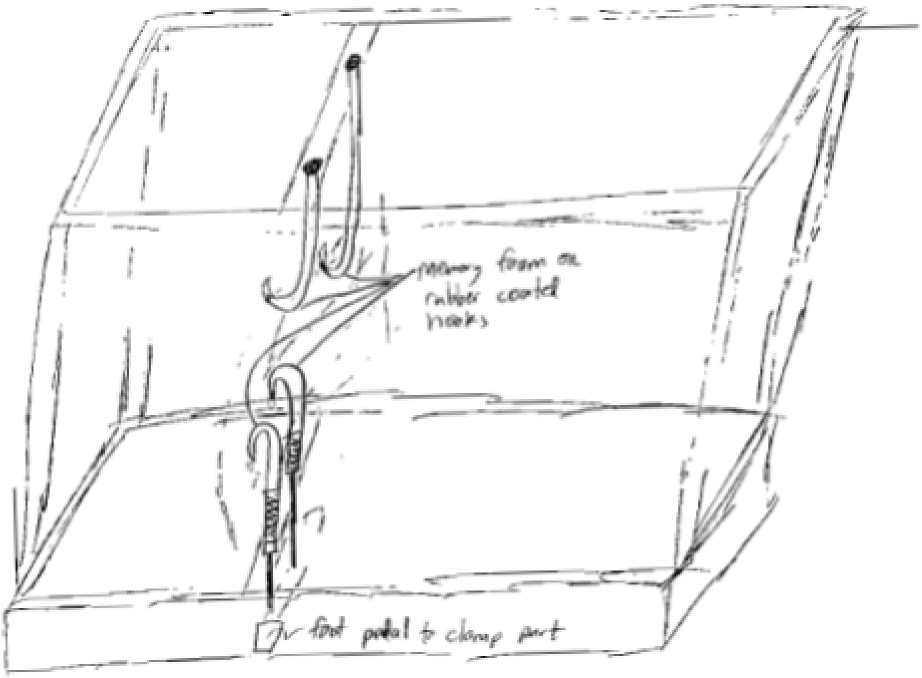
APPENDIX O: THE “TROUGH AND GROOVE”



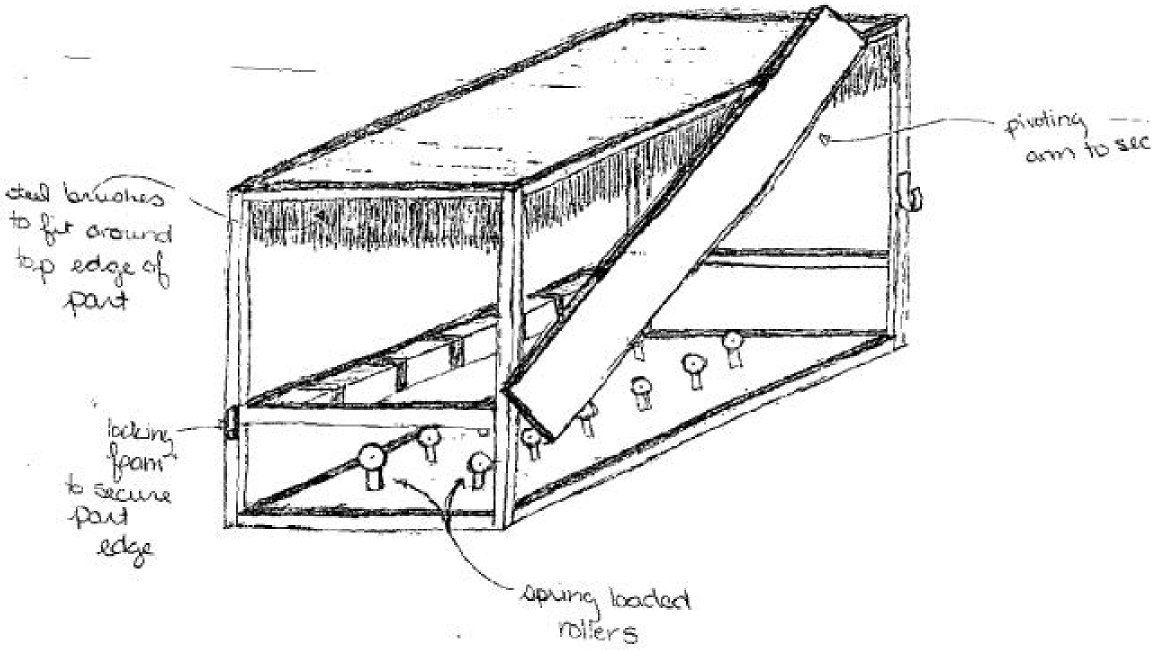
APPENDIX P: MAGNET DUNNAGE BAR ON STATIONARY PLATE



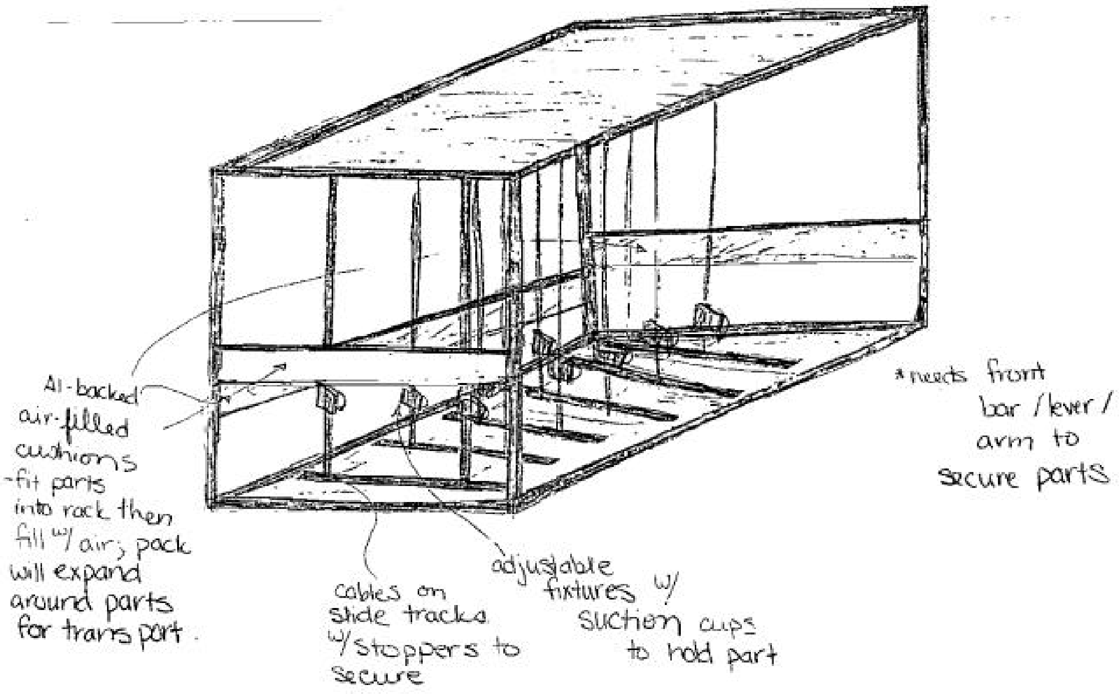
APPENDIX Q: THE “MEAT HOOKS” AND RATCHET SYSTEM



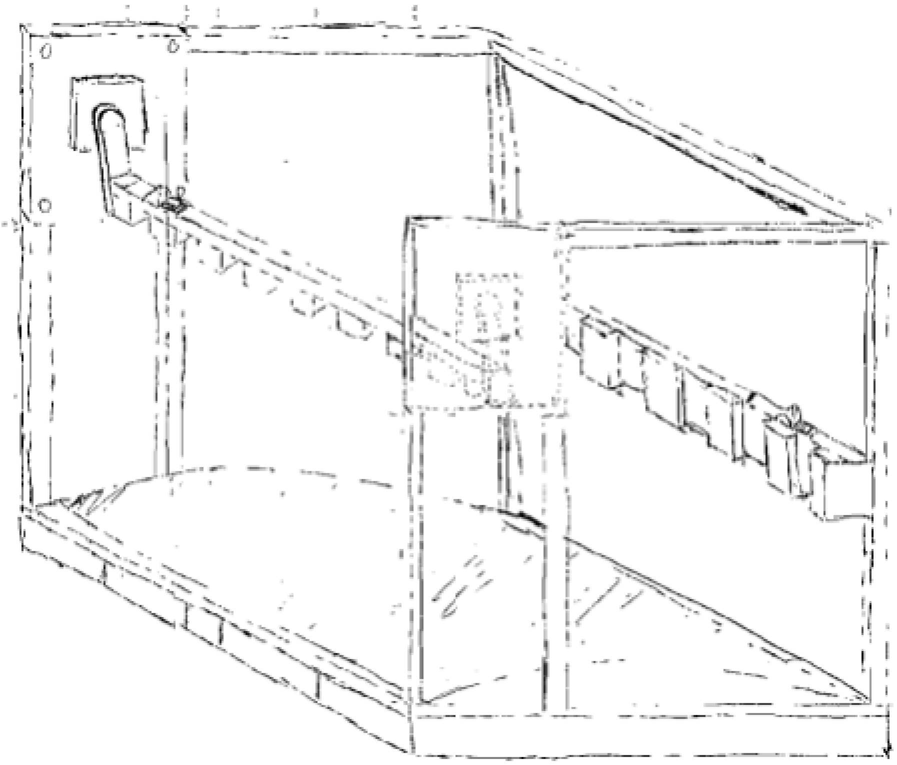
APPENDIX R: THE "CONCEPT COLLABORATOR"



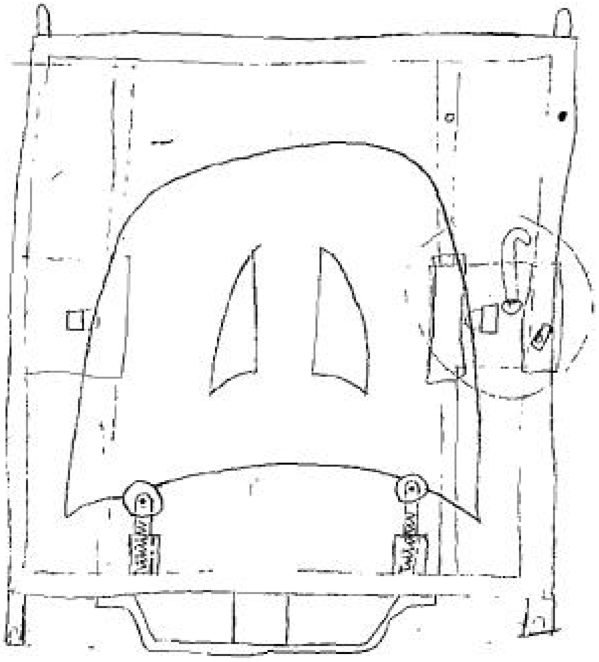
APPENDIX S: THE "TROJAN RACK"



APPENDIX T: THE “CLAMP MASTER 2007”

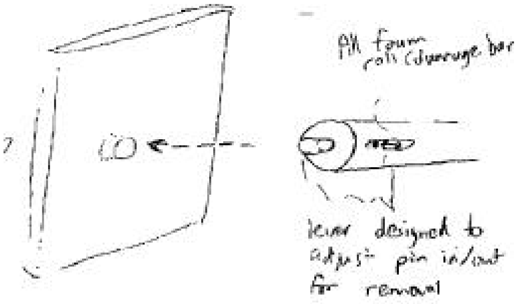


APPENDIX U: THE “HOODLUM ROLLER”



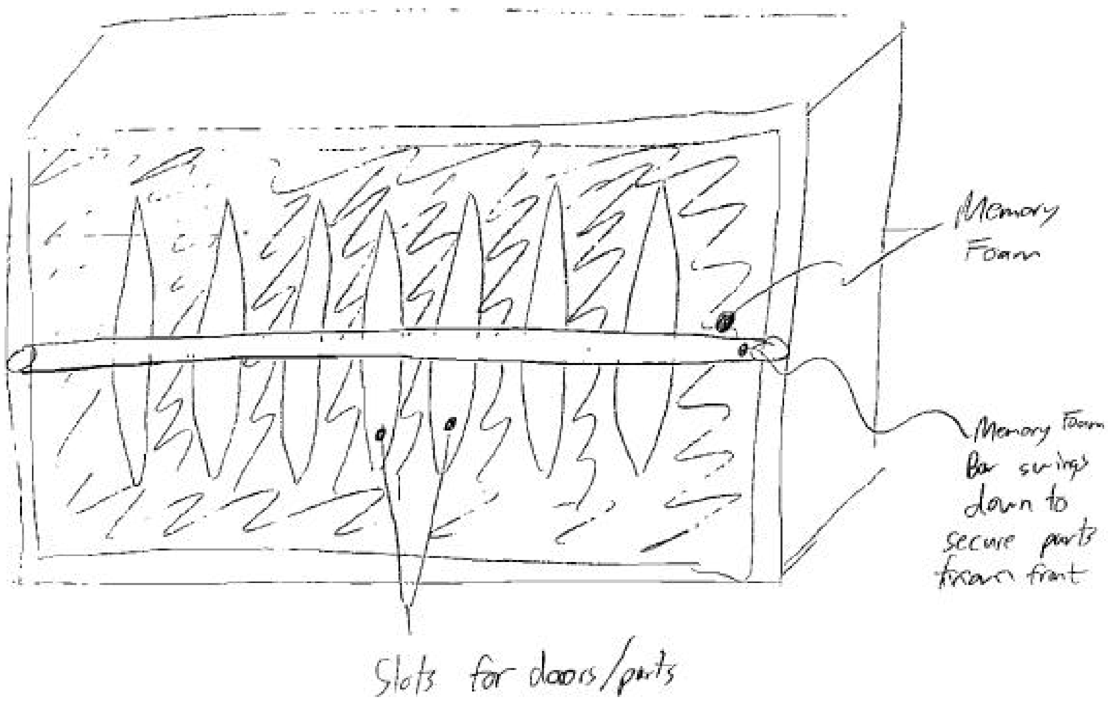
Spring system to
fit all hoods

APPENDIX V: CURTAIN ROD WITH PIN JOINT (A.K.A. THE “TOILET PAPER ROLLER”)

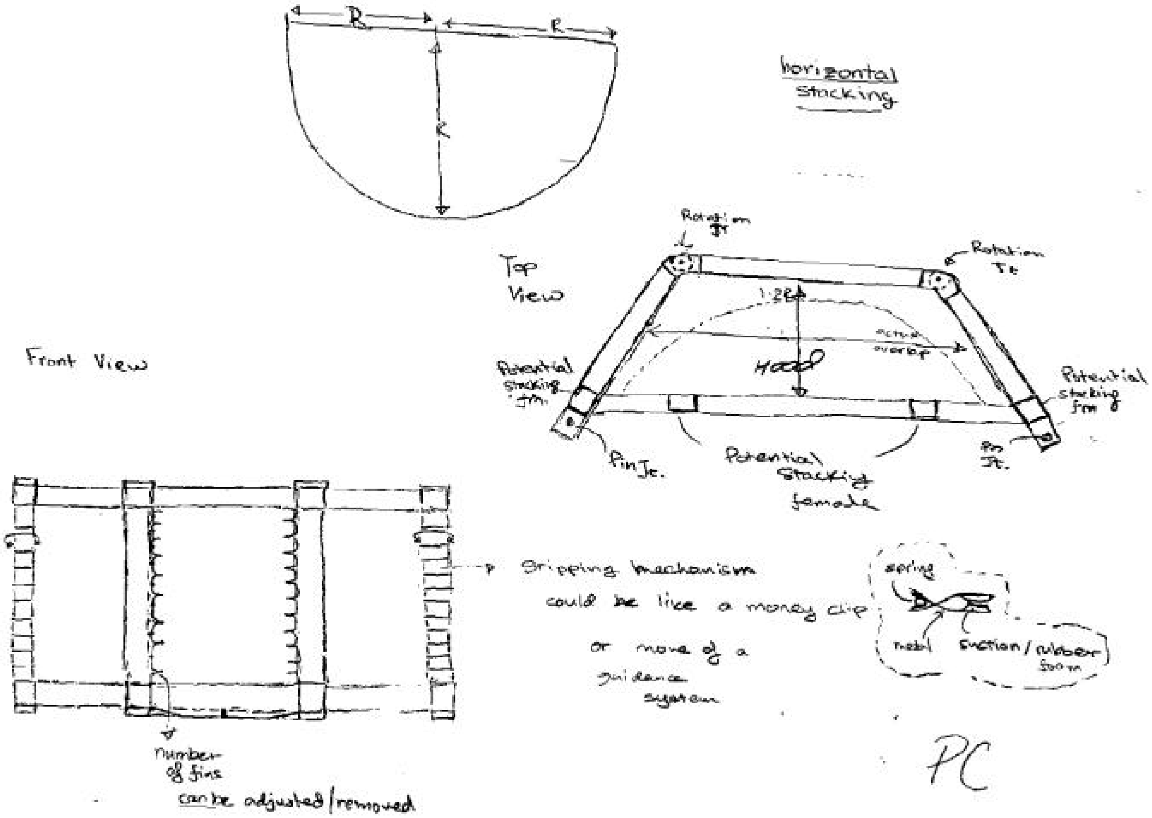


* The idea here is to completely detach the roll hall and set it on the ground while moving hoods. Holes can be drilled when necessary for new pin-joint spots (new models)

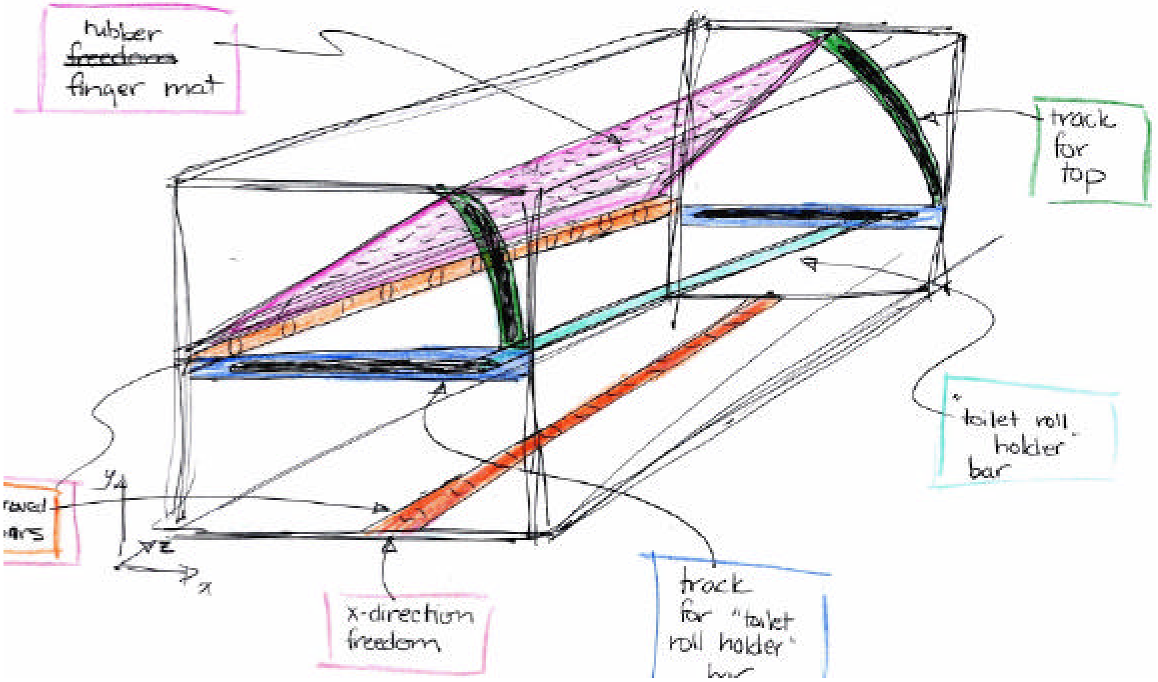
APPENDIX W: THE “MAGICAL SLEEVE MACHINE”



APPENDIX X: THE “SHAPE SHIFTER”



APPENDIX Y: A FEASIBLE DESIGN



APPENDIX Z: DAIMLERCHRYSLER'S HOOD WEIGHT AND DIMENSIONS

Figure 1. Picture showing the point where depth is measured. Information courtesy of DaimlerChrysler.

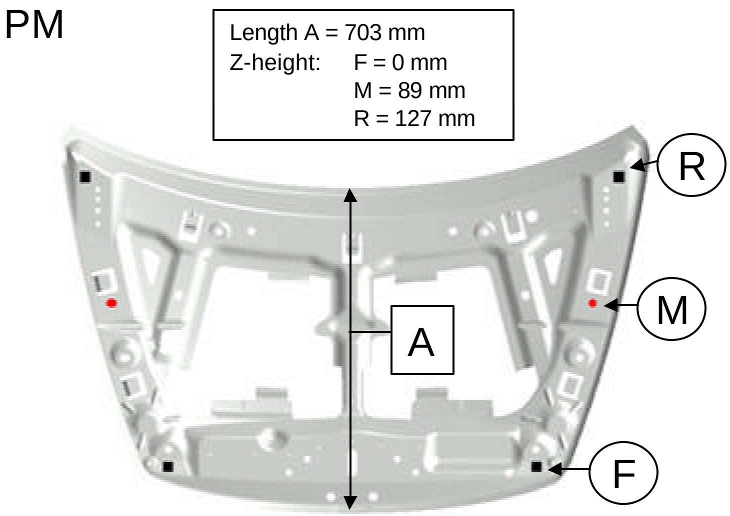


Figure 2. The most thin DaimlerChrysler hood. Information courtesy of DaimlerChrysler.

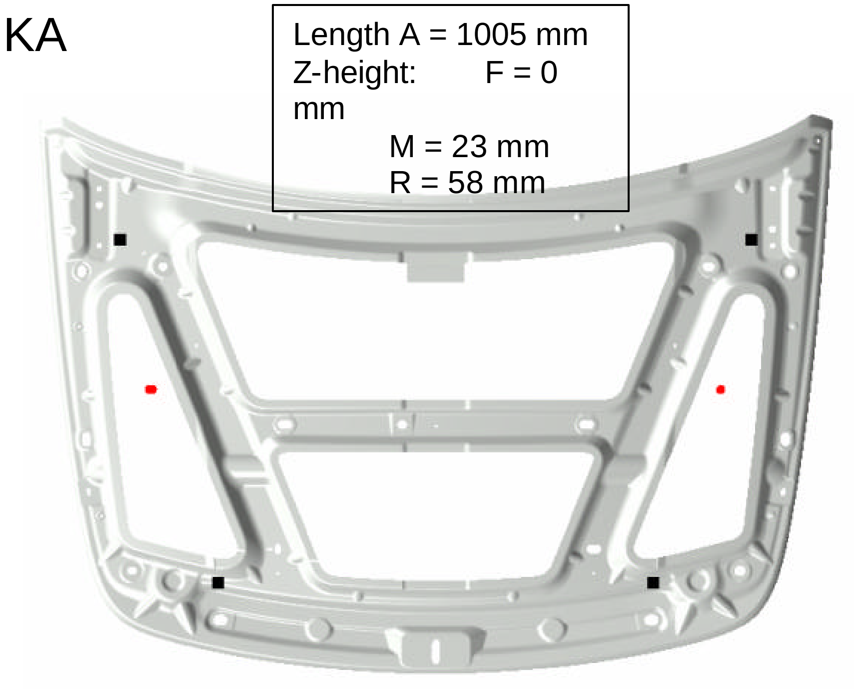
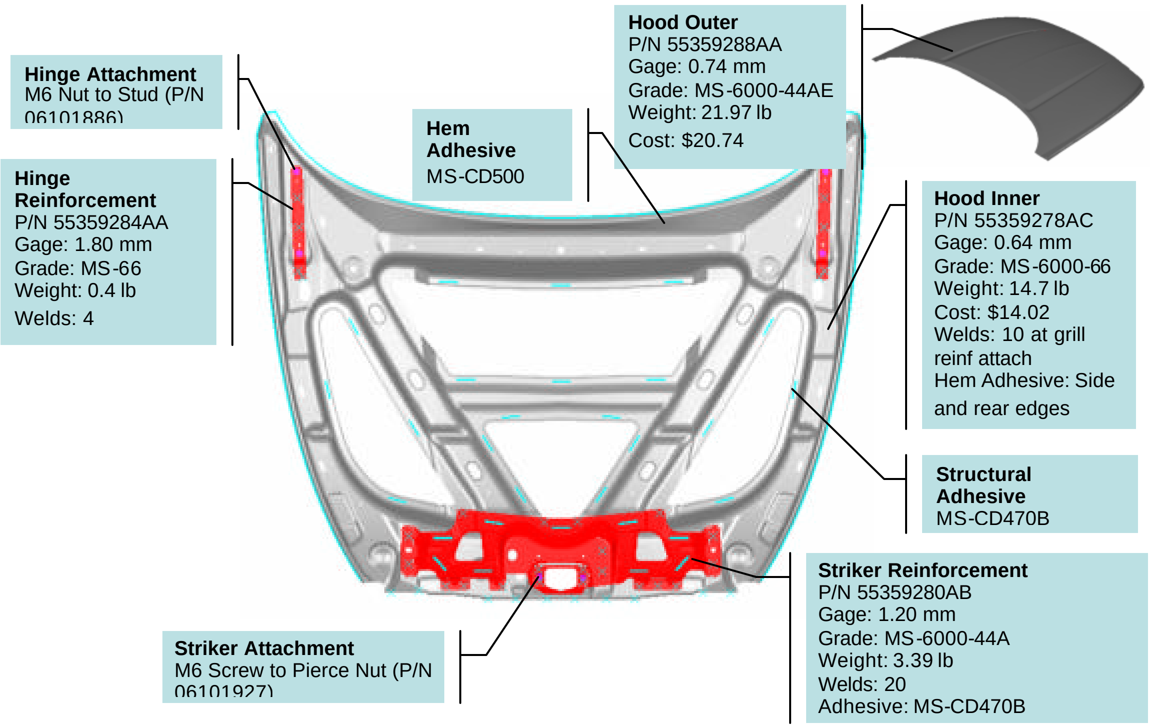
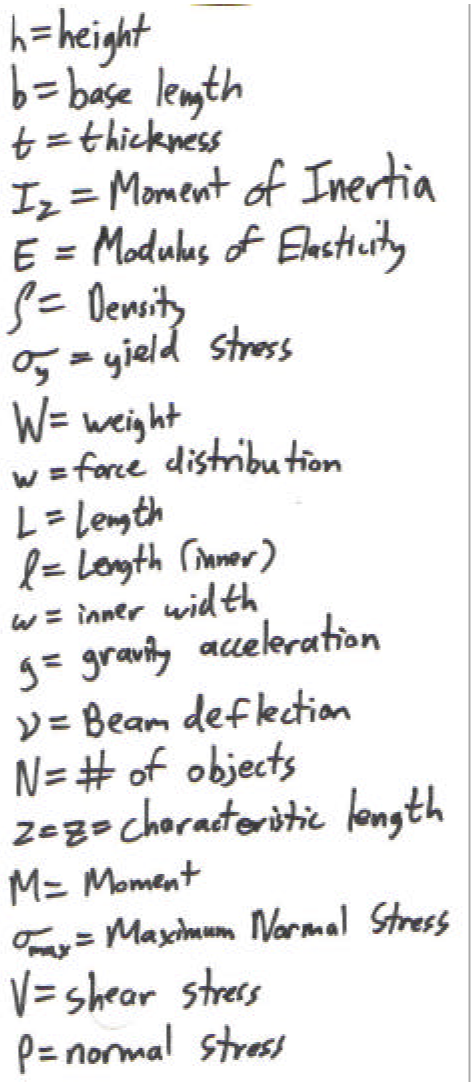


Figure 3. The heaviest DaimlerChrysler hood. The overall weight includes the hood inner, hood outer, striker reinforcement, and 2 hinge reinforcement plates. All of these components will be attached and supported by the rack design. The overall weight of the heaviest hood is 40.86 lbs. Information courtesy of DaimlerChrysler.


Hinge Attachment
M6 Nut to Stud (P/N
06101886)
Hinge Reinforcement
P/N 55359284AA
Gage: 1.80 mm
Grade: MS-66
Weight: 0.4 lb
Welds: 4
Hem Adhesive
MS-CD500
Hood Outer
P/N 55359288AA
Gage: 0.74 mm
Grade: MS-6000-44AE
Weight: 21.97 lb
Cost: $20.74
Hood Inner
P/N 55359278AC
Gage: 0.64 mm
Grade: MS-6000-66
Weight: 14.7 lb
Cost: $14.02
Welds: 10 at grill reinf attach
Hem Adhesive: Side and rear edges
Structural Adhesive
MS-CD470B
Striker Reinforcement
P/N 55359280AB
Gage: 1.20 mm
Grade: MS-6000-44A
Weight: 3.39 lb
Welds: 20
Adhesive: MS-CD470B
Striker Attachment
M6 Screw to Pierce Nut (P/N
06101927)

APPENDIX AA: NOMENCLATURE, EQUATIONS, FORMULA, AND CALCULATIONS USED TO COMPUTE MAXIMUM HANGING ROD DEFLECTION AND TEST FOR YIELD.

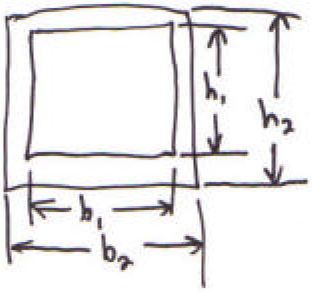
Nomenclature



h = height
b = base length
t = thickness
I_z = Moment of Inertia
E = Modulus of Elasticity
ρ = Density
σ_y = yield stress
W = weight
w = force distribution
L = Length
ℓ = Length (inner)
w = inner width
g = gravity acceleration
ν = Beam deflection
N = # of objects
z = z = characteristic length
M = Moment
σ_{max} = Maximum Normal Stress
V = shear stress
P = normal stress

Calculations

Hanger X-Section



$h_2 = b_2 = 3'' = .0762\,m$

$b_1 = h_1 = 2.75'' = .06985\,m$

$t = 1/8''$

$$I_z = \frac{b_2 h_2^3}{12} - \frac{b_1 h_1^3}{12}$$

$$I_z = \frac{.0762^4}{12} - \frac{.06985^4}{12}$$

$$I_z = 8.258 \cdot 10^{-7}\,m^4$$

Bedford → $E = 190$ GPa
$\rho = 7830\ kg/m^3$
$\sigma_y = 200$ MPa

Force Distribution

Hood Weight : W = Inner + Outer + Striker + 2x Hinge
W = 14.7 lb. + 21.97 lb + 3.39 lb + 2x .4 lb
W = 40.86 lb = 181.754 N

Hanger Plate : $t = .5'' = .0127\,m$
$L = 12'' = .3048\,m$
$w = 8'' = .2032\,m$

$W = (tLW)(\rho)(g)$
$W = (.0127 \cdot .3048 \cdot .2032)7830(9.8)$
$W = 60.36\,N$

Sleeve: $t = \frac{1}{8}''$

Outer Dim. $\begin{cases} L = 3\frac{1}{4}'' = .08255\,m \\ w = 3\frac{1}{4}'' = .08255\,m \\ z = 2.28' = .057912\,m \end{cases}$

Inner Dim. $\begin{cases} \ell = 3'' = .0762\,m \\ w = 3'' = .0762\,m \\ z = 2.28'' = .057912\,m \end{cases}$

$$W = \rho g (LWz - \ell w z)$$

$$W = 7830(9.8)(.08255^2 \cdot .057912 - .0762^2 \cdot .057912)$$

$$W = 4.48\,N$$

\# of hoods: Smallest width $= Z = 58\,mm$

$$\#\text{hoods} = \frac{\text{hanging rod length}}{z}$$

$$\#\text{hoods} = \frac{2.4384\,m}{.058\,m} \Rightarrow 42 = N$$

Weight Distribution $= w$

$$w = \frac{N(\text{sleeve weight} + \text{hanger plate weight} + \text{hood weight})}{L \sim \text{rod length}}$$

$$\boxed{w = 42(4.48 + 60.36 + 181.754)/2.4384 = 4247.4\,N/m}$$

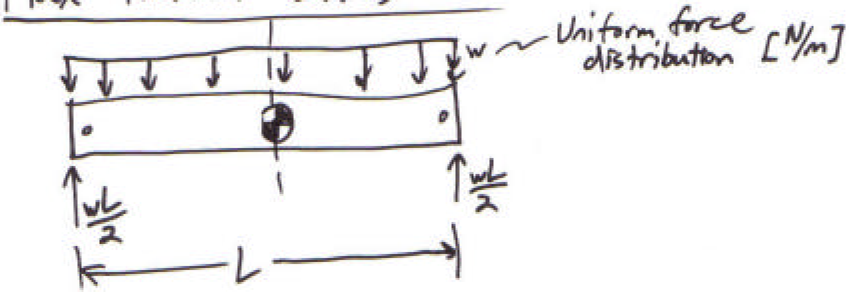
Max Deflection $L = 96'' = 2.4384\,m$

$$\nu = \frac{5wL^4}{384 E I_z} = [m]$$

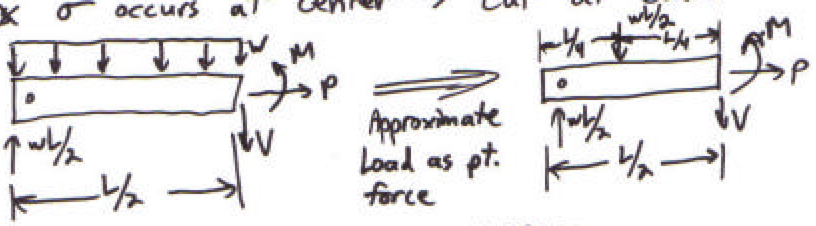
$$\nu = \frac{5(4247.4)(2.4384)^4}{384(190 \cdot 10^9)(8.258 \cdot 10^{-7})}$$

$$\boxed{\nu = .01246\,m = 1.246\,cm}$$

Max Normal Stress



*Max σ occurs at center → "Cut" at center



$$\circlearrowleft + \sum M_{\text{right end}} = 0 = M + \frac{wL}{2}\left(\frac{L}{4}\right) - \frac{wL}{2}\left(\frac{L}{2}\right)$$

$$\Rightarrow M = \frac{wL^2}{8} = \frac{4247.4(2.4384)^2}{8} = 3156.8\ \text{N}\cdot\text{m}$$

$$\Rightarrow \underline{\sigma_{max}} = \frac{My}{I_z}\bigg|_{y=1.5''=.0381\text{m}}$$

$$= \frac{3156.8 \cdot .0381}{8.258\cdot 10^{-7}} = 145.64\ \text{MPa}$$

$$\sigma_{yield} = 200\ \text{MPa} \Longrightarrow \boxed{\text{No yield!}}$$

APPENDIX AB: DIAGRAM OF HANGER ASSEMBLY WITH KEY DIMENSIONS.

APPENDIX AC: CALCULATIONS FOR MOMENT ABOUT POINT A AND SHEAR FORCE ON HOOKS.

Moments about A

$F_{g,h}$ = Force on hood due to gravity = 41 lbs.
$F_{b,h}$ = Force on hood due to braking = $F_{g,h}$ (conservative estimate)
$F_{g,p}$ = Force on plate due to gravity = 14 lbs.
$F_{b,p}$ = Force on plate due to braking = $F_{g,p}$ (conservative estimate)
x_h = Distance from hood center of gravity to centerline of plate = Max thickness of largest hood (conservative estimate) = 6”
y_h = Distance from joint to hood center of gravity = Max height of largest hood (conservative estimate) = 40”
y_p = Distance from joint to plate center of gravity = 8”
M_A = Moment on plate from hanger = 164 lb-ft

$$\sum Moments_A = -F_{b,hood} \cdot y_h - F_{g,hood} \cdot x_h - F_{b,p} \cdot y_p + M_A = 0$$

Shear Force on Hooks

d_h = diameter of one hook = 0.5”
a_h = area of one hook = 0.196 in^2
$F_{g,h}$ = Force on hood due to gravity = 41 lbs
$t_{avg} = F_{g,h} / a_h$ = Shear Stress = 208 psi

APPENDIX AD: FMEA OF FINAL DESIGN

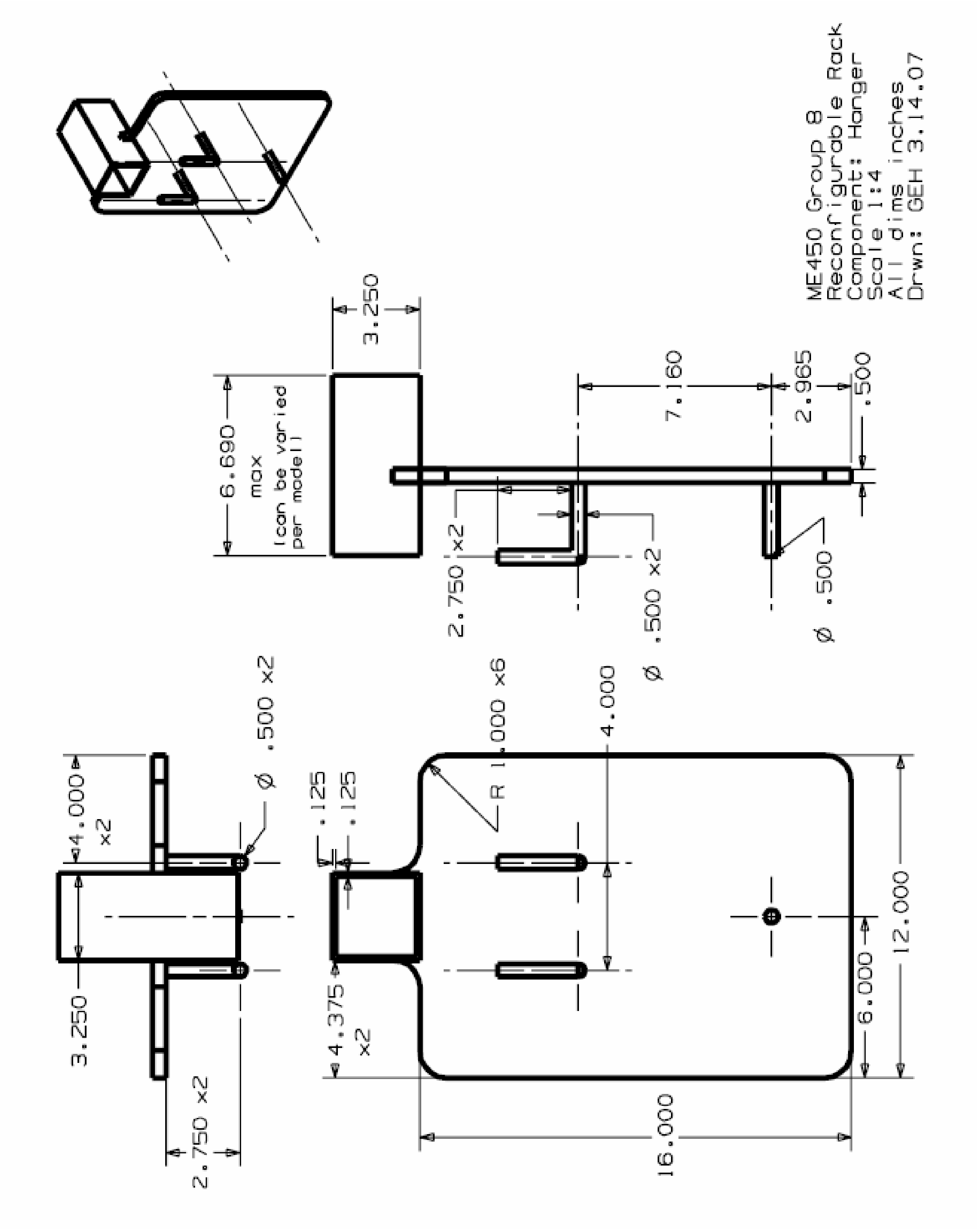
Product Name: Reconfigurable Racking System

Devel. David Clark
Gabriella Harrison
Mickael Bohn
Prateek Chourdia

Date: 14-Mar-07

Part Description & Functions	Potential Failure Mode	Potential Effect(s) of Failure	Severity (S)	Potential Causes / Mechanism(s) of Failure	Occurrence (O)	Current Design Controls / Tests	Detection (D)	Recommended Actions	RPN	New S	New O	New D	New RPN
Hanger Bar - reconfigurable, hangers placed on this bar	sagging	hard to switch hangers	3	repeated use, overloading, undersized bar	7	repeated loading, max loading	2	larger bar, stiffer material	42	2	5	1	10
	yield	hard to switch hangers	2	fatigue, overloading, undersized bar	4	max loading	2	stiffer material	16	2	2	1	4
	fracture	all parts damaged, hazard to persons in area	10	fatigue, overloading, undersized bar	2	repeated loading, max loading	1	larger bar, more ductile material	20	10	1	1	10
	fatigue	hard to switch hangers	6	repeated use, overloading, undersized bar	3	repeated loading	2	larger bar, more ductile material	36	6	2	2	24
	unbalanced loading	uneven wear on bar	4	overloading on one end	6	unequal loading	5	balance loading	120	4	4	4	64
	loose end fittings	hard to switch hangers	6	repeated use, overloading, undersized bar	7	repeated loading, max loading	3	special end caps	126	5	5	3	75
	scoring	hard to switch hangers	3	repeated use	9	durability testing for bar surface	3	score-resistant finish	81	2	7	2	28
	wear	hard to switch hangers	2	repeated use, undersized bar	10	durability testing for bar surface	4	wear-resistant finish	80	1	8	3	24
Pins on Hanger Bar Ends - reconfigurable, allows hangers to be changed	seizure	extra cost for time and material to remove/replace broken pins	8	holes out of line because frame bent out of square by transport / forklifts, repeated use	3	repeated removal / replacement, frame testing	3	stiffer frame, stiffer pin material	72	7	2	3	42
	binding	extra cost for time and material to remove/replace broken pins	8	holes out of line because frame bent out of square by transport / forklifts, repeated use	3	repeated removal / replacement, frame testing	3	stiffer frame, harder pin material	72	7	2	3	42
	misalignment	hard to switch hangers	7	holes out of line because frame bent out of square by transport / forklifts	5	frame testing	3	stiffer frame	105	6	3	3	54
	wear	hard to switch hangers	2	repeated use, undersized bar	9	repeated removal / replacement, max loading	4	stiffer pin material	72	2	7	3	42
Frame - reusable, creates envelope to protect parts during transport	bent out of square	creates failures of other components, hard to stack	4	repeated shipping and handling, forklifts	10	repeated loading, max loading, unequal loading, forklift loading, shipping loading	4	stiffer frame	160	3	8	3	72
	buckling	parts damaged, hazard to persons in area	10	repeated use, overloading, undersized bar	2	max loading, fatigue testing	1	stiffer frame	20	9	1	1	9
Dunnage Bar - reconfigurable, keeps parts from coming out during shipping	wear	damaged parts	2	handling / loading and unloading	10	durability testing for bar surface, repeated removal / replacement	4	wear-resistant finish	80	1	8	3	24
	loose	damaged parts, hazard to workers in area	5	repeated use, overloading, undersized bar	6	repeated removal / replacement	5	stiffer material, larger bar	150	5	5	4	100
	scoring	damaged parts	3	repeated use	9	durability testing for bar surface	3	score-resistant finish	81	3	7	2	42
	misalignment	damaged parts	6	holes out of line because frame bent out of square by transport / forklifts	5	frame testing	3	stiffer frame	90	6	4	2	48
Pins on Dunnage Bar - reusable, able to use for multiple parts	seizure	extra cost for time and material to remove / replace broken pins	8	holes out of line because frame bent out of square by transport / forklifts	7	frame testing	3	stiffer frame	168	7	5	3	105
	binding	extra cost for time and material to remove/replace broken pins	8	holes out of line because frame bent out of square by transport / forklifts, repeated use	5	repeated removal / replacement, frame testing	3	stiffer frame, stiffer pin material	120	7	4	3	84
	misalignment	hard to use	7	holes out of line because frame bent out of square by transport / forklifts, repeated use	3	repeated removal / replacement, frame testing	3	stiffer frame, stiffer pin material	63	6	2	2	24
	wear	hard to use	2	repeated use	3	repeated removal / replacement	4	wear-resistant finish	24	2	2	3	12
Hanger - reconfigurable, suspends part from hanger bar with hooks and within the frame's envelope	fracture where plate is welded to sleeve	damaged parts, hazard to workers in area	9	repeated shipping forces, gravity, and/or loading forces	2	repeated loading, max loading, unequal loading, shipping loading	1	larger weld area	18	8	1	1	8
Hanger Hooks - reconfigurable, attaches hook to hanger	fracture	damaged parts, hazard to workers in area	9	repeated shipping, gravity, and/or loading forces	2	fatigue testing, max loading, unequal loading	1	larger hook, more ductile material	18	8	1	1	8
	yield	hard to load / unload	7	repeated shipping, gravity, and/or loading forces	4	repeated loading, max loading, unequal loading, shipping loading	2	larger hook, stiffer material	56	7	2	2	28
	wear	hard to load / unload	3	repeated loading forces	8	repeated loading, shipping loading	4	wear-resistant finish	96	2	6	3	36
	loose fittings	damaged parts	4	repeated shipping, gravity, and/or loading forces	5	repeated loading, max loading, shipping loading	5	special covering	100	3	4	4	48

APPENDIX AE: HANGER DRAWING



APPENDIX AF: ASSEMBLY BILL OF MATERIALS

Quantity	Part Description	Supplier	Unit Price
3	1" SQ x 16GA/.065" STRUCT TUBE ERW A-513 STEEL 72" PRE-CUT	ASAP	16.52
4	1" SQ x 16GA/.065" STRUCT TUBE ERW A-513 STEEL 36" PRE-CUT	ASAP	10.76
1	1-1/4" SQ x 16GA/.065" STRUCT TUBE A-513 STEEL 36" PRE-CUT	ASAP	11.91
4	2" X 1" X 16GA (.065") STRUCT RECT TUBE A-500 STEEL 36" PRE-CUT	ASAP	15.37
2	1/4" PLATE HRPO STEEL 12" X 12" PRE-CUT	ASAP	27.07
1	1" ROUND PVC TYPE 1 GRAY 72" PRE-CUT	ASAP	26.6
1	7GA (.1793") SHEET HRPO STEEL 12" X 12" PRE-CUT	ASAP	23.67