Design of a Lunar Quick-Attach Mechanism to Hummer Vehicle Mounting Interface

David A. Grismore[1]
NASA Kennedy Space Center Intern, Cape Canaveral, FL, 32899

This report presents my work experiences while I was an intern with NASA (National Aeronautic and Space Administration) in the Spring of 2010 at the Kennedy Space Center (KSC) launch facility in Cape Canaveral, Florida as a member of the NASA USRP (Undergraduate Student Research Program) program. I worked in the Surface Systems (NE-S) group during the internship. Within NE-S, two ASRC (Arctic Slope Regional Corporation) contract engineers, A.J. Nick and Jason Schuler, had developed a "Quick-Attach" mechanism for the Chariot Rover, the next generation lunar rover. My project was to design, analyze, and possibly fabricate a mounting interface between their "Quick-Attach" and a Hummer vehicle. This interface was needed because it would increase their capabilities to test the Quick Attach and its various attachments, as they do not have access to a Chariot Rover at KSC. I utilized both Pro Engineer, a 3D CAD software package, and a Coordinate Measuring Machine (CMM) known as a FAROarm to collect data and create my design. I relied on hand calculations and the Mechanica analysis tool within Pro Engineer to perform stress analysis on the design. After finishing the design, I began working on creating professional level CAD drawings and issuing them into the KSC design database known as DDMS before the end of the internship.

I. Introduction

YI performed an internship with NASA (National Aeronautic and Space Administration) in the Spring of 2010 at the Kennedy Space Center (KSC) launch facility in Cape Canaveral, Florida as a part of the NASA USRP (Undergraduate Student Research Program) program. There were only six interns selected for the Spring USRP internship program at KSC. I began work on February 1st, 2010 and completed the internship on May 14, 2010.

I was assigned a design project within the Surface Systems NE-S group in support of the "next-generation" lunar rover, the Chariot rover or LER (Lunar Electric Rover). As such, the main body of this paper focuses on my work in the Surface Systems group and the design project that I was assigned to.

II. "Quick-Attach" Support Project – Surface Systems NE-S Group

A. Project Background

I was assigned to working with two ASRC (Arctic Slope Research Company) contract engineers, A.J. Nick and Jason Schuler, who support the LER through the development of support equipment. Refer to Fig. 1 below to see the Chariot Rover.

[1] Spring 2010 Intern, Surface Systems NE-S Group, Kennedy Space Center, and Oklahoma State University.

Figure 1 Chariot Rover with Habitat Capsule (LER)

Specifically, A.J. Nick and Jason Schuler designed the "Quick-Attach" mechanism, which is a remote-controlled, actuating mechanism that mounts onto the back of the LER. This mechanism allows various surface tools, such as a dozer blade or a front-end loader, to be attached and detached to the rover remotely, by a tele-operator. The surface tools are attached by simply driving the LER up to the implement, actuating a metal bar vertically on a ball screw and motor assembly until the bar is set below a series of hooks on the implement, and then actuating the bar up to the desired height to pre-load and pick up the implement via a set of hooks designed into all of the implements. The "Quick-Attach" gives the LER the capability to utilize many different surface tools without direct human intervention. A Pro Engineer (Pro-E) model of the "Quick-Attach" mechanism is shown below in Fig. 2*.

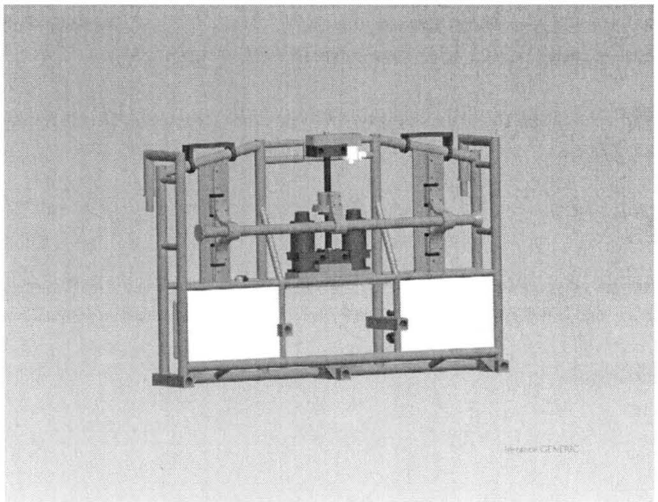

Figure 2 "Quick-Attach" Pro-E Model

B. Project Purpose/Description

However, NE-S does not have access to the LER more than a few times a year, as both rovers are kept at Johnson Space Center. This limits their capabilities to adequately test and evaluate the "Quick-Attach" mechanism and its various surface tools. As such, I was assigned the task of designing a lunar "Quick-Attach" mechanism to

* Nick, A.J. and Jason Schuler, "Quick-Attach" Support Project Verbal Consultation, Pictures & Pro-E Models, 1 March 2010.

Hummer vehicle mounting interface. In other words, my project was to design a physical interface that would allow NE-S to mount their "Quick-Attach" mechanism onto the front of a Hummer vehicle so that they could test the "Quick-Attach" (QA) at KSC on a regular basis.

C. Design Phase of Project

I began designing the interface by gathering basic information on the requirements of the "Quick Attach" mechanism. I determined from the initial information that it would be more logical to design the mounting interface in reverse, rather than designing the interface from the Hummer out to the "Quick Attach". This design decision was driven by the fact that there were already a set of specific dimensional constraints and requirements placed upon the design by the "Quick Attach" design itself. In addition, the interface design will need to be fairly tolerant to dimensional variations to ensure that it is compatible with more than one Hummer vehicle.

Based on these initial design constraints, I found that one of the reasonable locations to connect to the "Quick Attach" was at five pin holes located near the bottom of the mechanism that are used as a connecting interface with the LER (see Fig. 2). However, utilizing only these five pin-hole locations would place a very large moment on the "Quick Attach" structure. Therefore, the "u-tubes" located at the top of the "Quick Attach" were to be utilized for mounting as well (see Fig. 2). The "u-tubes" can be separated into two pieces, as there is a turnbuckle located within the horizontal portion of the upper "u-tubes", which allows the two pieces to be threaded into one another. For mounting purposes, the back half of the U-tubes would be separated from the "Quick Attach", leaving two threaded holes that could be used as a connecting point to the mounting plate via two threaded bolts. The design for the mounting plate that would interface directly with the back of the "Quick Attach" could now be designed, based on these initial design constraints. The "Quick Attach's" height and width dimensions were used as references for the overall size of the mounting plate. The Pro-E design for this mounting plate can be seen below, in Fig. 3.

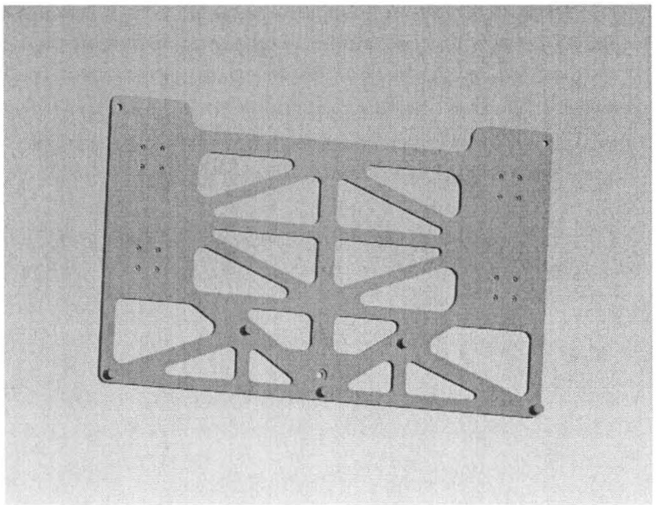

Figure 3 Pro-E Design of QA Mounting Plate

The plate is 1.25" thick and is to be made of 6061 T6 aluminum plate. The male insert pegs are to be made out of chrome-moly plugs and fastened into place with ¾" bolts. Significant material was cut out of the plate to decrease the overall weight of the mounting interface (see analysis for further information). No material was cut out of the upper left and right areas of the mounting plate because rail blocks will eventually be attached to those locations (see Fig. 9 on page 6 for further details).

After outlining an initial set of design ideas and requirements, I began gathering more specific information on the dimensional, loading, and vertical travel requirements of the mounting interface. According to NE-S, the mounting interface would likely need to actuate itself in order to give the proper upper and lower vertical limits for the "Quick Attach" itself (i.e. the LER suspension can sit much lower than the Hummer). We agreed that the "Quick Attach" needed to be able to reach a height of approximately 4" off the ground in order to equip a surface tool. Additionally, it needed to be able to lift itself to sixteen inches off of the ground to give the Hummer reasonable driving clearance (see Appendix B for further detail). Therefore, an actuator needed to be implemented into my design that was capable of twelve inches of vertical travel. To determine the maximum vertical load that would be placed on this actuator, I made the conservative assumptions that the Quick Attach weighs 250lbs, the implement could weigh up to 1,000lbs, and the auxiliary mounting structure (rail blocks, moving mounting plate, pins, bolts, nuts, etc.) could weigh no more than 250lbs. Therefore, the actuator needed to be able to lift a total of 1,500lbs.

Nook Industries, a company that designs and manufactures linear motion components and systems, offers a line of CC Linear Actuators. One of these actuators has a stroke of 12" and can carry a dynamic load of up to 1,500lbs. This actuator met both the load requirements and the vertical travel requirements necessary for the design. As such, I chose to integrate this actuator into my "Quick Attach" mounting interface design. The actuator is bolted to the moving mounting plate through a clevis end bracket and can be seen below in its fully extended actuation position in the Pro-E assembly model displayed in Fig. 4†.

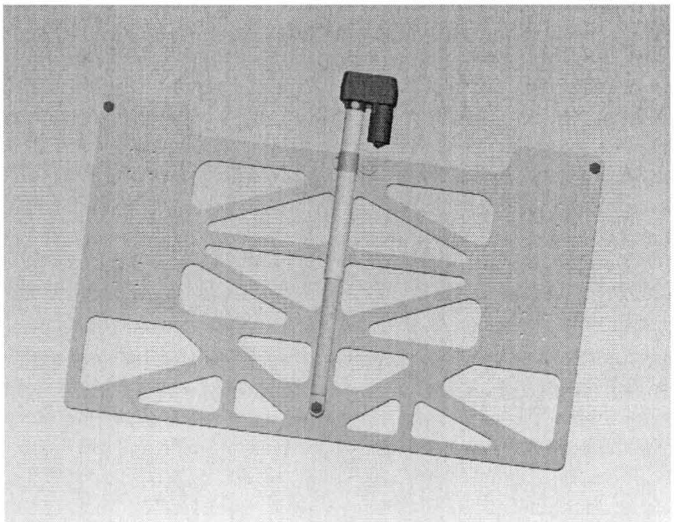

Figure 4 QA Moving Plate + 12VDC Linear Actuator

In order to insure accurate linear motion, a set of rails and rail blocks needed to be integrated into the design. Again, Nook Industries provides a series of precision profile rail systems that met the design needs. In order to determine which type of rail system was necessary, I performed a force/moment analysis on the entire Quick Attach mounting system. This analysis was performed within Excel and is detailed in the following pages. To begin the analysis, I had to make a few initial assumptions and then gather the pertinent data on the runner blocks based on those assumptions. This data is tabulated below in Fig. 5.

Runner Block Type	
NH45ER	
Block Separation (in)	Block Weight (lbf)
12	6.3934056
Dist. to Horiz. CG of Block (in)	Number of Blocks
0.6	4
Vert. Length of Block (in)	**Total Weight of Blocks (lbf)**
5.47244094	**25.5736224**

Figure 5 Runner Block Data (Excel)

In order to maintain a conservative set of assumptions throughout the design, I assumed worst-case loading scenarios to determine the maximum forces and moments that the rail blocks would be susceptible to. The appropriate forces and their perpendicular distances to the runner blocks are displayed in a free-body-diagram below in Fig. 6.

† Nook Industries, Various Pro-E Models, 8 March 2010, http://www.nookindustries.com/home.cfm.

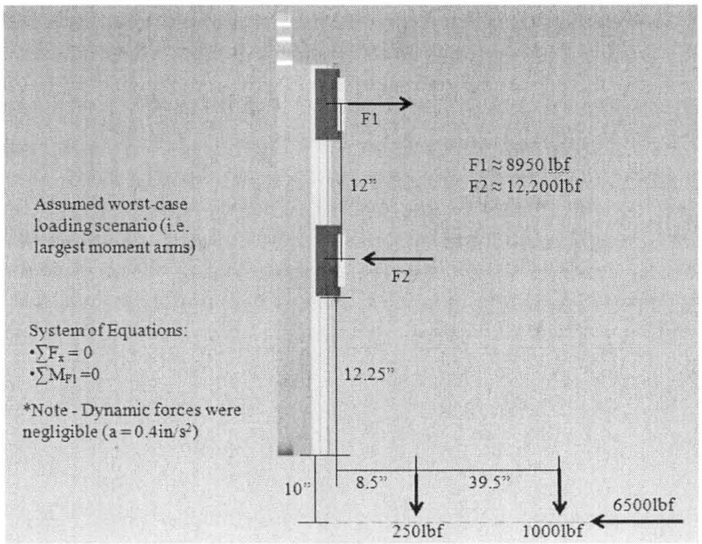

Figure 6 FBD Force Data

Finally, by doing a simple force balance in the horizontal direction and a moment balance at one of the two block locations, the resolved forces placed upon the blocks could be determined. This number is then divided by two as there are two rails with two blocks each. The force analysis was performed statically, as the dynamic forces involved were negligible (see Appendix A for further information). These calculated forces are displayed below in Fig. 7.

Calculated Forces	
Force in Lower Blocks (lbf)	**Force in Higher Blocks (lbf)**
12192.64304	**8942.643044**

Figure 7 Calculated Forces (Excel)

Once the forces on the blocks were calculated, I consulted a table of specifications provided by Nook Industries that indicated the maximum forces each type of rail block could withstand. I then had to verify that the type of runner blocks I selected to make the analysis assumptions off of met these force requirements. In this manner, the analysis was an iterative process. After several iterations, I determined that the NH45ER runner blocks with a twelve inch separation would meet the force requirements while still keeping the amount of rails required reasonable. Based on this rail and block design, the final design parameters could be determined. These parameters are displayed below in Fig. 8.

Final Rail and Block Design Parameters	
Amount of Track Required (in)	Total Weight (lbf)
29.47244094	46.86353076

Figure 8 Final Design Parameters (Excel)

As can be seen above, this rail and block design requires roughly 30" of track and adds almost 50lbs to the overall design. I implemented this rail and block system into my Pro-E model, which can be seen below in Fig. 9. It should be noted that I also designed a pinning system to go along with the rail system that allows the dynamic loads to be transferred away from the actuator when it is not actuating.

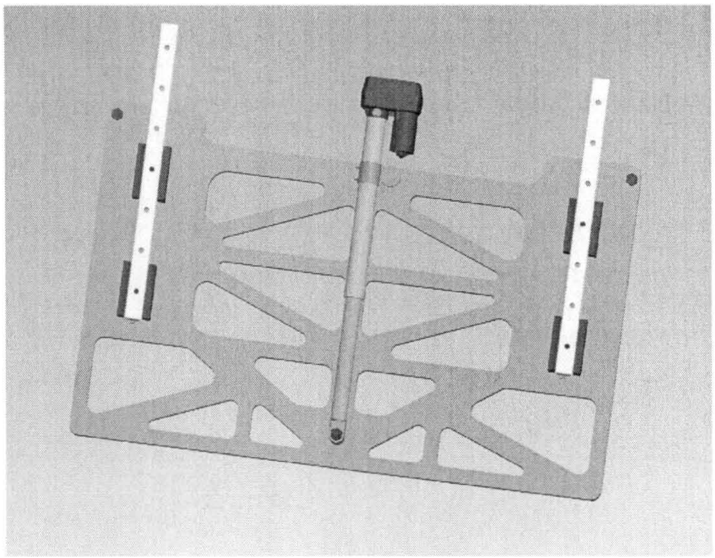

Figure 9 Pro-E Design of Moving Plate, Actuator, Rail and Block System

The next component of the assembly to be designed was the back mounting plate, which directly interfaces with the front of the Hummer vehicle. I located two attachment locations on the Hummer that would be utilized for this plate. The first and primary attachment point is a rectangular mounting structure positioned just underneath the front bumper of the Hummer. This mounting structure extends back underneath the vehicle and connects directly into the undercarriage of the vehicle. There are ten bolt-holes already drilled into this mounting structure, likely to mount an optional winch attachment. Conveniently, I was able to integrate these bolt-hole locations into my design and utilize the mounting structure as the main support for the back mounting plate. Again, another mounting location would be necessary to avoid placing a large moment on this back mounting plate. Fortunately, there are two additional attachment locations in the form of hooks located on the hood of the vehicle. See Fig. 10 below for these locations.

Figure 10 Hummer Attachment Locations

Before the Pro-E model of the stationary back plate was designed, accurate data on the exact locations of each feature on the front of the Hummer had to be collected. Since the back plate will interface directly with the Hummer, there is very little tolerance allowed with respect to the important features of the design (i.e. relative bolt-hole locations, hook-connection locations, height and width constraints, etc.). In order to minimize data measurement error, I used an advanced, portable Coordinate Measurement Machine (CMM) known as a FAROarm on the front of the Hummer vehicle to collect the dimensional data on all of its relative feature locations. The FAROarm is an arm-shaped CMM that has three joints that allow many degrees of manipulation for ease of data collection and is capable of highly precise measurements. Each joint constantly maintains and updates its relative location to the "zeroed location" of the FAROarm. This "zeroed location" is managed by an accompanying software tool that sets the zero location and then captures and stores the rest of the data in reference to that point. The FAROarm utilizes a place and click method for data collection. Refer to the picture below in Fig. 11 for further clarification.

Figure 11 Using the FAROarm to Collect Hummer Data

Once the data had been collected, I uploaded it into Pro-E and created a skeleton assembly based on the important feature data points. This skeleton consisted primarily of datum planes and data points located at the intersection of three of these datum planes. The data points were considered key feature locations and would serve as reference points for each component of the Hummer mounting plate assembly. This allowed the entire assembly to auto-update if a simple modification were to be implemented within the skeleton of the assembly, making it very easy to account for error during the design phase. Also, the creation of a skeleton and constraints to the points within the skeleton ensured that the manufactured parts would actually interface properly with the front of the Hummer, assuming they are manufactured properly and within tolerances. The Pro-E skeleton can be seen displayed below in Fig. 12.

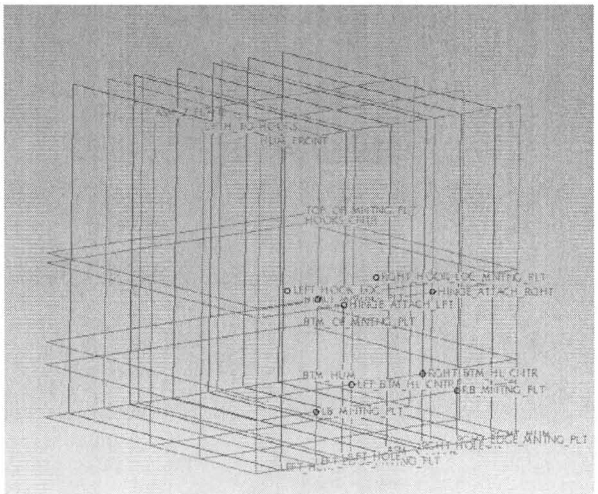

Figure 12 Skeleton for Hummer Mounting Plate Assembly

By utilizing this skeleton, the dimensional constraints of the stationary back mounting plate can easily be determined and implemented. In addition, this skeleton gives immediate insight into exactly where the bolt-hole locations and the hook locations are with reference to the back mounting plate location. Refer below to Fig. 13 to see the Pro-E model of the stationary back mounting plate.

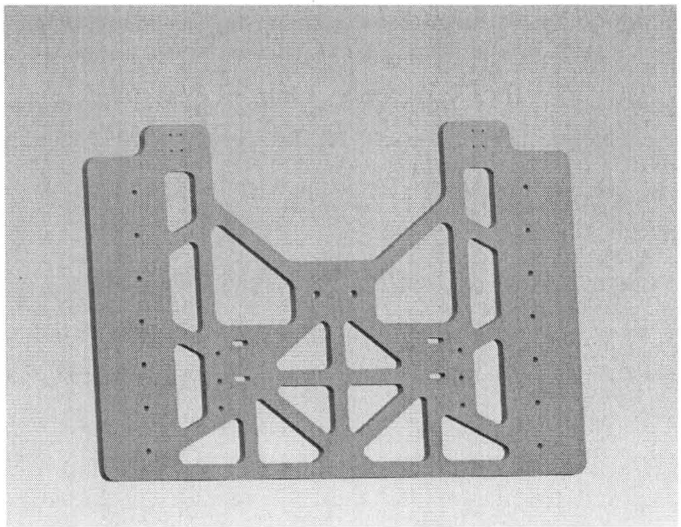

Figure 13 Pro-E Model of Stationary Back Mounting Plate

This plate is 1.25" thick and is to be made of 6061 T6 aluminum as well. Large portions of the plate were cut out to reduce weight and to increase the driving visibility for whoever is operating the Hummer vehicle (see Appendix B for further visibility details/concerns). Note that the bolt holes and slots near the center of the plate will be utilized for the mounting to the Hummer, the bolt holes running along the sides of the plate will be utilized for mounting the rails to the back plate, and the small bolt holes at the top of the plate will be utilized to mount the hook connections to the back plate (see next Pro-E model, Fig. 14).

The final remaining major component of the mounting structure assembly to be designed was the hook connection components. Since the hooks on the Hummer are located a significant distance away from the front of the Hummer, an additional component must be designed that can reach these hook connection points. When I considered the design of this component, I determined that it would need to be fairly generic and allow a wide range of positioning, as the exact distance from the back mounting plate to these hooks will vary depending on the vehicle the interface is being mounted onto. Therefore, I immediately knew that the design needed to allow linear and radial adjustment capabilities. I determined that a clevis, turnbuckle, rod end, and shaft collar system would meet these requirements. By utilizing this system of components, the hook connection's adjustability can be compared to that of an arm and hand. See the Pro-E model in Fig. 14 below for further understanding of the design[‡].

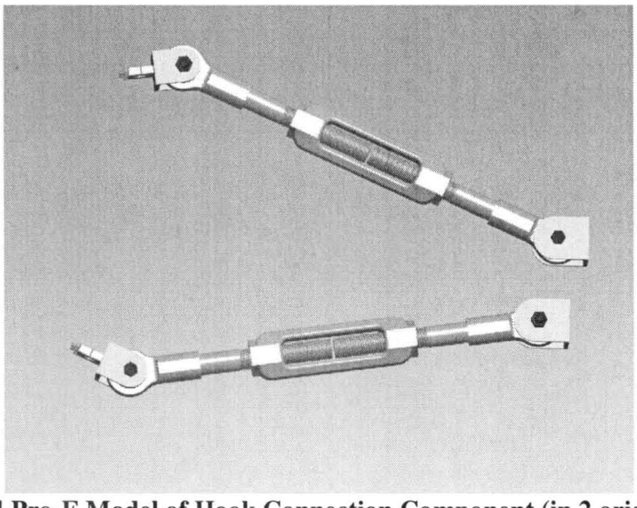

Figure 14 Pro-E Model of Hook Connection Component (in 2 orientations)

‡ McMaster-Carr Supply Company, Various Pro-E Models, 10 March 2010, http://www.mcmaster.com/#.

Note that the hook connection component is displayed in two different orientations above. This simply shows the multiple degrees of adjustment that the component is capable of. Again, the relative position, length, and adjustment capabilities of this component were based on initial analysis of the skeleton model displayed in Fig. 12 above.

Once all of the major components of the mounting interface had been designed, I created a full assembly of the design within the skeleton assembly, making sure that the key feature points were referenced as a parent constraint for the entire assembly. During this time, I made some slight additions to the design not detailed above in the forms of rail bracket supports (for the runner block pinning system) and actuator bolt supports. These components are trivial and thus are not detailed individually. The completed assembly can be seen below in Fig. 15.

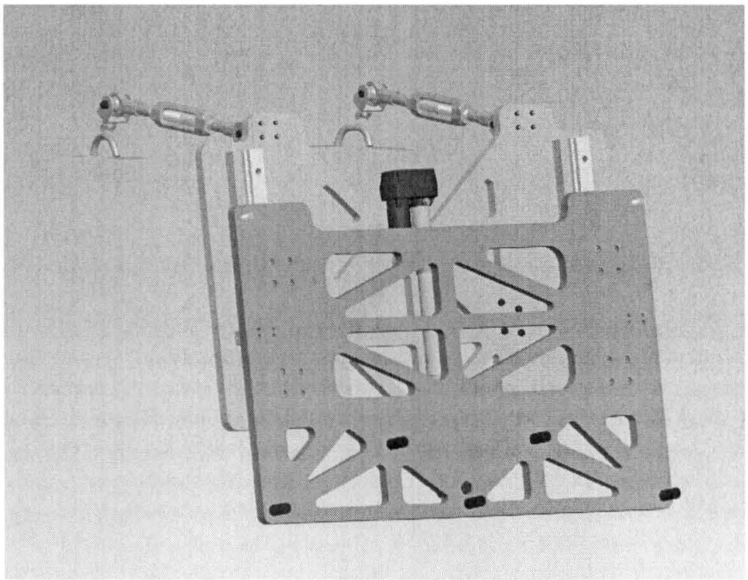

Figure 15 Complete Pro-E Mounting Interface Assembly

Refer to Appendix C to see a Pro-E concept of the completed mounting interface attached to a Hummer vehicle.

After finishing the design portion of my project, I began performing structural analysis on the design to verify that the design was feasible and could be made primarily out of Aluminum 6061 T6 (see Appendix A for exceptions), which would cut down considerably on manufacturing costs.

D. Analysis Phase of Project

The analysis phase of the project serves as validation of the structural integrity of my design. I began the analysis by performing an exhaustive set of stress analyses at each of the joints and fasteners throughout the design. The primary forms of stress analysis calculated were tensile stresses, shear stresses, bearing stresses, bending stresses, tear-out stresses, pull-through stresses, and thread engagement. I also performed a safety factor calculation on each component of the design. To keep the analysis concise, I will present only the principal equations used below and the results received will be included in Appendix D as an Excel spreadsheet.

Tensile stress	$\sigma = \frac{F}{A}$	F = Axial Force A= Cross-sectional area
Shear stress	$\tau = \frac{F}{A}$	F=Perpendicular Force A= Cross-sectional area
Bearing stress	$\sigma_b = \frac{F}{A * b}$	F= Perpendicular Force A= Diameter of Hole B= Length of Hole/Fastener Engagement
Bending stress	$\sigma = \frac{M * c}{I}$	M= Moment c = Distance to neutral axis I = Moment of inertia about neutral axis
Tear-out stress	$\sigma_t = \frac{F}{A * b}$	F= Perpendicular Force A=Diameter of Hole B= Length of Hole/Fastener Engagement
Pull-through stress	$\sigma_{p1} = \frac{F}{A_1 - A_2}$	F= Axial Force A_1= Cross-sectional area of fastener head A_2= Nominal cross-sectional area of fastener threads
Thread engagement	$R = \frac{A_{se} * \sigma_{ye}}{A_{si} * \sigma_{yi}}$	A_{se}= shear area external thread A_{si}= shear area internal thread σ_{ye}= tensile strength external thread σ_{yi}= tensile strength internal thread

Figure 16 Principal Stress Equations

In addition to the hand calculations, I performed a Pro-E Mechanica Von Mises stress analysis on the front and back plates. This was accomplished by setting fixed, rigid location constraints and applying the appropriate point and distributed loads onto the plates.

With respect to the front plate, I was only concerned with the bottom portion of the plate bending. Therefore, I only performed the analysis on the portion of the plate below the runner block attachment locations. I made the full horizontal length of the plate rigid just below the runner block attachment locations and applied a distributed load where the male "Quick Attach" chrome-moly insert pegs are located on the plate. See Fig. 17 below for clarification.

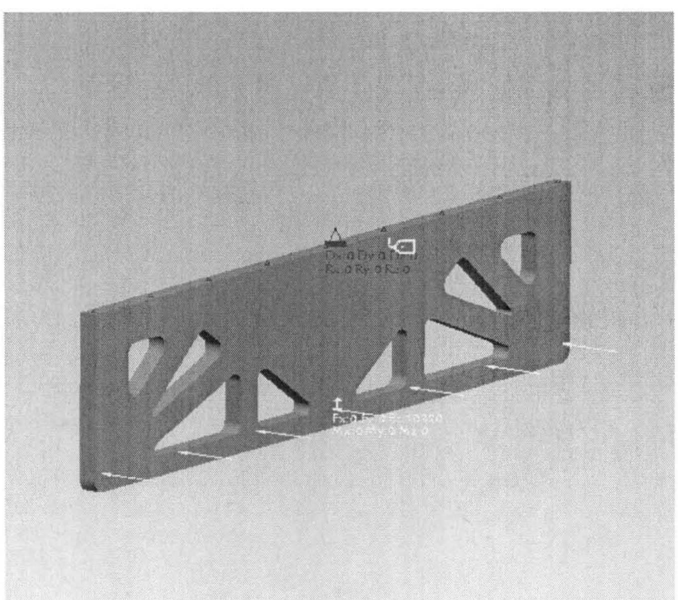

Figure 17 Front Plate Bending Analysis

After running the analysis, I determined that the original design would not hold up properly to the forces. Therefore, I redesigned the cuts in the bottom of the plate and ran the Mechanica Von Mises analysis iteratively until I met the 2x factor of safety criteria. The final results received are displayed in Fig. 18 below.

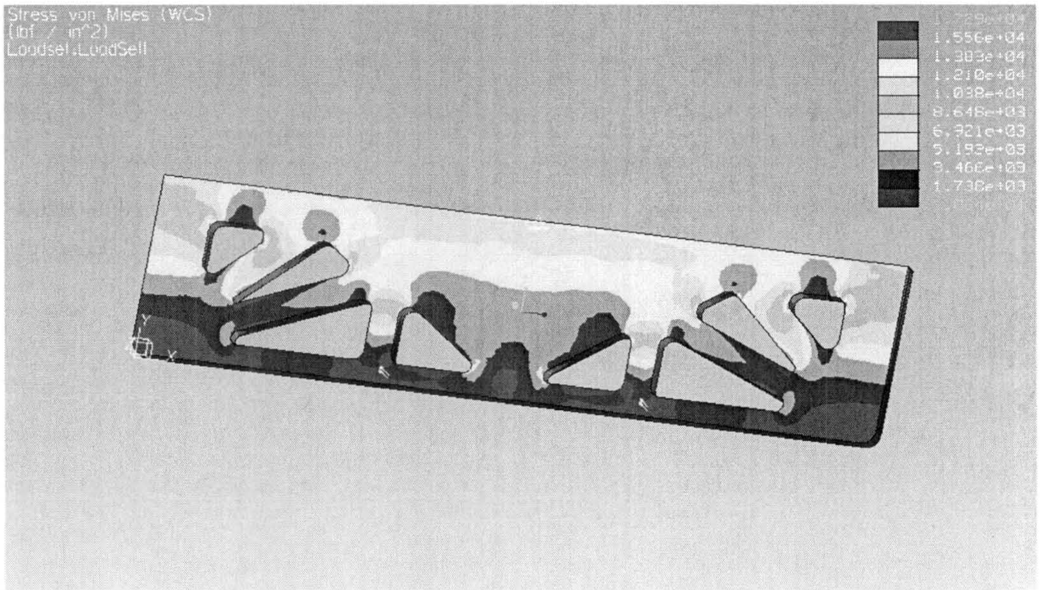

Figure 18 Mechanica Von Mises Analysis, Front Plate

As can be seen above, the maximum stress seen in the front plate is around 17ksi. This meets the 2x factor of safety criteria, as the yield stress of the aluminum is 40ksi.

Similar analysis was performed on the back plate of the mounting interface as well. The areas of concern on the back plate were the right and left ends where the rails are attached. The plate could potentially bend around its z-axis from these stresses. To ensure that the analysis was conservative, I removed the material in the center of the plate and analyzed the left and right portions of the plate individually. By applying the previously determined forces to the plate and rigidly constraining the edges of the plate where the material had been cut out from, I was able to perform a simple, conservative analysis on the plate within Mechanica. See Fig. 19 below for the analysis setup.

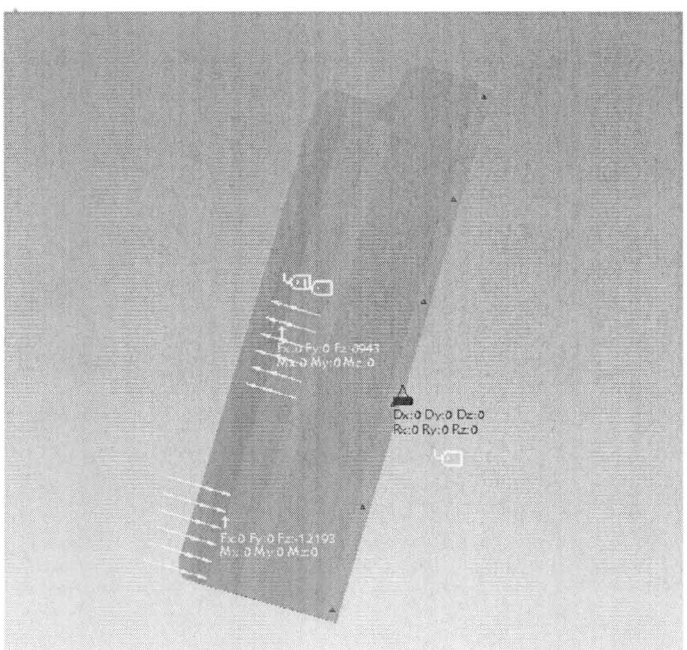

Figure 19 Pro-E Mechanica Back Plate Bending Analysis

After running the Von Mises stress analysis on the back plate, I noted that the stress was too high and did not meet the 2x factor of safety design criteria. After removing some of the truss cuts in the plate and increasing the thickness of the plate to 1.25 inches, the analysis indicated that I had over two factors of safety, as the maximum VM stress within the plate was now only 18ksi. When all of the other conservative assumptions are taken into account, the factor of safety exceeds well beyond two actually. The VM Mechanica analysis for the back plate can be seen below in Fig. 20.

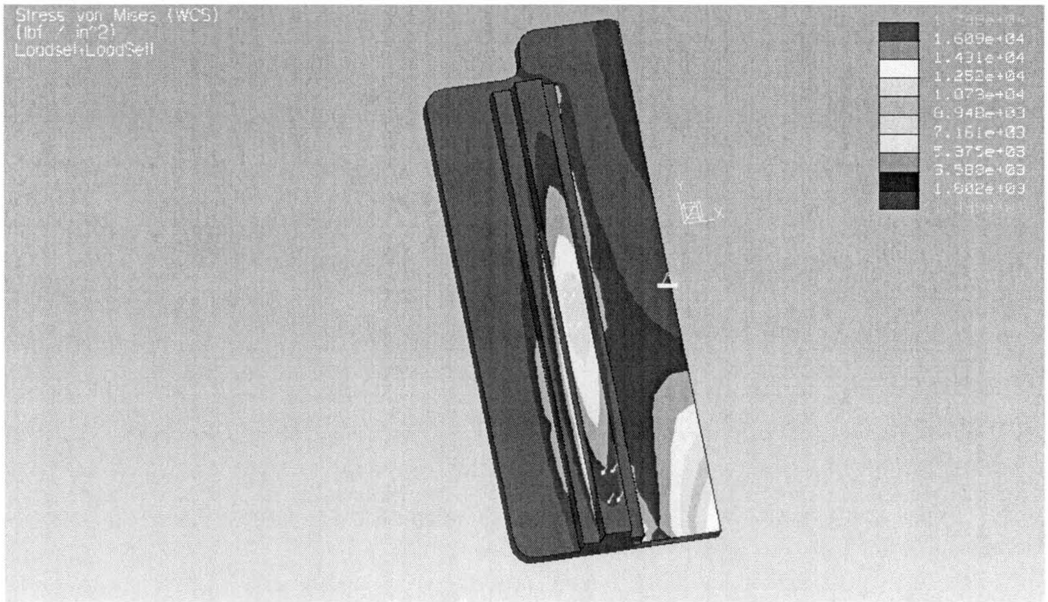

Figure 20 Mechanica Von Mises Analysis, Back Plate

As can be seen in the figures above, the Mechanica analyses both support my hand-calculations (refer to Appendix C) and further validate the integrity of the mounting interface design.

III. Conclusion

After completing the design and finishing the structural analysis, I began creating a set of professional level CAD drawings to be issued into the NASA design database at KSC known as DDMS. These drawings were not included within this report.

Currently, there is no budget to build my design. However, the drawing package would be utilized in the future during the fabrication process if budget were allocated specifically to build and use the Hummer mounting interface design. Additional future work includes the creation of a professional level MathCAD stress analysis package that details and organizes the hand-calculations performed throughout the analysis of the Hummer mounting interface design. I will continue to work on completing the drawings and the MathCAD analysis package before the end of my internship.

Appendix

A. Assumptions and Considerations Made During Design

- 14° = (arctan(16/62)) is max angle of ascent that Hummer will be capable of at Desert RATS w/ PUP equipped
- Assumed horizontal distance for angle of ascent calculation begins where front tires of Hummer meet ground
- Assumed worst case scenarios in force and moment analysis for rail block sizing
- Assumed at least 2 factors of safety in stress analysis
- Assumed actuator would only be subjected to 1500 pounds in worst-case loading scenario
- Force and moment analysis performed in Excel was done statically because dynamic forces were negligible
- Assumed 12 inches of actuation would be enough to reach upper and lower vertical limits
- Turnbuckles, rod ends, fasteners cost about $575 (most in turnbuckles and rod ends)
- Grade 8 bolts were used almost exclusively

- Chose Nook CC Linear Actuator ¾" Bolt Heavy Mounting Bracket to mount actuator to back plate - using Nook mount should guarantee capability to withstand necessary loads, no guarantee with "home-made" mounting structure
- All holes are sized as free-fits, except for threaded holes, actuator bolts (close-fit), and chromoly plug holes
- Recommend clevis mounts, plugs be fabricated out of 4140 steel (chrome-moly), and the rest fabricated out of Al 6061 T6
- 16" is enough clearance and top of mounting structure being 53" off the ground gives the Hummer driver acceptable driving visibility (front of Hummer hood is roughly 44.5" off the ground – 8.5" difference)
- Holes will be match drilled into moving plate QA male inserts for holding cotter pins when QA is available
- QA male inserts are currently exact same size as QA Pro-E model, will need to be changed to average size of the two actual QA built - at JSC currently

B. **Maximum Angle of Ascent Diagram**§

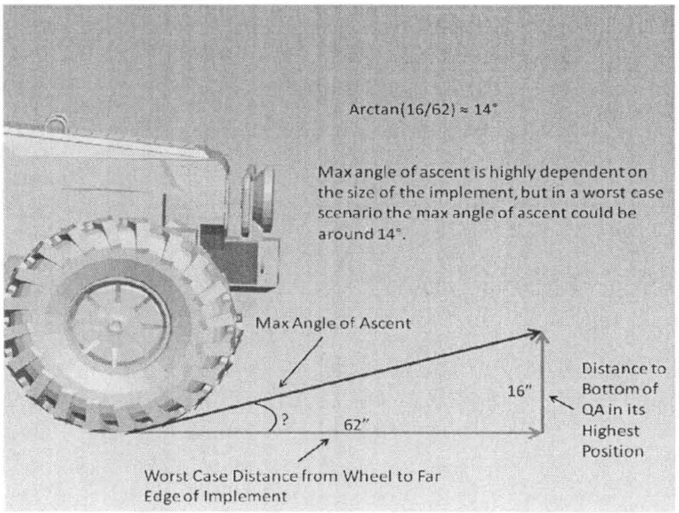

Figure 21 Max Angle of Ascent Diagram

C. Concept of Mounting Interface on Hummer with "Quick Attach"

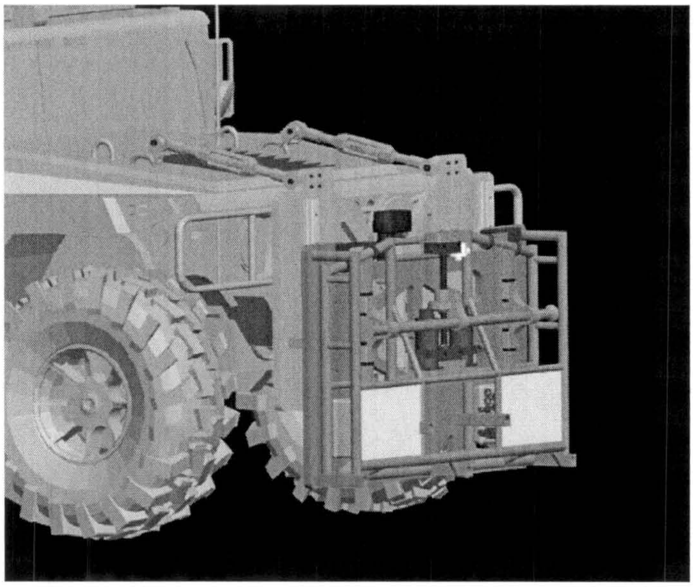

Figure 22 Mounting Interface Concept Pro-E Assembly

§TRL Design & Development, Hummer Google SketchUp Model, 19 June 2008.

D. Design Stress Analysis Results

	Hummer to QA Interface Design Analysis								
	Bolt/Pin Location	Quantity	Shear Stress	Tensile Stress	Bearing Stress	Bending Stress	Tear-Out/Pull-Through/Thread Strip-Out	FS	Rec. Mat'l.
	Actuator Clevis End	1	5ksi	N/A	823psi	N/A	N/A	12.6+	N/A
	Bottom Block Bolts	4	1043psi	25.0334ksi	468.75psi	N/A	N/A	6.95+	N/A
	Top Block Bolts	4	1043psi	33.934ksi	468.75psi	N/A	N/A	5.1+	N/A
	Pin Holder Bolts	8	6.970ksi	N/A	563.91psi	N/A	N/A	10.8+	N/A
	QA Threaded Bolts	2	2.137ksi	5.442ksi	960psi	N/A	1,920psi (TO), 6.240ksi (PT)	5.6+	N/A
	Chrome-moly Male Insert Pegs	5	265.3psi	3041.6psi	N/A	N/A	3,879psi (TO), 10.9ksi (PT), R=0.105 < 1 (TSO)	3.2+	Steel 4140
	Rail Bolts	14	937.5psi	3555psi	N/A	N/A	N/A	48+	N/A
	Pins	2	13.581ksi	N/A	1333.3psi	N/A	N/A	7+	N/A
	Act. Tube Bracket Bolt	1	5ksi	N/A	715psi	N/A	N/A	12.6+	N/A
	Pin Mount	2	1055psi	N/A	4223.6psi	14.2548ksi	N/A	2.45+	Al 6061 T6
	Front Plate*	1	N/A	N/A	N/A	17.12ksi (BTM) & 9,114 psi (TP) (2 dir.)	N/A	2+	Al 6061 T6
	Rail Mount Inserts	2	N/A	N/A	N/A	N/A	N/A	N/A	Al 6061 T6
	Back Plate Bolts	10	1177.7psi	12.242ksi	330psi	N/A	7.4ksi (PT)	4.8+	N/A
	Back Plate Clevis Bolts	8	8132psi	46ksi	658psi	N/A	12.2ksi (PT)	2.8+	N/A
	Back Plate*	1	N/A	N/A	N/A	18ksi	N/A	2+	Al 6061 T6
	Clevis Mount	2	N/A	N/A	22ksi	N/A	N/A	3+	Steel 4140
	Turnbuckles	2	N/A	5846psi	N/A	N/A	N/A	2.5+	N/A
	Rod Ends	2	N/A	13ksi	9.6ksi	N/A	N/A	7.8+	N/A
	Clevis Bolt 1	2	19.67ksi	N/A	N/A	N/A	N/A	3.2+	N/A
	Clevis Bolt 2	2	19.67ksi	N/A	N/A	N/A	N/A	3.2+	N/A
	Clevis Mount	2	N/A	N/A	22ksi	N/A	N/A	3+	Steel 4140
	Shaft Collar	2	N/A	N/A	15.283ksi	N/A	N/A	2.6+	Al 6061 T6
	Shaft Collar Bolts	4	N/A	50ksi	N/A	N/A	N/A	2.5+	N/A
Key:			Note - Although shear loading on threads				Note - E/D < 1.5 is acceptable when T>0.5D		
Red	Questionable Stress (below 2 fs)		and free fit/close fit applications are not						
Green	Allowable Stress		preferable, generous factors of safety						
			were ensured to account for these						

Figure 23 Design Stress Analysis Results

Acknowledgments

My primary mentors, A.J. Nick and Jason Schuler, deserve acknowledgments for providing me with guidance and engineering support throughout the duration of my internship. Additionally, they helped enhance my ability to make the right conservative engineering assumptions and they set an excellent example on how to coordinate and communicate with other professional engineers in the business environment.

Also, I would like to acknowledge the contributions of my supervisor, Rob Mueller, and my NASA mentor, Phil Metzger, who made it possible for me to work in the Surface Systems NE-S group. They also provided me with a challenging and engaging project to work on, and continually motivated me to learn throughout the internship.

"Design of a Lunar Quick-Attach Mechanism to Hummer Vehicle Mounting Interface"

Ms. Cathy Southwick

May 3, 2010

David Grismore

OSU Mechanical and Aerospace Engineering Department

NASA Kennedy Space Center Intern

Supervisor Signature: ______________________

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Introduction

I performed an internship with NASA (National Aeronautic and Space Administration) in the Spring of 2010 at the Kennedy Space Center (KSC) launch facility in Cape Canaveral, Florida as a part of the NASA USRP (Undergraduate Student Research Program) program. There were only six interns (including me) selected for the Spring internship program at KSC. I began work on February 1st, 2010 and will complete the internship on May 14, 2010. Due to an unusual set of circumstances that occurred while I was at KSC, this introduction will serve primarily as a preface and explanation for the content and organization that is presented within the main body of this paper.

Initially, I was assigned to work with Boeing contractors within the Systems Engineering and Integration (SE&I) group at KSC. Eric Oyer was to be my mentor within this group. However, before I reported to work my mentor was changed to John Swindal, also within the SE&I group. After three weeks of work, I was assigned to a new group per request because the previous group had no projects for me to work on. As such, the main body of this paper will be broken up into two sections; a small section regarding the first group I was assigned to and a section regarding the final group and project I was assigned to.

Group I (SE&I)

The Systems Engineering and Integration group is composed of primarily Boeing contractors. The group's function is to provide shuttle support and engineering assessment on technical issues concerning the integration of the six elements that make up the "shuttle system." In other words, any issue that involves the boundary between one element and any other element is their concern. These elements are the orbiter, external tank (ET), solid rocket boosters (SRBs), space shuttle main engines (SSME), and ground systems. As such, this group has a huge area of the shuttle program that they are responsible for. However, due to the scope and nature of the shuttle program there is no possible way that a single group can adequately support all six elements. Therefore, the primary function of this group is to organize, assess, and properly communicate these issues that occur within the shuttle system to the appropriate group for further analysis and assessment. This means the work performed by this group is primarily paperwork and that one needs considerable previous experience with the shuttle program to function within this group.

During the first three weeks of my internship I reported to this group. They had very little work for me to do the entire time I was there. I spent most of my time in meetings or shadowing my mentor. The nature of the group allowed there to be extended periods of time during which there was little work to be done. When there were no issues to be resolved between the different elements of the shuttle (which were referred to as "Fires"), then there was considerably less work to be done within the group. For example, I spent a few days listening to radio chatter all day between Pad B (where Endeavor would later be launched from on February 8th) and the rest of KSC in regards to the shuttle's progress in preparation for launch. My mentor and I were listening for IPRs (Initial Problem Reports) to be issued, which were problems large enough that they could threaten the launch of the shuttle if not addressed properly. However, there were often no IPRs to be reported. This meant there was little work to be done. Often when there was no work to be done, my mentor and I would visit other buildings and facilities at KSC. I visited the SSME (Space Shuttle Main Engines) Workshop, OPF (Orbital Processing Facility, SSPF (Space Shuttle Processing Facility), VAB (Vehicle Assembly Building), and Launch Complex 34 (location of Apollo 1 fire) located on the Air Force base side of Cape Canaveral. This gave me an unparalleled perspective on the sheer size and scope of the work that was done every day at KSC.

Although my job often involved little to no work, I was given the opportunity to work the STS-130 shuttle launch as shuttle support with the SE&I group. Again, this consisted primarily of monitoring the radio chatter between the pad and the rest of KSC looking for problem reports to be written and assessed. I actually did perform an engineering assessment pre-launch. A few Tyvek thruster covers that are placed over the thrusters on the nose of the orbiter had fallen off during preparation procedures out at the pad. See Figure 1 below for the location of the covers (William Harwood - CBS News/NASA TV , 1).

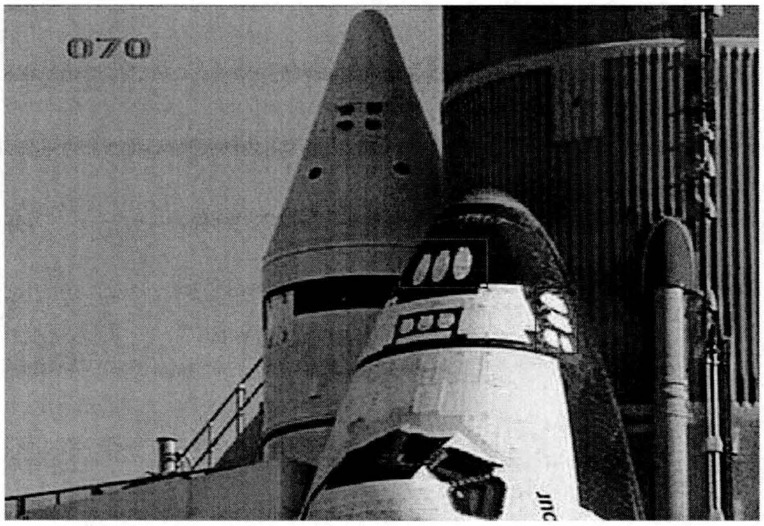

Figure 1 - Location of Tyvek Rain Thruster Covers on Nose of Space Shuttle

This is a concern because precipitation impingement could occur on the thrusters if it were to rain after the covers had fallen off. Therefore, I performed a simple engineering assessment on the state of these thrusters and whether or not the early removal of the Tyvek thruster covers would cause an issue. I reported that no problem would arise and returned to listening to the radio chatter.

Around T-9 (9 minutes before launch) mission control came to its final built-in hold to check with all of the different groups around KSC to determine if anyone had any constraints for launch. The radio chatter picked up considerably as each group hurriedly replied with a "go" or "no go" to the shuttle launch director. If no groups had any launch constraints then the final countdown to launch would begin. At that point there is no chance that the launch will be scrubbed. With a few minutes to launch remaining, I went outside the OSB1 (Orbital Support Building 1) and walked toward Pad B until I had a good view of the Shuttle. The shuttle launched at 4:14 am and lit up the sky just as the sun does. It was the last night shuttle launch ever.

Although the scope of the SE&I group was immense and the areas of NASA that I was exposed to were extremely important, the group had no project or assignment for me to work on. I informed my supervisor of this, but he was unable to provide me with my own technical project. Therefore, I talked to my intern coordinator, Benita Desuza, and informed her that I would like to be transferred to another group that could provide me with my own project to work on. She found me a group that would accept another intern and, more importantly, had numerous projects for me to choose from. I would begin work with the Lunar Surface Systems group on February 22nd.

Group II (LSS) – "Quick-Attach" Support Project

Project Background

On February 22nd I reported to the NASA Headquarters building at KSC and began work with the NASA NE-S Surface Systems group. Phil Metzger was my newly assigned mentor. He runs a lab out at the SLSL (Space Life Sciences Lab) building and has had many interns work with him before. However, I was not assigned a project within this lab because there was a more immediate project that needed to be done within the group. I was assigned to working with two ASRC (Arctic Slope Research Company) contract engineers, A.J. Nick and Jason Schuler, who support the Chariot Rover, the next generation lunar surface expedition vehicle. Refer to Figure 2 below to see the Chariot Rover (DeClama , 2).

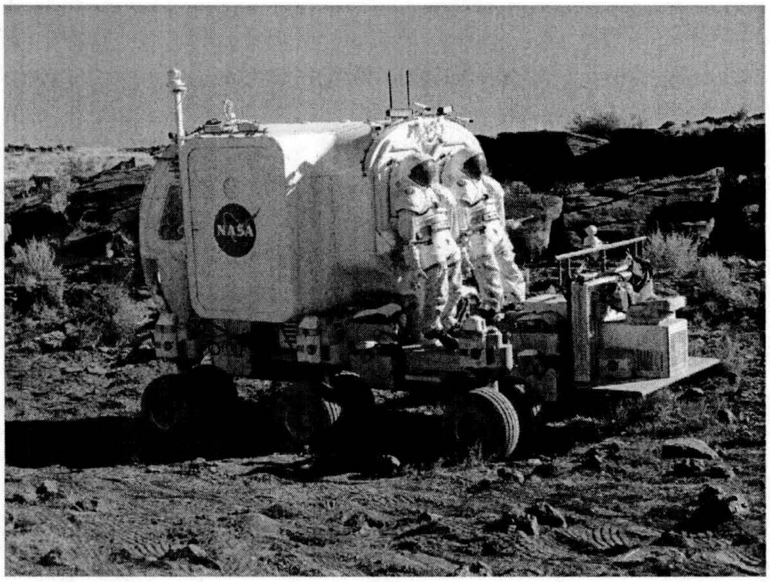

Figure 2 – Chariot Rover with Habitat Capsule

Specifically, A.J. and Jason designed the "Quick-Attach" mechanism, which is a remote controlled actuating mechanism that mounts onto the back of the Chariot Rover.

This mechanism allows various surface tools (such as a dozer blade or a front-end loader) to be attached and detached to the rover remotely, by a tele-operator. The surface tools are attached by driving the Chariot rover up to the implement, actuating a metal bar vertically on a ball screw and motor assembly until the bar is set below a series of hooks on the implement, and then actuating the bar up to the desired height to pick up the implement via its hooks. This mechanism gives the Chariot rover the capability to utilize many different tools without any human intervention. This would be very useful because these rovers could prepare a simple base on the moon or any other space surface system before humans return to it. A Pro-E picture of the "Quick-Attach" mechanism is shown below (Nick and Schuler , 3).

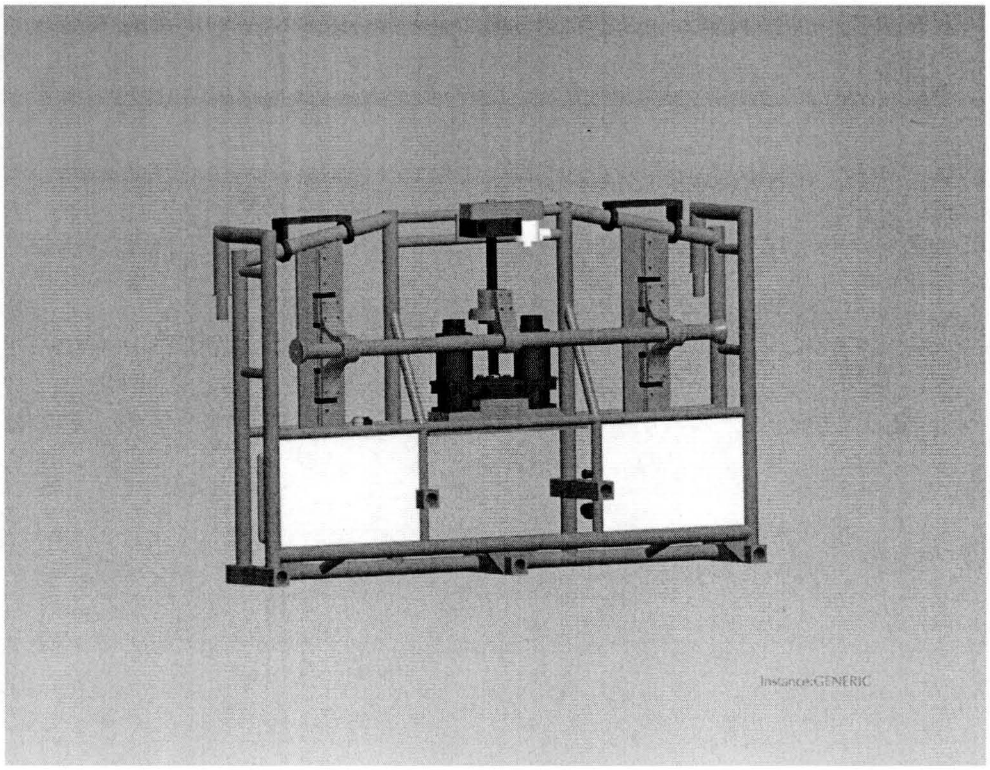

Figure 3 - "Quick-Attach" Pro-E Model

Project Purpose/Description

However, A.J. and Jason do not have access to a Chariot rover more than a few times a year (both rovers are kept at Johnson Space Center), which limits their capabilities to adequately test and evaluate the "Quick-Attach" mechanism and its various surface tools. As such, I was assigned the task of designing a lunar "Quick-Attach" mechanism to Hummer vehicle interface mount. In other words, my project was to design some physical interface that would allow Jason and A.J. to mount their "Quick-Attach" mechanism onto the front of a Hummer so that they could test the "Quick-Attach" (QA) at KSC on a regular basis. See Figure 4 below for clarification and relative perspective between the QA, the location of the mounting interface, the Hummer vehicle, and an implement (surface tool) (TRL Design & Development , 4).

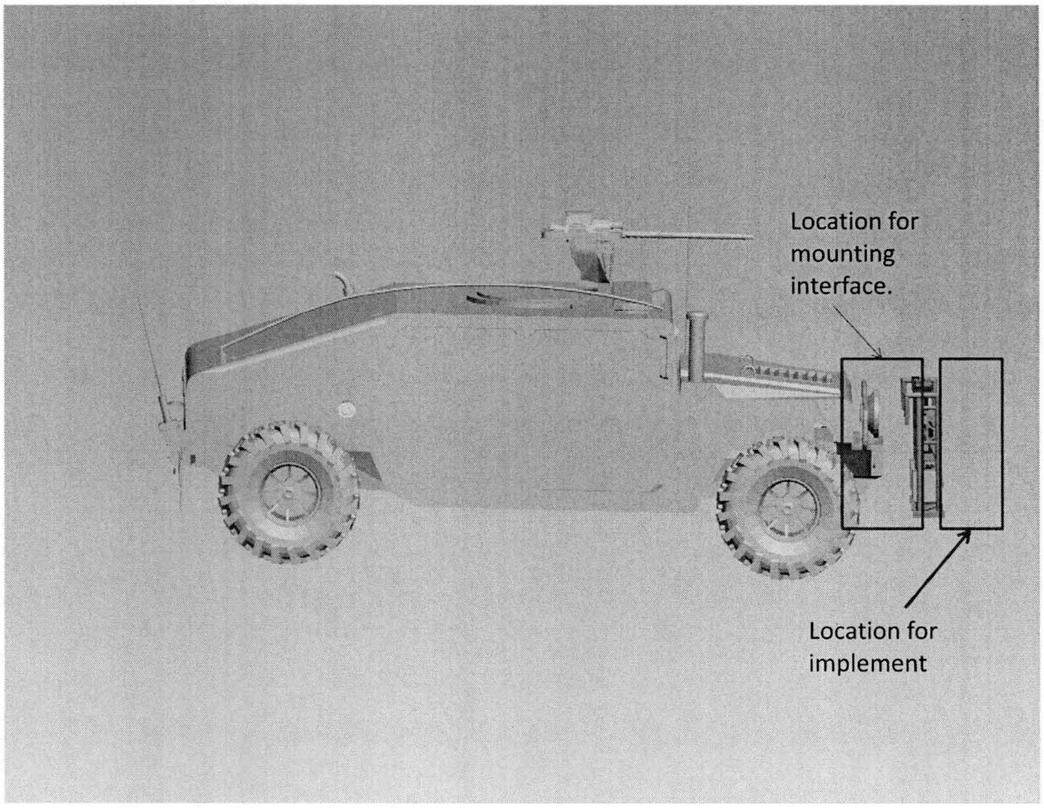

Figure 4 - QA to Hummer Perspective (Credit: Hummer Model - TRL Design & Development)

To begin the project, I outlined each task that would need to be performed in order to complete this project. The list is as follows:

- Become familiar with "Quick-Attach" Pro-E models
- Establish Functional Requirements of the mounting plate (Load capacity, vertical travel, dimensional requirements)
- Gather dimensional constraints and data of area of interest on Hummer
- Determine what metal to make the mounting plate out of – weight constraint of ≈225 lbs max
- Determine possible key points of attachment to Hummer and methods of attachment (fasteners/cables/turnbuckles)
- Begin development of Pro-E mounting plate design
- Perform structural loading analysis on mounting plate design
    - Perform hand calculation analysis on design to determine maximum yield stresses
    - Take design into Mechanica and analyze for maximum yield stresses
- Verify design meets loading requirements by comparing to analysis
- Take design to Prototype shop and determine feasibility of design
    - Do they have the tools necessary to fabricate the design?
    - Do Jason and AJ have access to the tools necessary to install the design?
    - Consider order of assembly once fabricated
- Make modifications/changes to design as necessary
- Put in work order with Prototype shop to get design fabricated
- Perform Proof-load test on mounting plate on one of the hummers

Design Phase of Project

After a few days of becoming familiar with the QA design I dove right into the designing of the mounting interface, as I figured I would gather all of the important design requirements, data, and attachment points as I went. I began by gathering basic information on the requirements of the QA mechanism. I determined from the initial information that it might be much easier to design the mounting interface in reverse, rather than designing from the Hummer out to the QA. This is due to the fact that there were already a set of specific dimensional constraints and requirements placed upon my design by the QA design itself. In addition, the interface I design will need to be fairly tolerant to dimensional variations to ensure that it is usable with more than one Hummer vehicle.

This led me to begin collecting data about the mounting plate that I would design to interface directly with the QA (the outermost piece of the entire interface). I found that one of the reasonable locations to connect to the QA was at five pin holes located near the bottom of the mechanism that are used as connections to the Chariot Rover anyway (see Figure 3). However, a very large moment would be placed on the QA structure if just these five pin-hole connections were used. Therefore, the U-tubes on the top of the QA were to be mounted to as well (see Figure 3). The U-tubes can actually be separated into two pieces, as there is a turnbuckle located within the horizontal portion of the upper U-tubes, allowing the two pieces to be threaded into one another. For mounting purposes, the back half of the U-tubes would be separated from the QA, leaving two threaded holes that could easily be connected to a mounting plate via two turnbuckles.

I now had enough information to design the mounting plate that would interface directly with the back of the QA. I used the QA height and width dimensions as reference for the overall size of the mounting plate. The Pro-E design for this mounting plate can be seen below, in Figure 5.

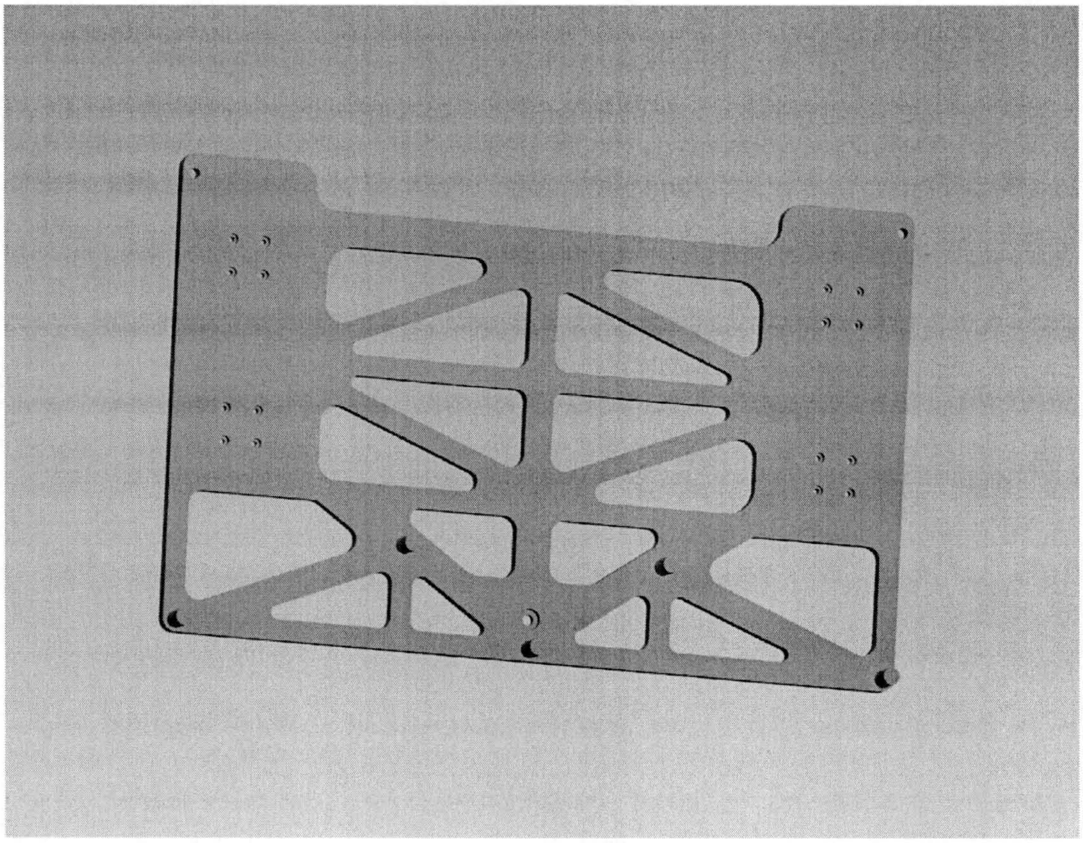

Figure 5 – Pro-E Design of QA Mounting Plate

The plate is 1.25 inches thick and is to be made of 6061 T6 Aluminum plate. The male insert pegs are to be made out of chromoly plugs and fastened into place with ¾" bolts. Significant material was cut out of the plate to decrease the overall weight of the mounting interface (see analysis for further information). No material was cut out of the upper left and right areas of the mounting plate because rail blocks will eventually be attached to those locations (see Figure 11 on page 14 for further details).

After outlining an initial set of design ideas and requirements I began gathering more specific information on the dimensional, loading, and vertical travel requirements of the mounting structure. According to Jason and A.J, the mounting interface would likely need to actuate itself in order to give the proper upper and lower vertical limits for the QA itself (i.e. the Chariot Rover sits much lower than the Hummer). We agreed that the QA needed to be able to reach a height of approximately four inches off the ground in order to equip a surface tool and it needed to be able to lift itself to sixteen inches off of the ground to give the Hummer some reasonable driving clearance (see Appendix A.2 for further detail). Therefore, I needed to put an actuator into my design that was capable of twelve inches of vertical travel. I also needed to consider what kind of load would be placed on this actuator. To determine the maximum vertical load that would be placed on the actuator, I made conservative assumptions that the QA weighs 250 pounds, the implement could weigh up to 1,000 pounds, and the auxiliary mounting structure (rail blocks, moving mount plate, pins, bolts, nuts, etc.) could weigh no more than 250 pounds. This meant that the actuator needed to be able to lift 1,500 pounds.

Nook Industries, a company that designs and manufactures linear motion components and systems, offers a line of CC Linear Actuators. One of these actuators has a stroke of 12 inches and can carry a dynamic load of up to 1,500 pounds. This actuator met both the load requirements and the vertical travel requirements necessary for my design. As such, I chose to integrate this actuator into my QA mounting interface design. The actuator is bolted to the moving mounting plate through a clevis end bracket and can be seen below at its fully extended actuation length in the Pro-E design displayed in Figure 6 (Nook Industries , 5).

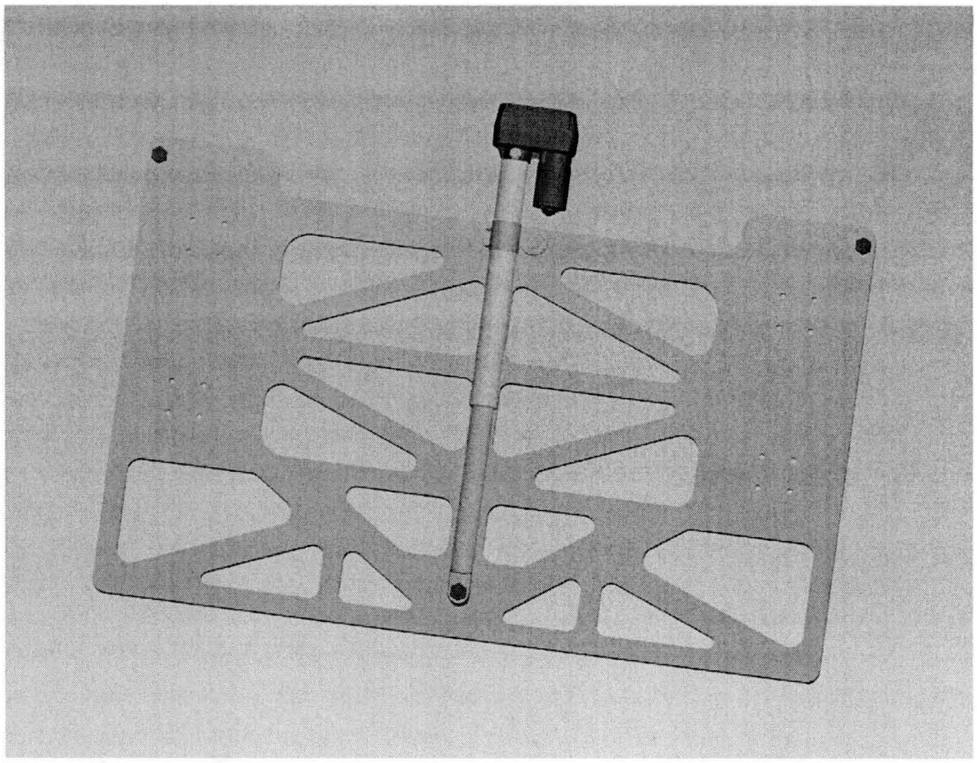

Figure 6 - QA Moving Plate + 12VDC Linear Actuator (Credit: Actuator Pro-E model provided by Nook Industries)

In order to insure accurate linear motion, a set of rails and rail blocks would also need to be integrated into my design. Again, Nook Industries provides a series of precision profile rail systems that met my design needs. In order to determine which type of rail system was necessary, I needed to first perform a force/moment analysis on the entire QA mounting system. This analysis was performed within Excel and is detailed in the following pages. To begin the analysis, I first had to make a few initial assumptions and then gather the pertinent data on the runner blocks. This data is tabulated below in Figure 7.

Runner Block Type	
NH45ER	
Block Separation (in)	Block Weight (lbf)
12	6.3934056
Dist. to Horiz. CG of Block (in)	Number of Blocks
0.6	4
Vert. Length of Block (in)	**Total Weight of Blocks (lbf)**
5.47244094	**25.5736224**

Figure 7 - Runner Block Data (Excel)

In order to maintain a conservative set of assumptions throughout my design, I assumed worst-case loading scenarios to determine the maximum forces and moments that the rail blocks would be susceptible to. The appropriate forces and their perpendicular distances to the runner blocks are displayed below in Figure 8.

Forces and Perpendicular Distance Data			
Mounting Plate Load (lbf)	QA Load (lbf)	Max Implement Load (lbf)	Max Wheel Slip (lbf)
80	250	1000	6500
Max Distance (in)	Max Distance (in)	Max Distance (in)	Max Distance (in)
1.1	10.1	49.6	36.73622047

Figure 8 - Force Data (Excel)

Finally, by doing a simple force balance in the horizontal direction and a moment balance at one of the two block locations, the resolved forces placed upon the blocks could be determined. This number is then divided by two as there are two rails with two blocks each. The force analysis was performed statically, as the dynamic forces involved were negligible (see Appendix A.1 for further information). These calculated forces are displayed in the Excel spreadsheet below in Figure 9.

Calculated Forces	
Force in Lower Blocks (lbf)	**Force in Higher Blocks (lbf)**
12192.64304	**8942.643044**

Figure 9 - Calculated Forces (Excel)

Once the forces on the blocks were calculated, I consulted a table of specifications provided by Nook Industries that indicated what the maximum forces each type of rail block could withstand. I then had to verify that the type of runner blocks I selected to do the analysis off of met these force requirements. In this manner, the analysis was an iterative process. I would select a certain type of runner block, perform the analysis based on that runner block's data, and then verify at the end whether or not that runner block met the force requirements that it would potentially be exposed to. After several iterations, I determined that the NH45ER runner blocks with a twelve inch separation would meet the force requirements while still keeping the amount of rails required reasonable. Based on this rail and block design, the final design parameters could be determined. These parameters are displayed below in Figure 10.

Final Rail and Block Design Parameters	
Amount of Track Required (in)	Total Weight (lbf)
29.47244094	46.86353076

Figure 10 - Final Design Parameters (Excel)

As can be seen above, this rail and block design requires roughly 30 inches of track and adds almost 50 pounds to the overall design. I implemented this rail and block system into my Pro-E design, which can be seen below in Figure 11 (Nook Industries , 5). It should be noted that I also designed a pinning system to go along with the rail system that allows the load to be transferred away from the actuator when it is not actuating.

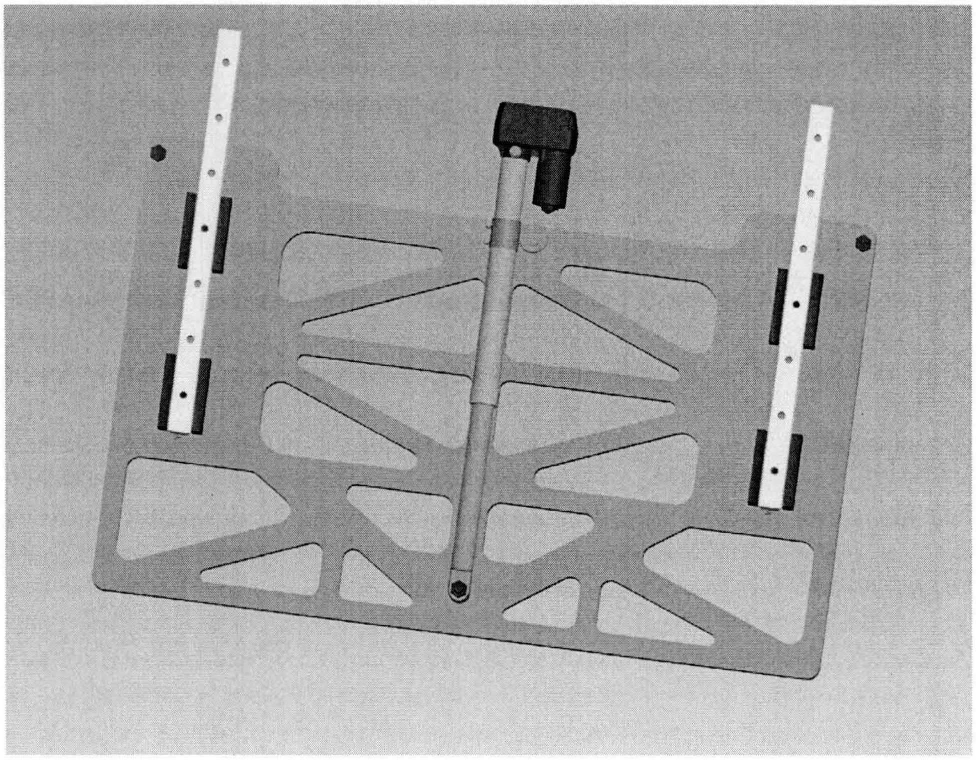

Figure 11 - Pro-E Design of Moving Plate, Actuator, Rail and Block System (Credit: Rail + Blocks by Nook Industries)

The next component of the assembly that needed to be designed was the back mounting plate that would directly interface with the front of the Hummer vehicle. I located two attachment locations on the Hummer that would be utilized. The first and primary attachment point for this mounting plate is a rectangular mounting structure positioned just underneath the front bumper of the Hummer. This mounting structure extends back underneath the vehicle and connects directly into the undercarriage of the vehicle. There are ten bolt-holes already drilled into this mounting structure, likely to mount an optional winch attachment. Conveniently, I was able to integrate these bolt-hole locations into my design and utilize the mounting structure as the main support for my back mounting plate. Again, another mounting location would be necessary to avoid placing a large moment on this back mounting plate. Fortunately, there are two additional attachment locations in the form of hooks located on the hood of the vehicle. See Figure 12 below for these locations.

Figure 12 - Hummer Attachment Locations

Before the Pro-E model of the stationary back plate was designed, accurate data on the exact locations of each feature on the front of the Hummer had to be collected. Since the back plate will interface directly with the Hummer, there is very little tolerance allowed with respect to the important features of the design (i.e. relative bolt-hole locations, hook-connection locations, height and width constraints, etc.). In order to minimize data measurement error, I used an advanced, portable Coordinate Measurement Machine (CMM) known as a FAROarm on the front of the Hummer vehicle to collect the dimensional data on all of its relative feature locations. The FAROarm is an arm-shaped CMM that has three joints that allow many degrees of manipulation for ease of data collection and is capable of precision measurements of up to 0.016mm. Each joint constantly maintains and updates its relative location to the "zeroed location" of the FAROarm. This "zeroed location" is managed by an accompanying software tool that sets the zero location and then captures and stores the rest of the data in reference to that point. The FAROarm utilizes a place and click method for data collection. Refer to the picture below in Figure 12 for further clarification.

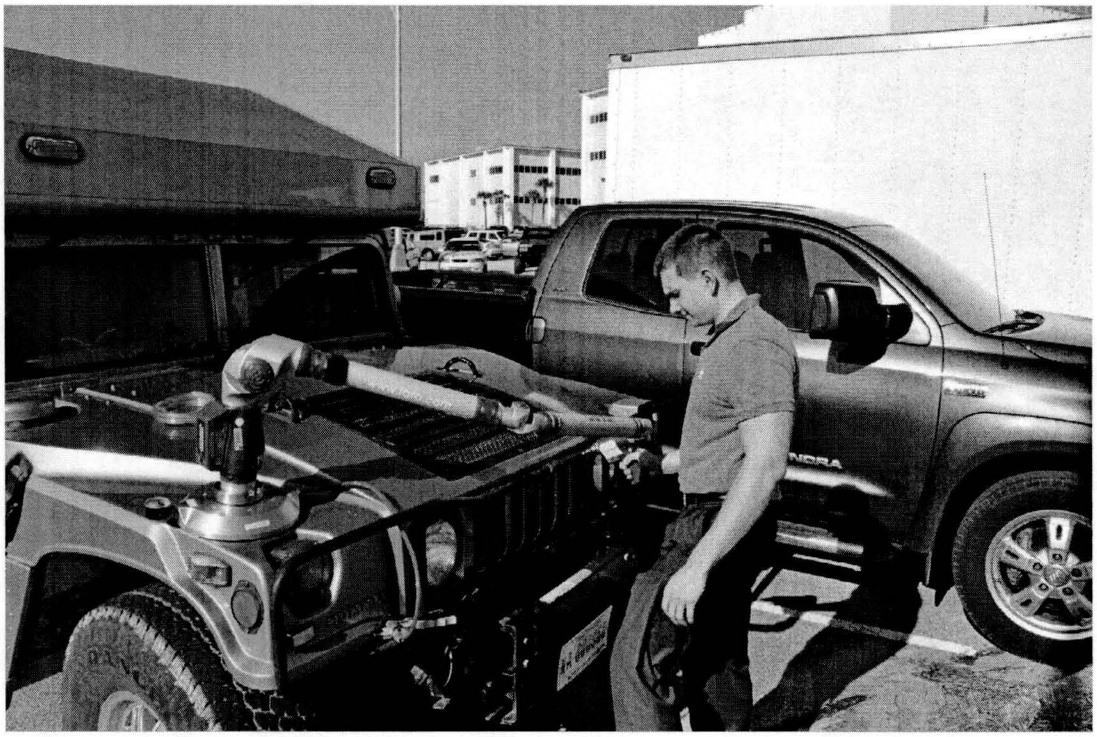

Figure 13 - Using the FAROarm to Collect Hummer Data

Once the data had been collected I uploaded it into Pro-E and created a skeleton assembly based on the important feature data points. This skeleton consisted primarily of datum planes and data points located at the intersection of three of these datum planes. The data points were considered key feature locations and would serve as reference points for each component of the Hummer mounting plate assembly. This allows the entire assembly to auto-update if a simple modification is made within the skeleton of the assembly, making it very easy to account for error during the design phase. Also, the creation of a skeleton and constraints to the points within the skeleton ensures that the manufactured parts will actually interface properly with the front of the Hummer, assuming they are manufactured properly and within tolerances. The Pro-E skeleton can be seen displayed below in Figure 13.

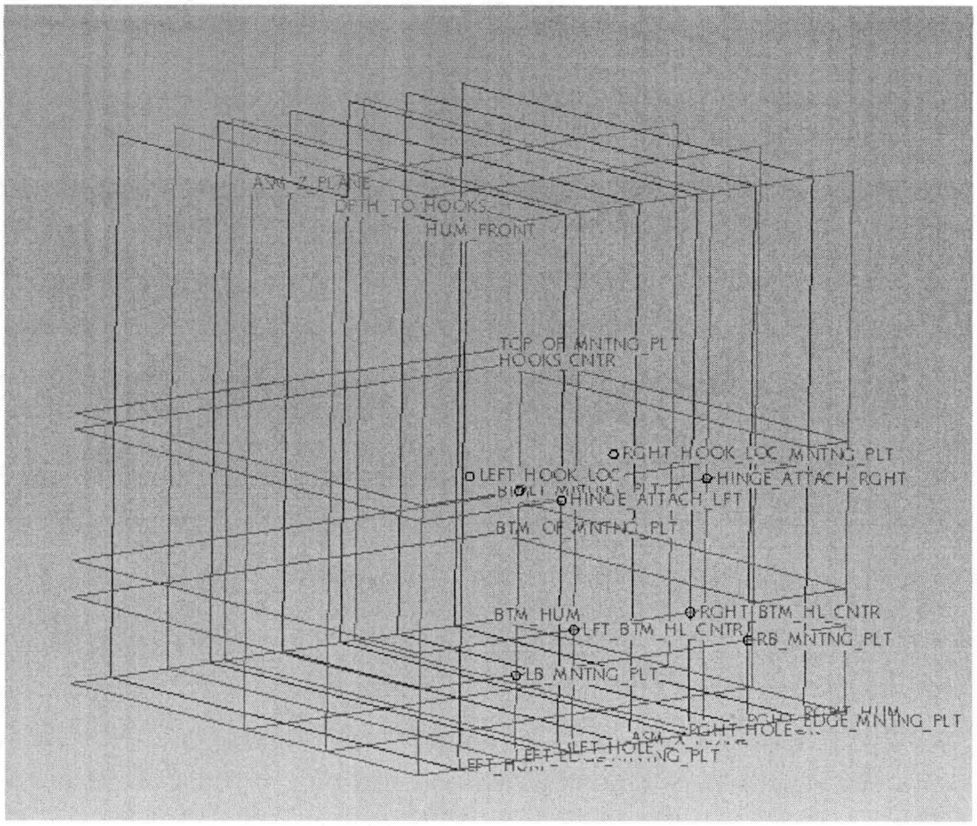

Figure 14 - Skeleton for Hummer Mounting Plate Assembly

By utilizing this skeleton, the dimensional constraints of the stationary back mounting plate can easily be determined and implemented. In addition, this skeleton gives immediate insight into exactly where the bolt-hole locations and the hook locations are with reference to the back mounting plate location. Refer below to Figure 14 to see the ProE design of the stationary back mounting plate.

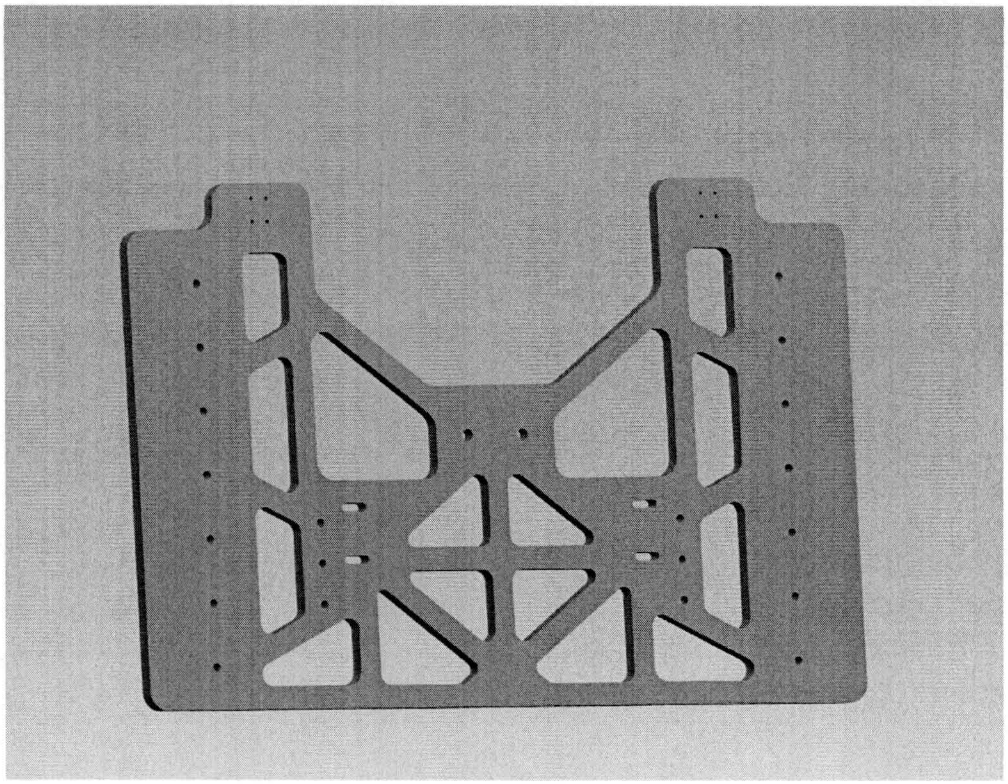

Figure 15 – Pro-E Model of Stationary Back Mounting Plate

This plate is one inch thick and is to be made of 6061 T6 aluminum as well. Large portions of the plate are cut out to reduce weight and to increase the visibility of whomever is driving the Hummer vehicle (see Appendix A.2 for further visibility details/concerns). Note that the bolt holes and slots near the center of the plate will be utilized for the mounting to the Hummer, the bolt holes running along the sides of the plate will be utilized for mounting the rails to the back plate, and the small bolt holes at the top of the plate will be utilized to mount the hook connections to the back plate (see next Pro-E design).

The final remaining major component of the mounting structure assembly is the hook connections. Since the hooks on the Hummer are located a significant distance away from the front of the Hummer, an additional component must be designed that can reach these hook connection points. When I considered the design of this component I determined that it would need to be fairly generic and allow a wide range of positioning, as the exact distance from the back mounting plate to these hooks will vary depending on the vehicle the interface is being mounted onto. Therefore, I immediately knew that I needed to allow linear and radial adjustment capabilities within this component's design. After performing some research, I determined that a clevis, rod end, and turnbuckle system would meet these requirements. I determined that I also needed an additional clevis near the end of the hook connection component so as to allow for small angle adjustments. This ensures that the shaft collar attached to the clevis is flush to the inside hook surface. In this manner, the hook connection component's adjustability can be compared to that of an arm and hand. See the Pro-E model in Figure 15 below for further understanding of the design (McMaster-Carr Supply Company , 6).

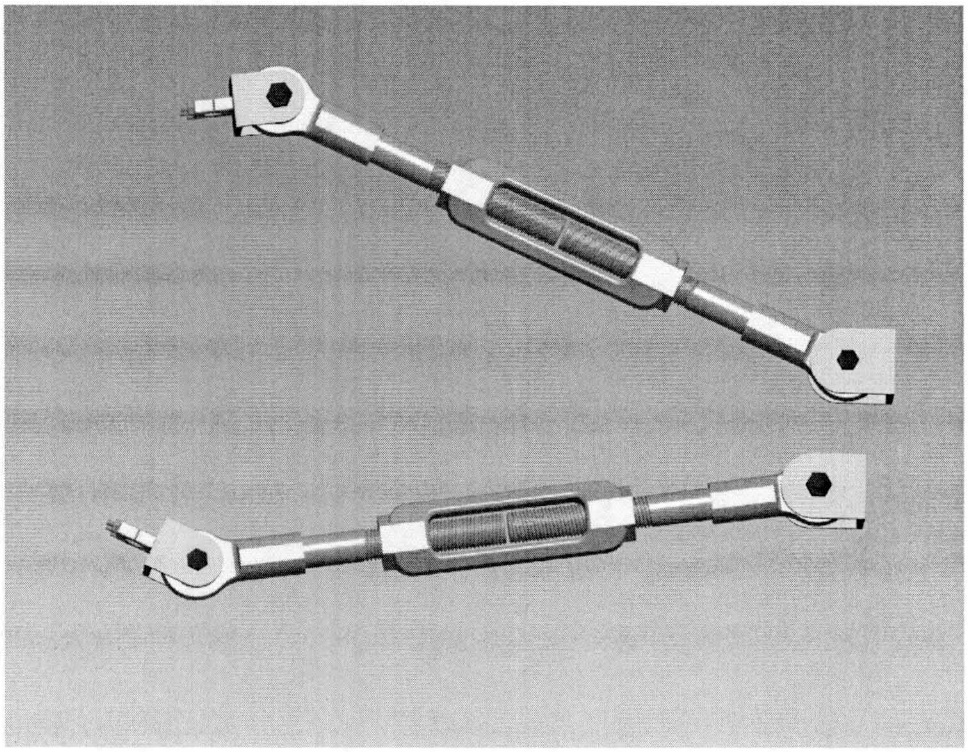

Figure 16 – Pro-E Model of Hook Connection Component (in 2 orientations) (Credit: Various bolts, turnbuckle, and rod end models provided by McMaster-Carr Supply Company)

Note that the hook connection component is displayed in two different orientations above. This simply shows the multiple degrees of adjustment that the component is capable of.

Again, the relative position, length, and adjustment capabilities of this component were based on initial analysis of the skeleton model displayed in Figure 13 above.

Once I had designed all of the major components of the mounting interface, I assembled them together within the skeleton assembly, making sure that the key feature points were referenced as a parent constraint for the entire assembly. During this time, I made some slight additions to the design not detailed above in the forms of rail bracket supports (for the runner block pinning system) and actuator bolt supports. These components were trivial and thus were not detailed individually. The completed assembly can be seen below in Figure 16.

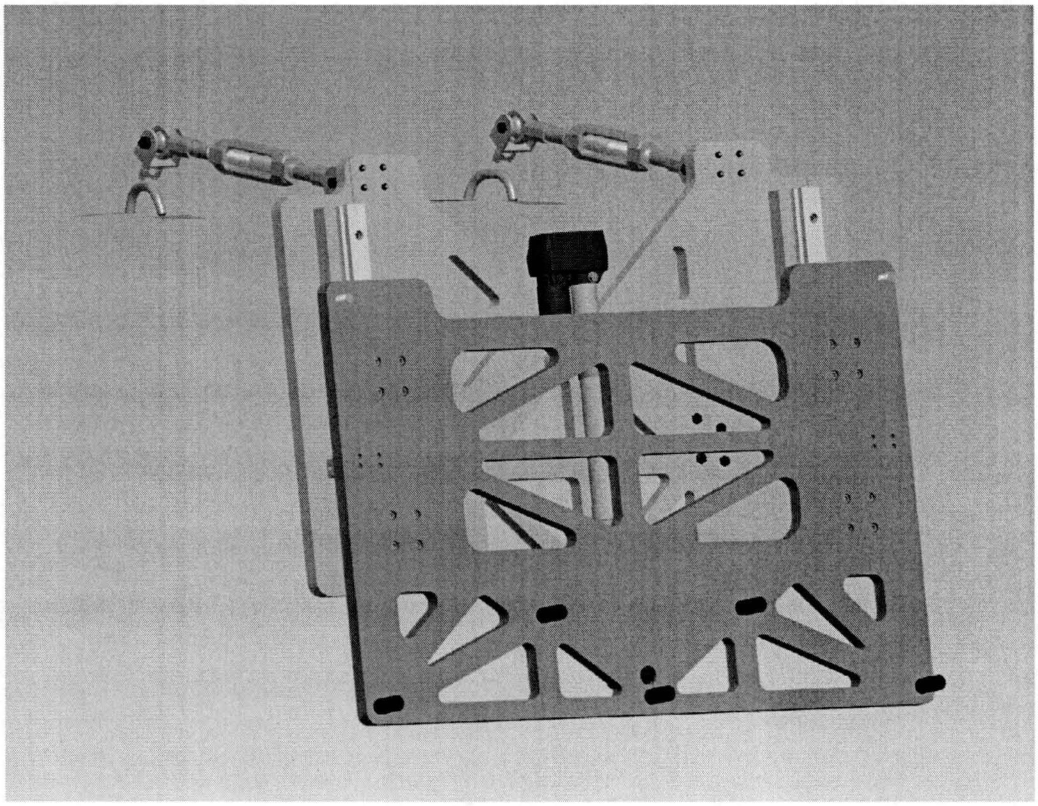

Figure 17 – Complete Pro-E Mounting Interface Assembly

Refer to Appendix A.3 to see a Pro/E concept of the completed mounting interface attached to a Hummer vehicle.

After finishing the design portion of my project, I began performing structural analysis on my design to verify that the design was feasible and could be made primarily out of Aluminum 6061 T6 (see Appendix A.1 for exceptions), which would cut down considerably on manufacturing costs.

Analysis Phase of Project

The analysis phase of the project serves as validation of the structural integrity of my design. I began the analysis by calculating the stress at each of the joints and fasteners that are used throughout the design. The primary forms of stress analysis that I performed were tensile stress, shear stress, bearing stress, bending stress, tear-out stress, pull-through stress, and thread engagement. I also performed a safety factor calculation on each component of my design. To keep this analysis concise, I will present only the principal equations used below and the results received will be included in Appendix A.4 as an Excel spreadsheet.

Tensile stress	$\boldsymbol{\sigma = \frac{F}{A}}$	F = Axial Force A=Cross-sectional area
Shear stress	$\tau = \frac{F}{A}$	F=Perpendicular Force A=Cross-sectional area
Bearing stress	$\sigma_b = \frac{F}{A * b}$	F= Perpendicular Force A= Diameter of Hole B= Length of Hole/Fastener Engagement
Bending stress	$\sigma = \frac{M * c}{I}$	M= Moment c = Distance to neutral axis I = Moment of inertia about neutral axis
Tear-out stress	$\sigma_t = \frac{F}{A * b}$	F= Perpendicular Force A=Diameter of Hole B= Length of Hole/Fastener Engagement

Pull-through stress	$\sigma_{pt} = \frac{F}{A_1 - A_2}$	F= Axial Force A_1= Cross-sectional area of fastener head A_2= Nominal cross-sectional area of fastener threads
Thread engagement	$R = \frac{A_{se} * \sigma_{ye}}{A_{si} * \sigma_{yi}}$	A_{se}= shear area external thread A_{si}= shear area internal thread σ_{ye}= tensile strength external thread σ_{yi}= tensile strength internal thread

Figure 18 - Principal Stress Equations

Locations of high stress, which are marked in red on the spreadsheet in Appendix A.4, do not quite meet the 2x factor of safety criteria. However, they were just shy of meeting that criteria. Furthermore, when all of the other conservative assumptions made throughout the analysis are considered, it becomes clear that these areas realistically have at least two factors of safety. In addition to the hand calculations, I performed a Pro-E Mechanica Von Mises stress analysis on the front and back plates. This was accomplished by setting fixed, rigid location constraints and applying the appropriate point and distributed loads onto the plates.

With respect to the front plate, I was only concerned with the bottom portion of the plate bending. Therefore, I only performed the analysis on the portion of the plate below the runner block attachment location. I made the full horizontal length of the plate rigid just below the runner block attachment location and applied a distributed load where the male QA insert pegs are located on the plate. See Figure 18 below for clarification.

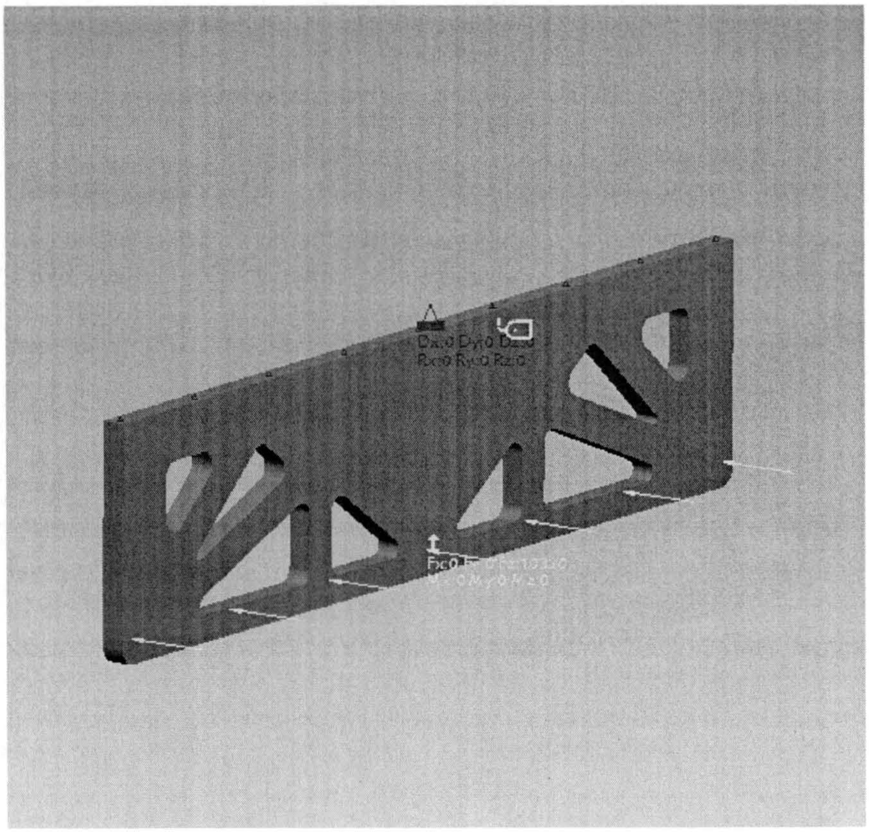

Figure 19 - Front Plate Bending Analysis

After running the analysis, I determined that my original design would not hold up properly to the forces. Therefore, I redesigned the cuts in the bottom of the plate and ran the Mechanica VM analysis until I met the 2x factor of safety criteria. The final results received are displayed in Figure 19 below.

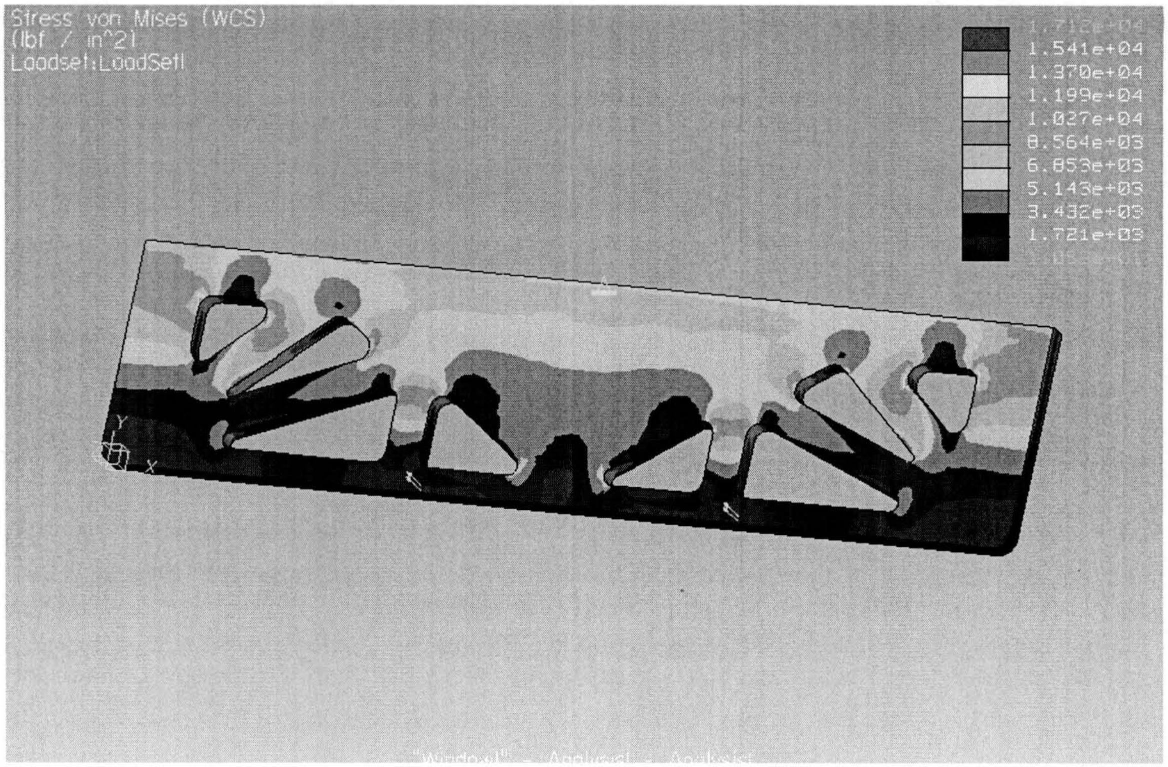

Figure 20 - Mechanica VM Analysis - Front Plate

As can be seen above, the maximum stress seen in the front plate is around 17ksi. This meets the 2x factor of safety criteria, as the yield stress of the aluminum is ~40ksi.

I performed similar analysis on the back plate of the interface as well. The areas of concern on the back plate are the right and left ends where the rails are attached. The plate could potentially bend around its z-axis from these stresses. To ensure that the analysis was conservative, I removed the material in the center of the plate and analyzed the left and right portions of the plate individually. By applying the previously determined forces to the plate and rigidly constraining the edges of the plate where the material had been cut out from, I was able to perform a simple, conservative analysis on the plate within Mechanica. See Figure 20 below for the analysis setup.

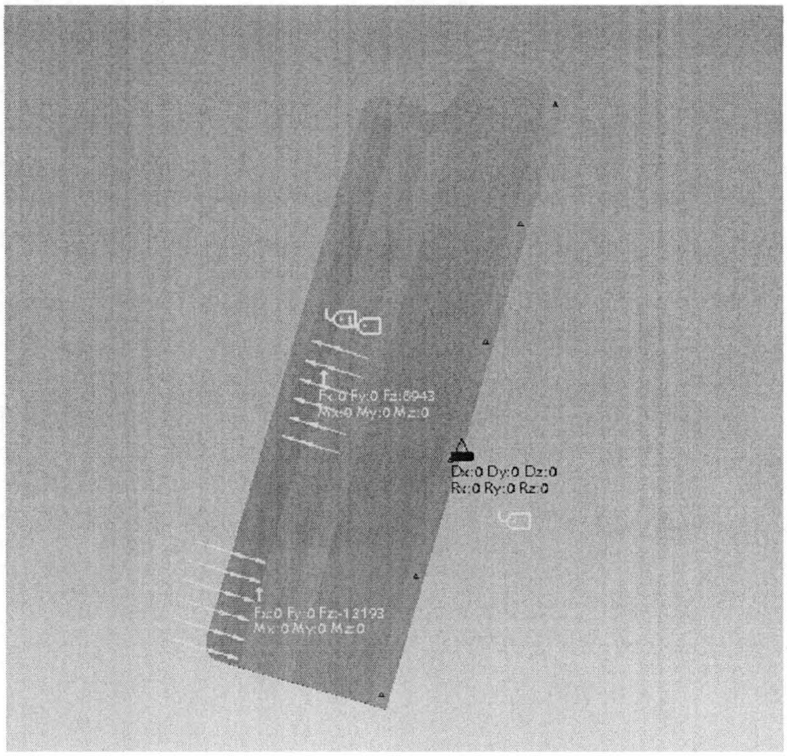

Figure 21 – Pro/E Mechanica Back Plate Bending Analysis

After running the Von Mises stress analysis on the back plate, I noted that the stress was too high. After removing some of the truss cuts in the plate and increasing the thickness of the plate to 1.25 inches, the analysis indicated that I had roughly two factors of safety, as the maximum VM stress within the plate was 22ksi. When all of the other conservative assumptions are taken into account, the factor of safety exceeds well beyond two. The VM Mechanica analysis for the back plate can be seen below in Figure 21.

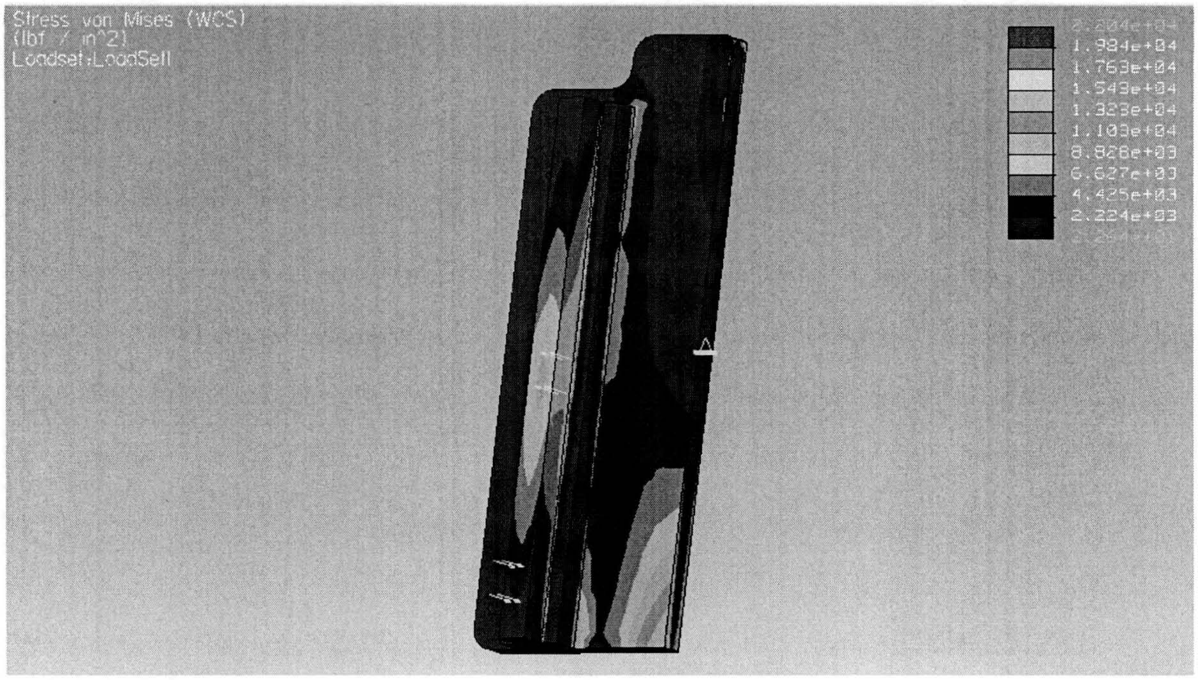

Figure 22 - Mechanica VM Analysis - Back Plate

As can be seen in the figures above, the Mechanica analysis both supports my hand-calculations (refer to Appendix A.3) and further validates the integrity of my design.

Conclusion

After completing my design and finishing the structural analysis, I began creating a set of professional level CAD drawings to be issued into the NASA design database at KSC. These drawings will not be included within this report.

Currently, there is no budget to build my design. However, these drawings would be utilized in the future during the fabrication process if budget were allocated specifically to building and using my design. I will continue to work on completing these drawings and should be finished before the end of my internship, May 14th.

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2. DeClama, Alexander. Potentia Tenebras Repellendi. 5 March 2010 <http://potentiatenebrasrepellendi.blogspot.com/2009_01_01_archive.html>.

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4. TRL Design & Development. "Hummer Google SketchUp Model." 19 June 2008.

5. Nook Industries. "Various Pro/E Models." 8 March 2010 <http://www.nookindustries.com/home.cfm>.

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Appendix A

A.1 Assumptions and Considerations Made During Design

- 14° (arctan(16/62)) is max angle of ascent that the Hummers will be capable of in Arizona at Desert RATS with certain implements equipped (PUP)
- Assumed horizontal distance for angle of ascent calculation begins where the front tires of the Hummer meet the ground
- Assumed worst case scenarios in force and moment analysis for rail block sizing
- Assumed at least 2 factors of safety in stress analysis
- Assumed actuator would only be subjected to 1500 pounds in worst-case loading scenario (equivalent to actuator's max dynamic load capabilities)
- Force and moment analysis performed in Excel was done statically because the additional dynamic force values were negligible (performed sanity check calculations)
- Assumed 12 inches of actuation would be enough to reach upper and lower vertical limits
- Materials minus actuator/rails, aluminum/steel plate and machinist time comes out to $475 (most in turnbuckles and rod ends)
- Grade 8 bolts were used almost exclusively
- Chose Nook CC Linear Actuator ¾" Bolt Heavy Mounting Bracket to mount actuator to back plate –using their mount should guarantee capability to withstand necessary loads, no guarantee with "home-made" mounting structure
- All holes are sized as free-fits, except for the threaded holes, the actuator bolts (close-fit), and chromoly plug holes (threaded)
- Recommend a few pieces be made of steel/chromoly (clevis mounts, plugs), and the rest will be made of Al 6061 T6
- 16" is enough clearance and top of mounting structure being 52" off the ground gives the Hummer driver acceptable driving visibility (front of Hummer hood is roughly 44.5" off the ground – 7.5" difference)
- Holes will be match drilled into moving plate QA male inserts for holding cotter pins when QA is available
- QA male inserts are currently exact size of QA Pro-E model, will need to be changed to average size of the two actual QA built - at JSC currently

A.2 Maximum Angle of Ascent Diagram

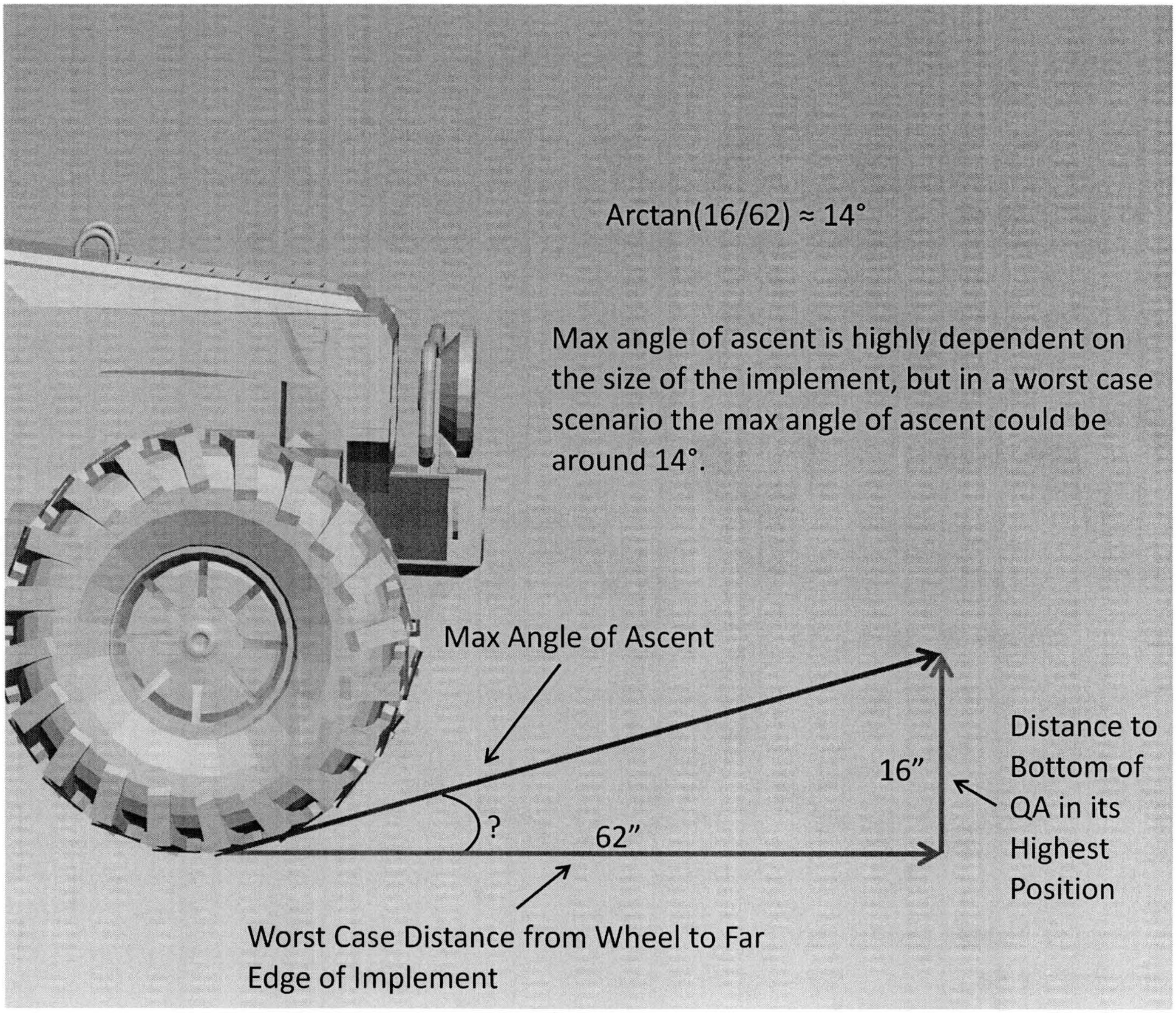

Figure 23 - Max Angle of Ascent Diagram (Credit: TRL Design & Development for Hummer Model)

A.3 Concept of Mounting Interface Attached to Hummer and QA

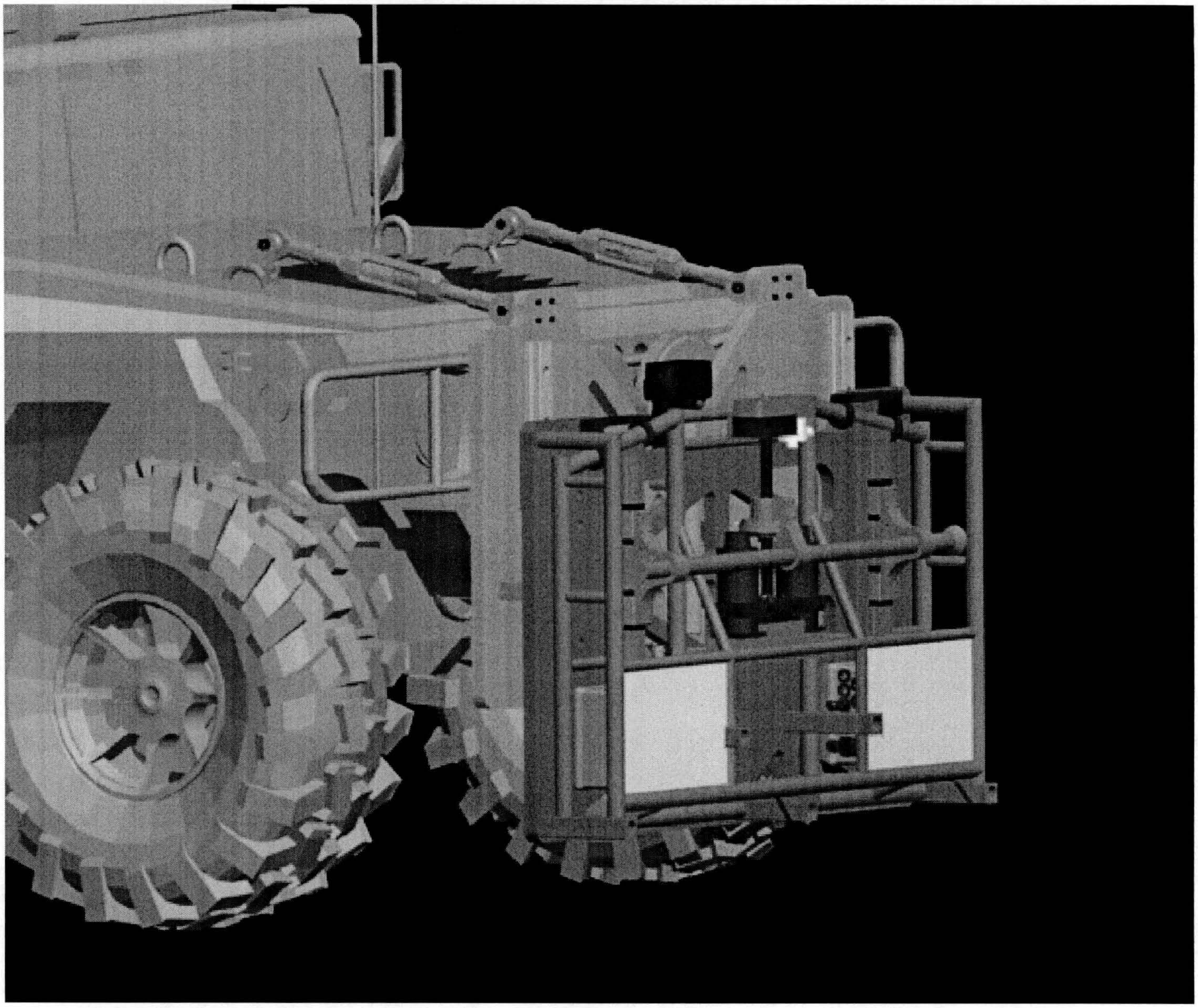

Figure 24 - Concept of Mounting Interface Attached to Hummer and QA (Credit: TRL Design & Development for Hummer Model)

A.4 Design Stress Analysis Results

	Hummer to QA Interface Design Analysis								
	Bolt/Pin Location	**Quantity**	**Shear Stress**	**Tensile Stress**	**Bearing Stress**	**Bending Stress**	**Tear-Out/Pull-Through/Thread Strip-Out**	**FS**	**Rec. Mat'l.**
	Actuator Clevis End	1	5ksi	N/A	823psi	N/A	N/A	12.6+	N/A
	Bottom Block Bolts	4	1043psi	25.0334ksi	468.75psi	N/A	N/A	6.95+	N/A
	Top Block Bolts	4	1043psi	33.934ksi	468.75psi	N/A	N/A	5.1+	N/A
	Pin Holder Bolts	8	6.970ksi	N/A	563.91psi	N/A	N/A	10.8+	N/A
	QA Threaded Bolts	2	2.137ksi	5.442ksi	960psi	N/A	1,920psi (TO), 6.240ksi (PT)	5.6+	N/A
	Chromoly Male Insert Pegs/Bolts	5	265.3psi	3041.6psi	N/A	N/A	3,879psi (TO), 10.9ksi (PT), R=0.105 < 1 (TSO)	3.2+	Chromoly
	Rail Bolts	14	937.5psi	3555psi	N/A	N/A	N/A	48+	N/A
	Pins	2	13.581ksi	N/A	1333.3psi	N/A	N/A	7+	N/A
	Act. Tube Bracket Bolt	1	5ksi	N/A	715psi	N/A	N/A	12.6+	N/A
	Pin Mount	2	1055psi	N/A	4223.6psi	14.2548ksi	N/A	2.45+	Al 6061 T6
	Front Plate*	1	N/A	N/A	N/A	17.12ksi (BTM) & 9,114 psi (TP) (2 dir.)	N/A	2+	Al 6061 T6
	Rail Mount Inserts	2	N/A	N/A	N/A	N/A	N/A	N/A	Al 6061 T6
	Back Plate Bolts	10	1177.7psi	12.242ksi	330psi	N/A	7.4ksi (PT)	4.8+	N/A
	Back Plate Clevis Bolts	8	8132psi	46ksi	658psi	N/A	12.2ksi (PT)	2.8+	N/A
	Back Plate*	1	N/A	N/A	N/A	22ksi	N/A	1.82+	Al 6061 T6
	Clevis Mount	2	N/A	N/A	22ksi	N/A	N/A	1.82+	Chromoly
	Turnbuckles	2	N/A	5846psi	N/A	N/A	N/A	2.5+	N/A
	Rod Ends	2	N/A	13ksi	9.6ksi	N/A	N/A	7.8+	N/A
	Clevis Bolt 1	2	19.67ksi	N/A	N/A	N/A	N/A	3.2+	N/A
	Clevis Bolt 2	2	19.67ksi	N/A	N/A	N/A	N/A	3.2+	N/A
	Clevis Mount	2	N/A	N/A	22ksi	N/A	N/A	1.82+	Chromoly
	Shaft Collar	2	N/A	N/A	15.283ksi	N/A	N/A	2.6+	Chromoly
	Shaft Collar Bolts	4	N/A	80.3ksi	N/A	N/A	N/A	1.86+	N/A
Key:			**Note - Although shear loading on threads and free fit/close fit applications are not preferable, generous factors of safety were ensured to account for these concerns**				**Note - E/D < 1.5 is acceptable when T>0.5D**		
Red	**Questionable Stress (below 2 fs)**								
Green	**Allowable Stress**								

Figure 25 - Design Stress Analysis Results