MOTION BASE DRIVING SIMULATOR

ME450, FALL 2006

TEAM NAME: Team 8

TEAM MEMBER: Michael Cheng
Philip Irawan
Hyun-Eun Kwak
Purnomo Putra

SECTION INSTRUCTOR: Prof. Kazuhiro Saitou

Date: 11 December 2006

(Kwak, Cheng, Irawan, Putra from the left)

Executive Summary……………………………………………………………………..1
Introduction…..…………………………………………………………………….....2
Customer Requirements and Engineering Specification……………………………...3
Concept Generation……………………………………………………………………..4
Cost and feasibility factors……………………………………………………..4
Concept brainstormed……….………………………………………………...4
Concept Selection…...………………………………………………………………….5
First Selected Concept Description……………………………………………………..7
First design specifications…..8
Prototype Description…………………………………………………………………..9
Prototype parts and connections……… …………………………………………10
Prototype electronics……………….……………………………………………11
Purpose of prototype……………………………………………………………11
Engineering Design Parameter Analysis…...……………………………………………12
Design for manufacturability……...……………………………………………..12
Placement of the Actuators……………………………………..…………..12
Simultaneous data combination……...…………………………………………13
Control modeling analysis………………………………………………………13
Static analysis……………………...……………………………………………14
Dynamic analysis……….......…………………………………………………14
Failure/Safety issues…………………... ………………………………………..16
Failure modes and effects analysis……………………………………………....16
Manufacturing Plan…………………….....…………………………………………..17
Aluminum sheet………………………………………………………………17
Base plate…………………….………………………………………………..18
Ball joint connector……………...……………………………………………18
Base connector………………...………………………………………………18
DFMA application……………...……………………………………………..19
Electronic Connections…………………………………………………………………20
Serial port……………………...……………………………………………20
Microcontroller chip…………………………………………………………20
H-bridge IC……………………...…………………………………………21
Firgelli Actuators……………….……………………………………………21
Programming Code………………………..……………………………………………22
Pitch function……………………...……………………………………………..22
Roll function………………………………………………………………………..22
Actuators Communication……...………………………………………………..23
Test Results…………………………………..……………………………………………23
Engineering Changed Notice (ECN)………..…………………………………………24
Discussion……..…………………………..………………………………………………25
Strengths…………………………...…………………………………………25
Weaknesses/Improvements………………..……………………………………..25
Scaled up full size model……………….………………………………………..26
Recommendations…..…….…………………………...……………………………..27
Conclusion…..…………..………..………..……………………………………………27
Information Sources.....…...…………...……………………………………………29
References………………………………………………………………………………30
Acknowledgements……….………..……………………………………………………..31
Appendix……..……...…………………………………………………………………32

EXCUTIVE SUMMARY

On 12 September 2006, our team met with UMTRI sponsors regarding plans to improve their car simulator. The current driving simulator does not simulate the physical motion experienced by real-world drivers. Currently, it is used for studies on driver distraction and warning systems, but without a motion base platform, users will often experience motion sickness. Therefore, our team has been asked to design and manufacture a motion base platform as well as develop and test the software used to control the platform.

Two design options were presented along with their respective manufacturing costs to the sponsor. The final design chosen was a miniaturized version of the simulator due to the high cost issues of the other designs. This design will implement the use of three miniaturized electric ball-screw actuators on a Nissan 350z model car with a 1:16 scale relative to the full size simulator. The max pitch and roll of the model car is 10 and 13 degrees respectively, with a response time of 17 ms and an acceleration of 0.3g.

Engineering design analysis such as control modeling, dynamic and static analysis was completed on the prototype. The weight of the car and aluminum, along with the available power and speed of the actuators were factors used in the analysis. Equations of motions were developed from the relationship between the actuators to the model car. This allowed the formulation of a transfer function which helped to determine the frequency and motion response of the model car. Dynamic analysis was completed to evaluate the maximum thrust force each actuator would be required to output.

All research was completed and individual parts were selected for the prototype. Three Firgelli PQ-12 miniature actuators with a max force of 7 Newton were ordered. The selection of Firgelli PQ-12s miniature actuators was done after careful stress analysis on the model car. It was calculated that the PQ-12s model actuators would provide the necessary force to position the model car at any desired position. Also the connections for mounting the actuators were designed and manufactured using aluminum scraps. The model car was selected relative to the length and stroke of the Firgelli actuators.

The electronics used to communicate between the driving simulator and actuators consist of a microcontroller chip, H-bridge Integrated Controller, circuit board, wires and a serial port. A breadboard was used to avoid too much soldering and reduce the complexity.

The programming software was written in Microsoft Visual Studio in C++. The program functions by reading pitch and rolls angles from an external source file and translate those angles to vertical displacements for each actuator. Currently, the program does not read real-time data outputted from the simulator. Further modifications need to be implemented on the code to allow this function.

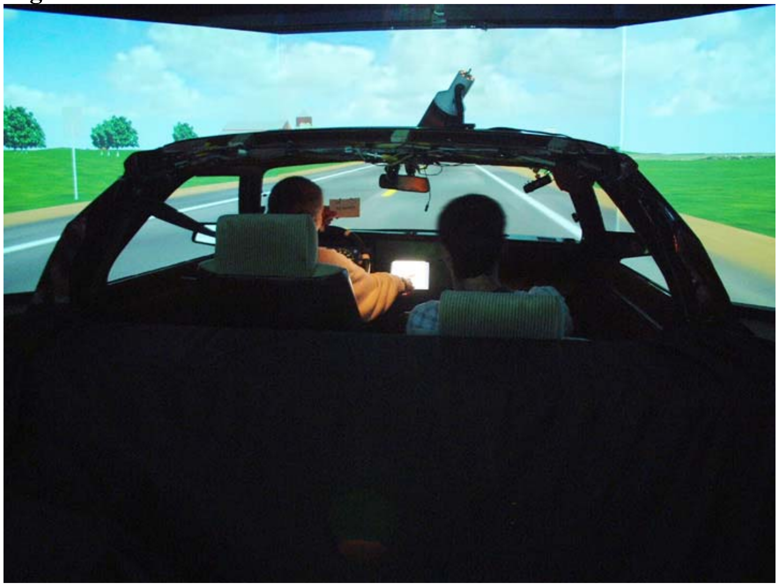
Several key engineering specifications were identified and used to validate the effectiveness of the prototype for the elimination of motion sickness. Some of these specifications included the response time, max static load, and the max pitch and roll angles. A functioning prototype has been completed and demonstrated for Design Expo.

INTRODUCTION

The University of Michigan Transportation Research Institute (UMTRI) is dedicated to increase driving safety and transportation system knowledge through research. It was founded in 1965 and currently employs 130 staff members, including full-time researchers, teaching faculty with the university, graduate students, and other support staff. It operates with a current annual budget of $14.5 million.

The current driving simulator at the UMTRI does not simulate physical motion (pitch and roll movements) experienced by real world drivers and passengers. As a result, a large number of drivers in the simulator experience motion sickness. The simulator is currently being upgraded to provide an even wider field of vision necessary for studies of driving in traffic. This will worsen the motion sickness experience. The goal of this project is to reduce or eliminate simulator users from experiencing motion sickness. This will be accomplished by designing and constructing a motion base platform and developing as well as testing the software that controls the motion of the platform based on vehicle data provided by the car simulator. The seat motion platform can serve as the foundation design for the entire cab platform in the future. The car simulator is shown in Figure 1 below.

Figure 1: Rear view of the car simulator cab



The customer wants the design to be compact and portable, due to available space in the car simulator room and transporting it to the design expo. It should be a design that can be easily scaled so that a large version could be built for the entire cab. There should be a short response time between the initial movement of the chair and the input data, preferably 17 ms or less. The design has to be safe, durable, and reliable. It has to be low cost because of budget constraints ($400 from the sponsor with possible additional funding from UMTRI). Finally, the design has to provide limited pitch, roll, vertical, and if possible, longitudinal movements.

CUSTOMER REQUIREMENTS AND ENGINEERING SPECIFICATIONS

The customer wants a motion base platform for the driver's seat so that physical motion and feedback can be generated for the user. We took the customer's requirements and translated them into engineering targets by transforming them into quantifiable factors. All of the customer's requirements were taken into consideration and were matched to the defined engineering targets for rating purposes.

The goal of the prototype is to minimize motion sickness and in order to translate this to an engineering quantification the team looked at quantifiable ways to fulfill this requirement. It was decided that the response time of user inputs from the simulator relayed to the prototype had to be about 17 milliseconds to alleviate the motion sickness. Another key customer requirement was regarding the safety of the user. This was translated to engineering targets by looking at the fatigue lifetime of the parts used and its ability to support an average person (100 kg). Table 1 below identifies some of the initial key customer requirements.

Table 1: Key engineering targets

Parameter	Quantity
Maximum Static Load	1600 N
Response Time	17 ms
Degrees of Freedom	2-3
Number of Actuator	3
Cost of Manufacturing	<$400
Pitch Angle	Max ±13 degrees
Roll Angle	Max ±13 degrees

Since the customer wants to conserve financial resources by not purchasing a next generation driving simulator, competitive comparison to similar products is not applicable. The prototype is designed to sustain a load of the car seat and an average person (1600 N) similar to the Vision Light simulator seen in Information Sources. However, due to the budget constraints the prototype will not be using actuators of the same quality and cost as Vision Light. Due to the lower quality of actuators used, the pitch/roll angles and acceleration of the prototype are not comparable to other simulators.

The QFD (Appendix A) shows the customer requirements and engineering specifications. Each item in the customer requirements and engineering specifications are compared and assigned a relationship level based on the relationship table on the QFD. Some of the requirements will have no connection to each other and thus will be assigned a relationship level of 1. Each of the customer requirements is also given a rank of importance with 1 being the most important and 0 being the least. After each requirement and specification is compared, each column of the engineering specifications multiplies the relationship level with the rank and sums all the values up.

The QFD diagram shows that safety of the driver is of utmost importance for the prototype as requested by the sponsor. The cost of the overall prototype ranks second, which is followed closely by the prototype's minimization of motion sickness. These three specifications match closely with the customer's top requirements.

CONCEPT GENERATION

During brainstorming, the team thought of the possible ways of installing actuators to the car seat and platform. All the concepts generated used the car seat package provided by UMTRI. The package consists of a car seat with its metal seat track attached, which in turn is attached to a wooden platform. Concepts were then developed regardless of costs and feasibility during this stage of brainstorming. One design involved the actuators being attached to an overhead platform, such as the ceiling. Another design involved the car seat and platform to be mounted on a central spring. Underneath to the four sides of the seat platform via metal connectors would be a stepper motor. The desired movement would be controlled by each stepper motor. Yet another design involves the use of magnetic forces. The basic concept of this idea was actually proposed by Professor Kazuhiro Saitou. His insight was to use a semi-fixed flexible base to help actuate the movement.

Cost and Feasibility Factors

The most important design driver when selecting concepts was the cost. This dictated the selection of our critical parts and design decisions. The customer wants movement components that will not pollute the simulator room. Therefore, we decided not to use hydraulic actuators because of the customer's fear that leakage might occur on the carpet of the simulator room. Pneumatic actuators could not be used because a compressor would need to be purchased, thus exceeding our already limited budget even further. Also, the air inside the actuators will condense, making water leakage probable. This resulted in having the majority of concepts use electric actuators.

At the next stage, we had to decide on the feasibility of the designs. The concept with the actuators attached to the ceiling would not work because the motion base has to be portable and scaled. Such design would be difficult to scale to a full-size cab because the strength of the actuators to suspend an entire cab in the air would be too great. Also, the actuators would always have to be extended, meaning not at the standard stroke length because of pitch and roll movements. The stepper motor concept would require more part connections than using electrical linear actuators. Five main concepts were narrowed down and discussed in detail. These concepts can be seen in the Appendix E.

Concepts Brainstormed

Concept A involves the use of 3 linear electric actuators, attached underneath the wooden platform of the car seat. The actuators would be arranged in a triangular layout, with two actuators located toward the rear of platform, and one toward the front of the platform. The actuators would be attached to a ground based platform, with three slots for the actuators. There would be slots on the side of the ground base for the connection of wires from the actuators to the microcontroller.

Concept B makes use of 6 actuators. Each actuator is group in pairs, with each pair arranged in a triangular format. One pair will be on toward the front of the platform, with the other two pairs toward the rear. The actuators themselves will not be perpendicular to the seat platform, but rather angled inwards. Each pair of actuators will be attached to individual metal plates on the ground.

Concept C consists of 8 actuators, with 4 on each side of the chair. However, only 4 total actuators touch the ground base. The ground base consists of two long pieces of metal, resembling snow skis. The actuators are joined by ball screws in connection with each other. The actuators that touch the ground base are on a joint that can slide backward and forward along the ground base.

Concept D, nicknamed “Barber’s Chair”, has one main support in the center of the platform, much like a barber shop chair. The support is divided into the parts, connected by a bearing. This allows the seat to gyrate on it. Actuators are connected perpendicularly to both the seat platform and the ground base at a triangular format.

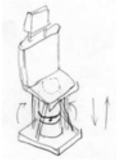
Concept E resembles two platforms connected together by four actuators perpendicularly at each corner. It is a similar design to Concept A, but will require less programming onto the actuators. However, it will be more expensive and will have more limited degrees of freedom.

We would like to note that on October 3, 2006, the team spoke with Professor Dan Ferris of Kinesiology and Biomedical Engineering department regarding his knowledge of actuators. At this meeting, we came up with a concept that would be more feasible for our budget. This concept involves the use of springs and bearings. Underneath the seating platform would be four springs, one at each corner of the platform. A cylinder with bearings on both top and bottom would be constructed and placed underneath the platform. Two motors, one in each axial direction, would be connected to the cylinder. The motors would move the cylinder in the right direction to provide pitch and roll movements. For example, if rolling to the left is desired, then the cylinder will move to the right side of the platform. This concept uses less powerful motors because the springs would provide some support for the load. The downside to this idea could be the response time. It may take longer for the platform to be in the desired position. A concept and CAD model of Professor Ferris’s idea can be viewed in Appendix G (concept J) and Appendix I respectively.

CONCEPT SELECTION

All the various concepts created were analyzed for their respective satisfaction of customer requirements. A fast chart and the morphological method were used to think of possible way to build the prototype, as shown in Appendix C and Appendix D. The top 5 concepts were then chosen and analyzed further. To help with the selection process, a Pugh chart was created for the top 5 concepts, as shown in Table 2 on the next page.

Table 2: Pugh chart of top 5 concepts selected

					
Customer Requirements	**Concept A (Datum)**	**Concept B**	**Concept C**	**Concept D**	**Concept E**
Safety	S	S	S	+	S
Inexpensive	S	-	-	-	-
Range of Motion	S	+	-	S	S
Ease of Scaling	S	S	S	S	S
DOF	S	+	-	S	-
Durable	S	S	S	S	S
Reliable	S	-	-	S	S
Portability	S	S	S	-	S
∑+	0	2	0	1	0
∑-	0	2	4	2	2
∑	0	4	4	5	6

After compiling the Pugh chart, it was decided that Concept A was chosen as the datum. Concept B which provides safety, ease of scaling, durability, and portability rivals that of Concept A. It also provided more degrees of freedom since it uses 6 actuators. This also provides a wider range of motion due to its additional 3 actuators. However, given the limited budget, 3 extra actuators are not affordable. Also, 3 extra actuators will increase the complexity of the design which increases the probability of failure in the design. This will render the reliability issue.

Concept C was the same as Concept A in terms of safety, ease of scaling, durability, and portability. But given the complicated movement design, the number and quality of parts needed to be purchased is too expensive. The range of motion is less than that of Concept A with this design. The degrees of motion are considerably less, with no roll movement possible. Again, with the complicated movement design, reliability is a major concern and inferior to Concept A.

Concept D has the potential to be safer than Concept A. It has a main column in the middle for weight support. But this column will be bulky and heavy, resulting in poor portability. Also, there is the additional cost of the main support column. Maintenance of the bearing in the column would be difficult, too.

Concept E is more expensive than Concept A because of the additional actuator. Cost is a major determining factor.

Given the customer's requirements, with cost being one of the single biggest factors, Concept A is the feasible concept to build upon. In terms of additional safety assurance, Concept D is better. However, this does not mean Concept A is unsafe. A hexapod might be built to provide additional support for Concept A. Its range of motion and degrees of freedom is less than that of Concept B, but our sponsor only required limited roll and pitch movements, and Concept A should provide those desired movements. Another idea that we came up with while meeting with Prof. Dan Ferris of Kinesiology Department can be shown in Appendix I and discussed further in Appendix N

FIRST SELECTED CONCEPT DESCRIPTION

Based on the Pugh chart, concept A appears to be the most suitable and appropriate design. However, this is likely to change due to the high cost of the actuators used in the design. Figure 2 below is a 3D model of our first design. CAD models of the first selected design can be also seen in Appendix H.

Figure 2: 3D view of Alpha design

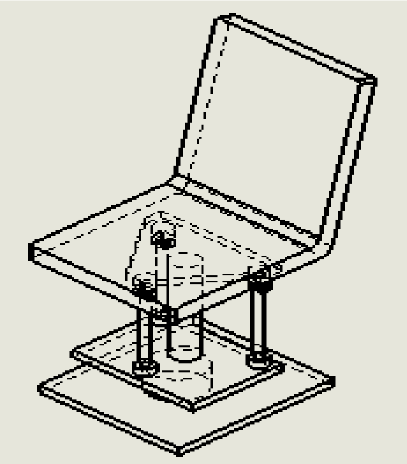


Figure 3: Bottom view of Alpha design

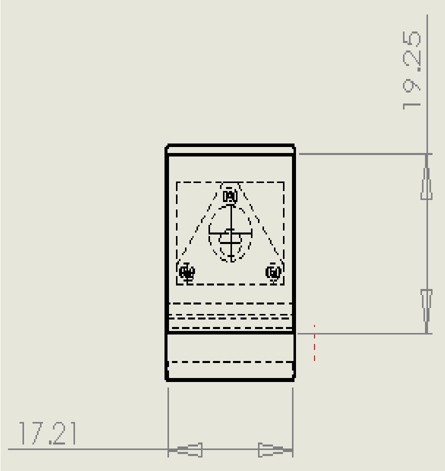


Figure 3 above shows the bottom view of our Alpha design. Notice the use of three actuators arranged in a triangular layout. The width and length of the ground base and seat platform are the same at approximately 17.21 and 19.25 inches, respectively. The standard length of the actuator is 9.50 inches, as shown.

Figure 4: Side view of Alpha design

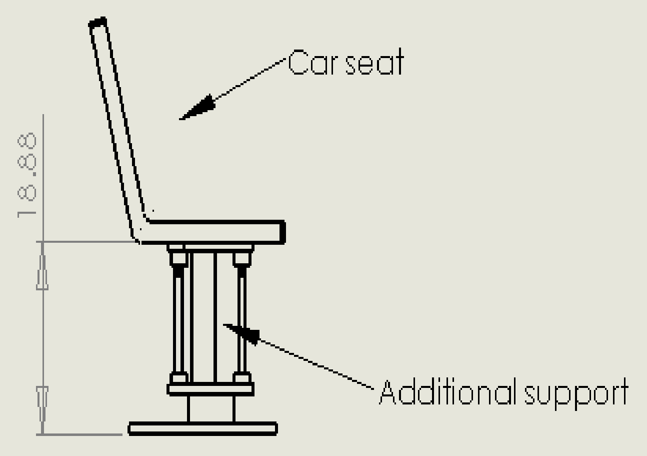
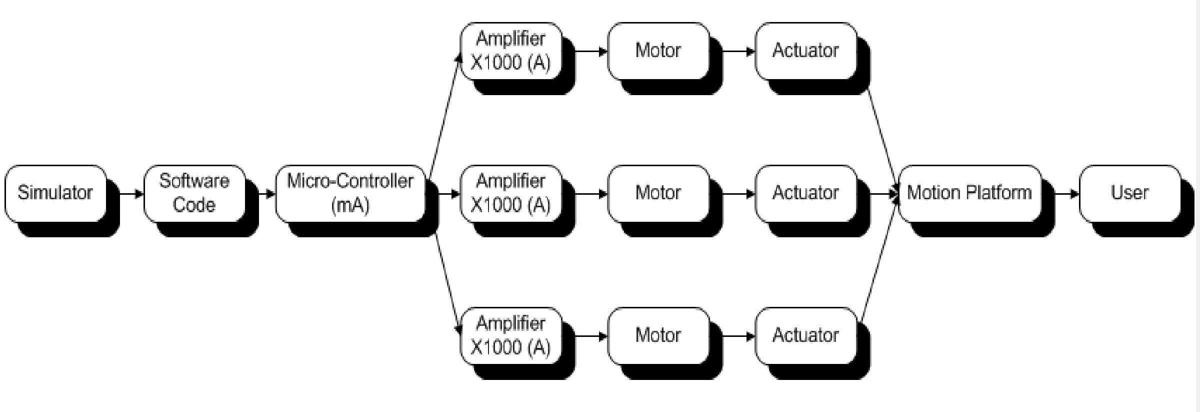


Figure 4 on the previous page shows the side view of the Alpha design. Notice there is an additional support between the actuator. This support will help take the load of the person off the actuators to pro-long the actuator duty cycle. The actual connection between the additional support and the seat platform is a spring and a ball screw joint. Therefore, it will not restrict the intended movement of the motion base. There is also another support toward the ground. This is mainly for user's comfort during use.

First Design Specifications

The team's first concept design uses three electric actuators that will cost approximately $150 each. The current actuators being considered for the design is the Linak LA12. Static stress analysis was done to ensure that the Linak LA12 will fulfill the required forces of 500 Newton needed for movement. No hydraulics actuators are considered because they would cost more and would not meet the response time requirements. A brief graphical description of the system layout of the prototype is shown in Figure 5 below.

Figure 5: Projected system layout of first design



This design will require the use of a micro-controller along with amplifiers to accurately control the movement of the actuators. In this design, the team would most likely use the Cerebot micro-controller developed by Digilent Technologies. The Cerebot can control all three actuators and allow additional amplifiers needed for the design.

The use of amplifiers are needed because the Cerebot can only deal in milliamps (mA) but the Linak LA12 actuators require current in the ampere range. Therefore, three additional amplifiers are needed for the design which will add considerably to the cost. The method of controlling the seat will be an open-loop control which provides no feed back. The seat will be given a calibrated amount of force (weight of the user) only based on the simulation scenario. Closed-loop control which is more stable and desirable will be implemented in the next generation development.

The overall projected cost of this design was estimated to be approximately $2,711 which is almost eight times the allotted budget of $400.

PROTOTYPE DESCRIPTION

The final design is similar to the first selected design. However, upon discussion with the sponsor, the final product will be scaled down. This was done primarily for cost purposes. Since the final product will be scaled down, instead of manufacturing a scaled down chair, a model vehicle will be used. This representation will be more realistic to the eventual goal of the sponsor, which is scaling the prototype to the full size cab simulator. A layout drawing showing how the subsystems of the prototype interact with the simulator can be seen in Figure 6 below.

Figure 6: System layout of prototype

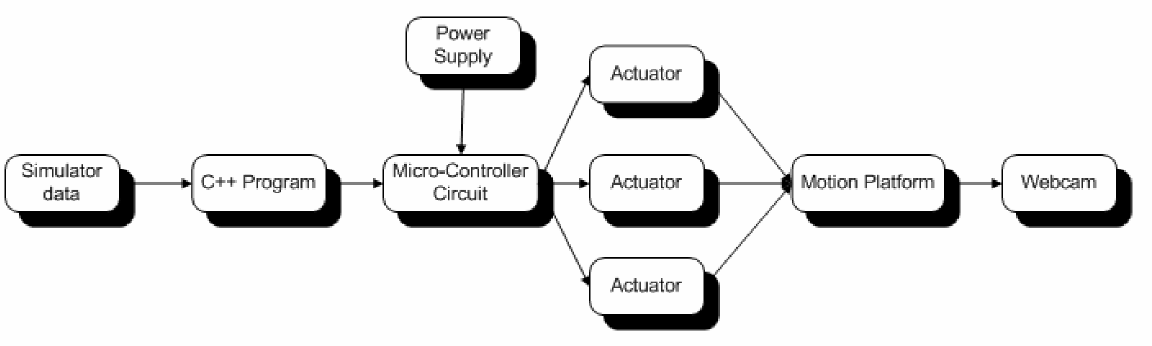
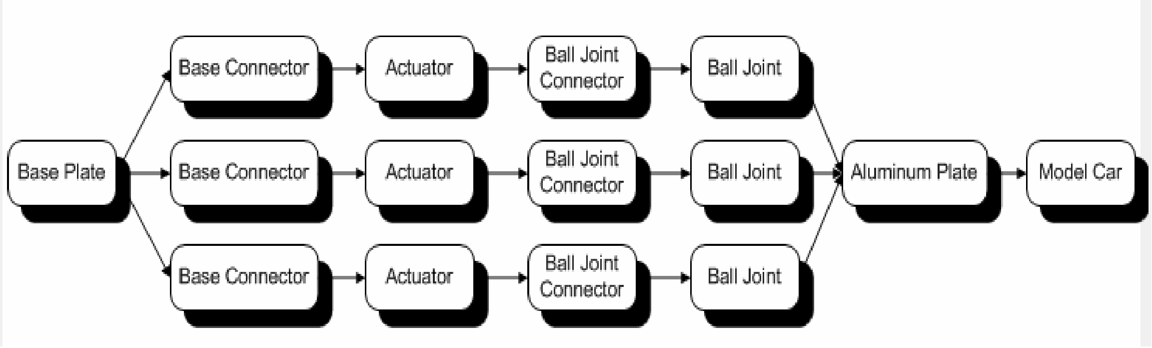


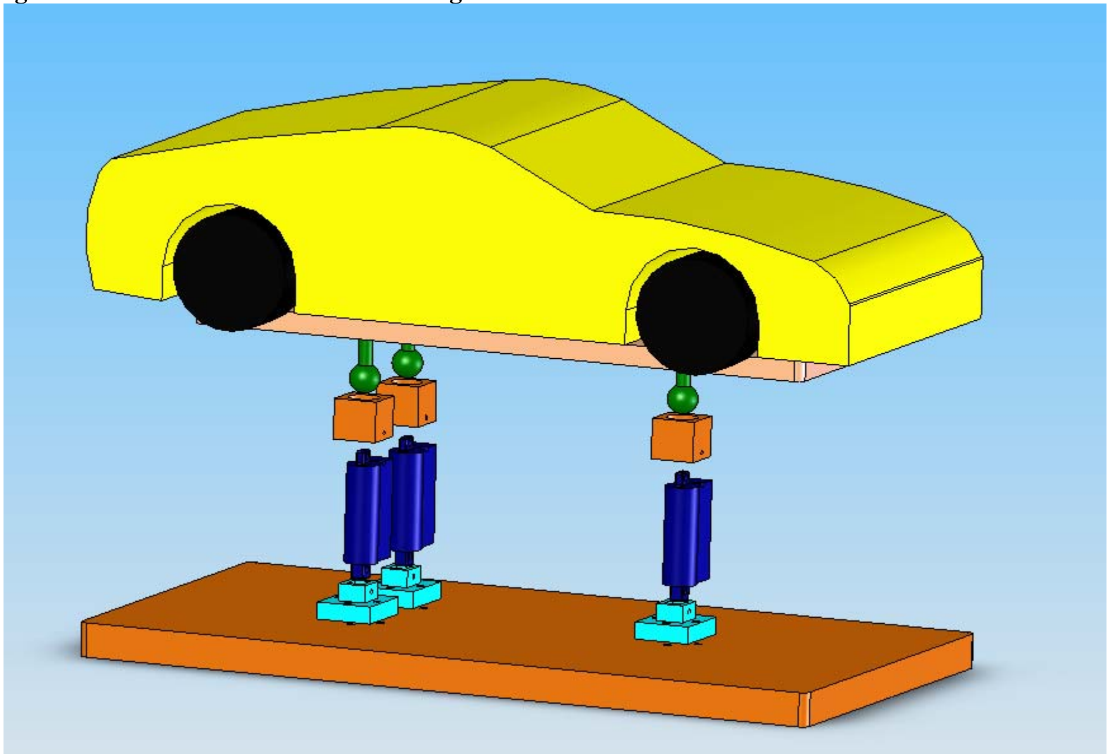
Figure 7 below depicts the subsystem layout of the mechanical connections that will be used for assembling the prototype together.

Figure 7: Mechanical connection layout of prototype



From the drafted system layout above, a CAD drawing of the final design was drawn up using Solidworks. An isometric view of the final design can be seen in Figure 8 on the next page. Further dimensional drawings of the final design can be viewed in the Appendix.

Figure 8: Isometric view of the final design



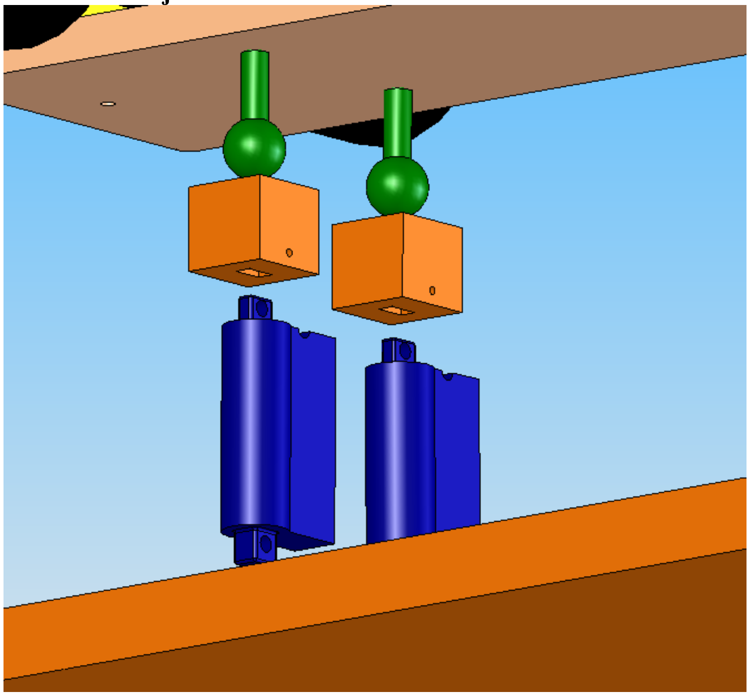
*Note the actuators, base connector, and ground base are not connected for ease of viewing

Prototype Parts and Connections

Supporting and moving the model car are three Firgelli PQ-12s micro linear actuators. Underneath the model, a thin aluminum plate was attached to base. This will provide a strong but light surface for actuator attachment instead of the original plastic material of the model. Unnecessary parts, such as the electric motor, were removed from the model to reduce weight.

Connected to the bottom of the aluminum plate are ball joints. The ball joints are housed in ball joint connectors. On the other end of the connectors are machined slots specifically fit the miniature actuators. This is seen in Figure 9 below. The actuators are fixed to the ground base and will be kept in place by ground base connectors. Individual parts of the prototype along with their respective dimensions can be viewed in Appendix L.

Figure 9: Connections between aluminum plate, ball joints, ball joint connectors and actuators



As the model car moves into the desired position, the ball joints will rotate around in the ball joint connectors, while the connection between the ball joints and the aluminum plate will remain fixed. The pitch and roll motions will need to be limited so the model car will not tip the ball joint out of the connector.

Prototype Electronics

The movement of the car model will be based on the data input from the computer. The prescribed data provides information such as the velocity, acceleration, pitch angles, and roll angles. The data and calculations will be accomplished in the computer. The data output will then be transfer to the micro-controller, which will convert the data into digital signals. These signal instructions will be transferred to the actuators. All connections will be made via the appropriate cables. A software program was created to relate the data to the movement of the actuators. The programming of the software is critical in calculating the data into actuator displacement. Based on the data points, the program must input the appropriate voltage and current to the actuators so that it can displace the correct stroke length to provide the accurate movement of the model.

Purpose of Prototype

The purpose of the prototype is to demonstrate a system that can be incorporated in the full size driving simulator at UMTRI. It was built at a scaled down model due to limiting budget but still provide the basic principles needed. The prototype also demonstrates the ease of scaling directly from the prototype itself since the model car can represent the actual simulator cab. Of course, part selection and static and dynamic analysis will be different for the full size cab since weight, size, and power consumption will differ significantly.

A Bill of Materials listing all the components required for production of the prototype can be seen in Table 3 below.

Table 3: Bill of materials for scaled model

Part(s)	Manufacturer	Part Number	Cost	Quantity	Final Cost
Model Car	Nikko	350z	$19.99	1	$21.19
Micro Actuators	Firgelli Technologies	PQ-12s	$65.00	3	$214.63
Aluminum Plate	UMTRI	Scrap	$0.00	1	$0.00
Aluminum Platform	UMTRI	Scrap	$0.00	1	$0.00
Micro Controller	Atmel	ATmega168	Sample	1	$0.00
w/ Power Supply	Radioshack	n/a	$25.00	1	$26.50
Web Camera	Dynex	DX-DTCAM	$19.99	1	$21.19
Unexpected/Misc. Cost	n/a	n/a	$5.00		$50.00
Total			$178.99	9	$333.51

ENGINEERING DESIGN PARAMETER ANALYSIS

The final prototype implements the concepts of three actuators in the first selected design to a scaled down car model of the car simulator cab. Engineering design analysis such as control modeling, failure/safety, dynamic and static analysis has been completed on the prototype and is discussed below.

Design for Manufacturability

Deciding the degree of miniaturization of the prototype to the actual cab was down to researching the current market for miniature actuators. Once the actuators were chosen, the team was able to calculate the relative size and weight for the car model. Calculations were completed and the overall scale for the model car to the full size cab was found to be on average 1:14 as seen in Table 4 below.

Table 4: Scaling from full size simulator to miniaturized prototype

	Length (inch)	Width (inch)
Full Size Cab	165	65
Model Car	11	5
Scale (Model Car : Full Size)	1:15	1:13

Placement of the Actuators

Pitch and roll angles were determined by the placement of the three actuators located under the aluminum plate. As actuators are placed closer together, larger pitch and roll angles are achievable. However, as actuators are placed closer, bigger thrust forces are required of the actuators and also increases the likely-hood of collision between the actuators. Lastly, appropriately spaced apart actuators will allow easier access for maintenance issues.

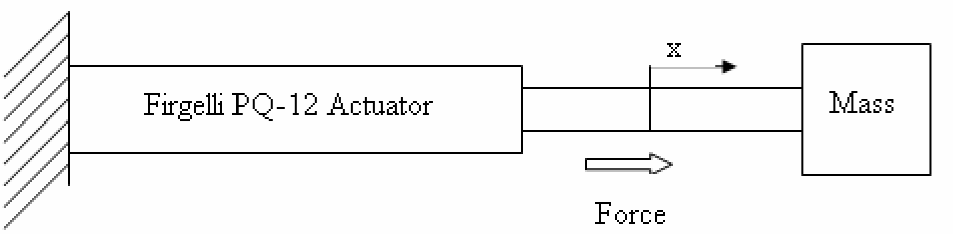
Simultaneous Data Combination

The roll, pitch and vertical movement data will be provided from the driving simulator program. Due to their small magnitude, we will exaggerate these motions on the platform. The prescribed limit of roll and pitch angle are set to be ±13˚ and ±10˚, respectively. The data will be translated into the real stroke of the actuators by using a simple tangent function since the distances between actuators are known. Considering the possibility of simultaneous roll and pitch motions, we have done our analysis on how much stroke the actuator should provide to simulate the movement. It turns out that the stroke has to be the maximum displacement of the actuator given these two different conditions.

Control Modeling Analysis

The miniature actuators that we ordered have a position sensor feedback that will give any displacement that we want regardless of the load that it carries. Therefore, there is no need for another controller. The objective of the following analysis is to provide a guideline for the scaled-up prototype which will be built in the future by UMTRI.

Figure 10: Force analysis of actuator to load mass



For simplification, the control modeling analysis was done only on the pitch situation of the motion because it only involves essentially two actuators at the same time (the rear actuators behave in the same manner). Based on Figure 10 above, the equations of motion were deduced. Essentially the actuator will be controlled by a current (u), which is the input. The actuator has a force-speed and force-current curve of which we can find out the constants (k_0 and b) that will govern the equation of motion.

$$F = k_0 u - b\dot{x} \qquad \textbf{Eq.1}$$

$$M\ddot{x} + b\dot{x} = k_0 u \qquad \textbf{Eq.2}$$

$$\frac{X(s)}{U(s)} = \frac{k_0}{Ms^2 + bs} \qquad \textbf{Eq.3}$$

Based on the second equation, a transfer function can be formulated. Hence, we can apply a controller and expect the desired frequency and settling time. Also, we can control the system such that it is stable in steady state.

The stroke extension length of the actuators will be based on two angles: the pitch angle, α, and the roll angle, β. For pure pitch, the movement of the actuators is apparent, with either both the rear actuators moving or the single front actuator moving. For pure roll movement, one of the rear actuator, depending on the desired roll, will have an extension stroke that's twice as long as the front actuator because of the distance from the center of the car model.

Static Analysis

Static loads were calculated by simple analysis. All the weight forces were summed up and equal to be zero ($\Sigma F = 0$). Then a static force an actuator had to hold was calculated and came out to be 3.26 ± 0.05 (N).

Dynamic Analysis

Since the project has been scaled, the engineering decisions have been slightly altered. The car model was chosen because it was one of the lightest available for purchase. The use of aluminum as the base material between the model and the actuators was due to its light-weight characteristic and adequate strength. The selection of Firgelli PQ-12s miniature actuators was done after careful stress analysis. It was calculated and found that the PQ-12 model actuators would provide the necessary force to position the model car at desired positions. The weight of the car and aluminum, along with the available power and speed of the actuators were factors used in the analysis. The governing equations for this analysis are shown in equations 1, 2, and 3 along with their parameters in appendix J.

A summary of the calculated dynamic thrust forces can be seen in Table 5 below.

Table 5: Summary of dynamic thrust forces

	Units	Max Pitch Thrust	Max Roll Thrust
Max. Front Thrust Force	Newton	4.62	5.45
Max. Rear Thrust Force	Newton	4.62	6.69
Max. Front Angular Vel.	Rad/sec	0.238	0.311
Max. Rear Angular Vel.	Rad/sec	0.238	0.311
Max. Front Angular Accel.	Rad/sec^2	25.93	67.89
Max. Rear Angular Accel.	Rad/sec^2	25.93	33.95
Max. Front Power	Watts	0.125	0.181
Max. Rear Power	Watts	0.125	0.147

To calculate thrust force of the actuator for each pitch angle, the velocity, acceleration, and Euler's equations were used with respect to the cylindrical coordinate as shown in Figure 11 in the next page. Acceleration was set to be 0.3g and velocity was varied from 1 mm/s to 27 mm/s, which was the maximum velocity of the actuator. Then, angular velocity and angular acceleration could be calculated with respect to each velocity by using Eq.4 and Eq. 5 (both are stated in appendix J). By substituting the calculated angular acceleration into the Euler's equation which is Eq.8 (in appendix J), the corresponding thrust force was then calculated.

To calculate thrust forces of the actuator for each roll angle, the same approach was used as pitch angle described above as shown in Figure 12 on page 16. However, the thrust forces for the front actuator and one of the rear actuators were calculated separately because angular velocity of the front actuator was half of that of the rear actuator. These different angular velocities would affect the angular accelerations for the front and rear actuators, so that different thrust forces were needed for front and one of the rear actuators.

To calculate thrust forces of the actuators for the combination of pitch and roll angle, the corresponding thrust forces for the pitch and roll angles were superimposed to create the desired movement. The moment of inertia of the car was assumed to be that of rectangular box and was calculated using parallel theorem. The maximum power needed to be supplied by a Firgelli PQ-12s miniature actuator for each velocity was calculated by multiplying the velocity by the corresponding thrust force.

$$V = r\dot{\theta} \qquad \textbf{Eq.4}$$

$$a^2 = (-r\dot{\theta}^2)^2 + (r\ddot{\theta})^2 \qquad \textbf{Eq.5}$$

$$(F \times d) - (m \times g \times l) = I \times \ddot{\theta} \qquad \textbf{Eq.6}$$

Figure 11: Dynamic analysis for pitch movement

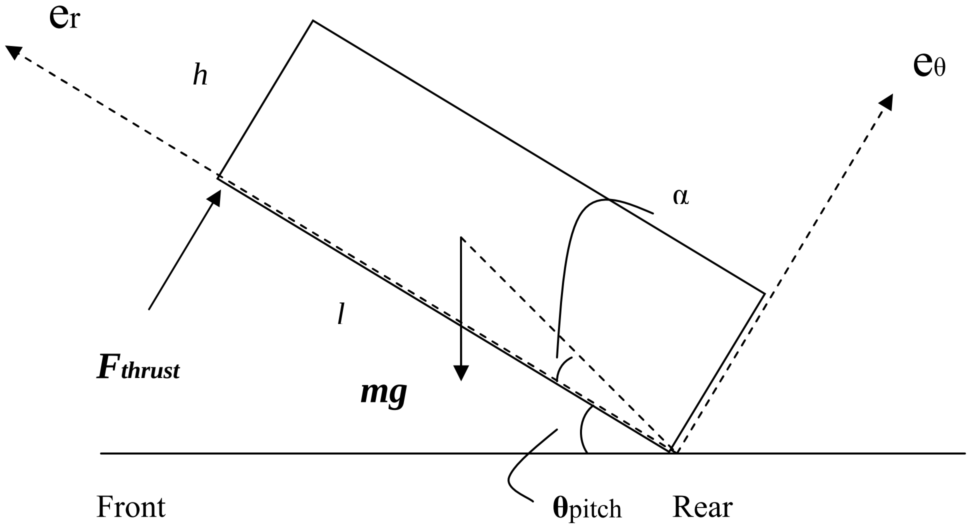
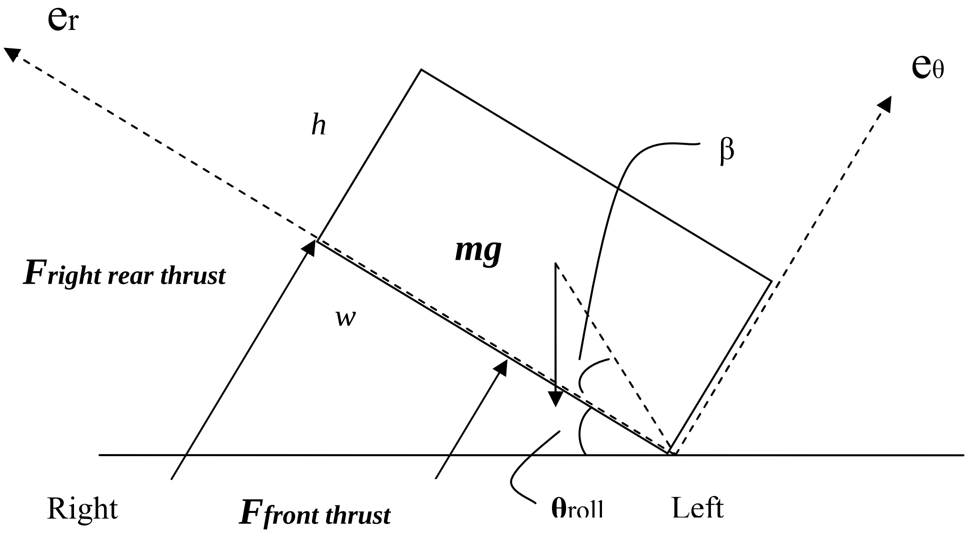


Figure 12: Dynamic analysis of roll movements



Failure/Safety Issues

The static and dynamic analysis has verified mathematically that the Firgelli actuators are capable of supplying the required dynamic and static thrust forces on the model car. All our calculations were carried out with a safety factor of 2.0. A summary of the forces can be seen in Table 5 below.

Table 5: Summary of forces

	Forces (Newton)
Max. Actuator Thrust	7
Max. Static Load	3.26
Max. Dynamic Load	6.69

In terms of the lifetime of the prototype parts, all the connectors and base plates are machined out of aluminum. The aluminum connectors and plates should pose no issues in terms of failure because of aluminum's long lifetime. The Firgelli actuators are ball screw and have a lifetime of over 100,000 cycles. The one area of concern is the low duty cycle of 20%. The actuators need to be cooled down periodically to prevent overheating of the actuator motor.

The ball joints connecting the actuators to the model car are not enclosed which could cause the car to tip over if the pitch and roll angles are sufficiently large. However, the prototype has been tested and limits have been placed on the pitch and roll angles to prevent this problem. The max pitch angle of 10 degrees and max roll angle of 13 degrees have been repeatedly tested and the prototype functions safely.

Failure Modes and Effects Analysis (FMEA)

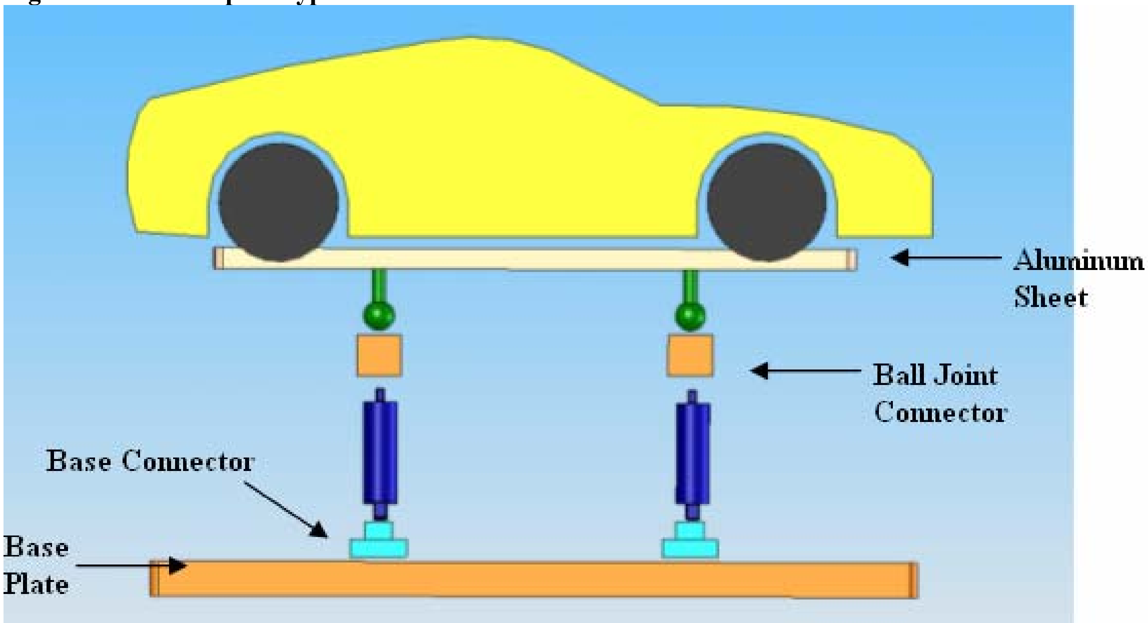
The FMEA in Appendix K breaks down the subsystem components and analyzes the possible failure mode of the prototype. The most potential and the greatest concern are the actuators. The other subsystems have a minimal chance of failure. Most of them will be a result of wear and tear, but the operations the prototype will endure should delay those failures for a very long time.

The severity of the potential effect of possible failures to the customers was rated from 1 to 10, with 10 being the most severe. The potential causes of failures were identified, and the chances of such occurrences were also rated from 1 to 10. Tests were developed for detecting each failure before product is released to production. The likely hood of detection was also rated for each component, with 1 being almost certainly detected and 10 being almost certainly undetected. Finally, there are recommended actions that will reduce failure possibilities, and a new Risk Priority Number (RPN) can then be estimated.

MANUFACTURING PLAN

The final concept design will mainly consist of one remote control car model, three linear miniature actuators, two aluminum plates at which the actuators will be mounted and small parts such as joints to accommodate the connection of each components. Since we are carrying out our design in 1:16 scale, we will spend most of the time assembling all the components into one complete system. Figure 13 below identifies all the parts of the prototype that requires manufacturing.

Figure 13: Parts of prototype that were machined



Aluminum Sheet

Stock of aluminum sheet with 0.52” of thickness has been provided by UMTRI. The car model has several threaded holes that can be used to connect the car to the aluminum sheet. The aluminum sheet will be placed at the bottom of the car model right in between the wheels. For the manufacturing process, the aluminum will be clamped on top of a scrap material on a CNC milling table. A milling tool with diameter of 1/8th will complete the process in a minimum time. Before milling the rectangular shape, two holes need to be drilled in the right position to ensure the accuracy of the holes with tight tolerances. A drill with diameter of 0.1040” will be used. (Spindle speed of 1500 RPM with feed rate of 2.5 inches per minute should suffice the process). The holes will be made as clearance without any threads. More holes will be provided to connect the joints of actuators to the aluminum sheet. Four filets will be applied to all edges to avoid possible injuries to user. The most crucial manufacturing phase for this process is when we are milling out the rectangular shape from the stock. The plan is to mill around the rectangular shape with small increments so the whole plate will pop out automatically once the tool reaches the thickness of the stock. Once this happened, the feed rate has to be turned off and all processes have to be stopped.

Base Plate

We used scrap aluminum with approximately 0.4” of thickness for the base of the system. The manufacturing for this component will mainly be sizing it to the appropriate dimension and putting non-sharp edges to avoid unwanted injuries to user. Some holes are necessary to connect the L brackets to the bottom of the actuator.

Ball Joint Connector

After attempting to look for the appropriate component to connect the ball joint to the joint from the actuator (yoke), we decided to custom made the component itself. The concept of this component is very simple which is essentially making a cylinder (mimicking a half sphere with diameter of 0.44”) in a cube. This sphere will act as a socket for the ball joint. At the bottom of the cube will be a hollowed cylinder that will connect to the head of the yoke. This material will be made out of aluminum. The manufacturing process will start by creating a circular pocket in the center of the square with certain a depth of 0.24” as measured by taking half of the diameter of the ball. Then we can continue the process by making a rectangular frame outside the hole with the total thickness of material as total depth. To make the hollowed cylinder at the other side of the component, we have to flip the component itself and do a separate process which is a circular frame milling with a diameter of 0.15”. All the required processes are built in programs on a regular CNC milling machine. A ¼” end mill should be able to finish the process nicely with spindle speed of 1300 RPM and feed rate of 2.5 inches per minute.

Base Connector

L-brackets were considered when we were figuring out how to connect the other end of the actuator to the base plate. Since the actuator only has a hole that orients in one direction, we would need four L brackets for each actuator. However, considering the limited usable space between actuators and also to simplify the connection, we decided to custom make the component itself. Essentially the component will have a pocket where the end of the actuator will sit on. The base connector has a hole that will connect to the actuator rigidly. Finally, two 6-32 holes will fix the base connector to the base plate. The manufacturing can be carried out on CNC milling machine using the appropriate drills (6-32 for the two holes and 3 mm drill for actuator-connector hole).

Manufacturing was planned out so that it was relatively easy to carry out and modified. Due to their simple shape and decent size, there is no foreseeable problem on machining the components.

After all the manufacturing was completed, we began with the assembly process. First, we will connect the aluminum sheet to the car. Then with appropriate joints, the actuators will be connected to the aluminum sheet. At the other end, the actuators will be connected to the base using base connector.

DFMA Application

For some of our components, we applied the Design For Manufacturing and Assembly approach to make our manufacturing/machining and assembly process simpler and faster. This will minimize our design and manufacturing so we can spend more time on integrating the electronics to the system. The following are five DFMA approaches that were applied to our components.

1. Design for Assembly Guidelines 1 – Minimize Part Counts
   Initially, we planned to use four L-brackets in order to fix or connect each actuator to the base plate. Since this will be very cumbersome given our constraints, we decided to custom make our base connector as explained in the initial manufacturing plan. Not only will this approach minimize our part counts, but also will add aesthetic and simplicity to the whole system.

2. Design for Assembly Guidelines 3 – Permits Assembly In Open Space
   This approach also applies for the base connector. The height difference between the slot and the hole's surface allows the assembler to tighten or loosen the screw without interfering with the actuator.

3. Design for Part Insertion 2 – Add Alignment Feature
   The components, ball joint connector and base connector, provide this feature. On the ball joint connector, the top part resembles a hollowed cylinder extension to help align the part and the bottom was machined specifically to fit with the actuators. The slot on the base connector will help house the bottom part of the actuator and make sure it is fixed.

4. Avoid Sharp Corners
   Most of the components are designed with filleted corners. This is required to avoid possible injuries to user. The aluminum plate and the base plate are the components that have this benefit.

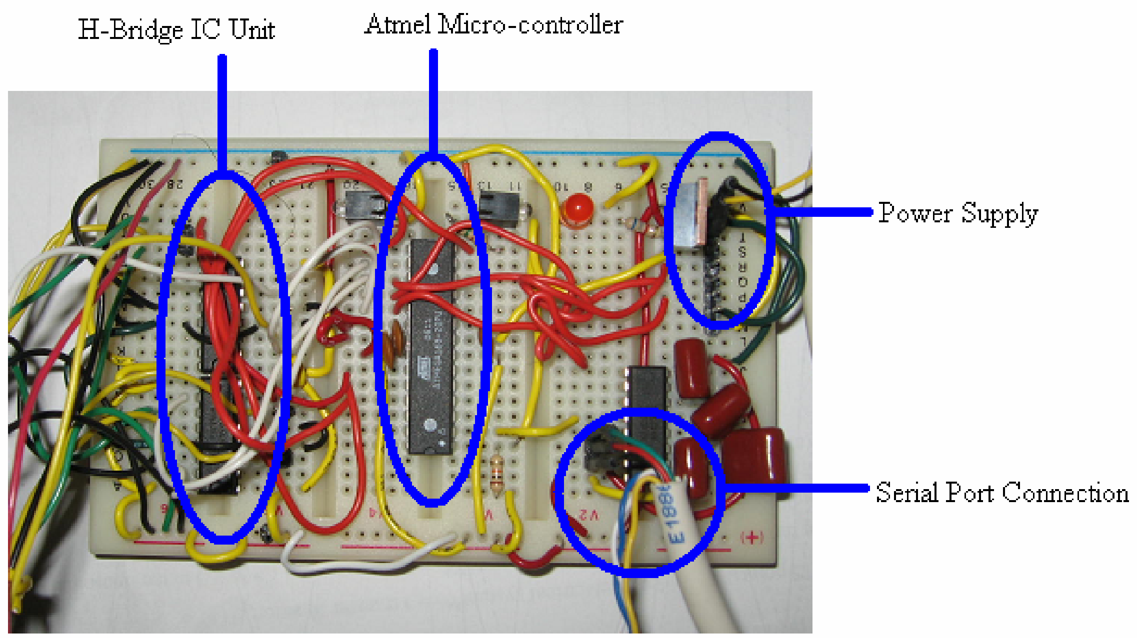
5. Design for Machining Guidelines – Use Standard Dimensions
   Some parameter of the components that are custom made and not dependent on the dimension of the actuator are designed using standard dimension. For example, the holes that connect the base connector to the base plate are using 6-32 thread and 0.1065" (drill no. 36) that is a standard hole to comply the tap. Also,

we ensured that other additional holes on other components are using common size or metric drills.

ELECTRONIC CONNECTIONS

Electronic hardware components are needed to communicate between the driving simulator and the actuator. The hardware consists of serial port, microcontroller chip, and H-bridge Integrated Controller (IC). Instead of using a printed circuit board (PCB), all the hardware was connected on a piece of breadboard to avoid too much soldering and complexity. Figure 14 below shows the PCB circuit used for the prototype.

Figure 14: PCB circuit for prototype



Serial Port (RS-232)

The simulator software is based on a Macintosh platform; hence a dummy PC (Windows based) is needed to be the medium between the simulator and the actuator. In the long term, a translation program will be created so that the dummy PC will be able to communicate between the Macintosh and the actuators. However, for our project, we worked with prescribed roll, pitch, and vertical data from previous testing sample to test whether the program and the electronics are actually integrated well. The data is saved in delimited format and the C++ program will read this data and compile it into output signals to the microcontroller. Here is where the serial port comes into help. It essentially is the communication port between the PC to the microcontroller. Several capacitors are needed to integrate the serial port into the breadboard.

Microcontroller Chip

The chip receives and interprets the signals from the serial port and translates it into actuators' stroke. The chip used for this project is Atmega 168 by Atmel Corporation. This chip has 16 Kbyte of memory which is sufficient to handle the data input with 20 Hz of data feed. It has a low operating voltage of 1.8-5.5 Volts and can handle 23 programmable Input/Output lines of data.

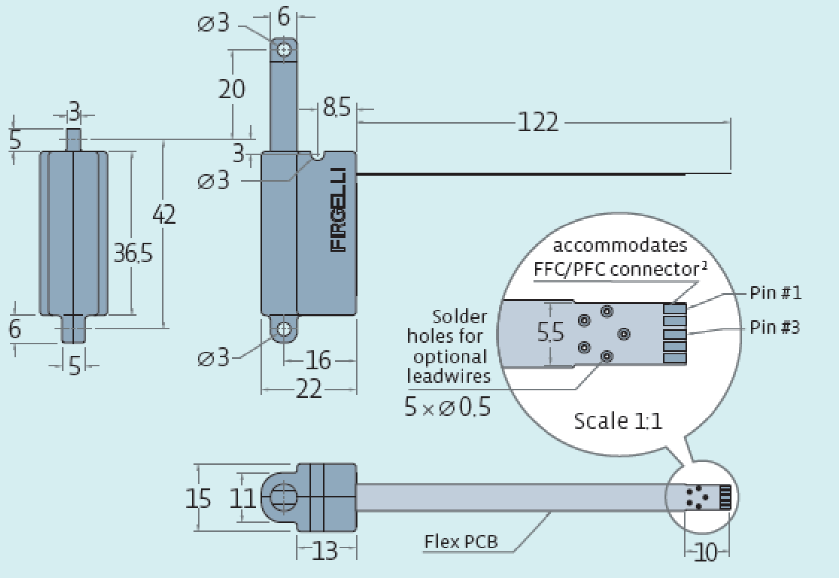
H-bridge IC

Since the actuator works based on the given polarity (±5V), an automatic switch is needed to control the stroke of the actuator. H-bridge IC is the perfect component for this goal. The microcontroller essentially sends a 0 or 1 signal representing the positive and negative polarity, respectively, to the H-bridge. Based on this signals, the H-bridge will automatically switch the way the current will run to retract or extend the actuators' stroke. The 5 actuator's pins are connected to the appropriate H-bridge pin. The H-bridge used in this circuit uses two IC chips that help to switch voltage as required.

Firgelli Actuators

The actuators used for the prototype are manufactured by Firgelli Technologies Inc. The actuators provide a very feasible solution offering flexibility in integrating them into a system with other sensors and controllers. The actuators have a stroke of 20 mm with a rated force of 7 Newton at 13 mm/s. There is a linear motor inside the actuator which requires 5 Vdc to extend and retract the stroke. The benefit of the Firgelli actuators is the built-in potentiometer which provides precise position feedback. Figure 15 below shows the dimensioning of the Firgelli actuators.

Figure 15: Actuator specification



The way how the raw interface works is simple. Two (pin2 and 3) of five leads in total are concerned with providing power to the actuators (5 Volts DC, ground). The moving direction of the actuators can be reversed by reversing the polarity of the power leads. The other three leads are connected to a linear potentiometer within the actuators that behaves as a voltage divider to provide a position feed back signals. Two (pin 1 and 4) of these leads are connected as inputs to the actuators to be provided reference and rail voltages. The other lead (pin 5) is connected to the potentiometer wiper that encodes positions from the actuators' potentiometer, where the position is represented by voltages. The voltage signal is between the two reference voltages and the level of voltage is proportional to the linear position of the actuators.

PROGRAMMING CODE

The programming code used to control the movement of the actuators was written in C++ Microsoft Visual Studio. The basis of the program is used to send data to individual actuators to extend the required distance. The programming code can be seen in Appendix M.

The program works by receiving pitch and roll angles from an external file. This external file is data from an actual simulator test run which contains the angles. The program will read the pitch and roll data iteratively until the end of the data. The angles are placed in arrays as they are read from the external file so they can be used later in the program. Once the pitch and roll angles are placed into arrays, the program enters a loop that reads each angle in the arrays until the array is empty before breaking out of the loop. The program then enters separate functions for analysis of pitch and roll data.

Pitch Function

The pitch function receives the pitch angle along with an actuator index. The actuator index is the numbering system used to classify each actuator. The front actuator is assigned the number 1, while the back left and back right is 2 and 3 respectively. With these two parameters, the function enters if-else statements (comparison statements) to determine how the actuator needs to react to the supplied pitch data. A positive pitch angle is classified as the front of the car tilting upwards and a negative angle as the back of the car tilting upwards.

An example of how the function works is to look at a random angle. If the function receives its two parameters as 5 and 2, it means that the desired angle is 5 degrees and the necessary movement on the 2nd or back left actuator. The function will enter if-else statements to determine which actuator is being analyzed. Once found, another set of if-else statements are triggered to determine whether the actuator should extend or retract to a calculated distance. Because our example is 5 degrees which means the front of the car tilts upwards, the function will determine that the actuator need not move and the distance is set to 0. Once this distance is found, the function will return to the overall program the distance the actuator should move. In our example, the program will return 0.

Roll Function

The roll function works similar to the pitch function. It receives the roll angle along with an actuator index number. The numbering system is the same as the pitch function. Using these two parameters similar if-else (comparison) statements are triggered to find the necessary distance the actuator needs to move. Like the pitch function, the roll function will return to the overall program the distance the actuator should move.

Actuators Communication

A separate function is used to control the movement of the actuators after the actuators are assigned distances to move from the Pitch and Roll functions. This function, named send_serial in the code, requires two parameters to accurately move the actuators. These two parameters being the actuator index number and its respective stroke position. This means that for each pitch/roll angle, three send_serial functions are called, one for each actuator.

TEST RESULTS

During actual testing, the prototype was fed with data saved from a previous simulator run. The data was fed to a computer that runs the C++ programming code which will in turn supply power to the actuators through the circuit board. The prototype processed through the data without any problems. However, because there was no screen to view the actual simulation path it was difficult to determine if motion sickness was eliminated.

In order to validate that the prototype works, the team tested the prototype against the key engineering targets set forth in Table 1 on page 3. Several of the engineering targets set on Table have been modified due to the miniaturization of the prototype. An updated version of some key engineering specifications can be seen in Table 5 below.

Table 5: Updated key engineering targets

Parameter	Quantity
Maximum Static Load	9.8 N
Response Time	17 ms
Degrees of Freedom	2-3
Number of Actuator	3
Cost of Manufacturing	<$400
Pitch Angle	Max ±10 degrees
Roll Angle	Max ±13 degrees
Vertical	Max ±20 mm

Testing for the maximum thrust load required testing each actuator's ability to thrust against the 9.8 Newton vertically. Theoretically, based on the engineering analysis done on the car, the actuators will generally share this maximum load throughout the simulation as discussed in the Parameter Analysis section. The response time of the user inputs from the simulator relayed to the prototype has been measured from 19 KHz data rate which transfers 22 bits for each transfer. From this calculation, the response time was obtained to be 1.1 msec which is sufficiently less compared to the desired target of 17 msec.

The number of actuators and the degrees of freedom targets has already been met due to the prototype design. As for the cost of manufacturing, it is below under $400 according to the cost estimation in the Initial Manufacturing Plan section.

In order to test if the maximum pitch and roll angles can be met, the prototype has to fully extend the strokes of the appropriate actuators to test these angles. If the actuators can fully extend its stroke to the full 20 mm, then based on engineering calculations the pitch and roll angles have been met. The actuators have been tested and can fully extend.

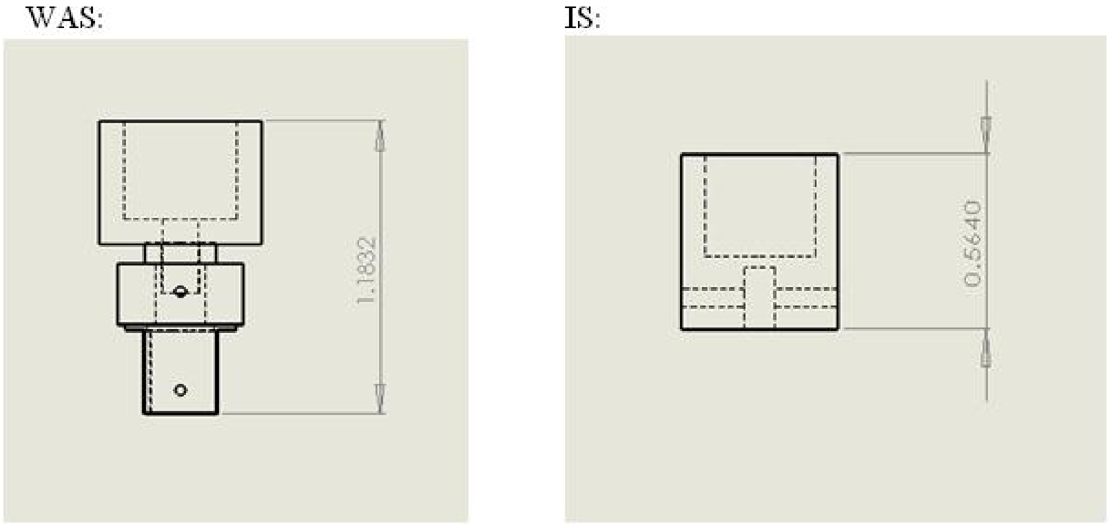
The final testing conducted on the prototype was to feed random values in to the simulator. This will allow us to test if the actuators are able to constantly respond to randomly changing stroke lengths. Also it can help determine if the prototype is durable enough to handle any type of extreme pitch and roll motions.

Ultimately, to test if the prototype fully works is to attach it to the real driving simulator and have the sponsor conduct a test drive. A camera can be placed inside the prototype and projected on a screen to see if motion sickness is eliminated. However, the car simulator was undergoing upgrades so it was not possible to connect the prototype to the actual simulator.

ENGINEERING CHANGES NOTICE (ECN)

One engineering change that occurred between the final design and the actual prototype was the ball joint connector. Previously, the connector consisted of two parts, the yoke and an aluminum socket for the ball joint. This part was redesigned for sturdiness into a single aluminum piece that incorporates both parts. This change allows a shorter manufacturing time and decrease number of mechanical parts. Figure 16 below shows this engineering change.

Figure 16: Engineering change of ball joint connector



Notes:

For robustness, the two combined connectors on the left figure were substituted by the part on the right. This modification leads to short manufacturing time and less mechanical part.

DISCUSSION

Although the prototype functions as expected, there are several weakness and areas that can be improved. The purpose of this prototype is to make it scalable to the full size cab in the future. Therefore, factors that scale the prototype to the full size cab are discussed in this section.

Strengths

The major strength of the prototype is the low cost of manufacturing. The prototype may not be comparable to other commercial simulators in the market but given the budget, it does provide the necessities of pitch, roll, and even vertical motion.

Also, the prototype is designed based on the UMTRI's cab dimension with 1:16 scale. Hence, this will help future team to scale the model up without having to redo the analysis. The current prototype will allow the scaled up designer to modify and test their program before applying it to the real model. Thus, a crash or error in the program will be prevented.

Only three actuators are being used to simulate the pitch, roll, and vertical movements. This is the optimized number of actuators to achieve all movements with limited budget although there may be slight complication on the program. Having one less actuator will save about $1000.00 for a medium performance electric linear actuator.

Weaknesses/Improvements

The most notable weakness is the slower than expected response time. This is due to the quality of the miniature actuators used and not the actual programming code. Using more responsive actuators will meet the sponsors required response time but will also cost more. Selections of the actuators for the full size model are critical to any future success in implementing a motion base.

Another room for improvement is to use higher quality parts. Currently, the parts are made of low quality aluminum which limits the maximum pitch and roll motions. Higher quality parts will allow a far more stable simulator run. The actuators itself are quite rigid when moving its stroke making the simulator appear uncomfortable. Purchasing higher quality actuators can resolve this issue.

The programming code needs to further be modified to handle all possible situations that may occur during simulation. Instances such as simultaneous pitch and roll situations are handled in the code but simultaneous pitch, roll and vertical motion have yet to be implemented. Also, the code currently reads data from an external file and not real-time data from the simulator. Minor changes need to be made to the code. A TCP/IP link will need to be established between the code and the simulator in order to transfer real-time data. It should not be too difficult but given the dissembled state of the simulator makes it impossible to achieve before the Design Expo.

Scaled-up Full Size Model

The real size model will be different from the scaled prototype in terms of assembly parts, controlling method, and a motion sickness. The following analysis assumes the real size model provides only pitch and roll motion as the scaled prototype does. For the more complex motions such as yaw needs more complicated analysis.

First, a different actuator will be used such as ball screw actuators due to relatively cheap price and comparable duty cycle. Specification of the ball screw actuator is determined by how much acceleration, velocity, amplitude, and frequency are needed. Amplitude of the actuator can be calculated by setting a required frequency. Then, amplitude can be acquired by setting how much acceleration is needed. Then velocity and acceleration can be accordingly calculated. Equations are provided below for those steps (where 0.3g is an assumed total acceleration of the driving seat)

$$\omega = frequency \qquad \textbf{Eq.7}$$

$$Amplitdue = 0.3 \times g \times \omega^{-2} \qquad \textbf{Eq.8}$$

$$Velocity = \omega \times Amplitude \qquad \textbf{Eq.9}$$

$$Acceleration = \omega^{2} \times Amplitude \qquad \textbf{Eq.10}$$

An electric motor is needed to drive the actuator at the desired frequency, amplitude, velocity, and acceleration. The speed of the motor can be calculated by multiplying the velocity of the driving seat to the lead (pitch) of the ball screw. Then, the torque needed for the motor can be calculated.

$$Speed\_of\_the\_motor = \frac{velocity\_of\_seat}{Lead\_of\_the\_ball\_screw} \qquad \textbf{Eq.11}$$

$$Torque\_of\_the\_motor = \frac{Force\_on\_the\_seat \times Lead\_of\_the\_ball\_screw}{2\pi} \qquad \textbf{Eq.12}$$

For the different type of actuators other than the ball screw actuator, different analysis is required.

Second, the real size model needs to be introduced with the closed-loop control instead of the open-loop control used in the scaled one prototype. Closed-loop control provides more realistic driving simulation, so that motion sickness can be significantly minimized. Closed-loop control is sent all the information about the variables affecting driving conditions, and sends out appropriate signals to the actuators to take the effect of the variables into account. The weight of a test driver is the most critical variable because the required speed of actuator and the power of the actuator motor are significantly determined by it.

Third, safety of a test driver needs to be ensured in case of the malfunction of the system. An immediate stop switch to cut the power off or a safety belt to secure the test driver can be the solution for the safety issue.

RECOMMENDATIONS

The overall prototype system can benefit from future improvements. The prototype should use higher quality parts to provide a higher performance level. This would give more freedom to the motion base itself. Currently, there is a limit on the pitch, roll, and vertical motion due to low quality parts. Another improvement is stability issues. Further design needs to incorporate extra parts or redesigned parts to better stabilize the model car. The ground base provides an adequate support and foundation for the prototype, but the connection between the model car and the actuators can be improved. The stabilization support should secure the model car to the actuators but yet still provide the freedom of movement to achieve the desired position. These parts should also be easy to manufacture. If budget permits, with the exception of the ground base, all other machined parts should be made of a material that has better material properties than aluminum.

The software for this system can be improved significantly. This can improve the ease of data input from the host simulator computer. A smoother, more simultaneous response is possible with better software codes. A dedicated programming specialist should work closely with the software.

The most significant component recommendation is changing the actuators. Using fast reacting actuators are essential in providing a quick response time correlating to the input data. Higher quality actuators not only improve speed significantly, but it can increase the load at which it can move at high speeds. It will also have a higher duty cycle, allowing the prototype to run for longer periods each time. The number of actuators can be increased to 6, much like the Stewart platform. It will provide more degrees of freedom and response time. A second piece can be incorporated between the ball joints and the actuator connectors. This second piece can enclose the entire sphere of the ball joint securely but still provide freedom of movement. The model car's weight can perhaps be reduced even further to ease the load off the actuators. The aluminum plate can be replaced with a titanium plate to further reduce load on the actuators.

All the stated recommendations require a greater budget and more time but are possible. It will greatly improve the overall performance of the prototype.

CONCLUSION

UMTRI's driving simulator does not provide any motion feedback to its user, and therefore motion sickness is a common occurrence. A motion base for the driving simulator is desired for the reduction/elimination of motion sickness and realistic physical feedback to the users. The design of the prototype was modified many times to meet the demands of the sponsor and financial constraints. The prototype was first designed to be a full size motion platform for a car seat. After extensive and in-depth research of necessary equipments to meet the engineering requirements, it was decided such design would require a large amount of money. An alternate design was developed as a mean of cost reduction. This designed lacked any vertical motion, a trade off we felt reasonable. It was a very intuitive design, but after analysis was complete, it also turned out to be a very expensive design, almost as expensive as the original design except with the trade off.

A meeting was held with the sponsor and an agreement was made to build a scaled down version of the original design. A cost analysis was performed and the required cost is within the $400 set budget. The miniature version consists of 3 Firgelli linear micro-actuators. A model car was used in place of a scaled down chair to more accurately represent what UMTRI will do to their full size driving simulator in the future.

Engineering analysis (static and dynamic analysis) was performed based on the parts acquired to satisfy the new customer requirements. This included the proper placement of the actuators to provide the required pitch, roll, and vertical motion.

Various aluminum acting as connectors and ground base were machined from aluminum and assembled together to the model car. The 3 actuators are connected to a micro-controller and to an aluminum plate attached to the model car. The micro-controller is connected to a laptop, where all programming and data input takes place. The program instructs the actuators to move to certain stroke lengths at certain conditions. Road course scenarios from the simulator computer are loaded to the laptop, and the actuators respond accordingly.

A scaled prototype has been manufactured which provides 10 degree pitch and 13 degree roll motions. Based on the heavy research, 10 degree pitch and 13 degree roll motions were determined to be feasible and comparable to the sponsors needs. The major factor limiting the performance of the prototype significantly depending on the quality of actuators was cost. The prototype was optimally designed and manufactured with the given budget. Relieving motion sickness cannot be resolved by the prototype but only by a real size model with being actually driver on the driver seat. The prototype only provides the mechanism that can be used for the next generation model. Upon completion of the prototype, validation tests were completed to test if the prototype met the engineering requirements.

The prototype of the motion base was successfully constructed, displayed, and demonstrated at the design expo on December 7th, 2006.

INFORMATION SOURCES

Studies were done on various designs from online sources provided by universities and organizations around the world. From the sources gathered, there was little, technical data concerning the movement of the car simulator. E-mails had to be sent to several organizations to acquire more technical and quantifiable data. Table 6 below summarizes some of the technical data found on only a few of the competing simulators. Figures 17 and 18 below are pictures of the competing simulators.

Table 6: Benchmarking of various motion simulator

	Kookmin University (Korean based)	Vision Light (MotionBase 3D150)	NADS (University of Iowa)
Pitch angle	±25 degrees	±18 degrees	±25 degrees
Roll angle	±20 degrees	±15 degrees	±25 degrees
Load	1970 Newtons	1500 Newtons	-
Degrees of freedom	6	3	13
Number of actuators	6	3	10
Acceleration	±0.6g	±0.7g	±0.99g
Price	-	$16,990	-

The three organizations and university showed pitch angles ranging from ±25 degrees and roll angles of ±24 degrees. As for the maximum static load, Kookmin's simulator could hold loads to as much as 1,970 Newtons. The simulators all used a different number of actuators leading to different degrees of freedom. The simulators were all priced above $15,000 which places them well above the team's current budget constraint of $400. Due to this constraint, all information will be used for bench marking purposes only and not for competition with the other simulators.

Figure 17: Vision Light MotionBase 3D150

Figure 18: National Advanced Driving Simulator

Actuators will be a key component to this project. From online vendors, specifications of the actuators are provided. This information will help us determine the type of actuators we need for this project. However, the team will need to research more information about actuators before selecting one to use.

The University of Michigan's Oncology Department was contacted because of the special bed they use to treat patients with radiation. The bed was titled at the desired angles with the use of electrical actuators. Unfortunately, this device was decommissioned a few years ago. We have contacted Professor Brent Gillespie of the mechanical engineering department and Professor Dan Ferris of kinesiology and biomedical engineering department for their expertise and opinions on actuators.

Several journals were examined for further studies, both from our own research and provided by our sponsor Dr. Paul Green of UMTRI. One journal is called Motion Cueing in the Renault Driving Simulator. This was about the driving simulator developed by European car company Renault. This was much too advanced but it gives us insight on the topic. Another journal we examined was called A Low-Cost Driving Simulator for Full Vehicle Dynamics Simulation. This gives us more information pertaining to manufacturing a low-cost simulator. However, the term "low-cost" in this journal is only relative to the other comparable simulator.

REFERENCES

Cheng, M., Irawan, P., Kwak, S, and Putra, P. (October 3rd, 2006). Interview with Brent Gillespie of the University of Michigan's Mechanical Engineering Department.

Cheng, M., Irawan, P., Kwak, S, and Putra, P. (October 3rd, 2006). Interview with Dan Ferris of Kinesiology and Biomechanical Engineering Department.

Cheng, M., Irawan, P., Kwak, S, and Putra, P. (September 12, 2006). Interview with Paul Green.

Firgelli Micro Electric Linear Actuators, Retrieved October 1, 2006, http://www.firgelli.com

Freeman, J.S., Watson, G., Papelis, Y.E., Lin, T.C. and Tayyab, A., *The Iowa Driving Simulator: An Implementation and Application Overview*, SAE Paper No. 950174 (1995).

Gillespie, T.D., *Fundamentals of Vehicle Dynamics*, (1992), SAE Publication.

Huang A.R.W. and Chen, C., *A Low-Cost Driving Simulator for Full Vehicle Dynamics Simulation*, (52)1, January 2003.

Huang, R. and Lee, W., *Modeling and Simulation of a PC-Based Driving Simulator*, JSME International Journal, Vol. 46, No. 2, (2003).

Reymond, G. and Kemeny, A., *Motion Cueing In the Renault Driving Simulator*, Vehicle System Dynamics, pp. 249-259, 2000.

Visible Light. *Simulator MotionBase 3d1,* Retrieved September 14, 2006 from http://www.visiblelight.com/motionbase/

National Advanced Driving Simulator. *The University of Iowa*, Retrieved September 15, 2006 http://www.nads-sc.uiowa.edu.

UMTRI Transportation Research Institute. *The University of Michigan*, Retrieved September and October 2006 from http://www.umtri.umich.edu.

VTI. *Swedish National Road and Transport Research Institute*, Retrieved September 15, 2006 from http://www.vti.se.

Yang, K.D., Song, J.K., Bae, D.S. and Song, C.S., *Design and Instrumentation of a Vehicle Driving Simulator*, Journal of Mechanical, Vol. 16, No. 4 (1997).

ACKNOWLEDGEMENTS

Prof. Dan P. Ferris
University of Michigan, Division of Kinesiology and Associate

Prof. Brent Gillespie
University of Michigan Mechanical Engineering Department

Dr. Paul A. Green
University of Michigan Transportation and Research Institute

Ron Klopfer
Firgelli Technologies, Inc.

Sutejo Kurniawan
University of Michigan, EECS Department

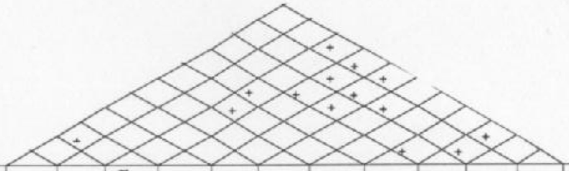
Prof. Kazuhiro Saitou
University of Michigan Mechanical Engineering Department

Jason Schweitzer
University of Michigan Transportation and Research Institute

Abraham Soedjito
University of Michigan, EECS Department

Appendix A

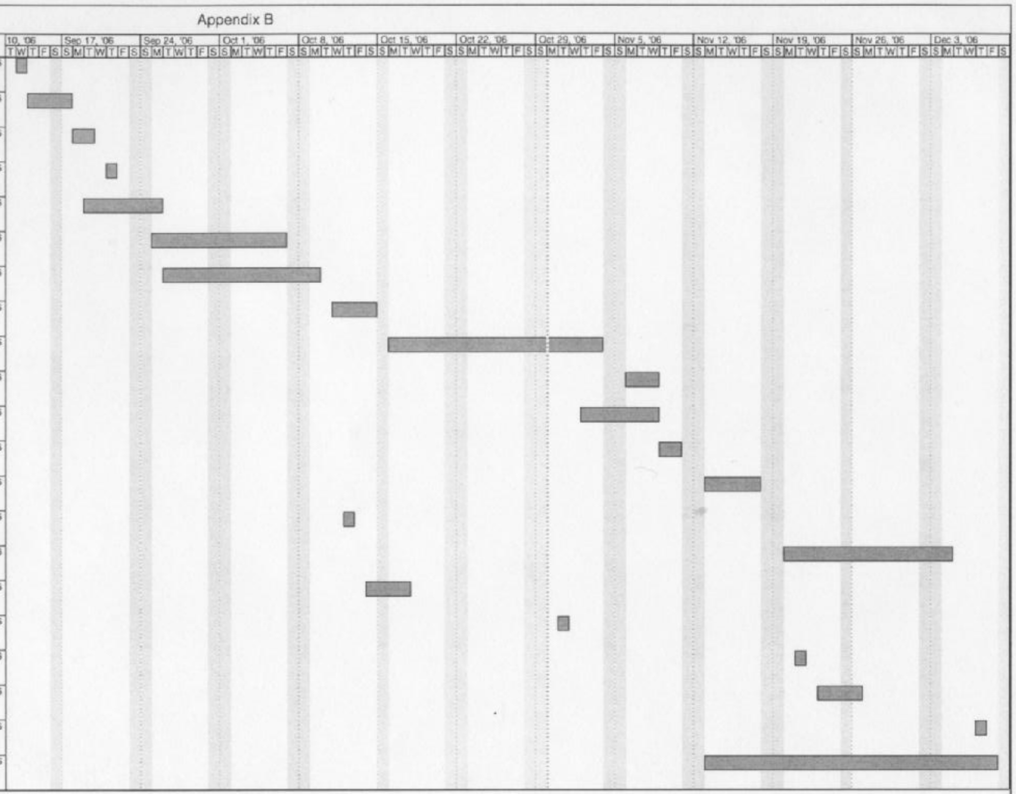
Not related
Weakly related
Neutral
Moderately related
Strongly Related



Part Characteristics Quality Charateristics	Normalized Importance to Customer (Relative Weight)	Response time of movement less than 17 ms	Fatigue Lifetime	maximum acceleration during pitch and roll motion not to exceed the limit motion range	Number of actuators needed	Dimension of driving simulator platform	Number of parts	Maximum angle for pitch and roll motions	Range of motion	Limit Power supply to actuator / output voltage	Cost of material and manufacturing	Ability to support an average person	TOTAL - QUALITY CHARACTERISTICS	RANK	Importance	Kookmin University Simulator	Visible Light MotionBase 3D100
Safety of a driver during simulation drive	1.0	1	9	5	1	5	1	9	1	3	1	9	45	1	4.72		
Short respond time of driving chair from receiving data	0.9	9	1	3	3	1	1	1	1	1	1	1	20.7	8	2.78		
Pitch and roll motions must be provided in moderate range	0.8	3	3	3	9	1	1	7	9	1	1	3	32.8	5	3.61		
inimum number of actuators is desired to minimize cost while providing feasible motion of driving chair	0.7	5	3	1	9	5	9	5	1	5	9	9	42.7	2	4.44		
Structural design to support wide range of weight of driver and wide motion of driving chair while driving	0.6	1	9	5	7	7	1	3	9	1	1	9	31.8	6	3.33		
feasible scale of prototype to produce real size of simulation driving	0.4	1	1	1	1	1	1	1	1	1	1	1	4.4	13	1.39		
higher motion of degrees of freedom to achieve more realistic driving simulation	0.9	1	1	5	7	1	7	5	7	1	1	1	33.3	4	3.89		
minimize motion sickness	1.0	9	1	3	7	1	5	5	7	1	1	1	41	3	4.17		
easy access to stop button for safety	0.8	1	1	1	1	1	1	1	1	1	1	1	8.8	9	2.50		
motion should not to be distorted regardless of weight of driver	0.7	7	1	3	7	1	5	3	5	1	1	1	24.5	7	3.06		
easy scaling of prototype to the cab simulator	0.7	1	1	1	1	1	1	1	1	1	1	1	7.7	10	2.22		
minimize noise of chair while driving	0.3	3	1	3	5	1	3	3	1	1	1	1	6.9	11	1.94		
longitudinal and vertical movement on prototype	0.2	7	1	3	3	1	1	3	1	1	1	1	4.6	12	1.67		
vibration feedback for the carseat	0.2	7	1	3	1	1	1	1	1	1	1	1	3.8	14	1.11		
Units		ms	Years	m/s^2	N/A	m	N/A	degree	n/degre	Volts	$	N					
Kookmin University Simulator		-	-	5.88	-	-	-	20	-	-	-	-					
Visible Light MotionBase 3D100		-	-	7	3	-	-	15-18	-	220	12000	980					
Target (Plan)		17	-	-	4	-	-		-	110	400	980					
Total		36	25	27.4	43.8	19.6	27.6	36	34.6	14	14.8	29.2					
Rating (%)		11.7%	8.1%	8.9%	14.2%	6.4%	9.0%	11.7%	11.2%	4.5%	4.8%	9.5%					
Ranked Importance		2	8	7	1	9	6	2	4	11	10	5					

Appendix B

ID	❶	Task Name	Duration	Start	Finish
1		Make Ghantt and QFD	1 day	Wed 9/13/06	Wed 9/13/06
2	▦	High level brainstorming / generate concepts	3 days	Thu 9/14/06	Sun 9/17/06
3		Formal meeting with sponsor and Prof. Saitou	2 days	Mon 9/18/06	Tue 9/19/06
4	▦	Design Review #1	1 day?	Thu 9/21/06	Thu 9/21/06
5	▦	High level analysis of chosen concept	5 days	Tue 9/19/06	Mon 9/25/06
6	▦	Confirm analysis with sponsor and Prof. Saitou	10 days	Mon 9/25/06	Fri 10/6/06
7	▦	Final detailed designs and drawings	10 days?	Tue 9/26/06	Mon 10/9/06
8	▦	Order parts and materials for manufacturing	4 days	Wed 10/11/06	Sat 10/14/06
9	▦	Manufacturing	15 days	Mon 10/16/06	Fri 11/3/06
10		Assemble prototype	3 days	Mon 11/6/06	Wed 11/8/06
11	▦	Programming	5 days	Thu 11/2/06	Wed 11/8/06
12		Combine self written program to prototype	2 days	Thu 11/9/06	Fri 11/10/06
13	▦	Combine prototype to Car Simulator software	5 days	Mon 11/13/06	Fri 11/17/06
14	▦	Design Review #2	1 day?	Thu 10/12/06	Thu 10/12/06
15		Extensive testing and necessary modification	12 days	Mon 11/20/06	Mon 12/4/06
16	▦	Fall Break	3 days	Sat 10/14/06	Tue 10/17/06
17	▦	Design Review #3	1 day?	Tue 10/31/06	Tue 10/31/06
18	▦	Design Review #4	1 day?	Tue 11/21/06	Tue 11/21/06
19	▦	Thanksgiving	3 days?	Thu 11/23/06	Sun 11/26/06
20	▦	Design Expo	1 day	Thu 12/7/06	Thu 12/7/06
21	▦	Final Report	21 days	Mon 11/13/06	Fri 12/8/06



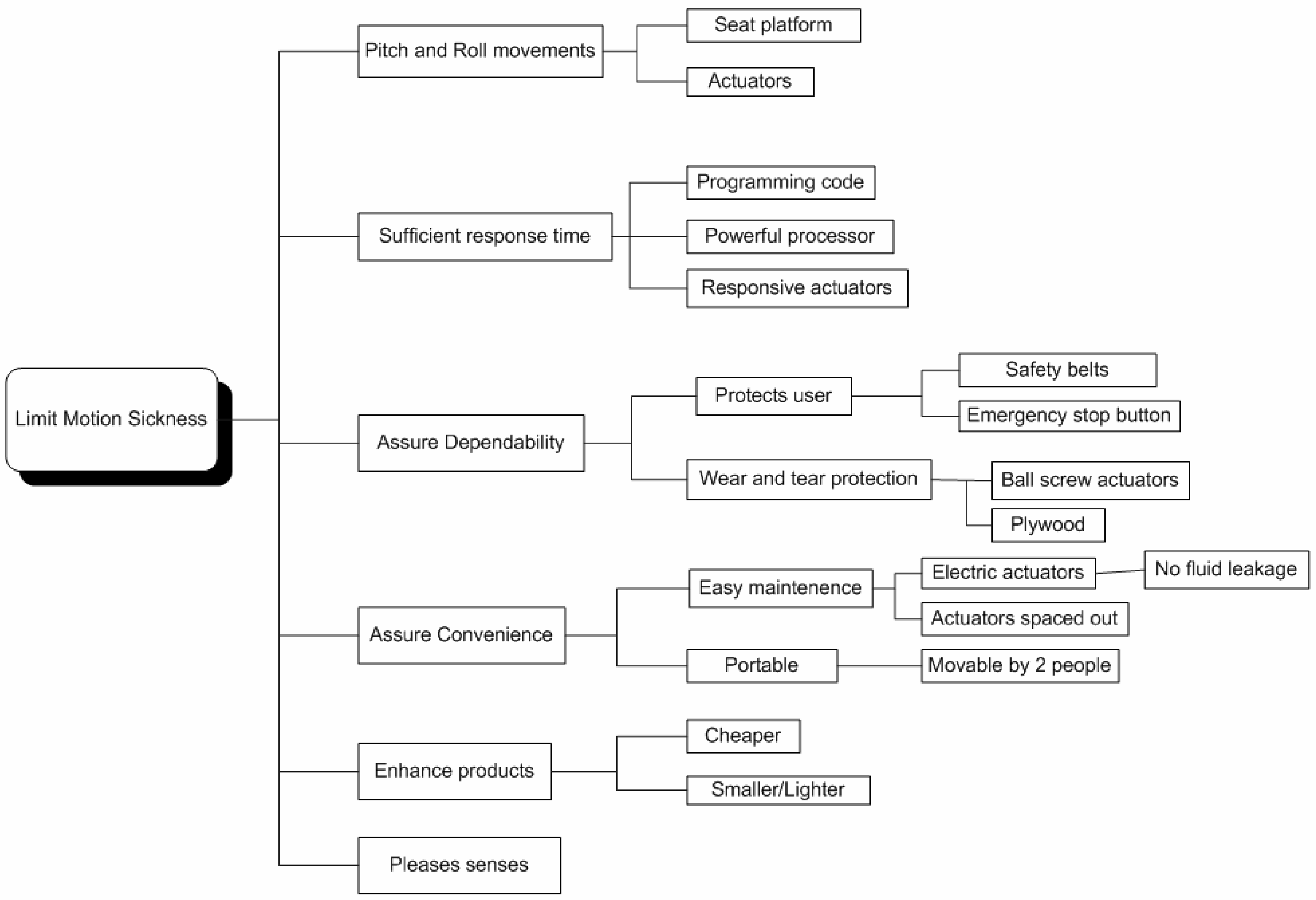
Project: Gantt Chart 10_3
Date: Mon 10/30/06

Task	▬	Progress	▬	Summary	▬	External Tasks	▬	Deadline	⇩
Split	⋯⋯⋯	Milestone	◆	Project Summary	▬	External Milestone	◆		

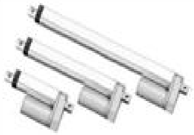
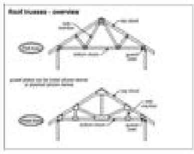
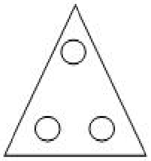
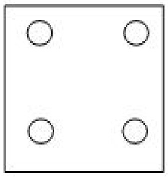
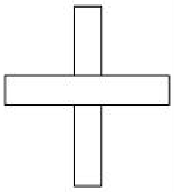
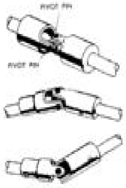
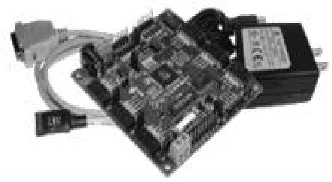
Page 1

APPENDIX C

FAST CHART



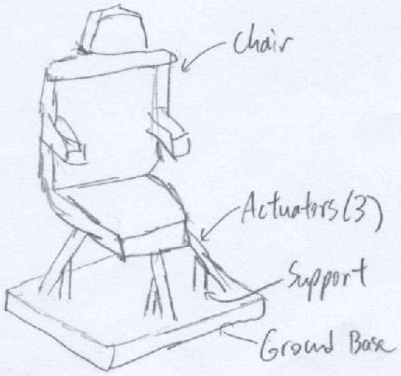
Appendix D - Morphological Chart

Function				
Actuate Movement	Electric Linear Actuator	Electric Rotary Actuator	Hydraulic Actuator	Pnuematic Actuator
				
Additional support	Spring	Truss Support	Beam Support	
				
Arrangement	Triangular	Square	Stewart Platform	Perpendicular Rod
				
Platform Connections	Ball Joints	Universal Joints 		
				
Connections	Microcontroller			
				

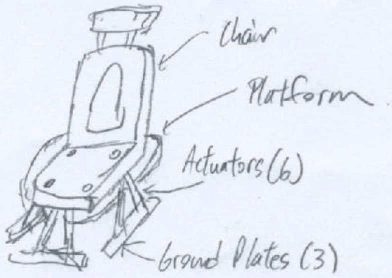
Appendix E

Electric Actuator Category

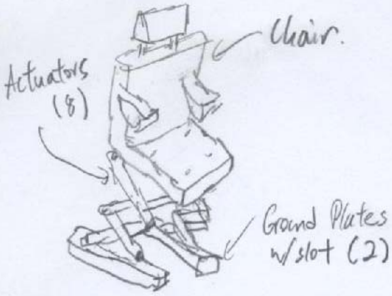
Concept A



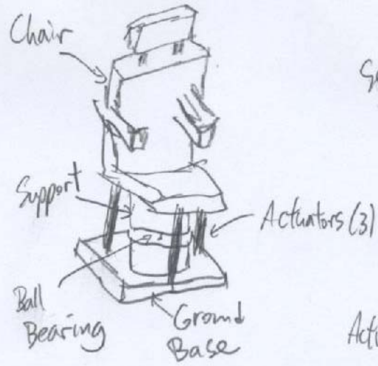
Concept B



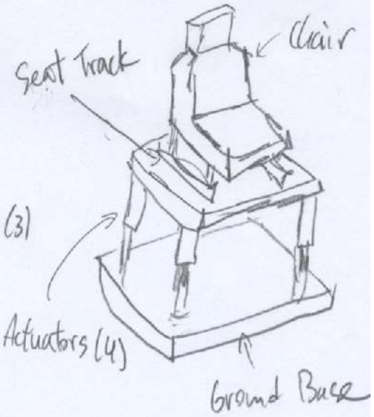
Concept C



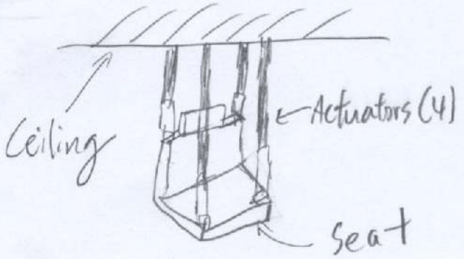
Concept D



Concept E



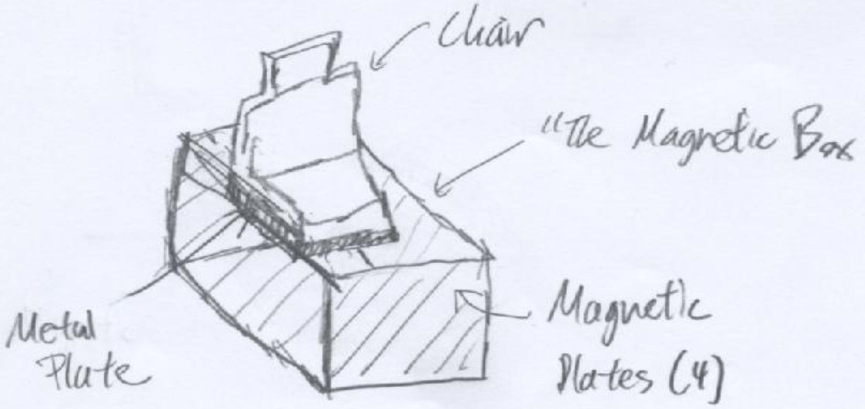
Concept F



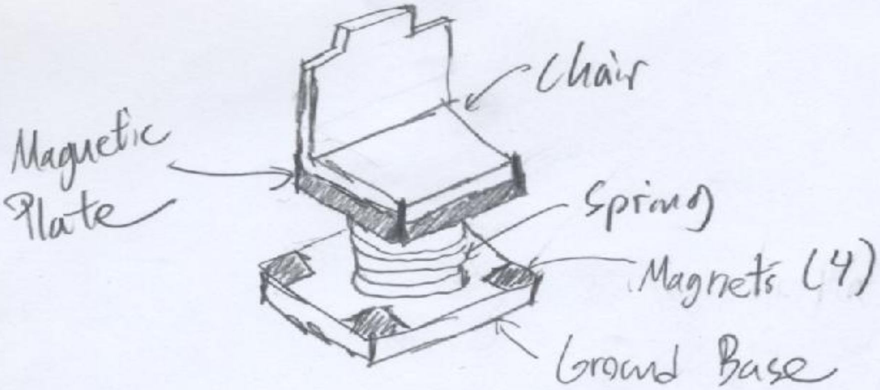
Appendix F

Magnetic Force Category

Concept G



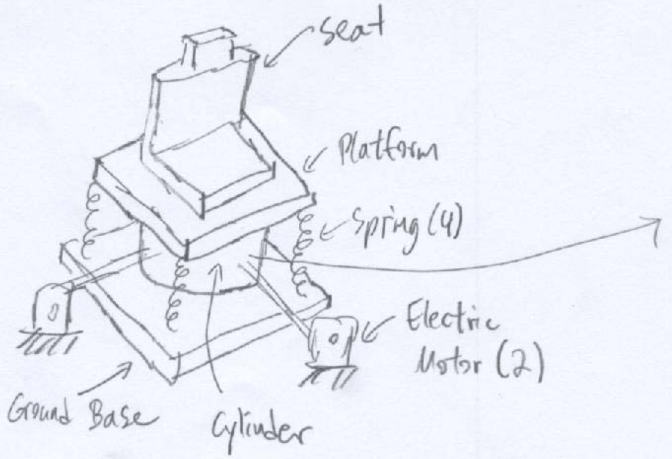
Concept H



Appendix G

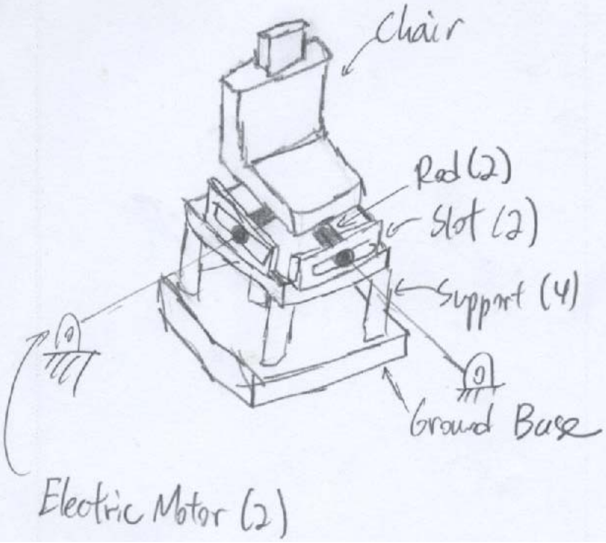
Spring/Bearing Category (Recently developed concept)

Concept I

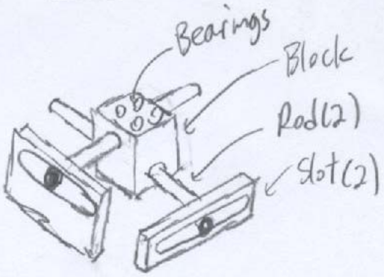


Cylinder

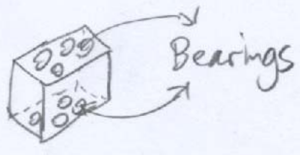
Concept J



Mechanism

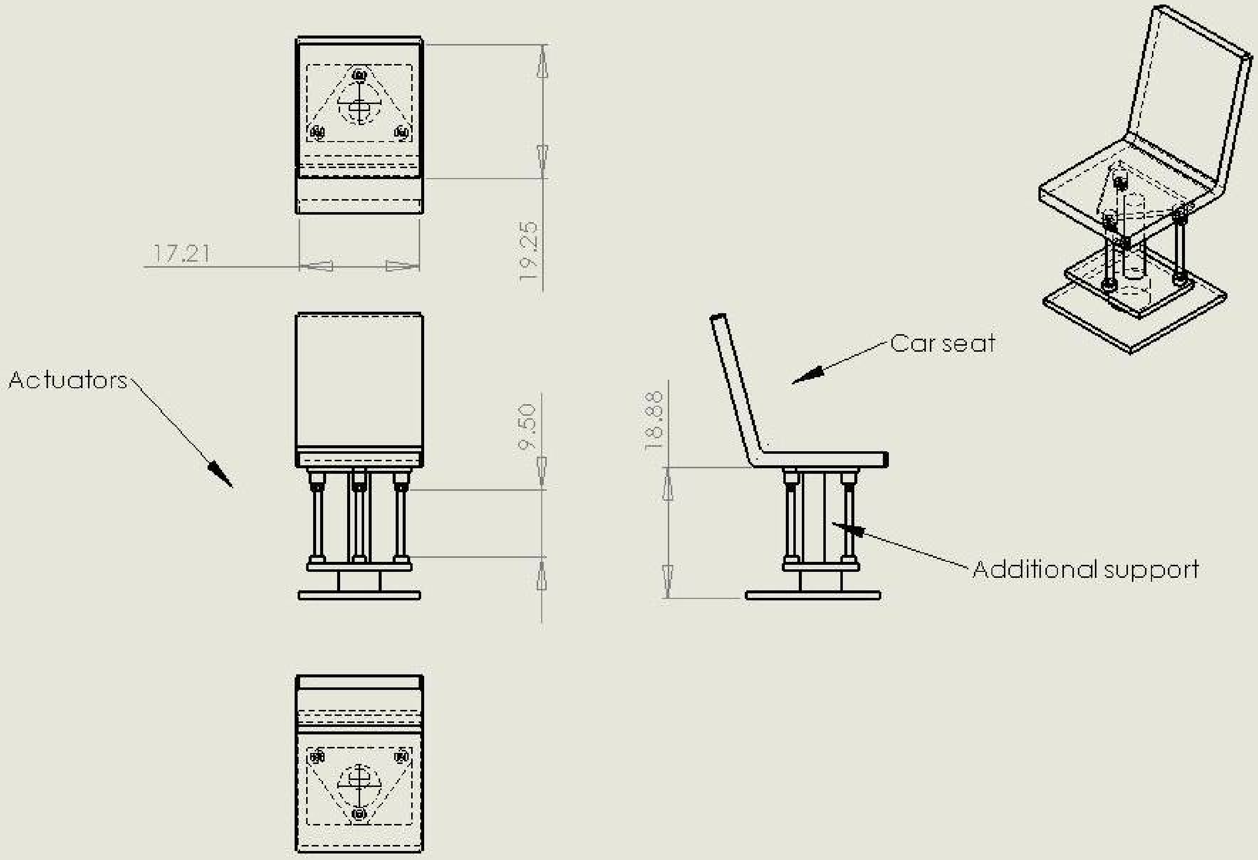


Block



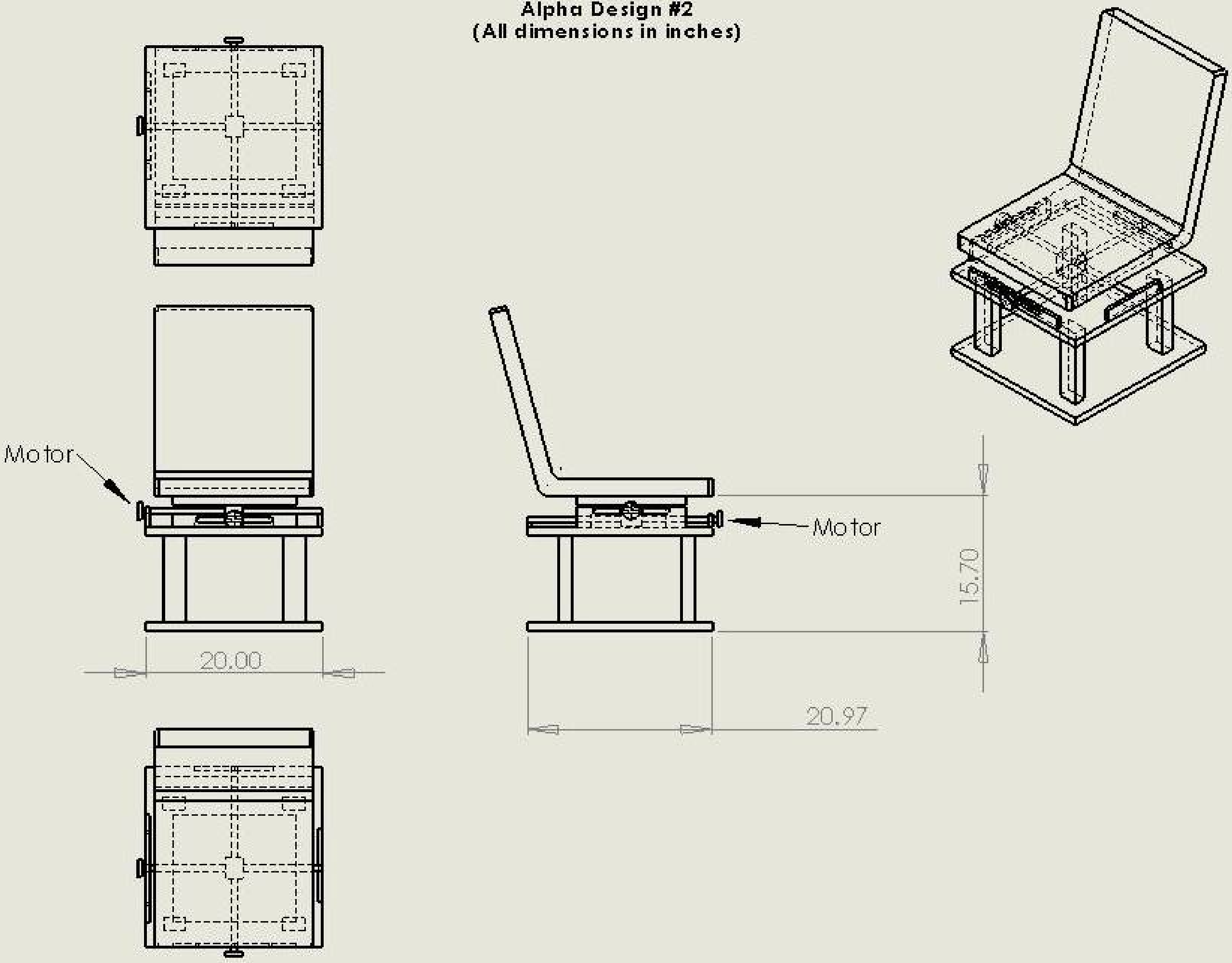
Appendix H

Alpha Design #1
(All dimensions in inches)



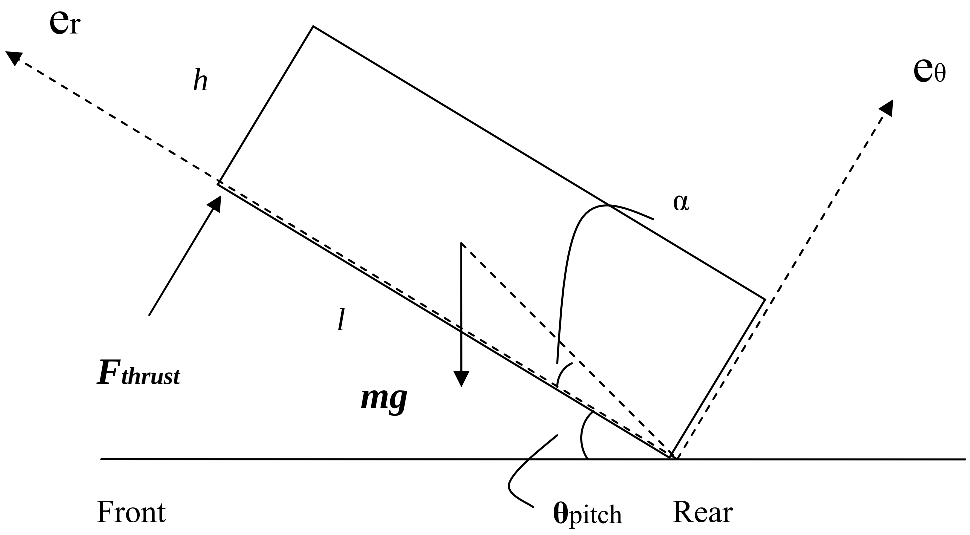
Appendix I

Alpha Design #2
(All dimensions in inches)



Appendix J

Dynamic analysis of pitch movement



All in SI Units

$$V = l\mathring{\theta}$$

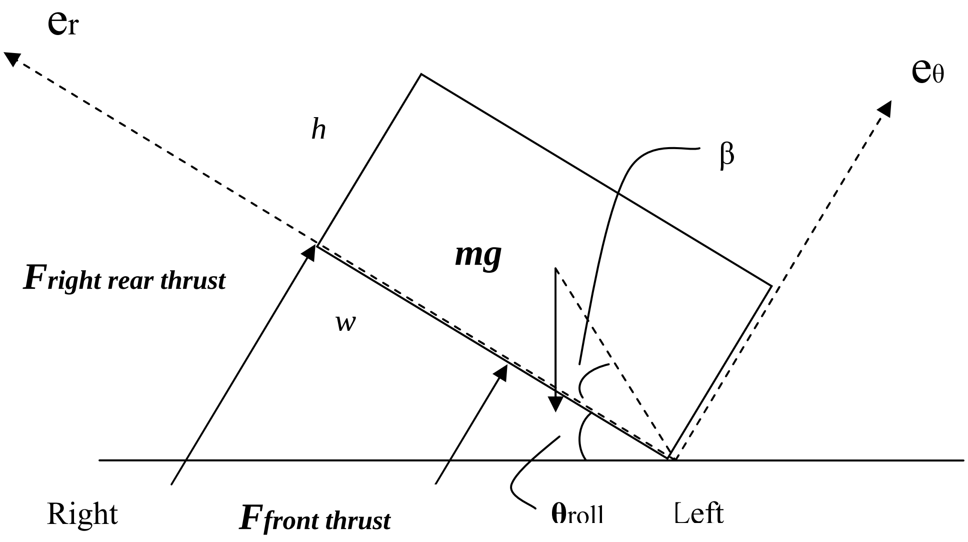
$$a^2 = (-l\mathring{\theta}^2)^2 + (l\overset{\circ\circ}{\theta})^2$$

$$I^{rear} = \frac{1}{3}m(h^2 + l^2)$$

$$\alpha = \tan^{-1}(\frac{h}{l})$$

$$F_{thrust} = \frac{1}{l}\left[I^{rear}\overset{\circ\circ}{\theta} + mg\cos(\theta + \alpha)\sqrt{\left(\frac{h}{2}\right)^2 + \left(\frac{l}{2}\right)^2}\right]$$

Dynamic analysis of roll movement



All in SI Units

$$V_{front} = \frac{w}{2}\overset{\circ}{\theta}$$

$$a_{front}{}^2 = (-\frac{w}{2}\overset{\circ}{\theta}{}^2)^2 + (\frac{w}{2}\overset{\circ\circ}{\theta})^2$$

$$I^{left} = I^{right} = \frac{1}{3}m(h^2 + w^2)$$

$$\beta = \tan^{-1}(\frac{h}{w})$$

$$F_{front\_thrust} = \frac{2}{w}\left[I^{left}\overset{\circ\circ}{\theta} + mg\cos(\theta+\beta)\sqrt{\left(\frac{h}{2}\right)^2 + \left(\frac{w}{2}\right)^2}\right]$$

$$V_{right\_rear} = w\overset{\circ}{\theta}$$

$$a_{right\_rear}{}^2 = (-w\overset{\circ}{\theta}{}^2)^2 + (w\overset{\circ\circ}{\theta})^2$$

$$I^{left} = I^{right} = \frac{1}{3}m(h^2 + w^2)$$

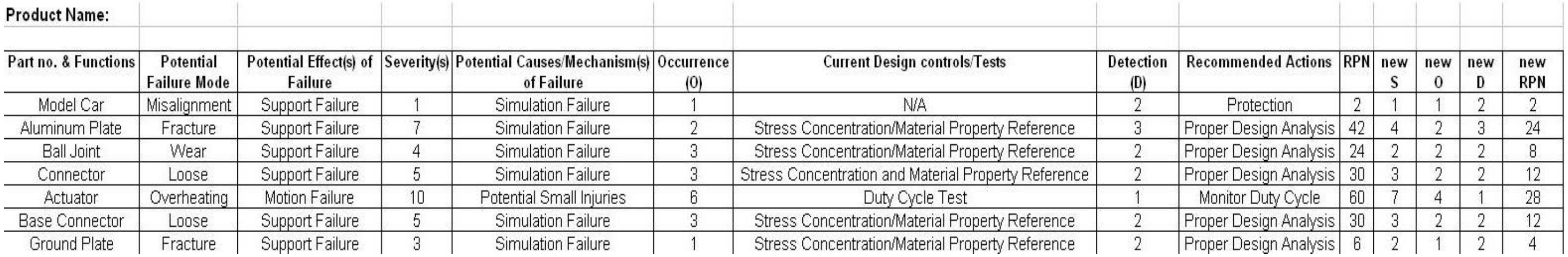
$$\beta = \tan^{-1}(\frac{h}{w})$$

$$F_{rear\_right\_thrust}\ \frac{1}{w}\left[I^{left}\overset{\circ\circ}{\theta} + mg\cos(\theta+\beta)\sqrt{\left(\frac{h}{2}\right)^2 + \left(\frac{w}{2}\right)^2}\right]$$

Parameter descriptions

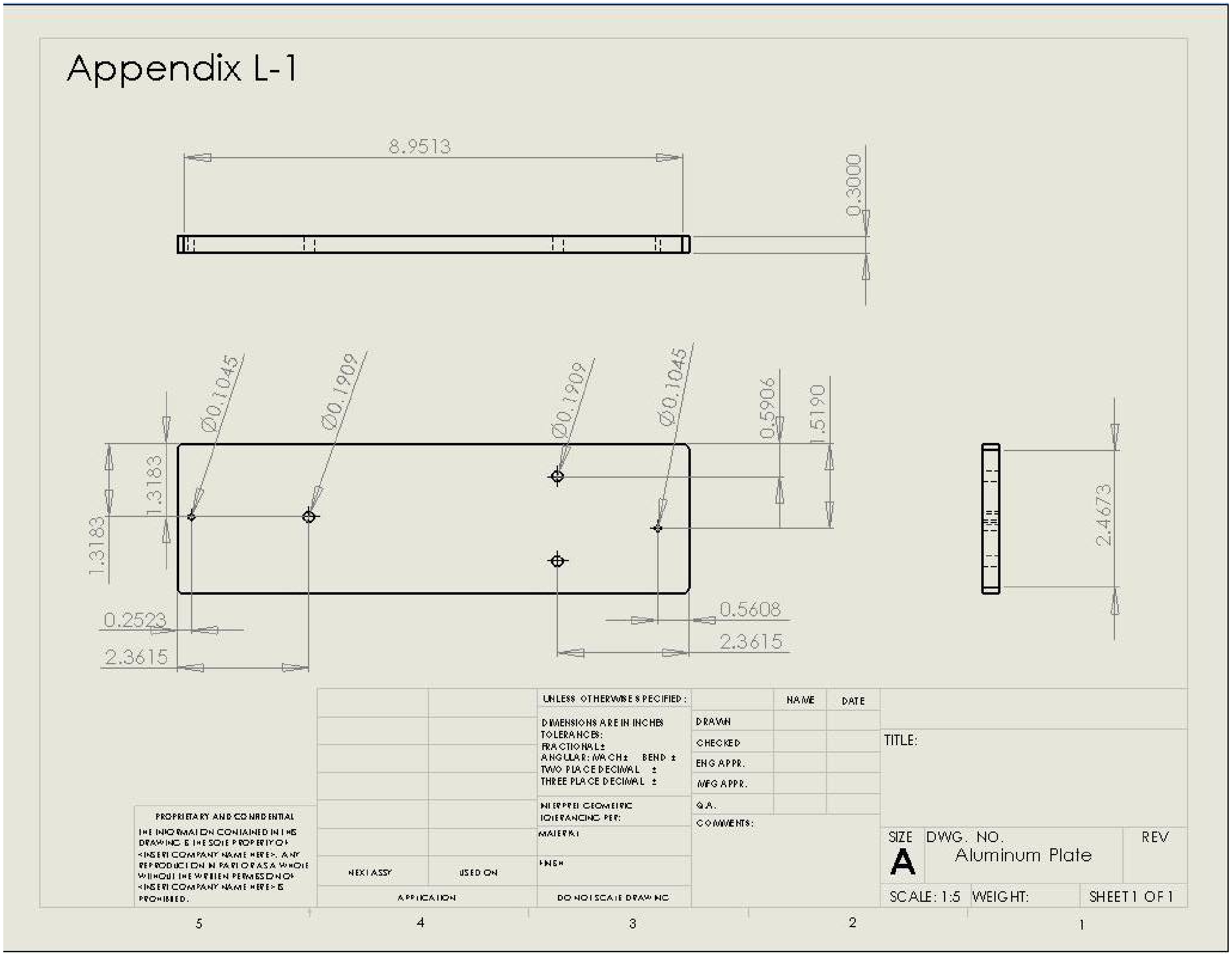
V = Velocity (m/s)
a = Acceleration (m/s^2)
$\overset{\circ}{\theta}$ = Angular Velocity (rad/s)
$\overset{\circ\circ}{\theta}$ = Angular Acceleration (m/s^2)
$I^{left} = I^{right} = I^{rear}$ = Moment of Inertia (kg *m^2)
m = Total mass (kg)
F_{thrust} = Thrust Force (N)
h = Height (m)
w = Width (m)
l = Length (m)
g = Gravity Acceleration (m/s^2)

Appendix K
FMEA Chart

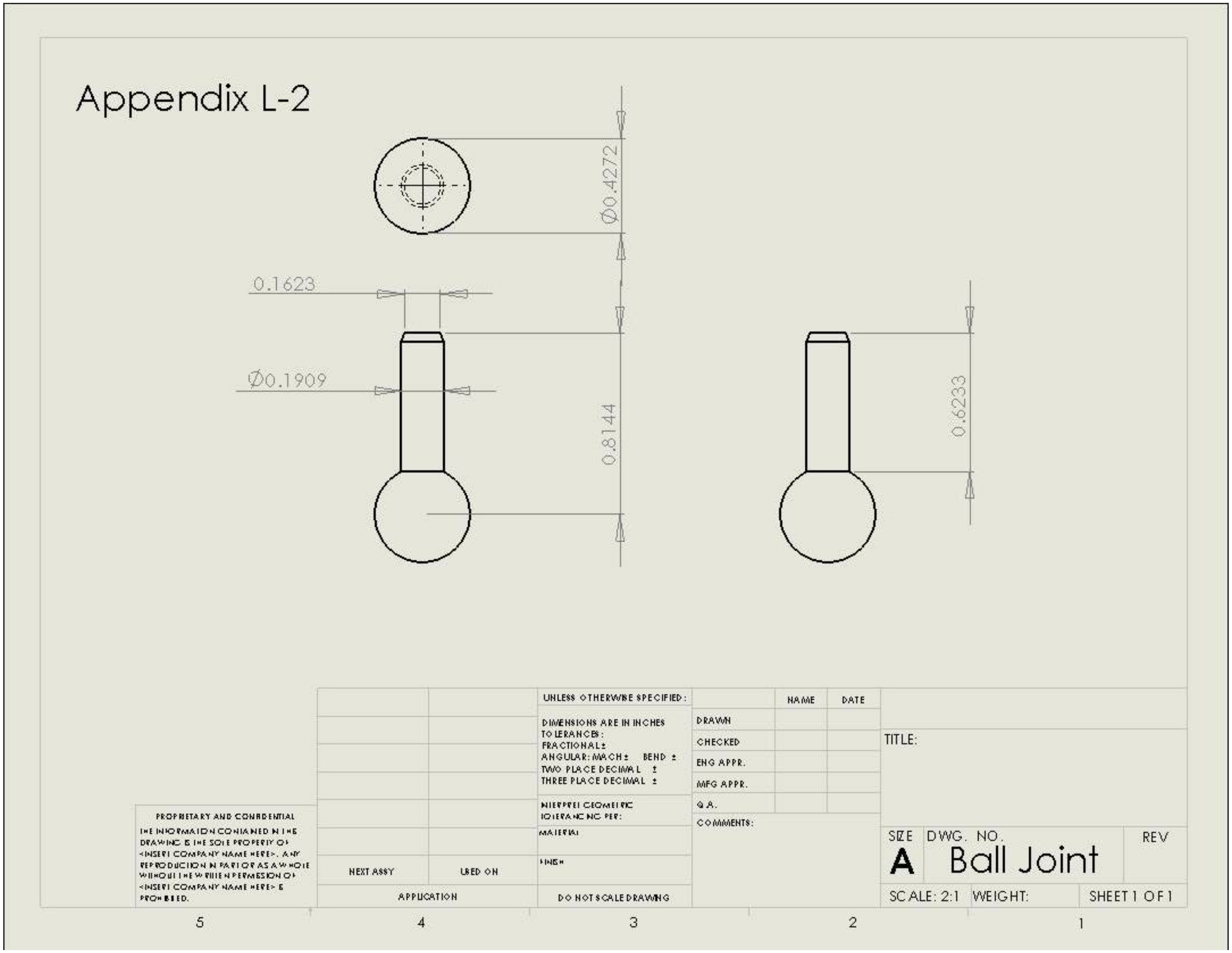


Product Name:

Part no. & Functions	Potential Failure Mode	Potential Effect(s) of Failure	Severity(s)	Potential Causes/Mechanism(s) of Failure	Occurrence (0)	Current Design controls/Tests	Detection (D)	Recommended Actions	RPN	new S	new 0	new D	new RPN
Model Car	Misalignment	Support Failure	1	Simulation Failure	1	N/A	2	Protection	2	1	1	2	2
Aluminum Plate	Fracture	Support Failure	7	Simulation Failure	2	Stress Concentration/Material Property Reference	3	Proper Design Analysis	42	4	2	3	24
Ball Joint	Wear	Support Failure	4	Simulation Failure	3	Stress Concentration/Material Property Reference	2	Proper Design Analysis	24	2	2	2	8
Connector	Loose	Support Failure	5	Simulation Failure	3	Stress Concentration and Material Property Reference	2	Proper Design Analysis	30	3	2	2	12
Actuator	Overheating	Motion Failure	10	Potential Small Injuries	6	Duty Cycle Test	1	Monitor Duty Cycle	60	7	4	1	28
Base Connector	Loose	Support Failure	5	Simulation Failure	3	Stress Concentration/Material Property Reference	2	Proper Design Analysis	30	3	2	2	12
Ground Plate	Fracture	Support Failure	3	Simulation Failure	1	Stress Concentration/Material Property Reference	2	Proper Design Analysis	6	2	1	2	4

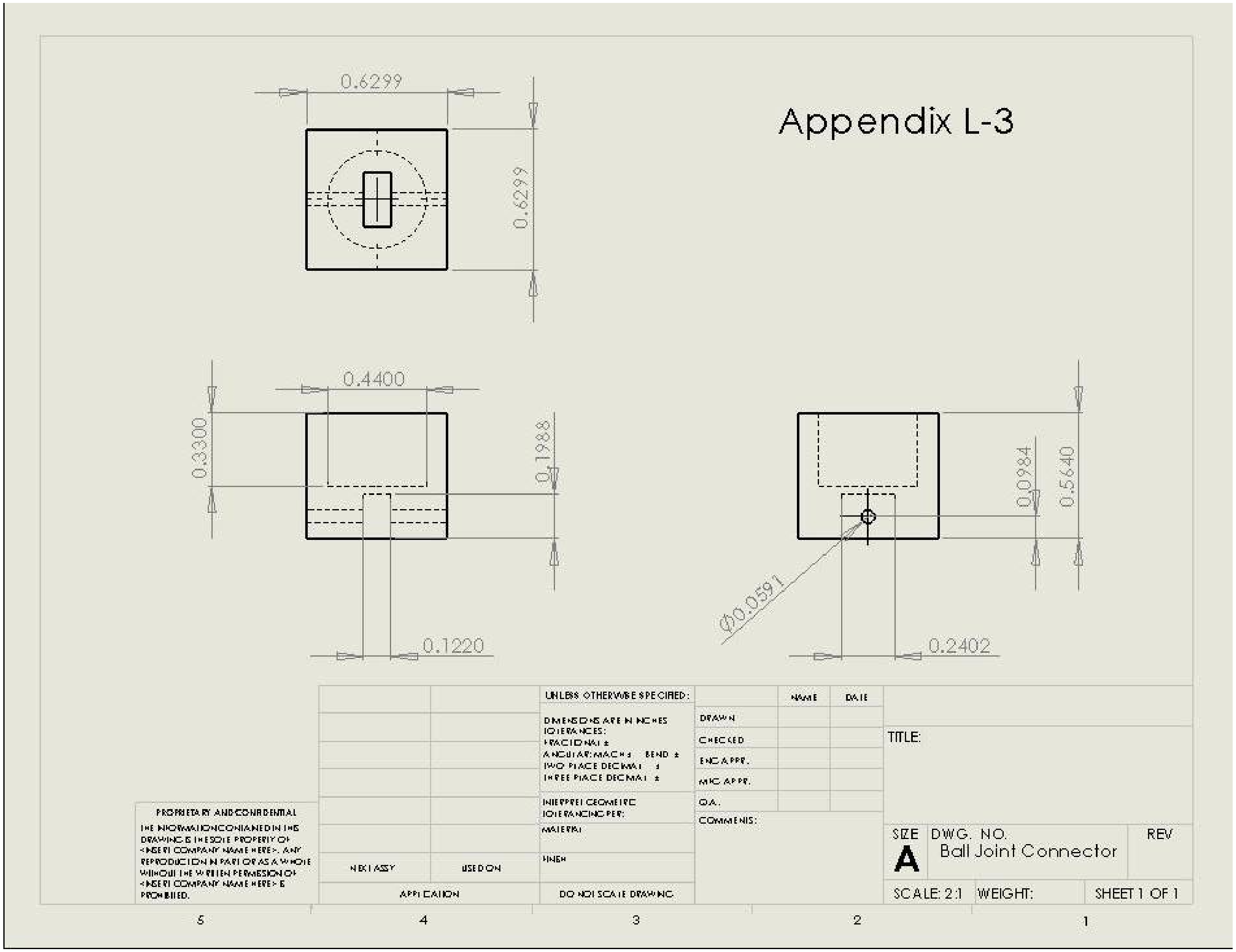

Appendix L-1
8.9513
0.3000
Ø0.1045
Ø0.1909
Ø0.1909
Ø0.1045
0.5906
1.5190
1.3183
1.3183
0.2523
2.3615
0.5608
2.3615
2.4673
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
SIZE
A
DWG. NO.
Aluminum Plate
REV
SCALE: 1:5
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.
5
4
3
2
1

Appendix L-2

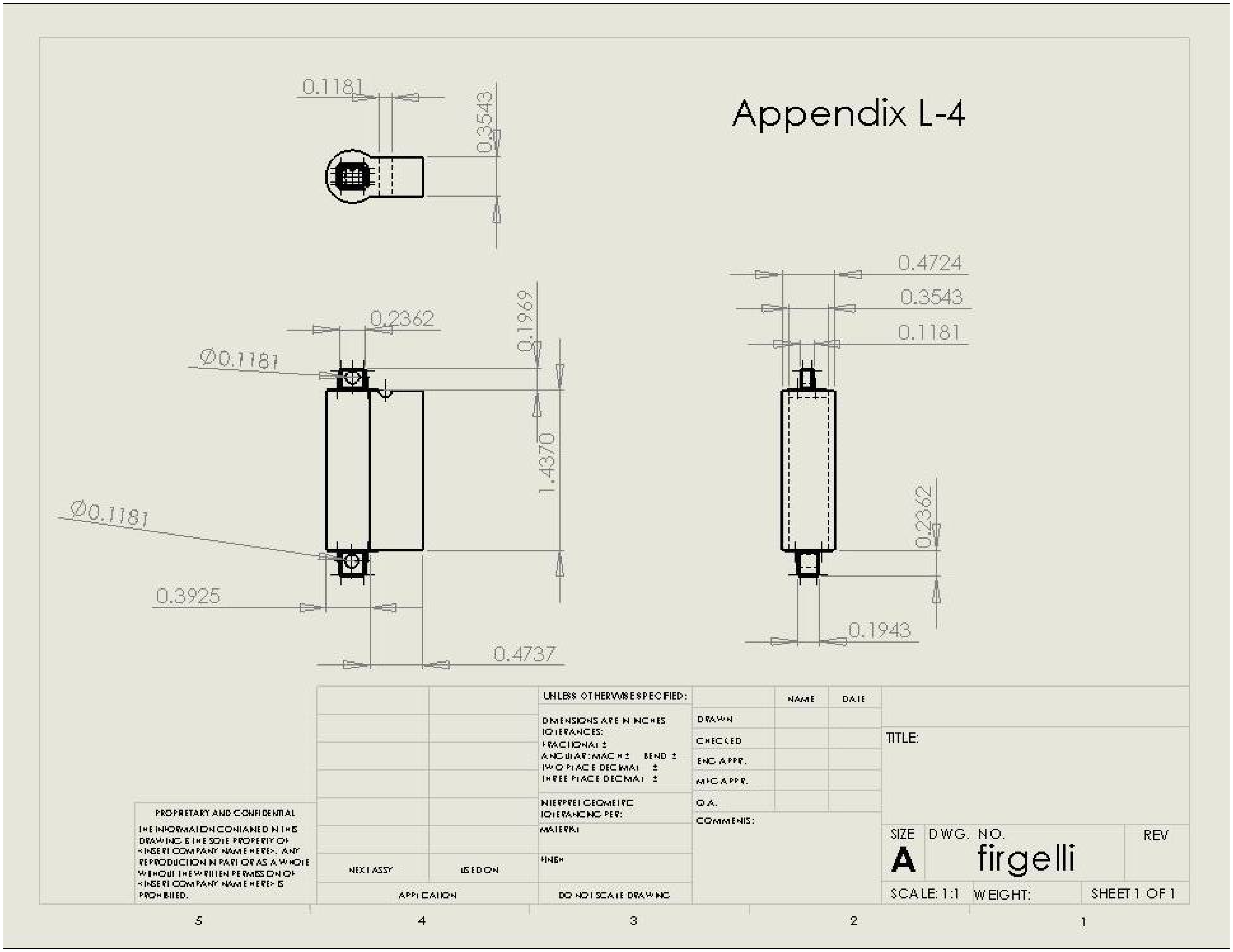


Ø0.4272
0.1623
Ø0.1909
0.8144
0.6233
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC
TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
SIZE
A
DWG. NO.
Ball Joint
REV
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1
NEXT ASSY
USED ON
APPLICATION
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.
5
4
3
2
1

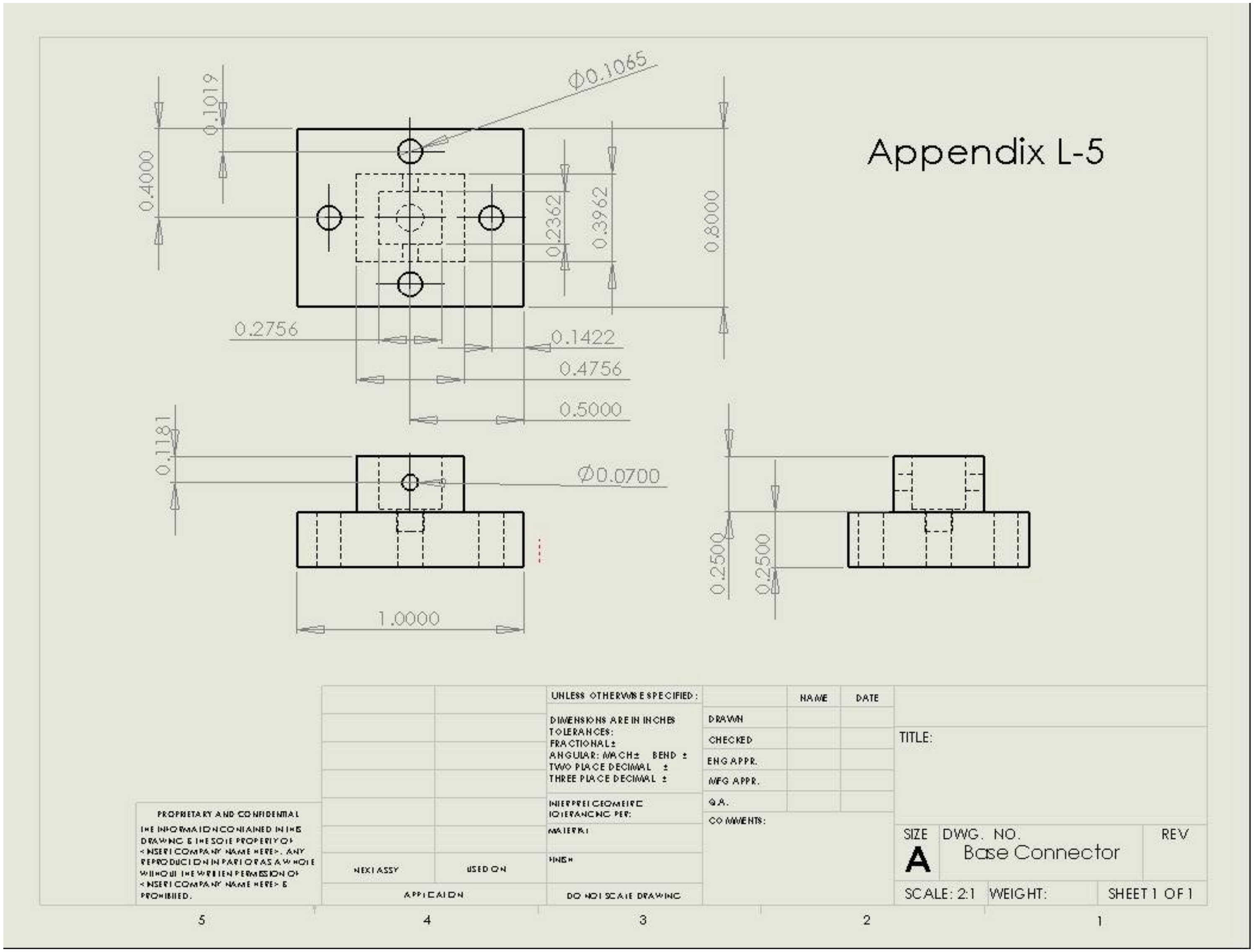
Appendix L-3


0.6299
0.6299
0.4400
0.3300
0.1988
0.1220
0.0984
0.5640
Ø0.0591
0.2402
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
SIZE
A
DWG. NO.
Ball Joint Connector
REV
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.
5
4
3
2
1

Appendix L-4

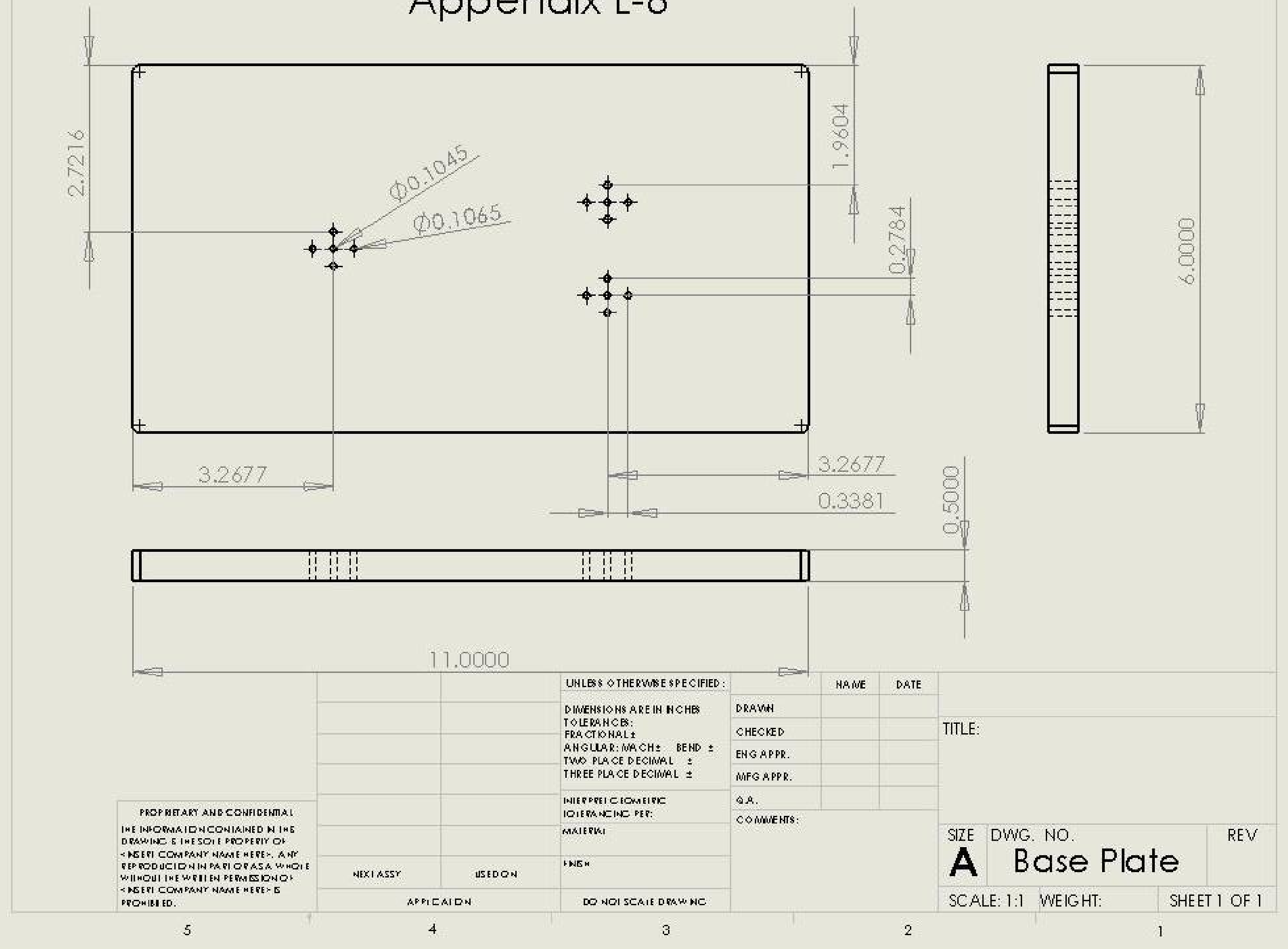

0.1181
0.3543
0.2362
Ø0.1181
0.1969
1.4370
Ø0.1181
0.3925
0.4737
0.4724
0.3543
0.1181
0.2362
0.1943
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC
TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
SIZE
A
DWG. NO.
firgelli
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.
NEXT ASSY
USED ON
APPLICATION
5
4
3
2
1

Appendix L-5



⌀0.1065
0.1019
0.4000
0.2362
0.3962
0.8000
0.2756
0.1422
0.4756
0.5000
0.1181
⌀0.0700
1.0000
0.2500
0.2500
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.
NEXT ASSY
USED ON
APPLICATION
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
SIZE
A
DWG. NO.
Base Connector
REV
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1
5
4
3
2
1

Appendix L-6


2.7216
Ø0.1045
Ø0.1065
1.9604
0.2784
6.0000
3.2677
3.2677
0.3381
0.5000
11.0000
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC
TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
SIZE
A
DWG. NO.
Base Plate
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.
NEXT ASSY
USED ON
APPLICATION
5
4
3
2
1

Appendix M
Programming Code

```
#include <windows.h>
#include <stdio.h>
#include <string>
#include <time.h>
#include <AtlBase.h>
#include <string>
#include <iostream>
#include <math.h>
#include <fstream>

#define MAXLINELENGTH 1000
#define NUMCOLUMN 3
#define PI 3.142
#define MAXARRAYSIZE 10000

using namespace std;

//stops the program for m seconds)
void sleep(unsigned int mseconds);
//stores pitch/roll data from an external file into an array
int storeToArray(double *pInput, int period, char* filename, int colNum);
//sends to the actuator the stroke length to extend/retract
void send_serial(char actuator_no, char pos);
//determines the stroke length each actuator needs to move given the pitch angle
double getPitchStroke(double angle, int act_index;
//determines the stroke length each actuator needs to move given the roll angle
double getRollStroke(double angle, int act_index);
//determines the stroke length each actuator needs to move given the vertical
double getVertStroke(double angle, int act_index);

int main(int argc, char **argv)
{
        /*Input Data*/
        double aPitchAngle[MAXARRAYSIZE];
        double aRollAngle[MAXARRAYSIZE];
        double aVert[MAXARRAYSIZE];//TBD

        /*Initialize array*/
        int j=0;
  double init = 0;
  while(j<MAXARRAYSIZE){
     aPitchAngle[j] = init;
     aRollAngle[j] = init;
     aVert[j] = init;
     j++;
  }

        /*Start parsing CSV, store to input array*/
        storeToArray(aPitchAngle, 10, "csvout.csv", 0);
        storeToArray(aRollAngle, 10, "csvout.csv", 1);

        /*Retract actuators*/
```

```
    send_serial((char)0, (char)110);
    send_serial((char)1, (char)110);
    send_serial((char)2, (char)110);

    /*Movement of each Actuator*/
    int i= 0;
    double flag1;
    double flag2;
    double flag3;

    while(true){
        /*Loop Forever*/
        if(getPitchStroke(aPitchAngle[i], 1) > getRollStroke(aRollAngle[i], 1)){
            flag1 = getPitchStroke(aPitchAngle[i], 1) ;
        }
        else{
            flag1 = getRollStroke(aRollAngle[i], 1);
        }
        if(getPitchStroke(aPitchAngle[i], 2) > getRollStroke(aRollAngle[i], 2)){
            flag2 = getPitchStroke(aPitchAngle[i], 2) ;
        }
        else{
            flag2 = getRollStroke(aRollAngle[i], 2);
        }
        if(getPitchStroke(aPitchAngle[i], 3) > getRollStroke(aRollAngle[i], 3)){
            flag3 = getPitchStroke(aPitchAngle[i], 3) ;
        }
        else{
            flag3 = getRollStroke(aRollAngle[i], 3);
        }

        send_serial((char)0, (char)120-5*flag1); //sends to each actuator the stroke length
        send_serial((char)1, (char)120-5*flag2); //sends to each actuator the stroke length
        send_serial((char)2, (char)120-5*flag3); //sends to each actuator the stroke length
        cout << "Actuator 1: " << 120-5*flag1 << "   Actuator 2: " << 120-5*flag2 << "
Actuator 3: " << 120-5*flag3 << endl;
        i++;

        sleep(200);
    }
    send_serial((char)1, (char)110);
    send_serial((char)0, (char)110);
    send_serial((char)2, (char)110);

    return 0;
}

double getPitchStroke(double angle, int act_index){
    double length = 113;
    double retVal;
    if(act_index == 2){
        if(angle<0){
            /*Tilt down*/
            retVal = length * tan(angle/180*PI);
            return retVal;
        }
```

```
			else if(angle>0){
				retVal = 0;
				return retVal;
			}
			else
				return retVal = 0;
		}
		else if(act_index == 3){
			if(angle<0){
				/*Tilt down*/
				retVal = length * tan(angle/180*PI);
				return retVal;
			}
			else if(angle>0){
				retVal = 0;
				return retVal;
			}
			else
				return retVal = 0;
		}
		else if(act_index == 1){
			if(angle<0){
				/*Tilt down*/
				retVal = 0;
				return retVal;
			}
			else if(angle>0){
				retVal = length * tan(angle/180*PI);
				return retVal;
			}
			else
				return retVal = 0;
		}
	}

	double getRollStroke(double angle, int act_index){
		double width = 38.6;
		double retVal;
		if(act_index == 2){
			if(angle<0){
				retVal = 0;
				return retVal;
			}
			else if(angle>0){
				/*Roll right*/
				retVal = width * tan(angle/180*PI);
				return retVal;
			}
			else
				return retVal = 0;
		}
		else if(act_index == 3){
			if(angle<0){
				/*Roll left*/
				retVal = width * tan(angle/180*PI);
				return retVal;
```

```
				}
				else if(angle>0){
					retVal = 0;
					return retVal;
				}
				else
					return retVal = 0;
		}
		else if(act_index == 1){
				if(angle<0){
					/*Tilt down*/
					retVal = (width * tan(angle/180*PI))/2;
					return retVal;
				}
				else if(angle>0){
					retVal = (width * tan(angle/180*PI))/2;
					return retVal;
				}
				else
					return retVal = 0;
		}
}

double getVertStroke(double angle, int act_index){
		double retVal;
		return retVal;
}

void sleep(unsigned int mseconds)
{
		clock_t goal = mseconds + clock();
		while(goal > clock()){};
}

void send_serial(char actuator_no, char pos)
{
		char szBuffer[80];
		DCB dcb = {0};
		DWORD dwRead, dwWritten;
		HANDLE hComm;
		OVERLAPPED ovlr = {0}, ovlw = {0};
		COMMTIMEOUTS cto;

		 char* port_name = "COM1";
		// Create events for overlapped operation
		ovlr.hEvent = CreateEvent(NULL, TRUE, FALSE, NULL);
		ovlw.hEvent = CreateEvent(NULL, TRUE, FALSE, NULL);

		// Open the port
		hComm = CreateFile("COM1", GENERIC_READ | GENERIC_WRITE,
		0, NULL, OPEN_EXISTING,
		FILE_ATTRIBUTE_NORMAL | FILE_FLAG_OVERLAPPED,
		NULL);

		if(hComm == INVALID_HANDLE_VALUE) printf("ASDF");
```

```
		// Get the state of the device and modify it
		dcb.DCBlength = sizeof(dcb);
		GetCommState(hComm, &dcb);
		dcb.BaudRate = CBR_19200;
		SetCommState(hComm, &dcb);

		// Set the timeout parameters nonsensically
		cto.ReadIntervalTimeout = 1000;
		cto.ReadTotalTimeoutConstant = 1000;
		cto.ReadTotalTimeoutMultiplier = 1000;
		cto.WriteTotalTimeoutConstant = 1000;
		cto.WriteTotalTimeoutMultiplier = 1000;

		SetCommTimeouts(hComm, &cto);

		// Send a command and receieve a response. Note that
		// we post the receive in advance of sending the
		// command in order not to miss anything
		char dumy[2];
		dumy[0] = actuator_no;
		dumy[1] = pos;
		WriteFile(hComm, (LPCVOID)dumy, 2, &dwWritten, &ovlw);

		if ( GetOverlappedResult(hComm, &ovlr, &dwRead, TRUE) )
		{
		szBuffer[dwRead] = 0;
		}
		// Close the device
		CloseHandle(hComm);

		return;
}

/*Function: storeToArray
USAGE: store values from CSV file to double array
CSV File Input Format: see csvout.csv
Parameters:
pInput: array pointer to be stored into (Array size MUST BE >= File line number!!)
period: period of rows to be stored ()
filename: the CSV filename to be read from (i.e. csvout.csv)
colnum: the column of the CSV file to be stored*/
int storeToArray(double* pInput, int period, char* filename, int colNum){
		/*Open input File stream*/
		FILE * pFile;
  char line [MAXLINELENGTH];
  double Pitch[NUMCOLUMN];
  double Roll[NUMCOLUMN];
  double Vert[NUMCOLUMN];
  char tempStr[NUMCOLUMN];
  int counter = 0;

  /*See if can open file...*/
  pFile = fopen (filename , "r");
  if(pFile==NULL){
				cout<<"Error opening file: \"" << filename << "\", Exiting program!"<<endl;
				return 0;
```

```
            }

        /*Read Column title*/
        fgets(line, MAXLINELENGTH, pFile);
        fgets(line, MAXLINELENGTH, pFile);
        fgets(line, MAXLINELENGTH, pFile);

        /*Read file until EOF*/
        while(fgets(line, MAXLINELENGTH, pFile) != NULL){
                        Pitch[0]=0;
                        Roll[0]=0;
                        Vert[0]=0;

                        /*See if line is too long*/
                        if (strchr(line, '\n') == NULL) {
                                /* line too long */
                                cout<<"Line too long, exiting program!"<<endl;
                                return 0;
                        }

                        /*Parse the line according to the period defined, always parse the first line*/
                        if(counter % period ==0 || counter == 0){
                                sscanf ( line, "%lf%*1s%lf%*1s%lf%", Pitch, Roll, Vert );
                                if(colNum == 0)
                                        pInput[0] = *Pitch;
                                else if(colNum == 1)
                                        pInput[0] = *Roll;
                                else
                                        pInput[0] = *Vert;
                                pInput++;
                        }
                        counter++;
        }
        /*Close file...*/
        fclose (pFile);

        return 1;
}
```

Appendix N

Alpha Design 2

We would like to note that on 10/03/2006, we spoke with Professor Dan Ferris of Kinesiology and Biomedical Engineering department regarding his knowledge of actuators. At this meeting, we came up with a concept that would be more feasible for our budget. This concept involves the use of springs and bearings.

Underneath the seating platform would be four springs, one at each corner of the platform. A cylinder with bearings on both top and bottom would be constructed and placed underneath the platform. Two motors, one in each axial direction, would be connected to the cylinder. The motors would move the cylinder in the right direction to provide pitch and roll movements. For example, if rolling to the left is desired, then the cylinder will move to the right side of the platform. This concept uses less powerful motors because the springs would provide some support for the load.

The downside to this idea could be the response time. It may take longer for the platform to be in the desired position. Because of the sudden realization of this concept, we will need to do further research, and therefore, this report will focus on the electrical actuators concepts. A concept and CAD model of Professor Ferris's idea can be viewed in Appendix G (concept J) and Appendix I respectively.