

# **Virtual Reality Flight Simulator and Educational Platform**

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**A Semester Progress Report Presented to**

**The Department of Engineering**

**Oral Roberts University**

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**In Partial Fulfillment of the Requirements for the Degree**

**Bachelor of Science**

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**Team SOAR**

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## **1. Introduction:**

### 1.1) Project Description

Team SOAR is designing and fabricating a professional quality, custom virtual reality aircraft motion simulator with six degrees of freedom utilizing a Gough-Stewart Platform design. The project idea arose when the team's advisor, Dr. Dominic Halsmer, discussed an educational aircraft research opportunity to two Team SOAR members interested in pursuing aircraft design. After much careful thought, these two students developed Dr. Halsmer's thoughts into this current project. This project is funded by Oral Roberts University's (ORU) President's Research Fund and Team SOAR is designing their project to specifications provided by personnel at ORU's Global Learning Center. These partnerships create vast opportunities for aircraft design education, as the funding guarantees a high build quality, while the virtual reality showcase room in the GLC exposes many to the final project. Because Team SOAR recognizes that they are not the first to build virtual reality aircraft motion simulators, this undergraduate level project will especially focus on two areas of uniqueness. First, the design process thoroughly utilizes engineering analysis to distinguish itself from layperson's project, and second, the simulator emphasizes aircraft design education for both engineering and non-technical audiences alike. These two areas of uniqueness will establish this project upon a solid foundation of engineering analysis, while visually welcoming others into the exciting world of aircraft design from an engineer's viewpoint.

Team SOAR has developed some secondary objectives for their project that support their primary goals. Since the project is designed as an educational experience, it must have a certain ease of use that enables non-technical GLC personnel to regularly operate and upkeep the assembly independent of Team SOAR members. In the same vein, a tutorial will be made for students of ORU's undergraduate Aircraft Design course, explaining how to create a custom plane using X-Plane 11's Plane Maker and Airfoil Maker add-ons and how to virtually fly their custom plane using Team SOAR's simulator. As a demonstration of the project's educational benefit and technical quality, the team desires to present their project at the ASEE June 2018 conference. Also, Team SOAR desires to bring about attention to their project by receiving public media coverage, which will paint ORU's commitment to scientific education in a beneficial public light. Finally, the members of Team SOAR would love to personally demonstrate their simulator's capabilities by welcoming ORU President Dr. William M. Wilson to a passive flight demonstration.

### 1.2) Applicable Standards

After much searching and waiting, the team received the ASME B30.23-2016 Personnel Lifting Systems standards on Monday, December 4th. The team believed this had the closest application to the overall project due to the focus on humans and the safety needed to lift and move them. The safety standard is for cableways, cranes, derricks, hoists, hooks, jacks, and slings. The most similar application is subsection 23 which is titled Personnel Lifting Systems. Within this subsection, the most applicable sections are those regarding design factor and construction of personnel lifting systems. Unfortunately, a closer examination of these sections reveals little relevance to the project. The team's platform does not seem to fall into the

categories of either suspended platforms or boom attached platforms, and those are the only discussed by these standards. The team initially had doubts that this set of standards could be applied to the project, so during the time period waiting for the standards to come in, they sent multiple emails to professionals in industry. None of these emails were returned, but the team will continue to research to find applicable standards for this project. Although ASME standards were originally suggested, the team believes there may be more applicable standards under the FAA.

## 2. Technical Content:

### 2.1) Flight Simulation Software

To achieve the best flight simulation experience, an appropriate simulation software had to be acquired. There were three flight simulation softwares considered for this project. These include: *X-Plane 11* that is produced by ©Laminar Research, *Prepar3D* that is produced by ©Lockheed Martin, and *Flight Simulator X* that is produced by ©Microsoft.

*X-Plane 11* was the first flight simulator to be considered. Its cost is sixty dollars before taxes. This is neither greatly expensive or inexpensive. Contained within the *X-Plane 11* download package is a fully functional Plane Maker add-on along with an Airfoil Maker add-on. These are vital to the educational aspect of the project. These add-ons seem to be very extensive and could be extremely useful in Dr. Halsmer's Introduction to Aircraft Design class. Another characteristic of *X-Plane 11* is its more than exceptional graphics and physics. It is also available through the online video game distributor ©Steam, of which the Global Learning Center has an accessible account. While undergoing structural and geometric research for the project, it was revealed that many similar projects also use *X-Plane 11* for their motion platforms. This gave great assurance for this simulation software. (X-Plane 11)

It is always important to consider alternatives when making critical decisions for a project, therefore the team broadened its selection of simulation software by also looking into ©Lockheed Martin's *Prepar3D*. Like *X-Plane 11*, *Prepar3D* is commonly used in projects that resemble this one. This was the primary reason for its consideration. Further research showed that it had comparable graphics and price to that of *X-Plane 11*. This proved that *Prepar3D* had the potential to become the project's primary simulation software; however, upon further inspection, it became clear that *Prepar3D* contained neither a Plane Maker nor an Airfoil Maker add-on. It is possible to purchase a third party with these functions, but that would cause much inconvenience and may add to the cost. For this reason, *Prepar3D* was dismissed from being the primary flight simulation software. (Prepar3D v4)

The final consideration was *Flight Simulator X*. When researching the best software for the project, these three simulators were often compared to one another with many arguing which one was the best. Due to this, it was decided that *Flight Simulator X* might be a viable option. It was revealed that, like *X-Plane 11*, it had a Plane Maker add-on. This gave it an advantage to *Prepar3D*; however, upon further inspection, it was revealed that *Flight Simulator X* has neither great graphics or physics. These are both essential qualities to the project's design. It gained slight redemption from this by being half the price of the other two options and the fact that it is

also available on ©Steam, a quality that *Prepar3D* did not have. This however did not give it the lead over either of the other simulators in the running for the project's selected software. (Microsoft Flight Simulator X: Steam Edition)

In conclusion, it was decided that *X-Plane 11* is the flight simulation software for this project. From what has been observed so far within the simulator, it seems to be visually and physically superior to the other two options. A key determining factor was its inclusion of the Plane Maker and Airfoil Maker add-ons. These are vital to the project. In the case that *X-Plane 11* fails to meet the requirements for the project, *Prepar3D* has been selected as the secondary option, while *Flight Simulator X* is the last resort option due to its inferior physics and graphical quality. *X-Plane 11* has been purchased and preliminary aircraft design and testing has begun.

## 2.2) Virtual Reality Compatibility Software

Unfortunately, none of the selected flight simulator software are virtual reality compatible by themselves. Virtual reality is essential to the definition of completeness for this project, so further research commenced. Luckily, a compatibility software was successfully discovered.

*FlyInside* is a third party software that acts as an interface between the flight simulator software and the virtual reality hardware. It can function with both the Oculus Rift and the HTC Vive; the two leading virtual reality headsets on market. *FlyInside* is also designed to be compatible with all three of the flight simulator software that have been discussed in the previous section. So far, no other compatibility software has been found to interface with the virtual reality, such that *FlyInside* has been chosen for this project. It is not overly expensive and, after pairing it with *X-Plane 11*, appears to operate exactly as the team needs it to. *FlyInside* has not been purchased yet because it is not immediately required, but will be purchased soon (Buy *FlyInside Pro*).

## 2.3) Determining the Center of Gravity of a Seated Man

The below section regarding the center of gravity utilizes data recovered from John J. Swearingen's study "Determination of Centers of Gravity of Man". It is desired that the center of gravity of the entire upper platform system, including the occupant, is contained, or nearly contained, within the plane of the junctional connection between the rods and the platform. Based on the concept of a Stewart Platform, this will allow for stable movement. The Center of Gravity of a Seated Man is shown in Figure 1.

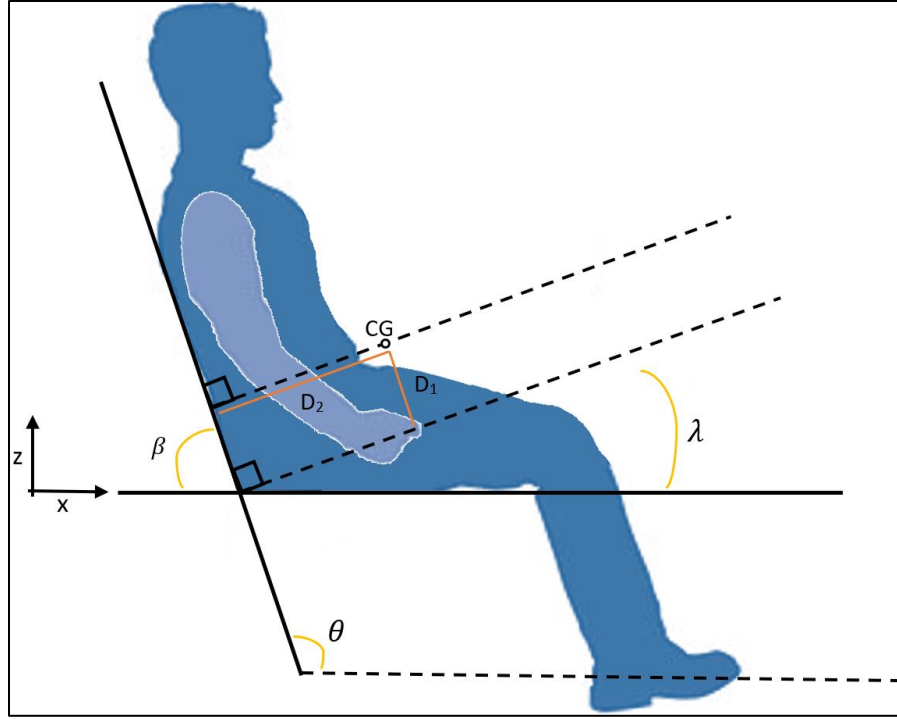


Figure 1: The Center of Gravity of a Seated Man

From page 20: Trunk  $115^\circ$ , knees  $145^\circ$ , hands on lap.

$$\theta = 115^\circ$$

$$\beta = 180^\circ - \theta = 65^\circ$$

$$\lambda = 180^\circ - 90^\circ - \beta = 25^\circ$$

$$D_1 = 7.75 \text{ inches}$$

$$D_2 = 9.4 \text{ inches}$$

From the figure above:

$$\begin{aligned} \overline{CG_x} &= -D_1 \cos \beta + D_2 \cos \lambda \\ \rightarrow \overline{CG_x} &= -7.75 \cos 65^\circ + 9.4 \cos 25^\circ = \mathbf{5.24 \text{ inches}} \\ \overline{CG_z} &= D_1 \sin \beta + D_2 \sin \lambda \\ \rightarrow \overline{CG_z} &= 7.75 \sin 65^\circ + 9.4 \sin 25^\circ = \mathbf{11 \text{ inches}} \end{aligned} \quad \left. \vphantom{\begin{aligned} \overline{CG_x} &= -D_1 \cos \beta + D_2 \cos \lambda \\ \rightarrow \overline{CG_x} &= -7.75 \cos 65^\circ + 9.4 \cos 25^\circ = \mathbf{5.24 \text{ inches}} \\ \overline{CG_z} &= D_1 \sin \beta + D_2 \sin \lambda \\ \rightarrow \overline{CG_z} &= 7.75 \sin 65^\circ + 9.4 \sin 25^\circ = \mathbf{11 \text{ inches}} \end{aligned}} \right\} \text{ (Results of the study)}$$

Due to the weight of the chair and platform, the center of gravity of the entirety of the upper platform with a seated person is expected to be lower than the above value for the z-direction. As a simple approximation, and for convenience in secondary results, the height of the center of gravity has been lowered by two inches.  $\rightarrow \overline{CG_z} = h_{cg} = \mathbf{9 \text{ inches}}$

#### 2.4) Determining the Fundamental Geometry of the System

Here, in Figures 2 and 3, an observation of the isolated heave experienced by a singular actuation arm system is made to simplify the geometric variables affecting the overall system. This is quite necessary considering that the system has an exceptionally complex geometry.

When confined to heave, the connecting junctions between the upper platform and the rods remain within a constant plane. This is exhibited below.

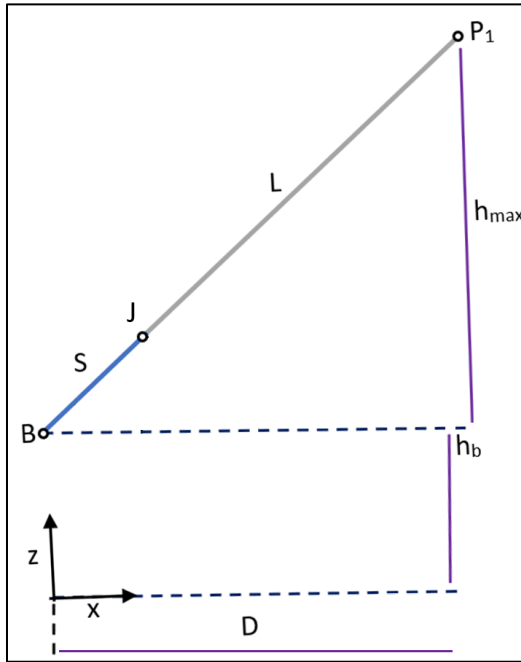


Figure 2: Actuating Arms (Max Height)

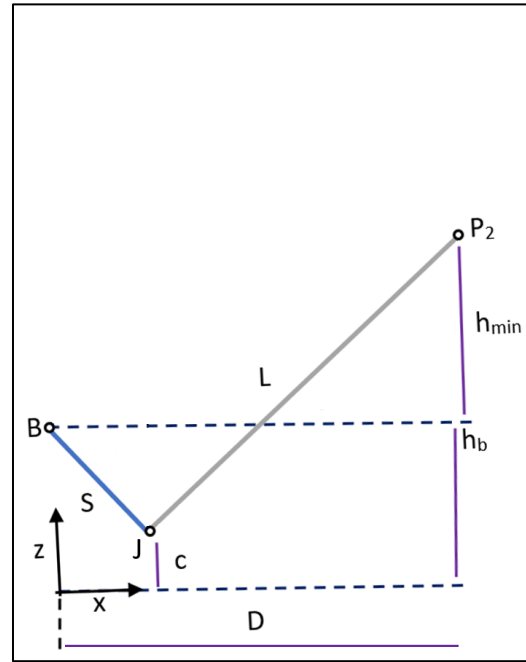


Figure 3: Actuating Arms (Min Height)

Where:

- $L$  is the length of the upper actuating arm.
- $S$  is the length of the lower actuating arm.
- $J$  is the joint between the upper and lower actuating arms.
- $B$  is the point of rotational actuation (motor shaft).
- $P$  is the location of the platform rotational junction.
- $D$  is the distance (within the  $x$ -direction) from  $B$  to  $P$ .
- $h_b$  is the height of point  $B$  from ground level.
- $h_{min}$  is the lowest heave position.
- $h_{max}$  is the highest heave position.
- $c$  is the clearance between point  $J$  and the ground when  $P$  is at  $h_{min}$ .

When Figures 2 and 3 are overlaid upon each other, geometric relationships can be made between the two extreme states of heave. This is observed in Figure 4.

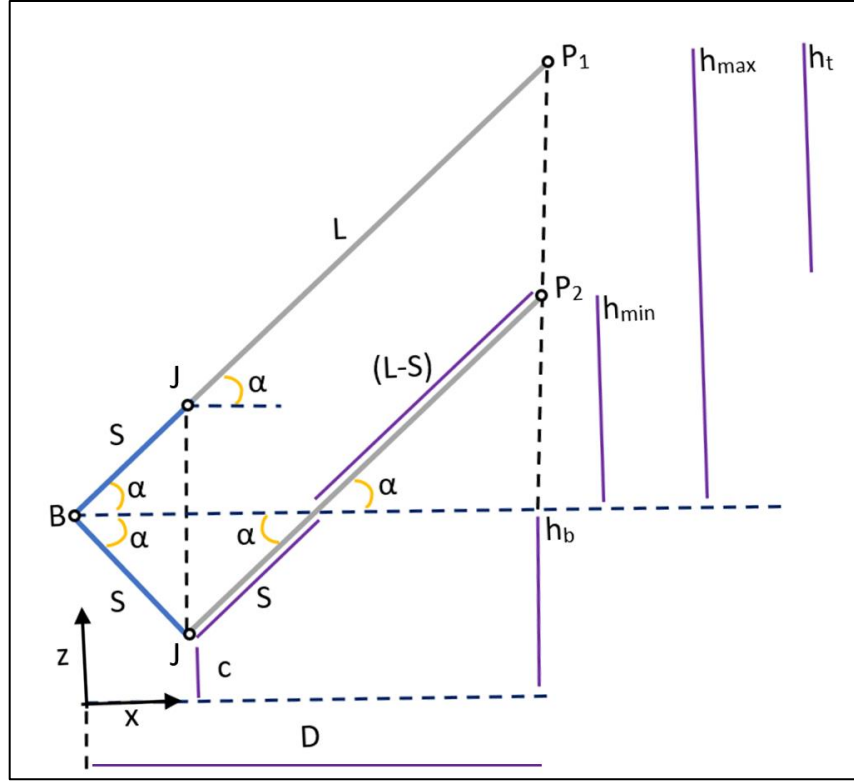


Figure 4: Relating Maximum and Minimum Heave Positions

Where:

- $\alpha$  is the angle of actuation produced by the motors. (Both states, maximum and minimum heave, have this angle of actuation for the sake of symmetry across the horizontal plane)
- $h_t$  is the total heave range experienced by the platform.
- $z_{P1}$  (not seen in the figure) is the total height, from the ground, to point  $P_1$
- $z_{P2}$  (not seen in the figure) is the total height, from the ground, to point  $P_2$
- $h_s$  (not seen in the figure) is the height of the platform's seat from the ground
- $h_{cg}$  (shown in the "Determining the Center of Gravity of a Seated Man" section) is the height of the Center of Gravity measured in the positive vertical direction from the platform's seat.

Geometrically from Figure 4:

$$\begin{aligned}
 h_{max} &= (L + S) \sin \alpha \\
 h_{min} &= (L - S) \sin \alpha \\
 D &= (L + S) \cos \alpha \\
 h_t &= h_{max} - h_{min} = (L + S) \sin \alpha - (L - S) \sin \alpha \\
 &\rightarrow h_t = 2S \sin \alpha \\
 h_b &= S \sin \alpha + c
 \end{aligned}$$

Using Eq. 1, 2, and 5:

$$\begin{aligned}
 z_{P1} &= h_{cg} + h_s + h_t = h_{max} + h_b = (L + S) \sin \alpha + S \sin \alpha + c \\
 &\rightarrow z_{P1} = (L + 2S) \sin \alpha + c
 \end{aligned}$$



$$z_{P2} = h_{cg} + h_s = h_{min} + h_b = (L - S) \sin \alpha + S \sin \alpha + c$$

$$\rightarrow z_{P1} = L \sin \alpha + c$$

Setting:

- $h_s = 1.5 \text{ ft} = 18 \text{ inches}$  (the average height of a standard chair)
- $h_{cg} = 9 \text{ inches}$  (“Determining the Center of Gravity of a Seated Man”)
- $h_t = 10 \text{ inches}$  (arbitrarily chosen total heave based on *GA-Dawg*’s simulation platform)
- $c = 2 \text{ inches}$  (arbitrarily chosen distance of clearance)

Using Eq. 7 and 4, along with the values above:

$$z_{P2} = 9 + 18 = 27 = L \sin \alpha + 2$$

$$\rightarrow L \sin \alpha = 25$$

$$\rightarrow \sin \alpha = \frac{25}{L}$$

$$h_t = 10 = 2S \sin \alpha$$

$$\rightarrow S \sin \alpha = 5$$

$$\rightarrow \sin \alpha = \frac{5}{S}$$

$$\rightarrow \sin \alpha = \frac{25}{L} = \frac{5}{S}$$

$$\rightarrow \frac{S}{L} = \frac{1}{5}$$

The overall system will contain six mirrored pairs of the actuating arm subsystem detailed above. Each  $P_i$  and  $B_i$ , along with the distance  $D$  between them, is laid out in an equilateral triangular formation (Figure 5). This alignment allows for the Hiem joints, the rotational mounts at both ends of each upper rod, to be set to a neutral point when the system is at rest. This will allow for a complete range of motion in either direction of the joint upon actuation. Figure 5 below depicts the general layout of this system.

Where:

- $Q$  is the distance between conjoined  $P_i$  locations.
- $O$  is the length of the extensions from the upper platform to the point  $P_i$ .
- $N$  is the distance between conjoined  $B_i$  locations.
- $D_B$  (not seen in the figure) is the inner diameter of the base platform represented by the circle seen below in Figure 5.
- $M$  is the point of triangulation upon the inner diameter of the base platform.

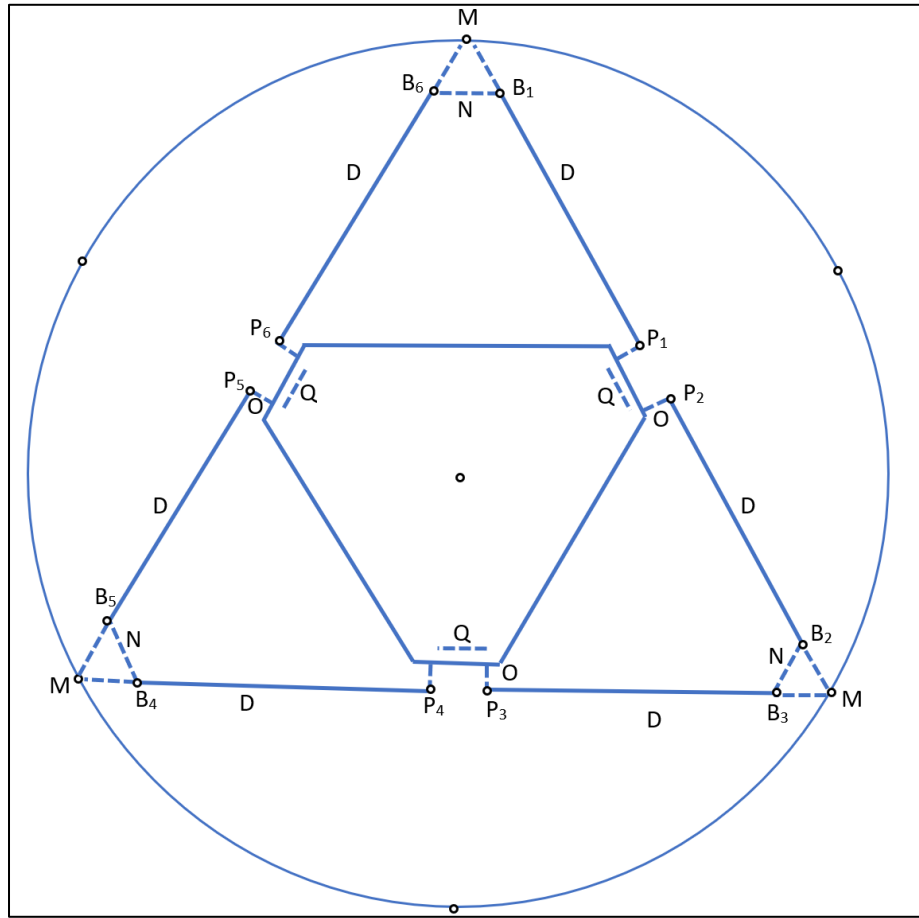


Figure 5: Geometric Arrangement of Platforms

When calculating the length between  $M$  points ( $L_M$ ), the chord length equation must be used.

$$L_M = 2r \sin \frac{A}{2} = D_B \sin \frac{120^\circ}{2}$$

$$\rightarrow L_M = \frac{\sqrt{3}}{2} D_B = 2D + 2N + Q$$

$$\rightarrow D_B = \frac{2}{\sqrt{3}} (2D + 2N + Q)$$

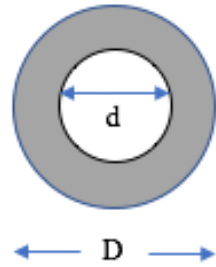
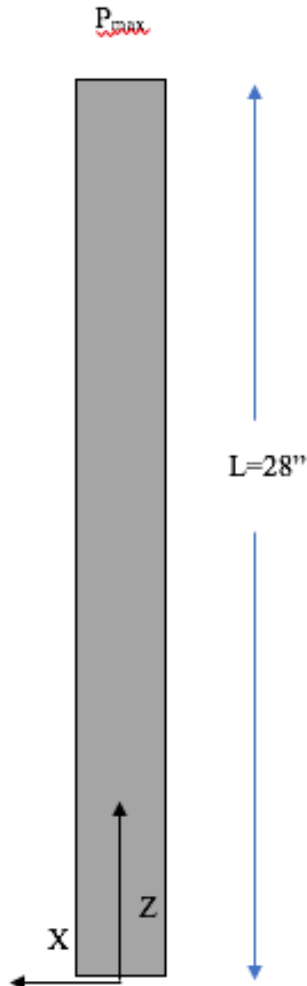
## 2.5) Stress Analysis

For analyzing the stress being experienced in each member of the design, the team will need to do an inverse-kinematic equation that governs the entire platform. This equation is quite complicated, however, and even with the help of documents found by PhD research students, it will take the team some time to solve. Since the team is needing to purchase materials here shortly, they had to come up with a simple solution to estimate what requirements the material will need to support. The solution was to simplify by creating a “worst case” impossible scenario. Since the team is saying that the max weight in the top of the platform will be 300 lbs, they did their stress estimations by applying the entire load to single members. Due to the setup

of the platform, this scenario should never occur, but if we can prove that our design can hold up well under this case, then there should be no chance of failure at any point during use. A factor of safety of 2 has been implemented as there is still not a set factor of safety defined by any standards as of yet. Using these parameters, stress analysis has been conducted on the upper connecting rods and bolts that connect to the Heim joints.

Upper connecting rod:

Analysis for Buckling:



A513 Steel

Material Properties:

Modulus of Elasticity  $E_{avg}$ : 29007.5 ksi

Yield Strength  $\sigma_y$ : 84,100 lb/in<sup>2</sup>

$d=0.75$  in

Defined Variables:

$P_{max}=300$  lb

$L=28$  in

Factor of Safety (F.S.) = 2

$$P_{Cr} = P_{max} \cdot F.S. = 600 \text{ lb}$$

$$I_x = \frac{\pi}{32} (D^4 - d^4) \text{ in}^4$$

$$P_{Cr} = \frac{\pi^2 EI}{L^2}$$

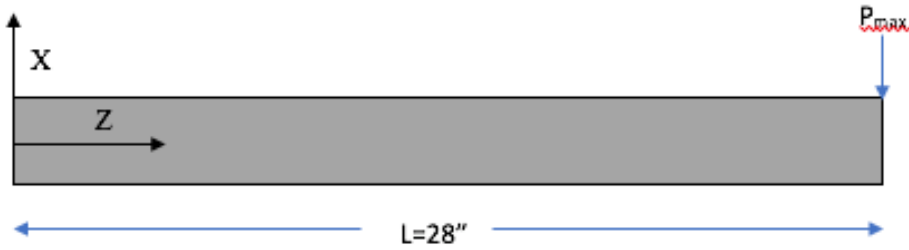
Rearranging and inserting Moment of inertia equation

$$\frac{\pi}{32} (D^4 - d^4) = \frac{P_{Cr} L^2}{\pi^2 E}$$

$$\frac{1}{32} (D^4 - 0.75^4) = \frac{600 \cdot 28^2}{\pi^3 \cdot 29,007 \cdot 10^3}$$

$$D = 0.759727 \text{ in}$$

The outer diameter will be larger than 0.76 in so no chance of buckling



Analysis for Bending:

$$\sigma_y = \frac{Mc}{I_y}$$

$$M = P_{cr} \cdot L$$

$$I_y = \frac{\pi}{32} (D^4 - d^4)$$

$$c = \frac{D}{2}$$

$$\sigma_y = \frac{2 \cdot P_{max} L \frac{D}{2}}{\frac{\pi}{32} (D^4 - d^4)}$$

Rearranging:

$$\frac{32 P_{max} L D}{\pi \sigma_y} = (D^4 - d^4)$$

$$\frac{32 \cdot 300 \cdot 28 \cdot D}{\pi \cdot 84,100} = (D^4 - 0.75^4)$$

$$D = 1.093 \text{ in}$$

This was useful information as our original plan was to go with an outer diameter of 0.875 in.

## 2.6) Fatigue Analysis

Outer diameter set to 1.125 in:

$$\sigma = \frac{Mc}{I_y}$$

$$M = P_{cr} \cdot L$$

$$I_y = \frac{\pi}{32} (D^4 - d^4)$$

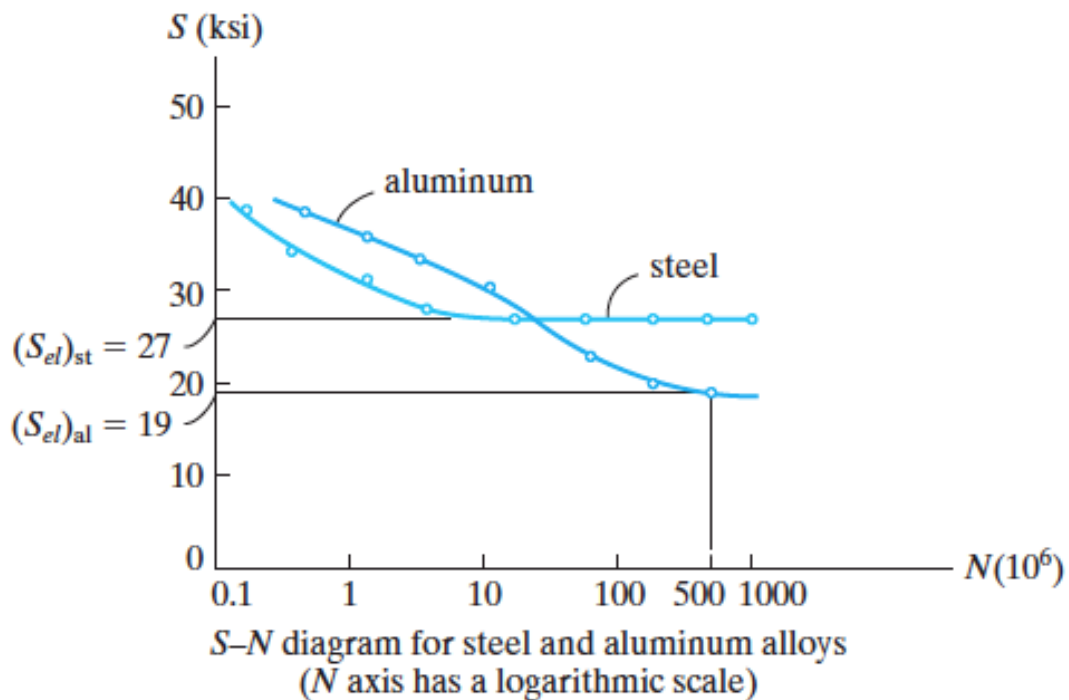
$$c = \frac{D}{2}$$

$$\sigma = \frac{P_{max} L \frac{D}{2}}{\frac{\pi}{32} (D^4 - d^4)}$$

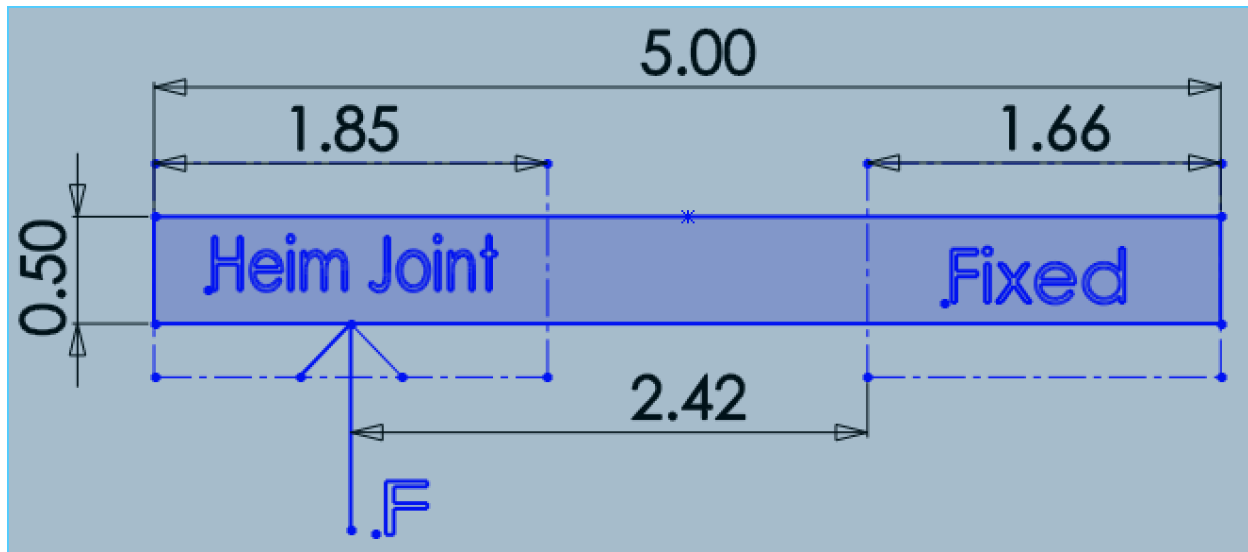
$$\sigma = \frac{150 \cdot 28 \cdot 1.125}{\frac{\pi}{32} (1.125^4 - 0.75^4)}$$

$$\sigma = 37.4 \text{ ksi}$$

Due to the graph given below from the Mechanics of Materials textbook, the beams should be able to support about 0.5 million cycles at this load. Since this load should never occur and the platform won't be in constant use to approach this value, the platform is not expected to fail due to fatigue.



## 2.7) Bolt Mechanics



- Zinc Plated Stainless Steel Grade 8
- Yield Strength: 130 ksi
- $F_{\max} = 300 \text{ lb}$
- Factor of Safety: 2



1/2-13 x 5 in. Zinc-Plated Grade 8 Hex Bolt

★★★★ Write the first Review Ask the first question

**\$2<sup>12</sup>** /each

### Product Overview

These Grade 8 cap screws are recommended for high stress bolting applications and are the among the strongest grade of fastener available in steel. The grade 8 bolt... See Full Description

Shearing analysis:

$$\text{Shear Stress: } \tau = \frac{F}{A}$$

$$\frac{F}{\frac{\pi * D^2}{4}} = \frac{2 * (300 \text{ lb})}{\frac{\pi * (.5 \text{ in})^2}{4}} = 3055.8 \text{ psi}$$

$$3055.8 \text{ psi} < 130,000 \text{ psi}$$

$\therefore$  Bolt will not fail due to shear stress

Minimum bolt diameter based on Shear:

$$\tau = \frac{F}{A} \rightarrow A = \frac{F}{\tau} \rightarrow \frac{\pi * D^2}{4} = \frac{F}{\tau}$$

$$\rightarrow D_{\min} = \sqrt{\frac{4 * F}{\pi * \tau_{\text{yield}}}}$$

$$D_{\min} = \sqrt{\frac{4 * (600 \text{ lb})}{\pi * (130,000 \text{ psi})}} = 0.0767 \text{ inches}$$

∴ The minimum diameter for a bolt with the maximum possible force is 0.0767 inches

Bolt bending analysis:

$$\begin{aligned}\sigma_y &= \frac{M * c}{I} \\ M &= F * L \\ I &= \frac{\pi * D^4}{64} \\ c &= \frac{D}{2} \\ \rightarrow \sigma_y &= \frac{32 * F * L}{\pi * D^3} = \frac{32 * (2 * 300 \text{ lb}) * 2.4225 \text{ in}}{\pi * (0.5 \text{ in})^3} = 118,442 \text{ psi} > 130,000 \text{ psi}\end{aligned}$$

Minimum bolt diameter:

$$D_{\min} = \left( \frac{32 * F * L}{\pi * \sigma_y} \right)^{\frac{1}{3}} = \left( \frac{32 * (2 * 300 \text{ lb}) * 2.4225 \text{ in}}{\pi * 130,000 \frac{\text{lb}}{\text{in}^2}} \right)^{\frac{1}{3}} = 0.48472 \text{ in}$$

F<sub>max</sub> on 0.5 in bolt:

$$F_{\max} = \frac{\sigma_y * \pi * D^3}{32 * L} = \frac{130,000 \frac{\text{lb}}{\text{in}^2} * \pi * (0.5 \text{ in})^3}{32 * 2.4225 \text{ in}} = 658.55 \text{ lb}$$

## 2.8) Inverse-Kinematic Problem

An inverse dynamics problem is one in which such variables as angular acceleration and position are given first, and the torque and forces are solved afterwards. It is this type of problem that the team can use to solve for the stresses and forces being experienced in every member. This type of analysis is very challenging and the team did not come across academic material to aid them in this effort until towards the end of the semester. As such, the team has made almost no progress as of now in solving this equation for their design. However, the team recently discovered a source called *Solving the Inverse Dynamics of a Stewart-Gough Manipulator by the Principle of Virtual Work* by Lung-Wen Tsai from the University of Maryland. The work seems to outline fairly clearly the method by which the team could solve the equation so they plan to begin working through his material at the beginning of next semester. The following figure was taken from that work to illustrate how it could be applied later.

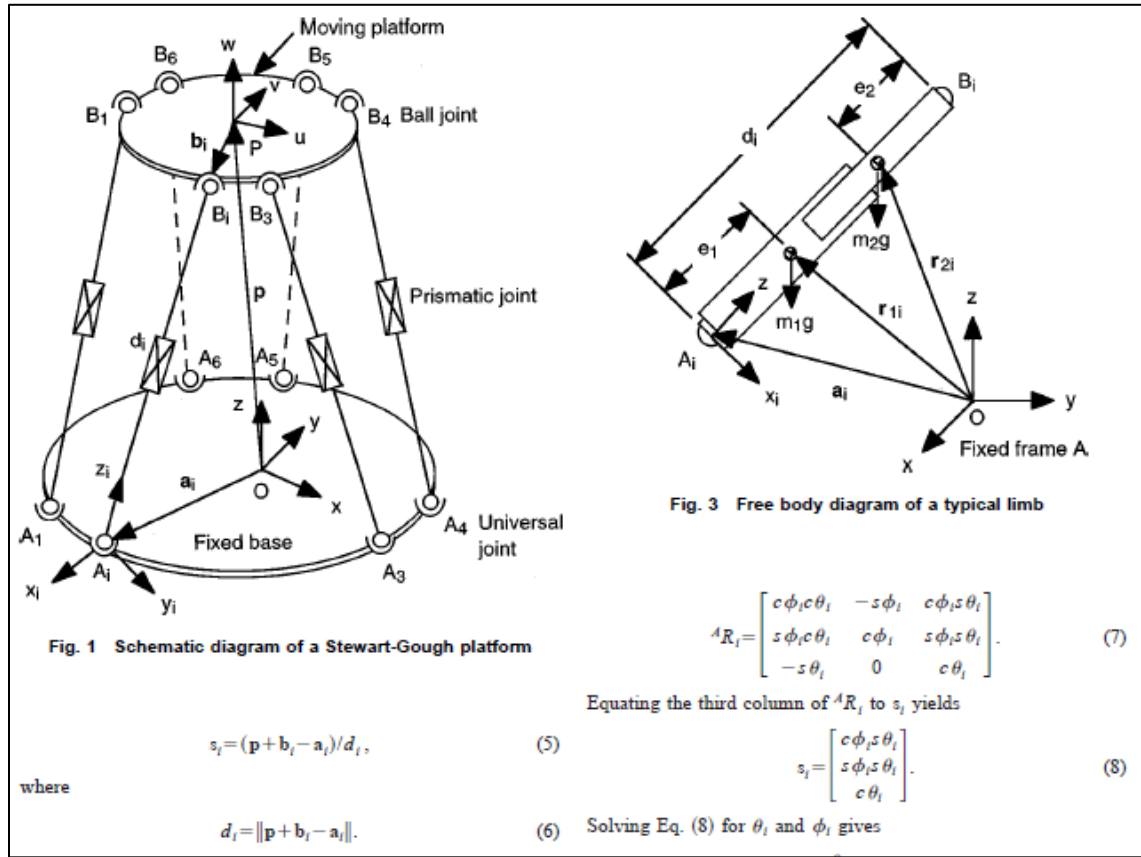


Figure 6: Diagram of a Stewart Platform for Inverse Kinematics Problem

## 2.9) Creating the ©SolidWorks Model

From Figures 4 and 5, along with the geometric relationships gathered from them, a ©SolidWorks schematic could be created. Before commencing in the official model of the team's system, a general understanding of creating a Stewart Platform within ©SolidWorks was required. This was first achieved by replicating Stewart Platform designs that were observed online. The first of these models was based upon the XSimulator member *Silentchill*'s custom Stewart Platform and can be observed below in Figure 7.





Figure 7: Basic ©SolidWorks model of *Silentchill's* System

Once this basic understanding of modeling a Stewart Platform had been made, the team initiated the design of a small model within ©SolidWorks that could be three dimensionally printed and interfaced with the simulation software to provide a proof of concept and to begin preliminary programming. This miniature model was based upon the design of *GA Dawg*, an online simulator platform designer. His fundamental layout highly resembled the team's and would therefore give a relatively appropriate demonstration of the team's system. Micro Servo 9g SG90 motors were purchased for this model before a design had been laid out. These provided the basis for dimensioning the small model. An exact ©SolidWorks model of these motors was downloaded from GrabCAD, an online CAD sharing site, for free (Simon). The model showed that the lower actuation arm of the micro servo is approximately 14.1 millimeters in length. When compared to *GA-Dawg's* lower actuation arm's length of 160 millimeters, a ratio of proportionality could be determined. This is shown by the equations presented below.

$$\frac{\text{Reference Scale Length}}{\text{Reference GA Dawg Length}} = \frac{\text{Desired Scale Length}}{\text{GA Dawg Length}}$$

$$\rightarrow \frac{14.1 \text{ (mm)}}{160 \text{ (mm)}} = 0.0881875 = \frac{\text{Desired Scale Length}}{\text{GA Dawg Length}}$$

$$\rightarrow 0.0881875 * \text{GA Dawg Length} = \text{Desired Scale Length}$$

Such that:

Table 1: Determined Scale Lengths Alongside the Originals

Dimension*	GA-Dawg's 6 DOF Build	Calculated Scale Length
1. Lower Actuation Arm	160 (mm)	14.1 (mm)**
2. Upper Actuating Arm	630 (mm)	55.55 (mm)
3. Distance Between Upper Mounts	101.6 (mm)	8.96 (mm)
4. Upper Platform Diameter	830 (mm)	73.2 (mm)
5. Lower Platform Diameter	1226 (mm)	108.118 (mm)

\*The dimensions of the scale model are shown in red within the Figures displayed below. They are numbered according to Table 1.

\*\*The length of the scaled lower actuating arms was not calculated, but rather determined by their physical length.

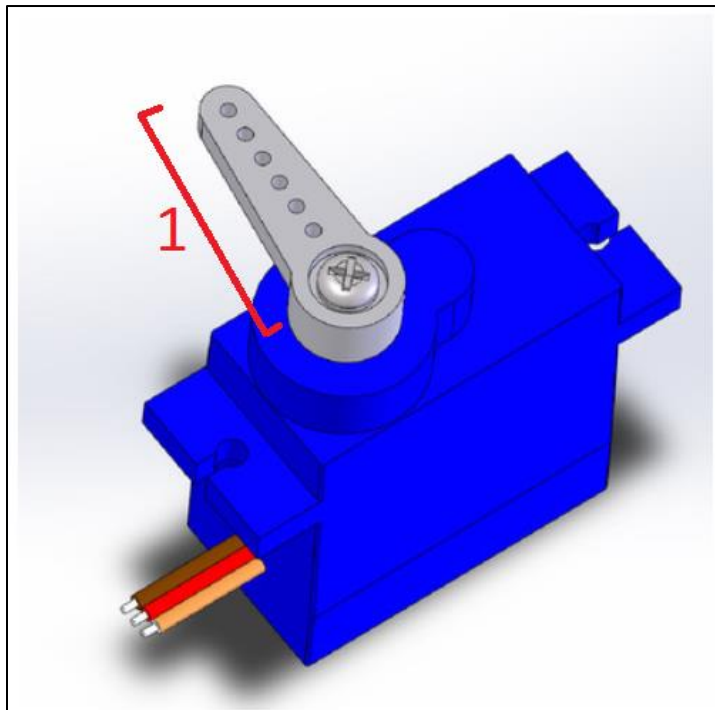


Figure 8: Micro Servo 9g SG90 (Simon)

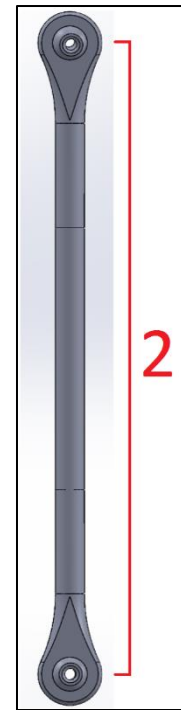


Figure 9: Upper Actuation Arm

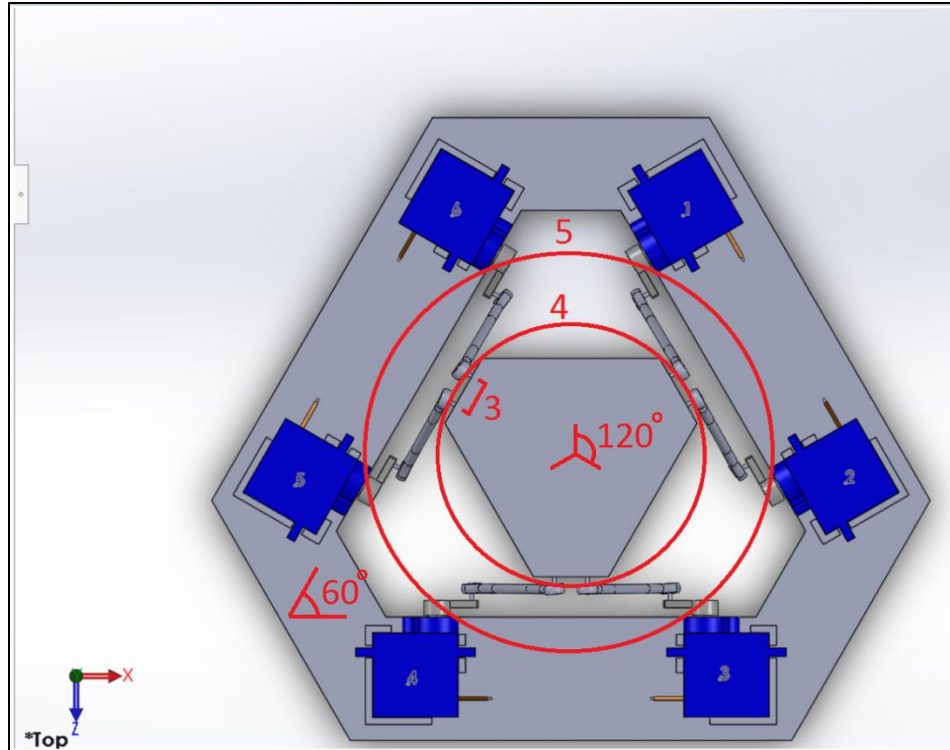


Figure 10: Top View of Scale Model Assembly with Dimension Indications

The completed ©SolidWorks model can be observed below in Figure 10. This model was then three dimensionally printed and assembled. The physical assembly is shown in Figure 11. Once assembled, the system was interfaced with simulation software so that trial operations could be performed. The electrical and computer aspects of this scale model are presented in the following subsection.

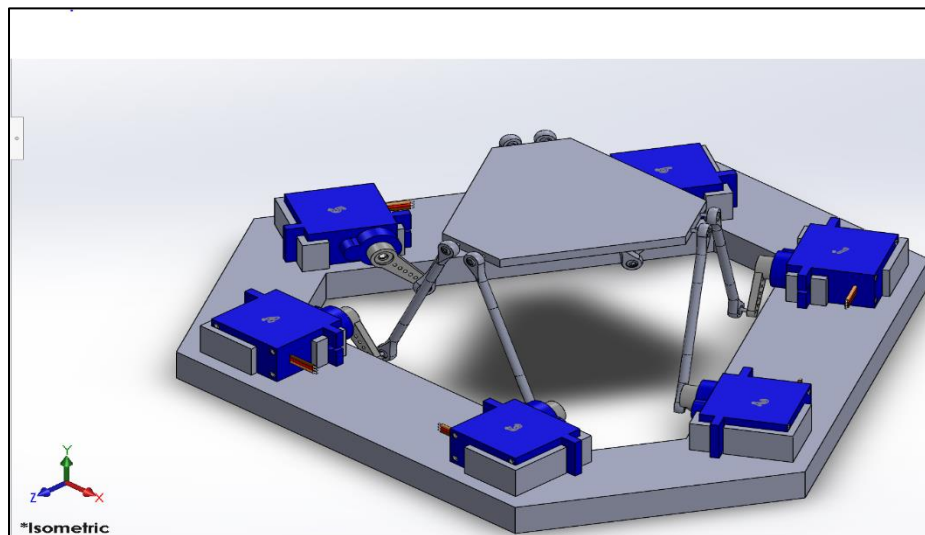


Figure 11: Isometric View of Scale Model Assembly

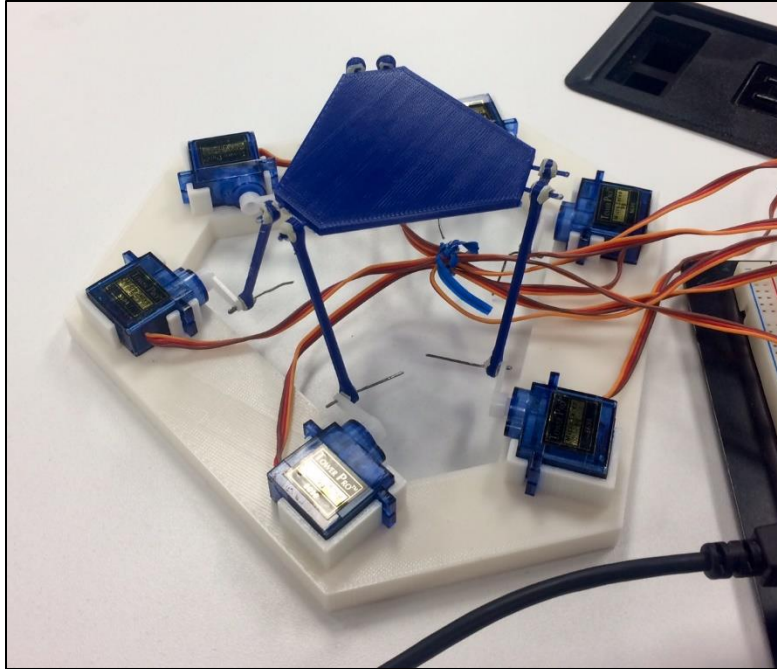


Figure 12: Constructed Scale Model Assembly

Once this scaled model was created, the team began designing the actual system within ©SolidWorks. Multiple Heim joints have been considered for this project through structural analysis. It was important to design the models of these joints to exact specification such that accuracy could be assured within ©SolidWorks.

The first one considered was the  $\frac{3}{4}$  inch Heim joint seen below in Figure 12. It was made to the specifications presented by QS Components, the company that manufactures them. It was assembled with an accompanying bung and two high misalignment spacers. A few measurements had to be assumed because they were not explicitly shown. The upper thickness of the bung was assumed to be  $\frac{1}{8}$  inch, the diameter of the ball joint was assumed to be  $1\frac{1}{4}$  inches, the fillets on the body of the joint were made to be  $\frac{1}{10}$  inch, and the curved portion of the high misalignment spacers were modeled to match the curvature of the ball. Obviously, this will cause some inaccuracies in the model; however, without additional measurement specifications, the model could not be made any more accurate.

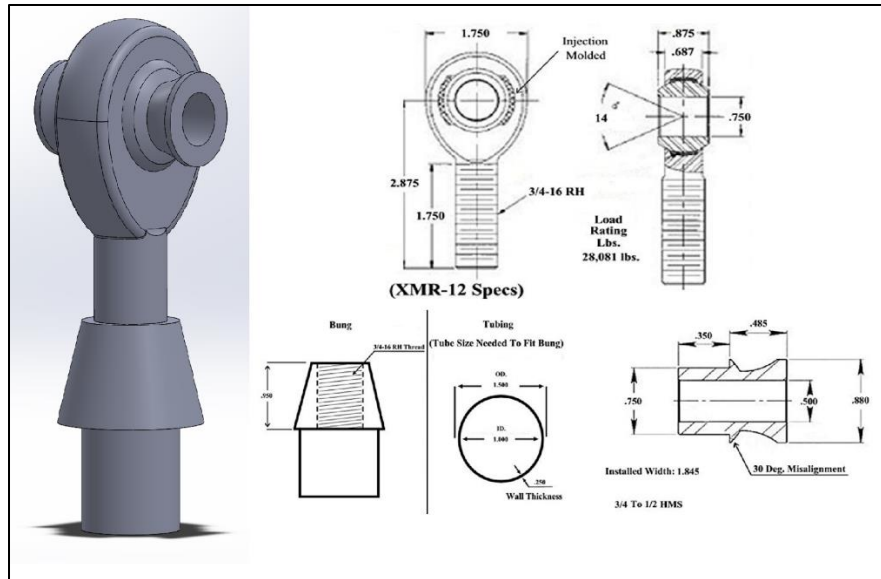


Figure 13: ©SolidWorks modeled  $\frac{3}{4}$  inch Heim joint made to specification

After additional structural calculations,  $\frac{1}{2}$  inch Heim joints were considered to reduce the overall weight of the upper platform system. All the dimensions were determined from within the schematic in Figure 13; however, any non-specified dimensions had to be assumed. The primary dimension to be assumed was the diameter of the ball contained within the Heim joint. This was estimated to be 0.9 inches. Additional Heim joints may need to be created if further structural analysis calls for it.

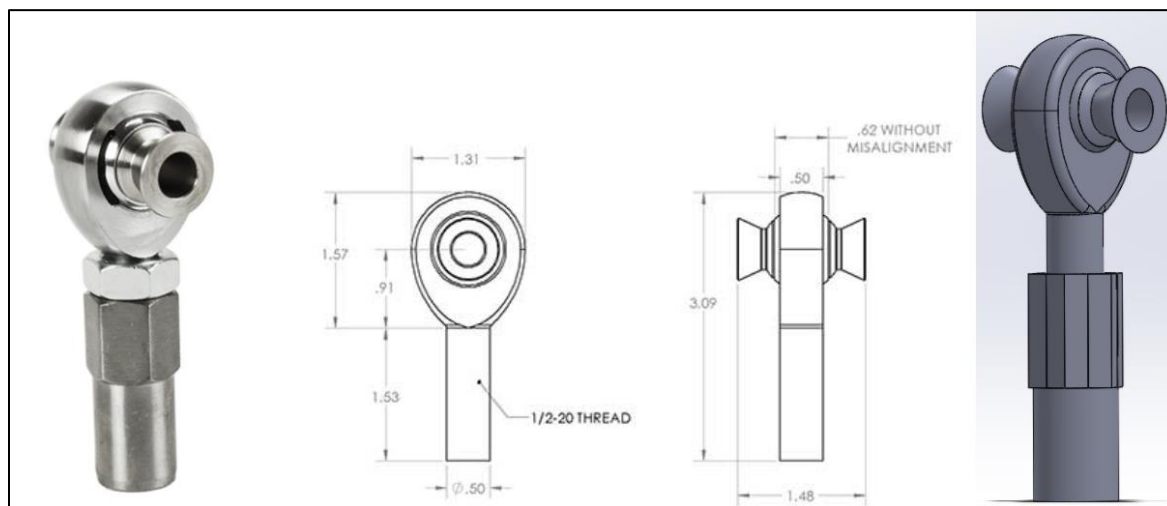


Figure 14: ©SolidWorks modeled  $\frac{1}{2}$  inch Heim joint made to specification

To further define the geometry and special requirements of the system, a simulator chair needed to be chosen and designed around. A high-quality white and black simulator chair was purchased, measured, and then designed in ©SolidWorks. The chair had varying degrees of recline that could be adjusted, but a permanent angle of  $9^\circ$  of incline was chosen as an appropriate and comfortable position. At this angle, the height of the chair is 36in. The width of the base is 21.25in. and the length is 21in. with a height of 4.5in. in the center, and 6in on the

edges. The chair was designed in ©SolidWorks to these dimensions and is displayed in Figure 14.



Figure 15: Simulator chair modeled in ©SolidWorks

It was then established that a leg room containment system needed to be developed to help secure the passengers legs and protect them from any collisions within the system. Our system also needed to be built with enough space to fit a passenger's legs without any collisions, and modeling the system helped visualize those design restraints. The leg room system was designed to accommodate people of different heights and sizes and be adjustable to various leg lengths. After measuring several lengths of people's legs from the knee down, an average length of 24in was decided upon and designed around. An angle of 45° was chosen as a balance of keeping the legs off the ground without having them stick out too far. The passenger's feet will be set on foot pedals and strapped into foot holsters. Although straps will hold the passengers feet in place, a simple pedal is displayed in the ©SolidWorks model shown in Figure 15 below.



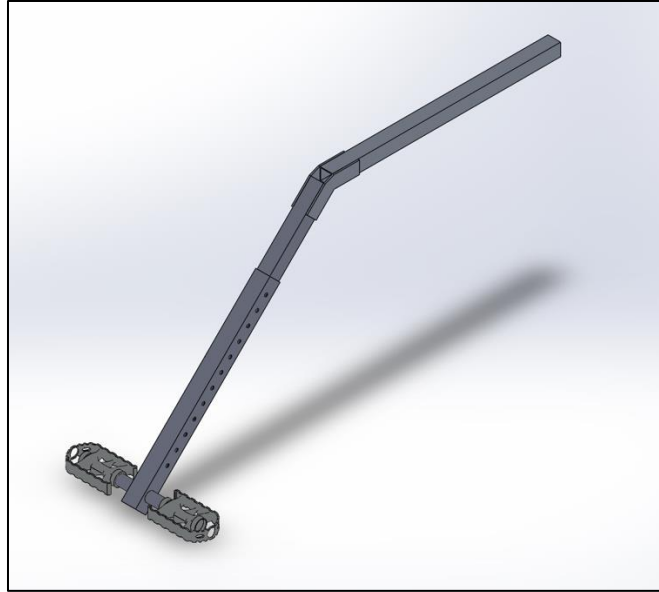


Figure 16: Foot Holder

To determine dimensional lengths of the overall system, the governing equations from the “Determining the Fundamental Geometry of the System” subsection were utilized. Table 2 displays the calculated dimensions from Eq. 3, 4, 8, and 9 when the  $D_B$  and  $N$  values were arbitrarily determined. Initial calculations all resulted in inadequate space for the occupant’s legs when the platform underwent maximum yaw – rotation about the Z-axis. Due to this dilemma, multiple iterations were performed.

Table 2: Geometric Alteration

$D_B^*$	$N^*$	$L$	$S$	$\alpha$
68 inches	10 inches	28.75 inches	5.75 inches	60.4°
96 inches	24 inches	28.1 inches	5.6 inches	62.3°
108 inches	28 inches	28.75 inches	5.75 inches	60.8°
120 inches	36 inches	27.5 inches	5.5 inches	65°
<b>108 inches</b>	<b>30 inches</b>	<b>27.5 inches</b>	<b>5.5 inches</b>	<b>63.8°</b>

\* Independent Geometric Variables

The independent variables were altered such that the actuation arm lengths could be determined. After this, the ©SolidWorks model would then be observed to give indication whether the feet of the simulator’s occupant would impact either the rotational arms or the motor mounts. The final variation in Table 2 is currently the best option, although further adjustment may need to be performed. This variation can be observed below in Figure 16, which exhibits the platform from above. Make note that the layout in Figure 5 is employed within the design schematic presented below.

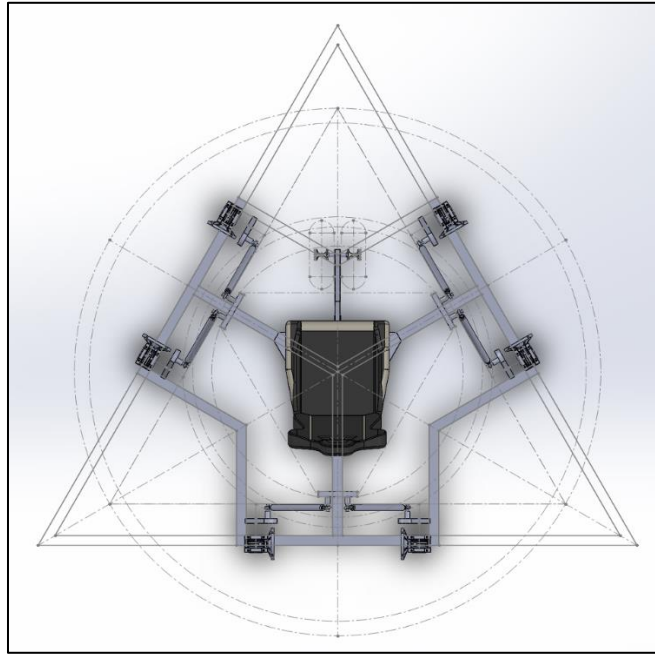


Figure 17: Top View of the Stewart Platform

In Figure 17 below, an image of the system undergoing theoretical maximum yaw can be observed. This was the point of greatest concern for passenger foot clearance. As can be seen in the figure, there is an oval outline that represents the feet of the platform's occupant. These ovals are measured to be 14 inches long and 5 inches wide. This should encompass most feet sizes. when the platform undergoes complete yaw, this sketch does not interfere with the Heim joints, such that the foot zones have safe clearance.

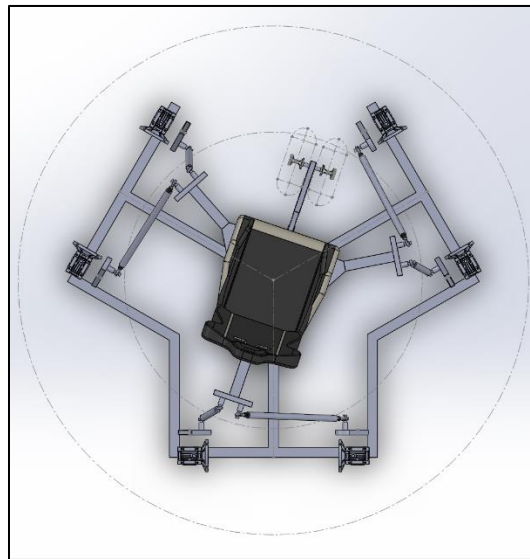


Figure 18: Top View of Stewart Platform Experiencing Maximum Theoretical Yaw



Although the selection of motors and gearboxes has not yet been solidified, an idea of what may be chosen has been presented. To produce a functionally accurate model, the WGA-50M-060-H1 60:1 Gearbox was selected as a stand in model shown in Figure 18. This model was taken directly from the Automation Direct website and may potentially be used on the actual system. Therefore, it was vital to incorporate them within the complete ©SolidWorks model to further solidify the geometry of the system. A complete isometric view of the platform is exhibited in Figure 20.

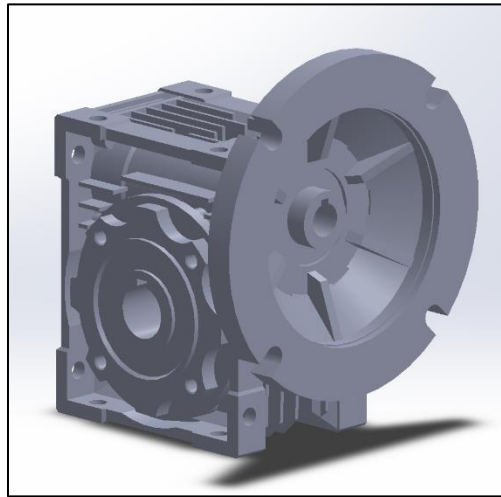


Figure 19: WGA-50M-060-H1 60:1 Gearbox



Figure 20: Isometric View of Stewart Platform

The base platform was reduced from its complete triangular structure so that the space constraints could be maintained. The pattern for this platform has been arbitrarily chosen as of now, but will become more greatly defined before construction begins.

#### 2.10) Scale Model Software Configuration

One main purpose of the scale model was to configure software settings and understand the capabilities of SimTools and *X-Plane*. SimTools controls the signal outputs to each of the

motors based on the levels selected in the Game Engine. The settings selected for the small-scale model are represented in Figures 21-23 below. These were customized to the design of the Stewart Platform and are expected to be used for the full-scale model.



Figure 21: RC Model SimTools Axis Assignments Settings Part One



Figure 22: RC Model SimTools Axis Assignments Settings Part Two



Figure 23: RC Model SimTools Interface Settings

### 2.11) Arduino Code

The following code was downloaded using Arduino IDE software onto the COM3 port which was connected to the Arduino UNO board. Using serial communication, the code allows SimTools to control the Arduino by putting commands in the Interface – Output slot shown in Figure 23 above.

```

/*****
// RC Model Servo
// Original code By EAOROBIE (Robert Lindsay)
// Edited by Aarondc and Matthew Samuelson
*****/
#include <Servo.h>
#define DEBUG 1 // comment out this line to remove
debuggin Serial.print lines
const int kActuatorCount = 6; // how many Actuators we are handling

// the letters ("names") sent from Sim Tools to identify each actuator
// NB: the order of the letters here determines the order of the remaining constants
kPins and kActuatorScale
const char kActuatorName[kActuatorCount] = {'A', 'B', 'C', 'D', 'E', 'F'};
const int kPins[kActuatorCount] = {2, 3, 4, 5, 6, 7};
// pins to which the Actuators are attached
const int kActuatorScale[kActuatorCount][6] = { { 0, 179 } ,
// Right Actuator scaling
{ 179, 0 } ,
// Left side Actuator scaling
{ 0, 179 } ,

```

```

        { 179, 0 } ,
        { 0, 179 } ,
        { 179, 0 }
    };

const char kEOL = '~';
// End of Line - the delimiter for our acuator values
const int kMaxCharCount = 3; // some insurance...
Servo actuatorSet[kActuatorCount]; // our array of Actuators
int actuatorPosition[kActuatorCount] = {90, 90};
// current Actuator positions, initialised to 90
int currentActuator;
// keep track of the current Actuator being read in from serial port
int valueCharCount = 0;
// how many value characters have we read (must be less than kMaxCharCount!)

// set up some states for our state machine
// psReadActuator = next character from serial port tells us the Actuator
// psReadValue = next 3 characters from serial port tells us the value
enum TPortState { psReadActuator, psReadValue };
TPortState currentState = psReadActuator;

void setup()
{
    // attach the Actuators to the pins
    for (int i = 0; i < kActuatorCount; i++)
        actuatorSet[i].attach(kPins[i]);

    // initialise actuator position
    for (int i = 0; i < kActuatorCount; i++)
        updateActuator(i);

    Serial.begin(9600); // opens serial port at a baud rate of 9600
}

void loop()
{

}

// this code only runs when serial data is available. ie (Serial.available() > 0).
void serialEvent() {
    char tmpChar;
    int tmpValue;

    while (Serial.available()) {
        // if we're waiting for a Actuator name, grab it here
        if (currentState == psReadActuator) {
            tmpChar = Serial.read();
            // look for our actuator in the array of actuator names we set up

#ifdef DEBUG
            Serial.print("read in ");
            Serial.println(tmpChar);
#endif

            for (int i = 0; i < kActuatorCount; i++) {

```

```

        if (tmpChar == kActuatorName[i]) {
#ifdef DEBUG
Serial.print("which is actuator ");
Serial.println(i);
#endif
            currentActuator = i;
// remember which actuator we found
            currentState = psReadValue;
// start looking for the Actuator position
            actuatorPosition[currentActuator] = 0;
// initialise the new position
            valueCharCount = 0;
// initialise number of value chars read in
            break;
        }
    }

// if we're ready to read in the current Actuator's position data
if (currentState == psReadValue) {
    while ((valueCharCount < kMaxCharCount) && Serial.available()) {
        tmpValue = Serial.read();
        if (tmpValue != kEOL) {
            tmpValue = tmpValue - 48;
            if ((tmpValue < 0) || (tmpValue > 9)) tmpValue = 0;
            actuatorPosition[currentActuator] =
actuatorPosition[currentActuator] * 10 + tmpValue;
            valueCharCount++;
        }
        else break;
    }

// if we've read the value delimiter, update the Actuator and start
looking for the next Actuator name
    if (tmpValue == kEOL || valueCharCount == kMaxCharCount) {
#ifdef DEBUG
Serial.print("read in ");
Serial.println(actuatorPosition[currentActuator]);
#endif
            // scale the new position so the value is between 0 and 179
            actuatorPosition[currentActuator] =
map(actuatorPosition[currentActuator], 0, 255, kActuatorScale[currentActuator][0],
kActuatorScale[currentActuator][1]);
#ifdef DEBUG
Serial.print("scaled to ");
Serial.println(actuatorPosition[currentActuator]);
#endif
            updateActuator(currentActuator);
            currentState = psReadActuator;
        }
    }
}
}

```

```
// write the current Actuator position to the passed in Actuator
void updateActuator(int thisActuator) {
    actuatorSet[thisActuator].write(actuatorPosition[thisActuator]);
}
```

## 2.12) Electrical System Block Diagram

The block diagram in Figure 24 is an initial design of the full-scale model electrical system. Further edits will have to be made when more calculations have been made regarding power, as well as modifications to the electrical components. Potentiometers and resistors will be implemented when necessary. Wiring schematics will also be created of each of the electrical components in order to assist the manufacturing process.

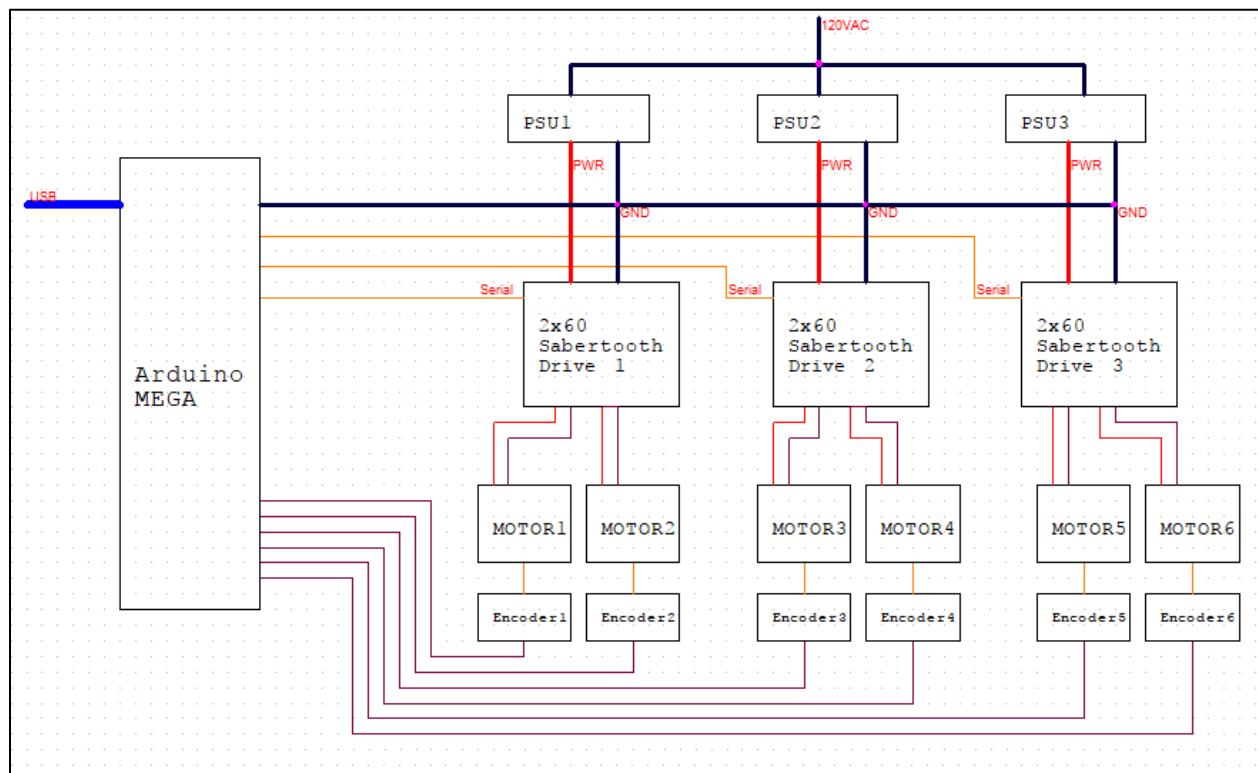


Figure 24: Electrical System Block Diagram

## 2.13) Design Constraints

The finished model is to be housed in the GLC. As such, part of the design constraints is to make sure that the finished platform will be able to move in and out of the building. Nate and David took a day to go over to the GLC and measure all the doorways and hallways the platform will need to go through. Since the platform will be disassemblable, the only part that is of true concern in this regards is the diameter of the base of the platform. From the measurements taken, the platform needs to be less than 8.5 ft in diameter. From the team's design, they believe the base should be well under this diameter and thus be of no concern. The overall design also needs to be done in such a way that it is not too heavy to be able to transport it to the GLC.



Some other constraints deal with the heave of the platform. From research done on online forums, the team discovered that 10 inches of heave gives a wide range of motion for the platform. Therefore, the team designed under the constraint that they desired to have a max heave of 10 inches. They also needed to design in such a way that the legs of the person sitting in the chair would at no point be hitting any of the supporting beams. This was not as easy to nail down a dimension for this constraint as it changed often due to the change of the design. However, in the ©Solidworks model, it was always taken into consideration where the feet of the user might be hitting various objects and was designed around.

The team plans to implement other constraints from applicable standards, however, the standards the team just recently received do not give as much relevant information as the team was hoping. So as of now, the team has been operating under the assumption of a factor of safety of 2 for all their design analysis. To maintain this, they have set the constraint that the top platform can weigh no more than 300 lbs. Since they plan on allowing people up to 250 lbs to ride in the simulator, they must design the upper platform with the chair to weigh 50 lbs or less. The team is also operating under a fairly tight time constraint as they aim to have a functioning platform by the end of February so as to have time to calibrate it and make modifications as necessary.

Lastly, the team is operating under a fixed budget which is discussed in the project execution section.

### 3. Project Execution:

#### 3.1) Timeline

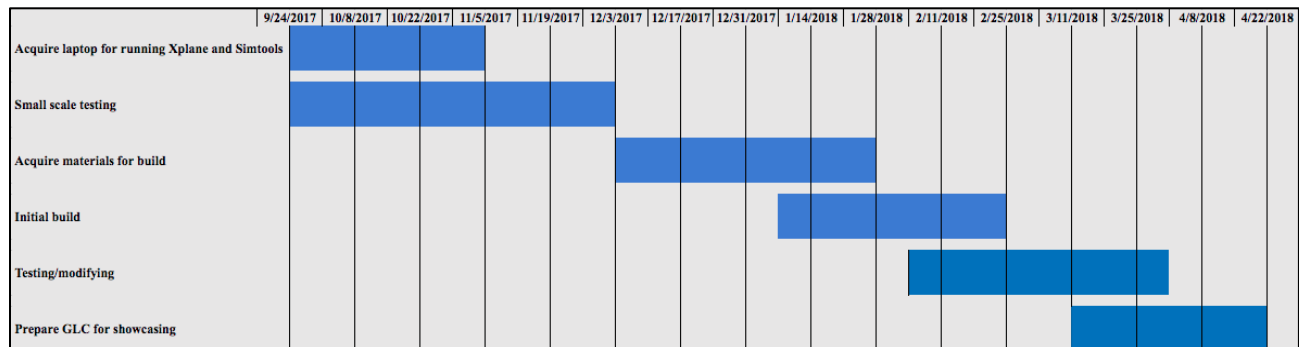


Figure 25: Timeline for the project

The original timeline for the project has been altered slightly from its original projection. The team set some fairly ambitious project goals at the beginning of the semester due to the magnitude of the project, however, due to some setbacks, some of these goals have been pushed back. The major setbacks arose due to the fact that the stress analysis for the platform ended up being significantly more complicated than originally anticipated. As was previously discussed, the team ended up having to do an impossible worst case scenario to make an estimation for the parts needing to be ordered. With this complete, the team can begin moving forward with purchases. The original timeline, however, had the team beginning ordering of parts at the

beginning of December. This ended up not being possible so this has been pushed back and the team plans to begin ordering parts before they leave for the winter break.

In addition to this, the team understands they do not have the complete analysis necessary to order all their parts. For this reason, the “acquiring materials for build” section has been pushed back to the end of January. This will give the team time to finish other minor design elements and order the right pieces necessary. The beginning of the build has also changed from starting over the winter break to beginning at the start of the Spring semester. This was due to the fact that the ordering of parts got pushed back and because the team learned that the machine shop will most likely not be available over the break. However, the team is not discouraged as they anticipated some setbacks like this and is why they set such ambitious goals in the first place. They believe they are still well within the scope of completing this project by the end of next semester.

### 3.2) Funding and Resources

Team SOAR is a fully funded project sponsored by the Presidential Research Association at Oral Roberts University through a \$6,700 grant. The grant was awarded on the terms that it would be used to create an educational tool for the aircraft design course. Within these stipulations, Team Soar decided to orient the project towards an educational virtual reality simulator experience, which led to our partnership with the Global Learning Center, the virtual reality lab at ORU.

After reaching out and proposing the project’s vision, Team SOAR was connected with Mike Mathews the Chief Information Officer of ORU who oversees the Global Learning center. This partnership has both connected us with additional experienced professionals in the field of virtual reality and provided us with numerous resources to make our project a reality. In our discussions with the GLC, we came to an agreement that they would hold and display the flight simulator as a virtual reality exhibit for their laboratory. They also provided us with an \$1,500 advanced laptop computer to be used as a dedicated host for our simulator software that will power the VR technology. The GLC has also provided us with a throttle and joystick control set as well as an HTC Vive headset that can be used on loan until a permanent headset is purchased.

In addition to the Global Learning Center and the Presidential Research Fund, initial contact has been established with Aaron Allen, James Allen, and other connections from the Engineering Advisory Board. Below is a summary of our resources and connections.



Table 3: Current Funding and Support

Resource:	Cost/Amount:	Sponsor:	Contact:	Notes:
Research Grant	\$6700	Presidential Research Fund	Dr. Halsmer	
Laptop Computer	\$1500	Global Learning Center	Mike Mathews	
Joystick and Throttle Controls	\$250	Global Learning Center	Mike Mathews	
HTC Vive	\$600	Global Learning Center	Mike Mathews	On Loan
Total Funding and Support: <b>\$9,050</b>				

### 3.3) Space and Machining Requirements:

Because this system is being manufactured in house, it is important to outline exactly what manufacturing processes are going to be used the required machinery for the project. First of all, the system will be built in the Engineering Machine Shop, and a work space will be outlined that is at least 10ft wide and 10ft long. Before any manufacturing is performed, proper safety measures will accounted for and the machining expert will be consulted. Primary machines that will be used are the band saw and the drill press. Some parts such as the small lever arms will be machined using a CNC program on the mill, and other parts such as spacers will be machines on the lathes. The steel base will welded together using Tig welding techniques. Many components will be bolted together requiring the use of various wrenches and other tools. A transportation procedure will also be developed and followed to safely move the system from the machine shop to the Global Learning Center once it has been completed.

### 3.4) Cost Estimates:

The expenses of this project are detailed in the tables below, and split in the following subcategories: mechanical costs, electrical costs, software costs, additional costs, and labor costs. Labor costs are figurative, and omitted from the total cost estimate. Most costs are an overestimate to account for unexpected additional costs or changes.

Table 4: Mechanical Bill of Materials Cost Estimate

Product	Cost Estimate	Qty.	Total
AC Induction (or) Servo Motors	\$100	6	\$600
Gearboxes	\$150	6	\$900
Heim Joints and related materials	\$30	12	\$360
Aluminum Plates, Rods and Tubes	\$300	N/A	\$300
Structural Steel	\$500	N/A	\$500
Fasteners, Bolts, Spacers, Additional Costs	\$300	N/A	\$100
Total Estimated Cost of Mechanical Components: <b>\$2,760</b>			

Table 5: Electrical Bill of Materials Cost Estimate

Product	Cost Estimate	Qty.	Total
Power Supply Units	\$100	6	\$600
Arduin MEGA	\$40	1	\$40
Sabertooth Motor Drives	\$180	3	\$540
Cables & Connectors	\$100	N/A	\$100
Total Estimated Cost of Electrical Components: <b>\$1280</b>			

Table 6: Software Cost Estimate

Product	Cost Estimate	Qty.	Total
Xplane11	\$60	1	\$60
SimTools	\$60	1	\$60
FlyInside	\$60	1	\$60
Total Estimated Cost of Electrical Components: <b>\$180</b>			

Table 7: Additional Cost Estimate

Product	Cost Estimate	Qty.	Total
HTC Vive	\$600	1	\$600
Simulator Chair	\$90	1	\$90
Various Shipping Charges	\$150	3	\$150
ASEE Conference Registration	\$467	N/A	\$467
ASEE Posters	\$90	N/A	\$90
Total Estimated Cost of Electrical Components: <b>\$1,397</b>			

Table 8: Wage Estimate

Engineer	Wage Estimate	*Hours	Total
David Ahrens	\$40/hr	160	\$6400
Nate Frailey	\$40/hr	160	\$6400
Connor McCain	\$40/hr	160	\$6400
Jordan Reutter	\$40/hr	160	\$6400
Matthew Samuelson	\$40/hr	160	\$6400
John Voth	\$40/hr	160	\$6400
Total Estimated Cost of Engineering: <b>\$38,400</b>			

\*Hours are estimated to be 5 hours a week for 32 weeks (two semesters).

Table 9: Total Cost Estimate

Division	Estimated Cost
Mechanical	\$2,760
Electrical	\$1,280
Software	\$180
Additional	\$1,397
Total Estimated Cost: <b>\$5,617</b>	

### 3.5) Team Member Responsibilities

For this project, the team members responsibilities have been fairly well defined so as to be able to set personal goals to aid in execution of the project. John Voth is the team's original leader but due to his other obligations for head RA and other leadership roles, David Ahrens has joined him so that the two are now considered co-leaders of the project. John's roles in leading the project have primarily been to maintain communications with the stakeholders of the project such as Dr. Halsmer and members of the GLC. He has also been keeping up with requirements and activities involving the ASEE conference. David's leadership roles have primarily focused on working with the team members to set up meetings and keeping the team on task for specific deadlines.

In addition to their leadership responsibilities, David and John have also been working on certain design aspects of the platform. David helped Nate Frailey with work on certain geometries and also on work for the center of gravity calculations earlier in the semester but shifted to be working with John and Connor McCain on the stress analysis of the platform. John, David, and Connor have all been working on figuring out defining equations that govern the stress in each member of the design. In addition to this, Connor has also been working heavily with *X-Plane 11*. Connor and John are the only two members of the team that have taken aircraft design so they know best the desires of Dr. Halsmer for the class. Due to this, Connor has been working with the design editor within *X-Plane* to see its capabilities for the class. To test the physical properties of *X-Plane*, Connor designed multiple aircraft with extreme features and tested them for flight alterations. They performed as expected, so he will continue to design his own aircraft from Dr. Halsmer's class in *X-Plane*'s Plane Maker. He also plans to write a tutorial so that future students will know how to utilize the software to apply what they are learning in class.

Nate Frailey has handled most of the 3D design of the platform. He has done extensive work to define all geometric relationships between members so as to find optimal ratios for the layout. He also did much research to create a ©Solidworks model for a generic Stewart Platform that was 3D printed and used to make a small scale model for testing the software that will be used to control the motion of the platform. Having defined all the geometries and relationships, he then moved into creating the ©Solidworks model for the full scale system with his defined geometric relationships. He modeled each individual component to the specifications he found online and specifications Jordan Reutter gave him for the material they planned to use for build. He has almost completed the entire model with some assistance from Jordan.

Primarily, Jordan Reutter has been functioning as the team's manufacturing engineer. Jordan has done extensive research on available parts that the team can use to complete the design. He has researched various different types of materials and vendors for each component while also ensuring that the parts fit the teams structural requirements and are cost effective. He has chosen Heim joints, lever arms, bolts, and other components. He has also looked into what motors and gearboxes are available so as to direct the team to which ones will best fit design specifications. He has been working closely with the design team to develop an organized Bill of Materials from the part design specifications, as well as document a manufacturing procedure of how to assemble the design. Once complete, the team will be able to follow the build document

to most effectively and efficiently create the Stewart Platform. In addition, he has also assisted in the design, creating a 3D model the chair and foot rest used in the ©Solidworks assembly as well as doing some other minor work on the model.

Matthew Samuelson is the team's electrical engineer and has been handling all aspects relating to electrical components and power. He has done extensive work on researching the software and hardware needed for interfacing the computer program SimTools with the motors controlling the motion of the Stewart Platform. This involves configuring axis and degree of freedom settings with in order to fine tune motor motion. He also did much programming by editing the Arduino code to communicate with the SimTools software. He has successfully set up a breadboard based system that controls a small scale model and links directly with SimTools. He has also worked on creating electrical schematics and block diagrams for the system. He plans to perform more circuit calculations in order to determine how much power will be required for the system. He additionally assists the other members with various minor projects and calculations.

#### **4. Progress:**

##### 4.1) Semester Progress

Much progress was made by Team SOAR this semester. Initial accomplishments include securing the \$6,700 funding from the President's Research Fund, initiating a positive relationship with GLC personnel, acquiring VR equipment on loan from the GLC, and obtaining a high-end laptop to run the necessary software at a high quality. Much research then went into determining which parameters would define the geometry of the Stewart Platform, resulting in much engineering analysis. This research transitioned into modeling the first iteration of the ©SolidWorks model. With the prototype modeled, the team presented their work at the regional ASEE conference at Oklahoma State University. The initial ©SolidWorks model was then scaled down into a smaller prototype size and 3D printed. This prototype was subsequently assembled and interfaced with the appropriate software, successfully providing much feedback about the software side of the project in the area of programming. This also gave the team experience to know how to configure the settings of the full-scale model. In addition, team members explored the possibilities of *X-Plane*, confirming the software to have a physics engine of satisfactory quality.

After the successful modeling of the first iteration of the design, the team learned much feedback about their model. Then, they delved deep into the engineering analysis of their system, analyzing the project's statics, dynamics, geometric relations, strength of materials, and more. Nearly all load-bearing fixtures of the system were analyzed. Combining the feedback from the prototype and the engineering analysis, the team completely revised their ©SolidWorks model of the prototype. Such revisions in the second model include adding foot space for the user, changing the diameter of the base platform, and updating the specific geometries of the motors, Heim joints, chair.

With very specific requirements now established, the team again researched their materials with a fine toothed comb. Team SOAR then updated their bill of materials and closely

analyzed their budget to ensure enough funds to finish the project well. Then, they organized a list of intended purchases.

#### 4.2) Definition of completeness

By the end of the spring semester of 2017, Team SOAR will have successfully built a Stewart-Gough Platform motion simulator capable of all 6 degrees of freedom. To make the user's flight experience as realistic as possible, the team will also incorporate virtual reality technology. The completed simulator will be manufactured with a high degree of professionalism and safety, satisfying Global Learning Center personnel enough to permanently house the project in their building. Finally, the simulator will enable Dr. Halmser's ORU undergraduate Aircraft Design course to create custom aircrafts and utilize the simulator so that students experience what it's like to soar.

#### 4.3) Plans for next semester

In order to fulfil the definition of completeness, Team SOAR has designed a detailed plan for the coming semester. To begin, all of the components will be purchased before Christmas break or immediately following the break. As the parts are in route, the tutorial for Plane Maker will be written and much work will go into completing the inverse kinematic equation, so these efforts will not take away from the assembly time later. The platform assembly along with the implementation of the electrical components will begin as soon as the materials reach the machine shop. David, Nate, Jordan, Connor, and John will be split into two groups to work on either the top or bottom platform assembly using the dimensions in the ©SOLIDWORKS model. Matthew will be constructing the electrical network for the entire system. Because of the bill of materials and the manufacturing process Jordan has already written, the actual assembly should be complete in 6-7 weeks.

After the assembly has been completed, the simulator will be fully functional and ready for calibration and testing. As part of this process, Matthew will be programming the system to function with SimTools in order to connect *X-Plane* with the controller of the simulator and the virtual reality equipment. Following assembly completion, Team SOAR will run the simulator through multiple trials in varying situations including no seat occupant running basic motion for each degree of freedom, no seat occupant multiple flight styles in *X-Plane*, and with a seat occupant in similar applications of the simulator. The simulator will need to be calibrated with a very low tolerance for error because differences between the virtual reality headset and the simulator motion will make the user nauseous. For the designed application in education, the simulator motion must not be too extreme as to make the majority of users sick. Proper and consistent calibration will be vital for the remaining project time.

By the end of March, Team SOAR plans to unveil the simulator at ORU's Global Learning Center. As the simulator is being tested and calibrated, preparations will also need to be made to ready the 3D and virtual reality room in the GLC. The simulator will be moved to the GLC room upon completion and will need to be examined for any accidental alterations that happened during the move. A tutorial will be written to explain how to operate the basic functions of the simulator and *X-Plane* so the employees of the GLC will be able to run the

system as an educational tool without the members of Team SOAR present. The team plans to ask Dr. William M. Wilson to take the inaugural flight in the simulator as a symbol of the University and the President's Research Grant. In June, the Team also plans to present at the ASEE National conference proceedings in Salt Lake City, Utah.

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