Interim Design Report

Group 13
Tabletop Torsion Machine

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Team Member Bios

Brendan Keane – Team Leader
Brendan is a senior mechanical engineering student at Florida State University. He is graduating in May of 2015 and has had 3 internships at Florida Power & Light. After graduation, he plans on finding a full time job to start his career in the engineering industry.

Logan McCall – Fabrication Advisor
Logan is a Florida State student that was born and raised in Panama City, Florida. He is a senior Mechanical Engineering student that plans on graduating in the fall of 2015. His background comes from previous work experience throughout college, and plans on joining working community upon graduation.

Reginald Scott – Financial Advisor
Reginald is a senior mechanical engineering student at Florida A&M University. He has obtained two internships. One of which was as a design engineer at TECT Power. The second was a manufacturing engineer at Nestle Waters. Reginald is expected to graduate in May 2015. He then will be pursuing an entry level full time job within the mechanical engineering field.

Mark Swain – Administrative Coordinator
Mark is a senior mechanical engineering student at Florida State University. He has performed research with multiple teachers during his time at FSU. After graduating with a BS in May 2015, Mark plans to pursue his MS in mechanical engineering through the BSMS program offered here at FSU.

Acknowledgments

Both Dr. Hruda and Mr. Flater have contributed greatly to the success of this project. Dr. Hruda has a strong background in material science and has brought many new ideas to the design. She has been there to double check the work of the team. Mr. Flater has supported the teams’ decisions and puts full confidence in the team to reach the final goal. He is always available to answer any questions or considerations the team has brought to his attention.

Abstract

The Air Force Research Laboratory Munitions Directorate at Eglin Air Force Base does thorough material testing for their products. A major material test they utilize is the torsion test. Their current machine is very large and is ineffective when testing small specimens. They have a need for a smaller, tabletop torsion tester that can generate up to 250Nm of applied torque and stay within a budget of $2000. A smaller machine will produce much more accurate measurements when testing small specimens. After receiving all of the needs and constraints from the Air Force sponsor, multiple potential designs for the machine were created. Each component of the machine was analyzed separately in order to ensure the overall optimum design is chosen. The final design utilizes a DC motor with controller to generate the torque. Detailed CAD drawings for each part have been made and have undergone FEA in order to ensure quality. The parts and potential vendors are in the process of being finalized so final purchase orders can be made. After the parts are received, any necessary machining will be done and assembly of the machine will begin. A program will also be used to output the applied load on the specimen.

I. Introduction

A. Project Overview

Material testing is an essential part of designing new and improved products. Knowing how a material acts under certain conditions allows engineers to create an optimal design. The Air Force Research Laboratory (AFRL) Munitions Directorate at Eglin AFB is currently testing materials to use with their products. These products range from warheads to the frame of a fighter jet. In order to ensure optimal performance and user safety, many material tests are performed. The current torsion machine at Eglin AFB is very large and is only effective when testing large specimens. They have a need for smaller, tabletop torsion testing machine. A smaller machine will lead to more accurate data when testing small specimens. These small specimens are used in order to test materials that are similar to the geometry of the product in the field. The data that will be gathered from the new machine will more accurately characterize the materials and how they react under certain conditions. This will result in more accurate models and simulations used by the AFRL.

In general, there are 4 major components of a torsion machine. These components include load generation, load application, load measurement and housing. Additionally, the Air Force sponsor has requested that the free end of the specimen has 1 degree of freedom in the axial direction. A DC motor and controller will be used in order to generate the load required to twist the specimens, which will be held in place using 6-jaw chucks. A strain rosette will be placed on the transmitting shaft in order to output the applied load on the specimen. Finally, the housing will be made out of aluminum and will utilize a 2 rail ball bearing guide in order to allow the free end to have 1 degree of freedom in the axial direction.

B. Background

The Eglin Air Force Base’s Munitions Directorate has done extensive research in the field of testing mechanical properties of materials commonly used in projectiles. They are interested in how different materials react under different loads to simulate different scenarios of diverse mediums that the munitions will be fired at. This being said, the group is constrained to the size of the specimens that they can generate. The reason for limited plate thickness is not a matter of cost, however it is a matter of geometry. When the Munitions Directorate is fabricating components of the munitions they use raw stock that is as close to final shape as possible to conserve waste material. In order to properly characterize the materials that ends up in a product they have to test similar geometry in order the get accurate results. A representation on how the Directorate gets their samples is shown below in Figure 1. [1]

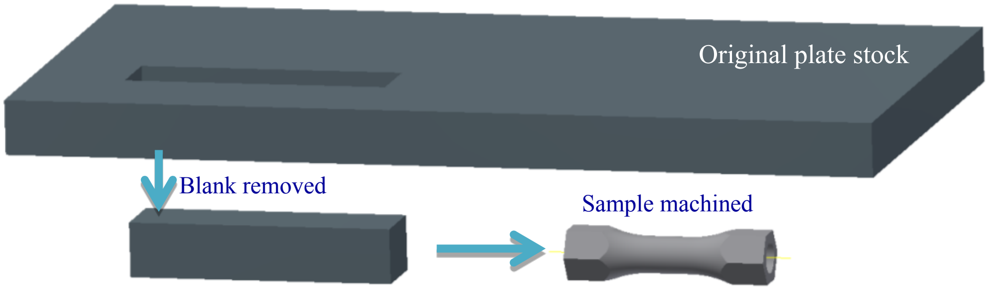

Figure 1 Example of sample production from plate stock [1]

Since materials of interest are often in the form of thin sheets or plates, this makes the specimen that is generated relatively small, having dimensions roughly the size of a human thumb. The exact dimensions can be seen below in Table 1, and a drawing of the specimen can be found in Figure 2.

Table 1. Specimen Dimensions

Dimension	Measurement (mm)
Total Length	58.4
Gauge Length	12.7
Width	14.3
Inner Diameter	9.09
Fillet Radius	27.9
Hex Length	10.4

For most common torsion testing the specimen is roughly a foot long and roughly an inch in diameter. But, due to the constraint of the thickness of the plate that they are machining the specimens from; problems arise from using equipment that test more common (larger) sample sizes. These problems normally come in the form of electrical noise in the signals they are receiving from the sensors they have testing. There becomes a point at which the data has no meaning because the signal has been extrapolated beyond its limits, or it is experiencing a low Signal-to- Noise ratio(SNR). [2]

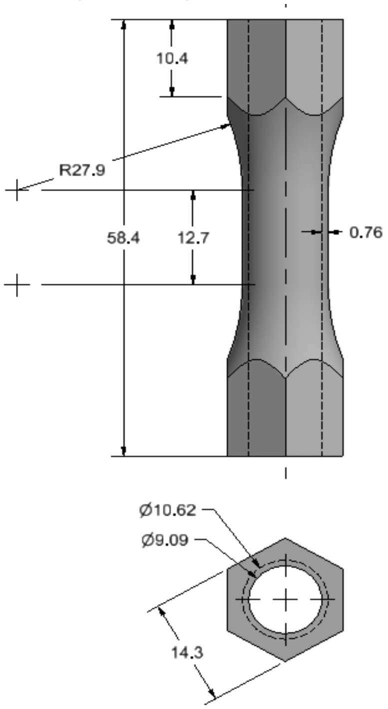

Figure 2: Actual dimensions of the samples given in millimeters. [1]

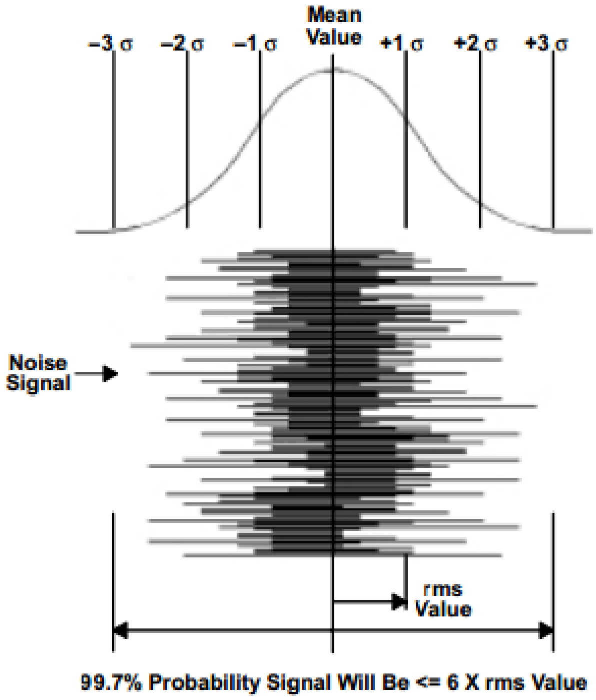

Figure 3: Gaussian Distribution of Noise Energy showing different standard deviations in relation to the mean value. [3]

In its most simple form the signal to noise ratio can be defined as the rms (root-mean-square) value of the voltage divided by the rms value of the noise. The higher this ratio is, the more accurate your results will be. As seen above in Figure 3 below, noise energy can be expressed over the Gaussian Distribution of Noise Energy. In this case σ is the standard deviation of the Gaussian distribution and the rms value of the noise voltage and current. In this example data it is clear to see that when the data falls close to $\pm 1\sigma$ it is going to be fairly close to the mean value, which in this case is the true value from the signal. For this given data it will fall in $\pm 1\sigma$ 68% of the time. [3]

For material testing in the Munitions Directorate the accuracy of their data might be the difference in penetrating the target, or causing catastrophic damage to the surroundings, so the noise in their data needs to be minimized in their signal. Eglin is currently using a testing machine that only exerts roughly 2% of its total load capacity. This is due to the size and power of the machine that they are using to test the samples. Running at such a low torque causes the machine to send out an extremely small signal. In turn to actually understand, and see the signal the data has to be amplified, but since the data was taken from such a small range of the machine's ability; the data, once amplified, has a lot of noise.

To achieve a higher SNR Eglin has asked our group to design and build a much smaller, more accurate machine. This machine would run at roughly 20 to 40% of its capacity yielding data that would have much less noise associated with it the size and power of the machine. [1]

C. Constraints and Specifications

From the background information delivered by the sponsor, constraints have been created and put on this project. The constraints are used to limit the design in order to make sure it complies with the sponsor's requirements. The constraints put on this project are:

- Max load on specimen to Max axial load ratio must be 20% or above. (Currently ~ 2.3%)
- Minimum of 50Nm axial loading by the machine
- Budget - $2,000 (Not including the motor)
- Max surface area of machine – 2ft x 3ft
- Must do monotonic (one direction), and cyclic (2 direction) Free-End Torsion Loading
- Free end has one degree of freedom (axial direction due to contraction/expansion of specimen)
- Must be compatible with the DIC

Additionally, design specifications have been created by the team and sponsor. These specifications cover the measurable design and engineering features of the final machine. The design specifications desired by the sponsor include:

- Max surface area of machine – 2ft x 3ft
- Minimum of 50Nm axial loading by the machine
- Max load on specimen to Max axial load ratio must be 20% or above. (Currently ~ 2.3%)
- Must be able to be moved by human (Max weight ~ 50lbs)
- Must have minimum strain rate of 1.5 degrees/s

Furthermore, performance specifications have been created. These are expectations of the performance of the torsion machine during use. The performance specifications put forth by the sponsor are:

- Must be compatible with the DIC
- Must have digital or analog applied stress/force output
- Must be able to input desired cyclic displacement
- Lowest signal to noise ratio as possible

The success of this project will be based on how well the final design abides by the constraints and specifications placed on it. It is expected that not every aspect will be perfect but as long as the machine is able to deliver acceptable results as decided by the sponsor, it will be successful. From these constraints and specifications, the following Needs Statement was developed:

"Design a more effective way of testing small specimens in free end torsion."

II. Design and Analysis

A. Function Analysis

Figures 4 and 5 show the functional analysis for the tabletop torsion machine. Figure 4 breaks down each major component and explains the purpose for each part. Figure 4 starts with the 5 general aspects of the table top torsion device. Moving from left to right, the Figure gets more specific by showing what was chosen and its purpose. Figure 5 shows a very basic breakdown between the mechanical and electrical aspects of the project as well as shows the general flow of the machine.

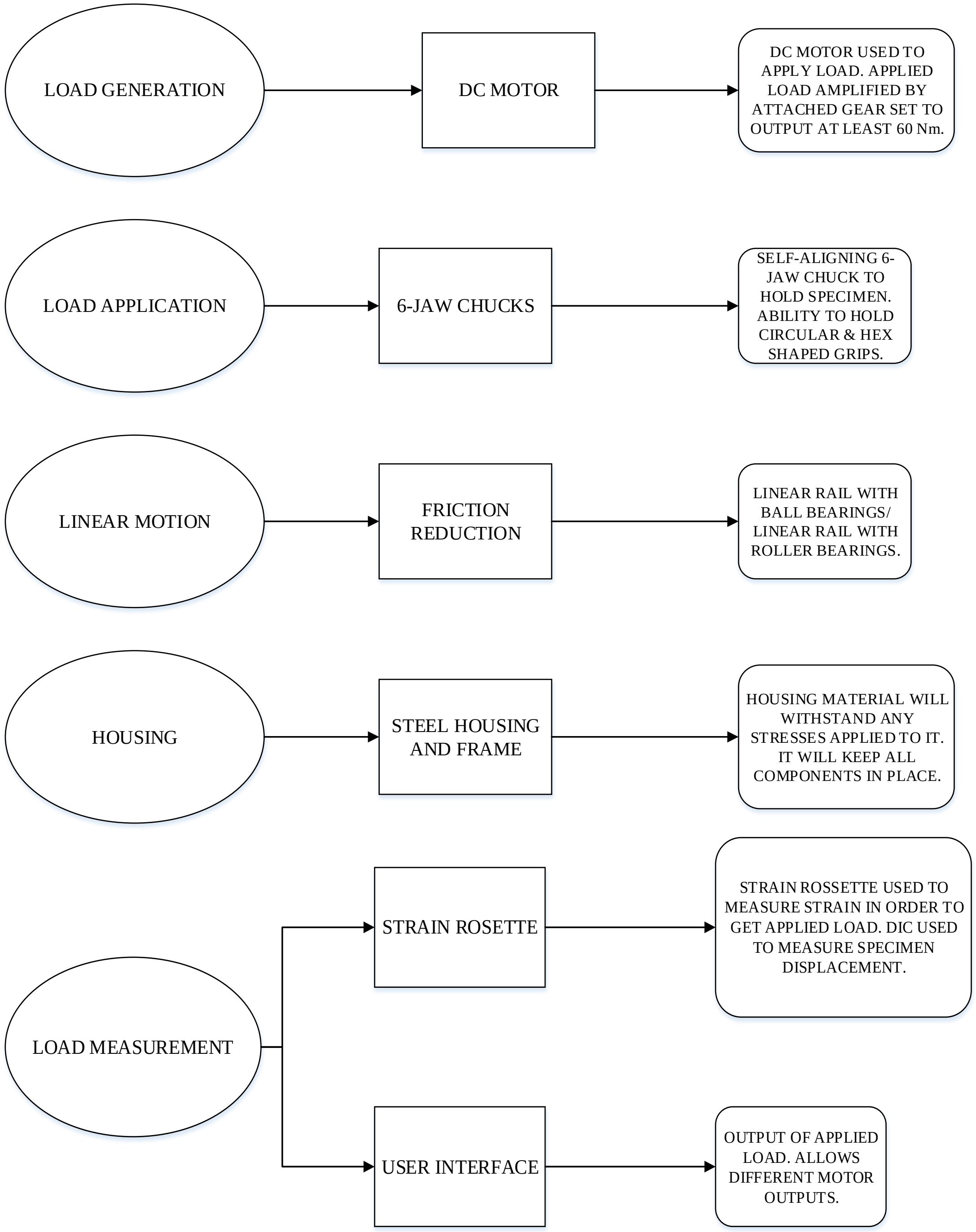

Figure 4 Functional Analysis of Mechanical and Electrical Components

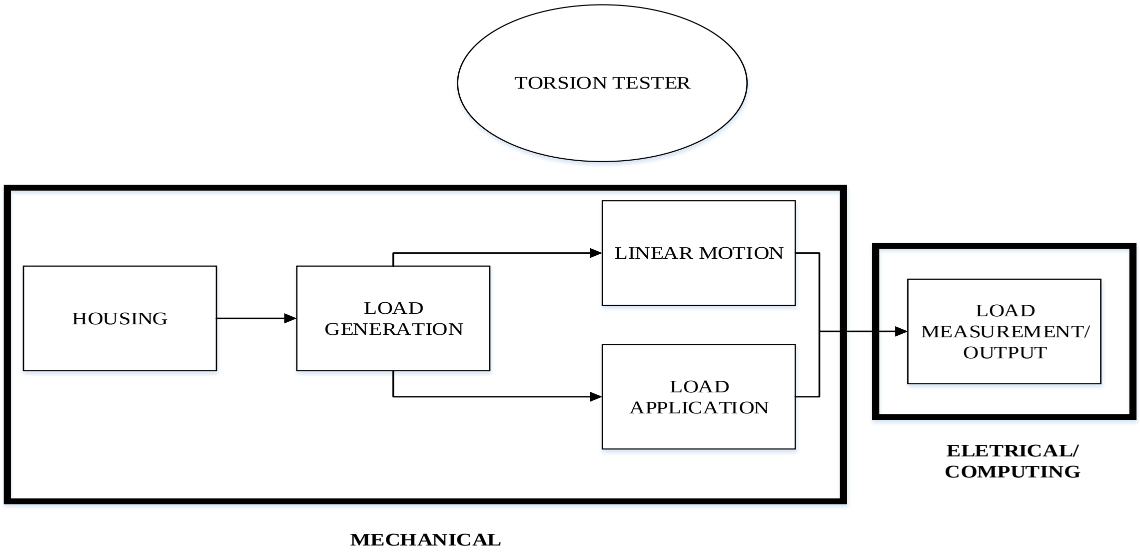

Figure 5 Flow chart depicting relationship of torsion tester systems

B. Design Overview

In this section, the components chosen for each part of the design: load generation, load application, load measurement, linear motion, and housing will be discussed. Each category had multiple potential options that were considered, and after utilizing a decision matrix approach, the most effective component for each category was selected.

B.1 Load Generation

For the tabletop torsion device that is being constructed, there were three main option that were discussed as possible ways to generate the load. These options were: manual powered by a crank system, a hydraulic motor and controllers, and a DC motor and controller. These three options were compared and after a careful review of the benefits and limitations of each, the DC motor was determined to be optimal choice for this build. A DC motor with some type of controller was deemed the most appropriate for this design because of the repeatability, accuracy, and cost effectiveness when compared to the other two options. The manual crank system would not be nearly as accurate or repeatable, which is one of the main criteria when doing any type of laboratory work. This tester must be able to reproduce results to ensure that the data collected is reliable. The hydraulic pump and motor system would be able to reach the accuracy and repeatability of the DC motor system, but was ultimately not selected because it required too many parts when compared to the DC motor and would require more maintenance and money. Moving forward, DC motor and controller systems will be examined and compared to ensure that the best and most cost-effective parts are selected.

B.2 Load Application

Three gripping mechanisms were examined for the torsion machine. These included a 3 tooth chuck, 4 tooth chuck, a vise grip, and a collet. It is important that a proper gripping mechanism is chosen in order to achieve the highest accuracy possibly. The grip must not allow for any slip or off axis loading. For this design, the 3-tooth chuck was initially selected as the most effective method for gripping the samples. The benefits of the 3-tooth chucks are that they are relatively inexpensive while still being able to hold a variety of different sample geometries and sizes. The 4 tooth chuck was not selected because it is unable to hold hexagonal specimens, and the machine should have that variability should the sponsor choose to test different geometries. The vise was not selected as the optimal choice for this design because it would weigh substantially more than any other of the potential components. The collet was deemed ineffective as well for this design because although a single collet is very inexpensive, a collet can only hold a very specific size of specimen. So if the size of the specimen is every changed, then a new collet would need to be purchased. Therefore, because of the variability, cost-effectiveness, and ease of use provided by a 3-jaw chuck, it was deemed the optimal choose for load application. However, after consulting the sponsor, a 6-jaw chuck was selected to hold the specimens. A 6-jaw chuck operates on the same principles of a 3-jaw chuck, but provided a greater surface area to hold the specimen with which will ensure that the specimen does not experience any slippage during testing.

B.3 Load Measurement

The torsion tester will be used in conjunction with the DIC (Digital Image Correlation) that is provided by the Sponsor in order to determine the strain present in the sample during testing. Using a high speed camera and measuring the particle displacement on the surface of the specimen, the strain experienced can be calculated. Therefore, it is only necessary for the design to determine the stress that the sample undergoes during testing. With this in mind, a strain rosette was decided upon after comparing it with a torsional spring for load measurement.

This design includes placing a strain rosette on the transmission shaft that connects the motor to the gripping mechanism used to hold the specimen. The shaft will be made out of a highly resilient material that will only undergo elastic deformation which results in a linear relationship between strain (γ) and stress (τ). The slope of this relationship represents the shear modulus (G). This allows a program to easily solve for the applied stress since the properties of the shaft are known. The equation for strain, stress and the shear modulus are shown below. Additionally, strain rosettes are easy to replace and require very little installation time as long as someone has experience with soldering. Due to their geometry, the direction that a strain rosette is placed is not important, making it very easy to implement in to a design. They are also not too expensive and are highly accurate.

$$\gamma = \frac{\Delta l}{l_0} \tag{4}$$

$$\tau = \frac{F}{A} \tag{5}$$

$$G = \frac{\tau}{\gamma} \tag{6}$$

where:

Δl = change in length (m)
l_0 = original length (m)
F = force (N)A = area (m^2)
G = shear modulus (Pa)

The sponsor will be able to provide the strain rosettes as well as signal conditioning equipment from his facilities, so the cost associated with using this method for load measurement has been greatly diminished.

B.4 Linear Motion

As discussed previously in the constraints, the free end of the torsion tester must allow for 1 degree of axial freedom during testing. This is to permit the specimen to expand or contract while loading is applied to produce the most accurate results possible. For this design, three potential constructs were compared that utilized varied geometries and bearings. After performing a selection process it was decided that to allow for this motion, the free end will be placed on a 2 rail ball bearing system. This platform will let the free end smoothly translate back and forth with minimal friction. This design was selected over the other choices because it was deemed the most inexpensive due to the use of ball bearing over linear roller bearings, and the least likely to fail under the torsion applied.

B.5 Housing

After performing a material selection process for the construction of the housing, the material selected for this build was aluminum. However, after speaking with faculty and considering other factors in the fabrication of the housing, it was determined that steel was the optimal material for this design. Steel will provide an extra factor of safety that will allow for the torsion tester to withstand all potential forces and torques applied to the frame. Steel is also easier to machine and weld for the machinists that were consulted in the shop, and although the steel is slightly more costly than aluminum, the added benefits of the safety factor and ease of fabrication are considered to be worth the extra cost. During the construction of the frame extensive study was done on a single member of the frame to determine the maximum stress along the axial direction. As seen below in Figure 6, using a wall thickness in the steel member that is capable to be drilled and tapped to receive the additional components of the machine had a factor of safety way out of the realm of failure for this application. The deformation as shown is rated at most at 5 micrometers, which for the frame is an accepted value It should be noted that such a cushion was developed, because not only does the components need enough threads to grab onto, the frame needed to be as rigid as possible within reason to allow the most accurate reading during the test. More of the FEA testing is discussed in Appendix.

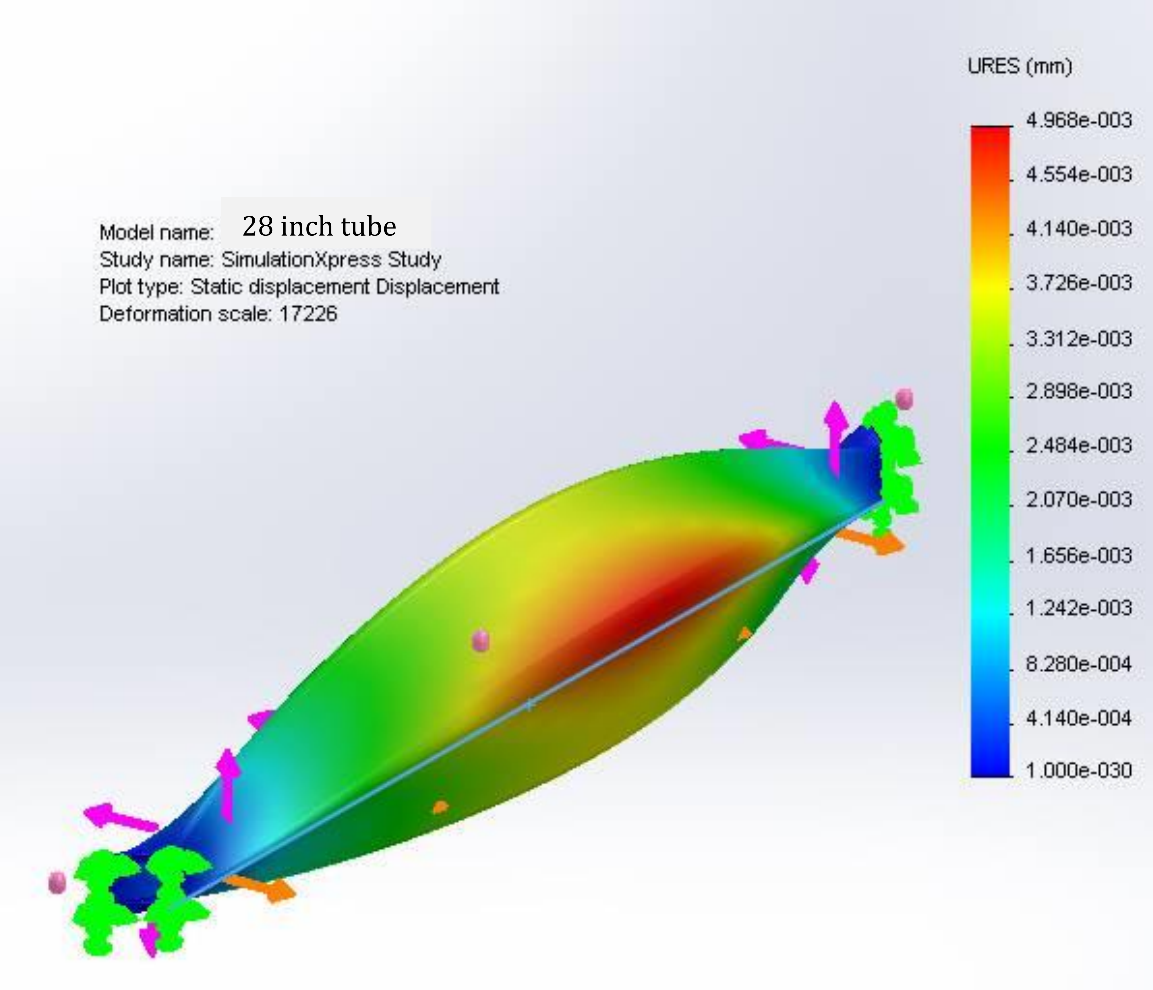

Figure 6 FEA on steel member of frame (mm)

B.6 Optimal Build

The optimal build with all components added can be found Figure 7. As can be noted by the figure, all components are labeled and shows the relative scale of everything together. The exact components in this CAD will differ a bit to the actual components that are purchased, but this figure is to give scale and proof of concept.

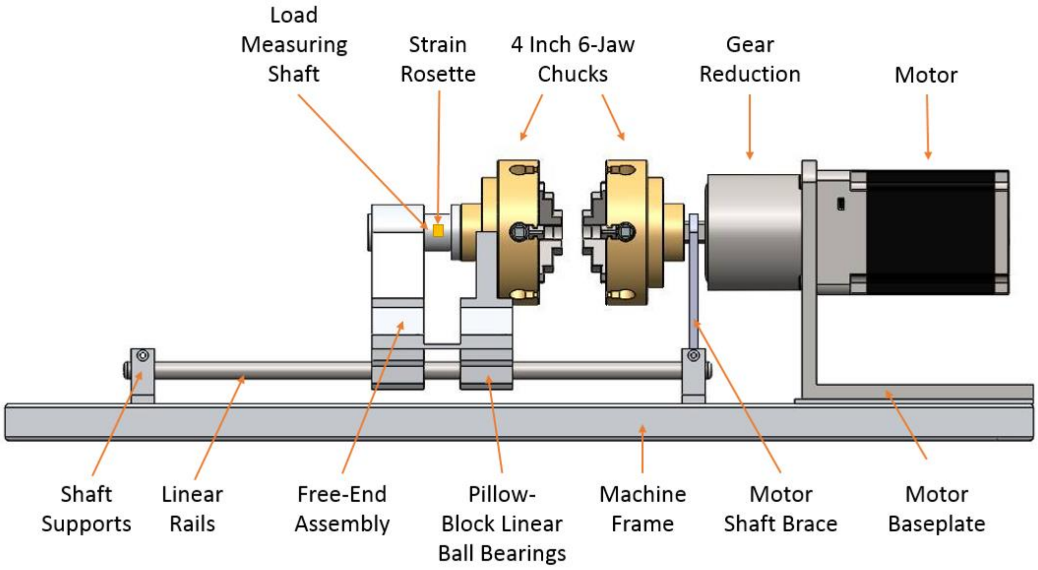

Figure 7 Optimal design CAD assembly

B.7 Programming Considerations

The original design for this project includes a fully programmable DC motor working with LabVIEW. This would require an interactive user interface on a computer. The user interface would allow the user to choose the type of loading and load amount desired. This route has proven to be very costly due to the many components needed to hook up a DC motor to a computer while allowing control and feedback. Additionally, the team consists of only mechanical engineers with limited knowledge and experience with programming and controlling. For these reasons, completing the project on time and within budget seems unrealistic. In order to avoid this problem, an alternative has been brought to attention. This alternative is using a variable frequency drive motor. This route does not require programming and is much more cost effective.

III. Risk and Reliability Assessment

There are some risks and reliability factors that can affect the success of this project. The main component of this project is the motor that generates the torque. With any DC motor there is always the chance of burning out. This will lead to an unsuccessful project and a waste of the majority of the budget. The appropriate motor with the right holding and stall torque must be chosen in order to avoid this problem. Another major risk is the material selection and shape of the housing and frame of the machine. If any of the stress calculations or FEA was done improperly, there is a chance that the torque felt by the housing and frame will be strong enough to deform it. This will lead to higher costs and the possibility of failure for the project since the housing holds all of the components in place.

IV. Procurement

One of the major challenges of this project is obtaining the necessary components all while remaining within the constraint of the budget of $2000. The DC motor is the cornerstone of this project. Once it is ordered and received, detailed measurements of the weight and geometry will be obtained. The remaining components, including the gear set, microcontroller, linear guide rails with block bearings, and the amount of raw materials needed for the housing will depend on the dimensions of the DC motor. All components of the housing will have to be machined, so it is critical that we procure the necessary raw materials as soon as possible so that the machining process can begin. The 6-jaw chucks are one of the few components that are not dependent upon the size and geometry of any of the other components. The vendor that the chucks will be purchased from is LittleMachineShop.com, however this vendor is not yet on the approved vendor list. The group is in the process of getting this shop verified through the college so the purchases can be made. Each chuck will cost $170. The current motor at the top of our list is an AKM Series Brushless Servo motor and is pending final approval of our sponsor, this motor was found at Grainger.com.

V. Communications

Over this past semester the team has great communication with each other, their faculty advisor, and their sponsor at the Air Force. The team uses texting on their cell phones to send daily messages and information. Any documents or updates are uploaded to a Facebook page that each member is a part of. The team and faculty advisor meets every Wednesday to discuss updates on the project, new ideas, and any challenges the team has faced during the previous week. Additionally, the team and the sponsor have a video teleconference every other Thursday to talk about the overall project progress and any concerns regarding the project.

VI. Environmental and Safety Issues and Ethics

This project does not have any environmental issues associated with it. However, some safety issues to exist. Since there is a motor and moving parts the machine does have some safety issues. The user must understand these risks and not touch the actual machine during operation. Also, the user must understand the risk if testing a brittle material since they tend to have catastrophic failure and its possible for debris to fly off. There will be a plexi-glass wall to protect the user, however debris can still get over the wall. It is expected that the user will abide by all OSHA regulations in the workplace.

VII. Project Management

A. Scheduling

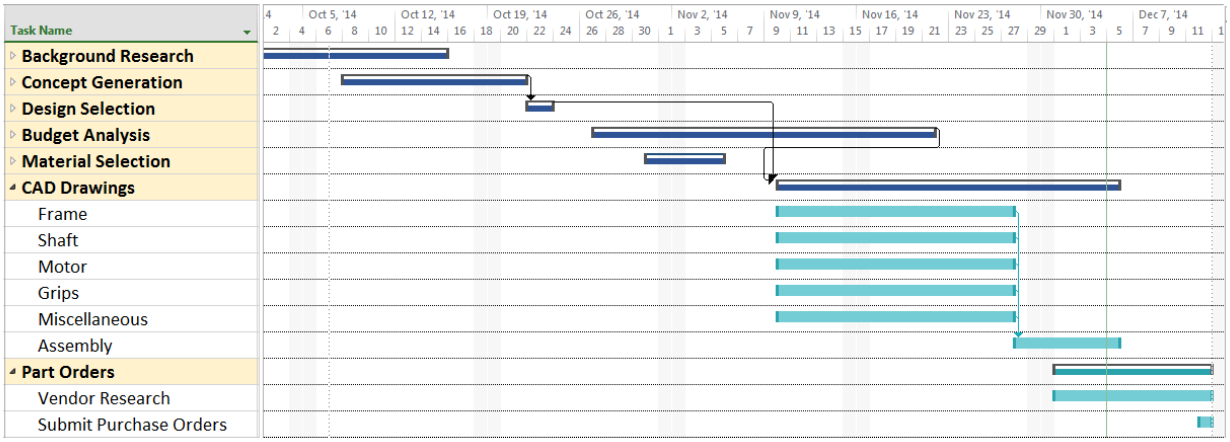

Figure 8 Gantt chart of the Fall semester

Taking a look at the Gantt chart in Figure 8 provided above shows a quick look at what has been accomplished, and what still needs to be finished before the end of the semester. As the chart suggests, the

CAD has recently been completed and the final design has been sent to our sponsor to ensure that it meets expectations. The final task before the end of the semester that must be completed is ordering the parts. At the time this paper was submitted, the group is in the process of researching vendors for the right components for the build.

B. Resource Allocation

Taking a look at the Gantt chart in Figure 8, each task has a specific amount of time allocated for it to ensure that all tasks have enough time to be completed. The background research has been conducted as a team, with each member responsible for being knowledgeable on all subject areas related to the design. It is imperative that all parties associated with the group are all familiar with the background information so that each member understands what is required to complete the design. Concept generation has also been done as a primarily team-oriented activity. Multiple potential designs have be produced by all members of the team and through group discussion the critical design characteristics for the optimal build were determined. The calculations have also been conducted by the team as a whole to ensure accuracy of the results determined.

The design selection has also been be done as a team, with the guidance and feedback of the sponsor to ensure that all avenues are considered. The quality matrices used to determine the optimal design components were developed by the team. Once a design was chosen, a simple CAD model was produced of the design. Logan McCall will take the lead on the CAD production, and will ensure that the drawings are produced within the time frame. Under the direction of Logan, the rest of the group will help to produce any CAD parts and drawings deemed necessary.

Once the CAD design is completed, the budget analysis will be conducted by Reggie Scott. The responsibilities of this analysis are to determine the cost of each part, allocate funding from the budget for each piece, and select vendors from which each part can be obtained. Once vendors are selected, the parts will be ordered and those that need machining will be sent to the machine shop.

Due to the scope of the project and the difficulties that are sure to be encountered with each step, each member of the team will be responsible for helping with all facets of the design procedure. Although Logan and Reggie will be taking the lead in two of the areas specified above, Brendan and Mark will also be assisting with each process as well. Additionally, with spring semester approaching new challenges will be brought up and will require the effort of the whole team. This includes ensuring the quality of all parts received and assembling the actual machine. Any other considerations that develop in the next semester will be divided among the team in an appropriate manner.

C. Budget

One thing that must be noted before going into detail on the budget is the selection of the load application part of the design. A DC motor will be used for this machine, however there are many options to choose from. As stated earlier, a motor with a variable frequency drive is being considered as the most cost

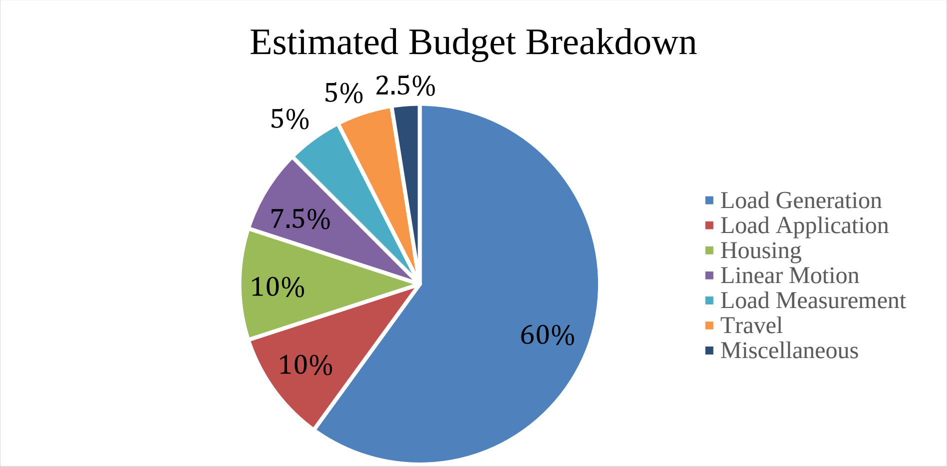

Figure 9 Estimated budget breakdown for the design in terms of percentage

effective choice. These motors have a controller that is working directly with the motor rather than going through a user interface on a computer. Although not as precise as a motor with a user interface through a computer, this option will still be able to meet the requirements from the sponsor. However, if the sponsor insists on using a motor and controller that works through a computer user interface, budgetary constraints may become an issue. The motor and controller combinations that have been looked at as possible options for this machine range in cost anywhere from about $1,200 to upwards of $10,000. The products on the high end of that spectrum would be able to perform the job required quite well, but with such a large price tag that is clearly not a viable option. However, the sponsor has informed the group that if a viable motor and controller is found that could be beneficial to the design but may be a little too expensive, he may be able to assist in procuring those items. So moving forward the group plans to construct a shopping list of parts that are within budget and a "wish list" of parts that, if funding from the sponsor is provided, could be used to make the design even better. This "wish list" will accompany a proposal that provided an explanation as to why the higher priced option would be beneficial to the overall design. Then our sponsor can choose whether or not to assist in the purchase of these items. The sponsor has also stated that many of the load measurement tools such as strain gauges and signal conditioning equipment can be provided by him as well because his workshop has much of these devices already on hand in his workplace that can be utilized on our design.

Continuing with the budget, an estimated breakdown of the spending by category can be found in Figure 7. This budget is not taking into consideration the assistance that may be provided by the sponsor, so if assistance is provided these values would shift. As already discussed, the motor, controller, and gearbox necessary to generate the torque is expected to require the largest percentage of the budget. These pieces are essentially the cornerstone of the design, and if necessary the other parts of the machine can be redesigned to make accommodations within the budget. Load application will require the purchase of two self-aligning 6-jaw chucks, as well as the transmission shaft between the jaw and the gearbox. The housing will be constructed out of stock material that must be machined and welded together. The room in the budget for the housing will be to ensure that enough material can be purchased to have a stable, reliable frame for the torsion tester. 7.5% of the budget has been allotted to the linear motion aspect of the design. This is for the purchase of the rails, bearings, and mount system that the free-end of the torsion tester will sit on. After initial pricing estimates, the cost of these pieces range greatly, and many of the vendors on the College's approved list are on the higher end, so efforts are being made to get approval for other vendors. As discussed above briefly, most of the load measurement equipment necessary for the design will be provided by the sponsor. Therefore, only a small fraction of the budget was allocated for this area in the event that some small purchases such as adhesive and wiring for the strain gauges is required. Finally, the last two pieces of the budget are for travel and any miscellaneous expenses of the design. The group traveled to the AFRL earlier this semester, and the gasoline for that trip was provided for in the budget. The miscellaneous allocation is for any small purchases that must be provided for such as printing costs or things of that nature.

VIII. Conclusion

The Munitions Directorate at Eglin Air Force Base presented the team with the task of producing a more effective torsion testing machine. The new torsion testing machine must satisfy geometric constraints as well as functional constraints that were provided by our sponsor. After conducting background research, 5 categories of interest were developed; load generation, load application, linear motion, sensors, and housing. Multiple concepts were generated for the critical components and were compared using decision matrices to select the optimal design. The optimal design was constructed from the highest ranking components in each category.

A DC motor will generate the load need to torque the specimen. The team is currently looking into an alternative to a fully programmable motor working with LabVIEW due to its high cost, complexity, and time constraint on the project. The alternative is a VFD DC motor, which has controls directly hooked up to the motor, instead of going through a LabVIEW user interface. This would allow the team to focus on other aspects of the project instead of the programming and controlling part, which is difficult for a team of all mechanical engineers.

In order to grip the specimens, two 6-jaw chucks will be used. Orders for these chucks will be made before the end of fall semester. A 2 rail ball bearing guide will be used in order to account for the free-end. The team is currently working on finding the right vendor and price for this component. The sponsor will be providing the strain rosette sensors needed for this project. This allows the team to use the money originally allocated for sensors for another part of the design. It also saves time looking for a proper and reliable vendor since the sensors must be of high quality. Finally, the team chose aluminum for the housing and frame for the machine. The frame will have a hollow rectangular cross section in order to reduce the mass and cost of the overall machine. However, after talking to other professors the team will use steel instead of aluminum to add an extra factor of safety on the housing. This will ensure that the machine will not deform in any way during operation due to the high stresses felt by it.

The team expects to finish this project on time and within budget. This was made possible by the decision to go with the VFD DC motor. As long as the sponsor agrees with this decision final orders will be made and assembly will begin during spring semester.

Over the upcoming break, the team will go over the final design and determine if there is any room for improvement. Then preliminary shopping will be done to price out materials and components and a final bill of materials will be produced. After the break the team will converse with the sponsor to get the go-ahead on the final design, and purchase orders will be placed.

IX. References

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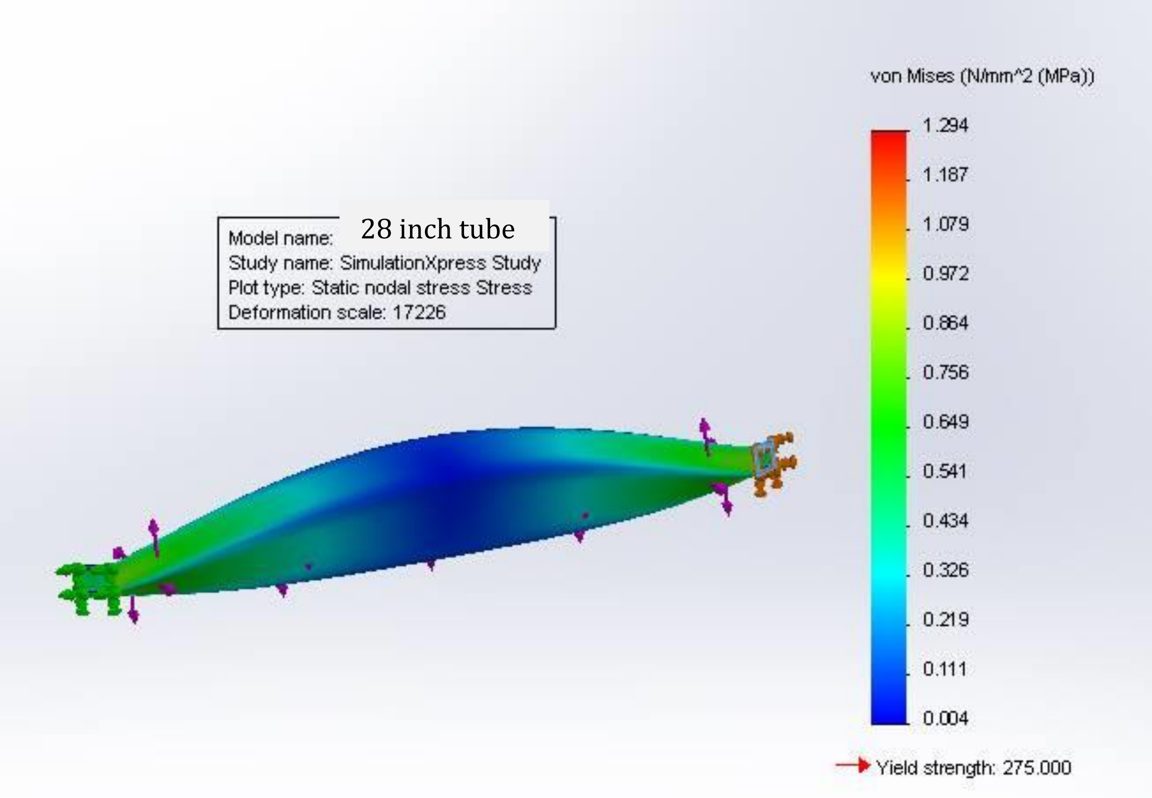
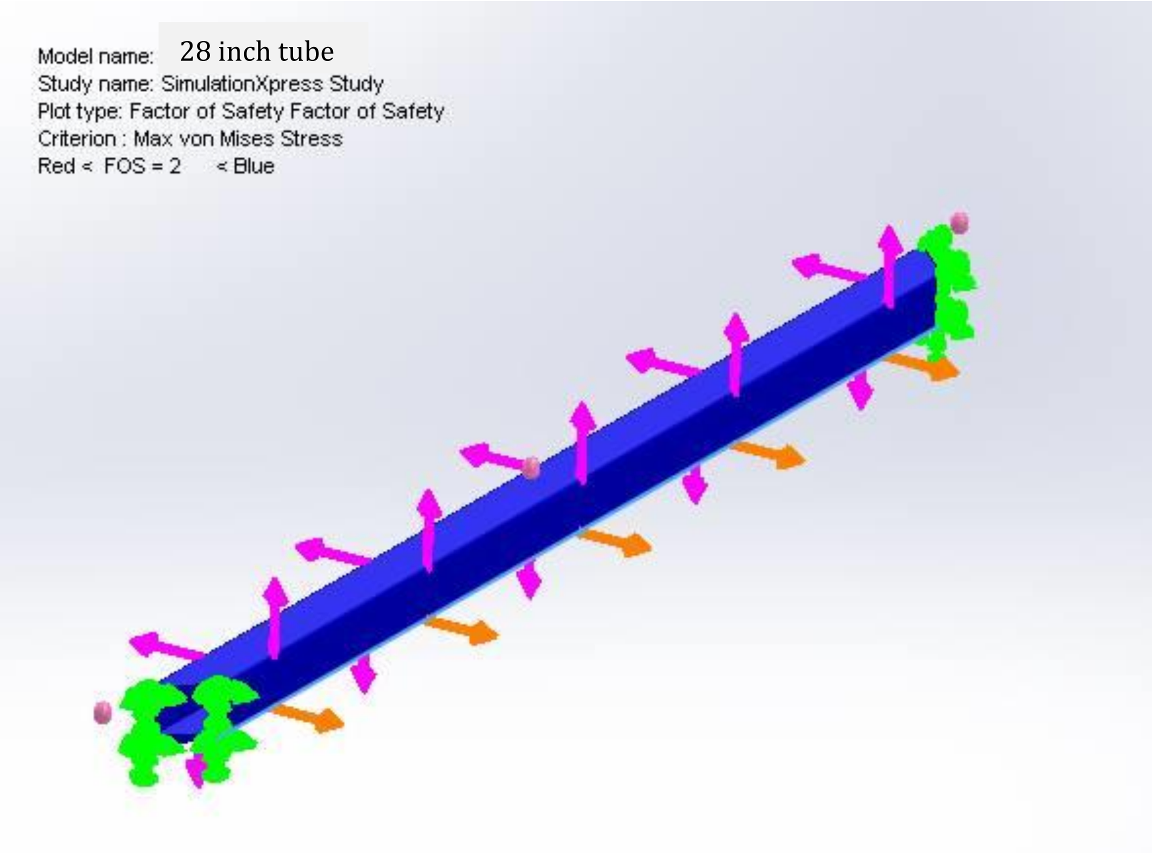
X. Appendix



Model name: 28 inch tube
Study name: SimulationXpress Study
Plot type: Static nodal stress Stress
Deformation scale: 17226



Model name: 28 inch tube
Study name: SimulationXpress Study
Plot type: Factor of Safety Factor of Safety
Criterion : Max von Mises Stress
Red < FOS = 2 < Blue