

Installation of TVC Actuators in a Two Axis Inertial Load Simulator Test Stand

Adam Dziubanek

NASA, Marshall Space Flight Center, Huntsville, Alabama, 35808

Abstract

This paper is about the installation of Space Shuttle Main Engines (SSME) actuators in the new Two Axis Inertial Load Simulator (ILS) at MSFC. The new test stand will support the core stage of the Space Launch System (SLS). Because of the unique geometry of the new test stand standard actuator installation procedures will not work. I have been asked to develop a design on how to install the actuators into the new test stand. After speaking with the engineers and technicians I have created a possible design solution. Using Pro Engineer design software and running my own stress calculations I have proven my design is feasible. I have learned how to calculate the stresses my design will see from this task. From the calculations I have learned I have over built the apparatus. I have also expanded my knowledge of Pro Engineer and was able to create a model of my idea.

I. Introduction

An ILS is a structure used to test the dynamic characteristics of an actuator on a rocket engine. See Figure 1: Two Axis ILS Stand for a visual reference. The future configuration of the Two Axis ILS at the Marshall Space Flight Center (MSFC) will be designed to test a heritage SSME actuator. An actuator is used to control the trajectory of a rocket by means of Thrust Vector Control (TVC). The pendulum on the ILS is designed to simulate the inertia of a SSME nozzle. Since conventional means would not allow an actuator to be installed in the new test stand I collaborated with design engineers and technicians and created a possible alternative. Figure 2: Possible alternative

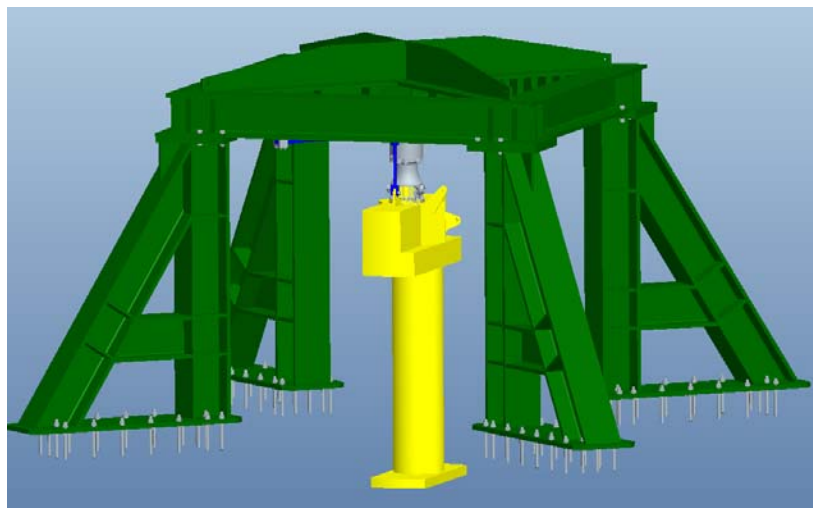


Figure 1: Two Axis ILS Stand

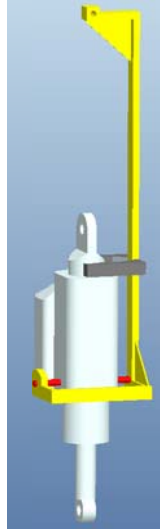


Figure 2: Possible alternative

II. Supporting Information

The reason actuators cannot be installed in the usual manner is because of the geometry of the Two Axis ILS stand. Compared to a Single Axis ILS stand the Two Axis ILS stand clevis mounts are directly under the I-beam. See Figure 3: Top View Two Axis and Figure 4: Top View Single Axis for comparison. As shown below the single ILS stand has an opening at the top where an actuator can easily fit through with use of an overhead crane. The Two Axis stand does have an opening on the top but it is not straight down. An attachment of some kind is required to install an actuator in the Two Axis ILS stand.

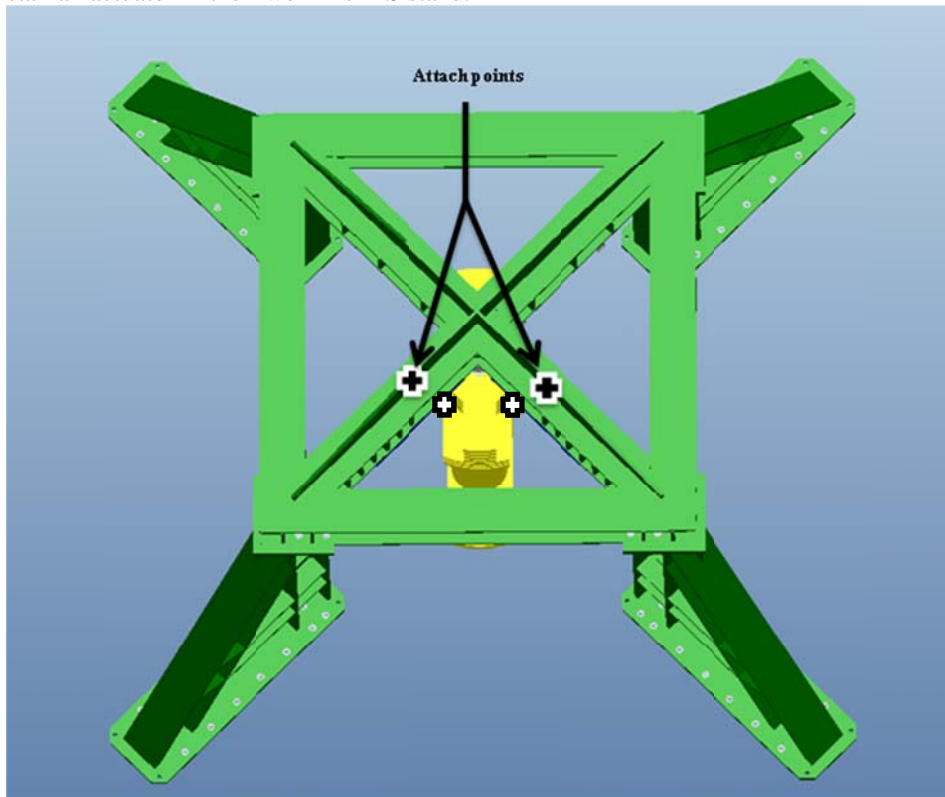


Figure 3: Top View Two Axis

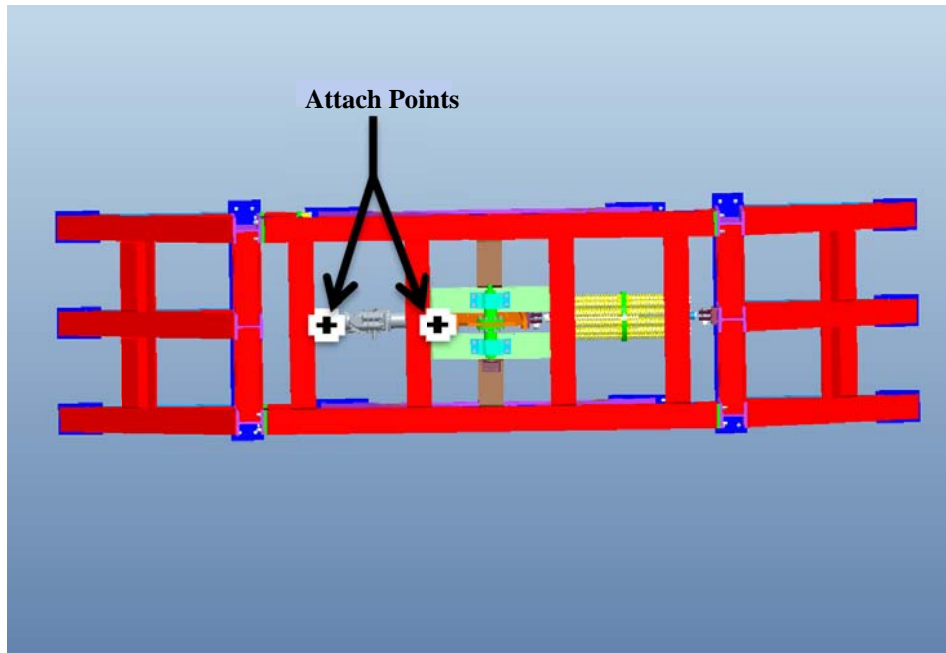


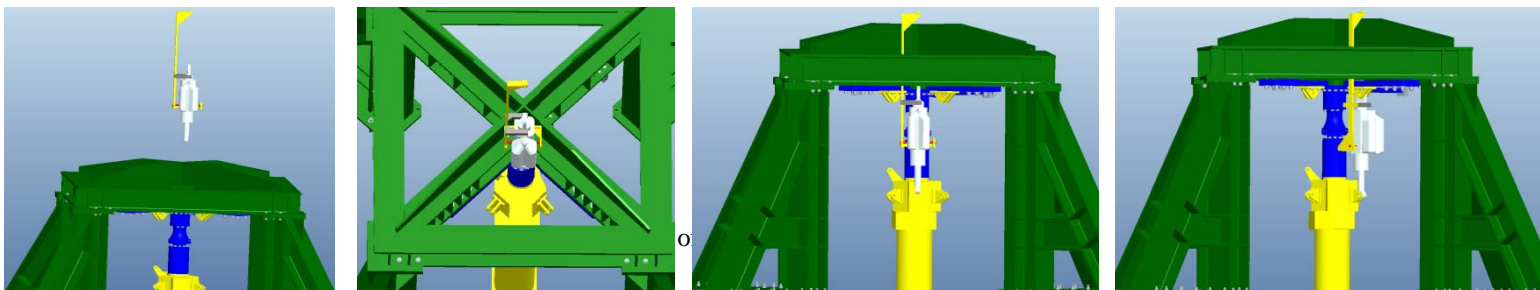
Figure 4: Top View Single Axis

Below is a detailed explanation of the design and mounting procedures. Each actuator can weigh up to 250 lbs. A NASA Factor of safety (F.S.) of 5 was added to the 250 lbs. making it 1250 lbs..

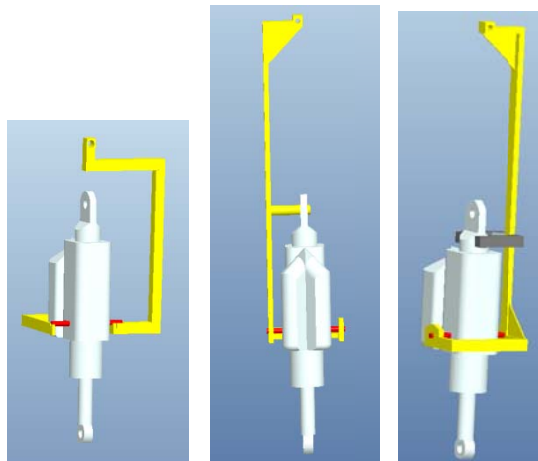
The C Hook

The “C-Hook” design would allow the crane mount to fit through the opening on the top and then shift over into the clevis.

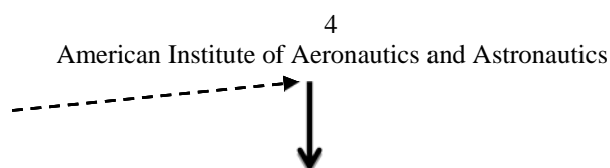
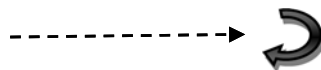
demonstrates the integration of an SSME actuator into the Two Axis ILS.



This design went through several iterations until it was optimized to have the strongest frame while still keeping the weight of the fixture to a minimum. See **Error! Reference source not found.** The first iteration (far left) was the basic concept. The red rods coming out of the actuator are the lifting pins. The pins are mounted at the actuators center of gravity. This led to the question as to whether the actuator would tip forward when picked up from this angle. A centering rod was added to keep the actuator parallel with the fixture arm. A second question arose when one considered the lifting point was behind the center line of the actuator. After a slight adjustment the lifting point was moved over the center line of the actuator. There is a possibility the actuator may tilt left or right when lifted by the crane. Further analysis is needed to determine whether the lifting point needs to be moved to the left or right of the center line of the actuator to counteract the effect. On the most recent version of the fixture the centering rod was removed and replaced with rubber bumpers on either side of the actuator. This was done because once the fixture was in position there was no way to mount the rod end of the actuator into the clevis of the Two Axis ILS.



All designs at MSFC must go through an extensive stress analysis. Below are a few calculations when considering this design. Please note these calculations were with the understanding it is one solid part. This was done to simplify the calculation process. If this part was manufactured it would be welded together at all joints. A fixed point was used instead of a dynamic point because of the low speed of the crane and also to simplify calculations.



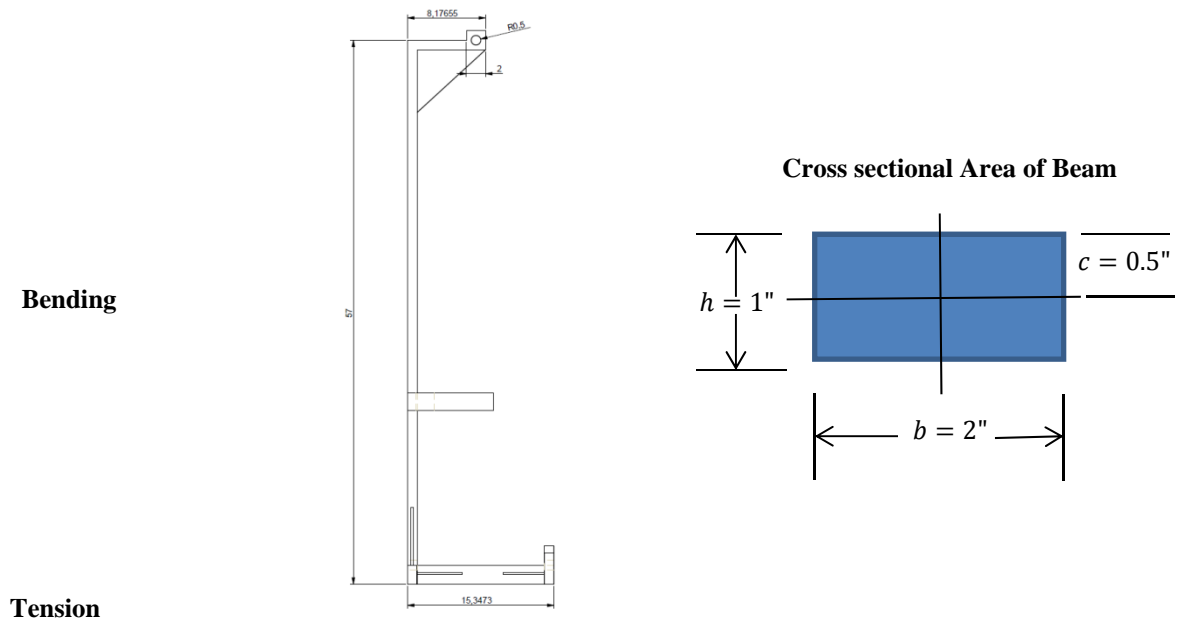


Figure 7: Free Body Diagram

$$\sigma_t = \frac{P}{A} = \frac{400}{2} = 200psi$$

Where,

σ_t = Tension stress of beam
 P = Weight of frame plus actuator
 A = Area of beam

Bending

Moment of Inertia Equation for a Rectangle

$$I = \frac{1}{12}bh^3 = \frac{1}{12}(2)(1)^3 = 0.17in^4$$

$$M = (400)\left(\frac{15.34}{2}\right) = 3068in - lb$$

$$\sigma_b = \frac{Mc}{I} = \frac{(3068)(0.5)}{0.17} = 9023psi$$

Where,

σ_b = Bending stress of beam
 M = Weight of frame plus actuator multiplied by the moment arm of the lifting point
 c = Radius of height

Total of Stress

$$\sigma_{tot} = \sigma_t + \sigma_b = 200 + 9023 = 9223psi$$

Where,

σ_{tot} = Total stress
 σ_t = Total of tension stress

σ_b = Total of bending stress

The material used is steel which has a Material Strength (M.S.) of 58000psi ultimate and 36000psi yield.

$$M.S._{ult} = \frac{F_{tu}}{\sigma_{tot}(S.F._{ult})} - 1 = \frac{58000}{(9223)(5)} - 1 = 0.25773$$

$$M.S._{yld} = \frac{F_{ty}}{\sigma_{tot}(S.F._{yld})} - 1 = \frac{36000}{(9223)(3)} - 1 = 0.3011$$

Where,

$M.S._{ult}$ = Ultimate material strength of steel divided by ultimate material strength multiplied by the ultimate safety factor

$M.S._{yld}$ = Yield material strength of steel divided by yield material strength multiplied by the yield safety factor

F_{tu} = Ultimate material strength of steel

F_{ty} = Yield material strength of steel

σ_{tot} = Total stress from fixture

$S.F._{ult}$ = MSFC Ultimate safety factor

$S.F._{yld}$ = MSFC Yield safety factor

III. Conclusion

This design is a feasible alternative to the problem of installing actuators in the Two Axis ILS stand. The current configuration has been over designed for the load. With a M.S. ultimate factor of +0.25 and a yield of +0.30 the frame has more than enough strength to support the load of an actuator. Furthermore the design could probably be modified with hollow square tubing to reduce the weight of the structure. This fixture could also be modified for different sized actuators

References

This paper was created with the resources of the Marshall Space Flight Center (MSFC) in cooperation with the education office.

Stress equations were used from “Mechanics of Materials, Second Edition, Ferdinand P. Beer & E. Russell Johnston, Jr”.

Stress equations were taught to me by Chris Baker, Stress analysis, ER35 MSFC.

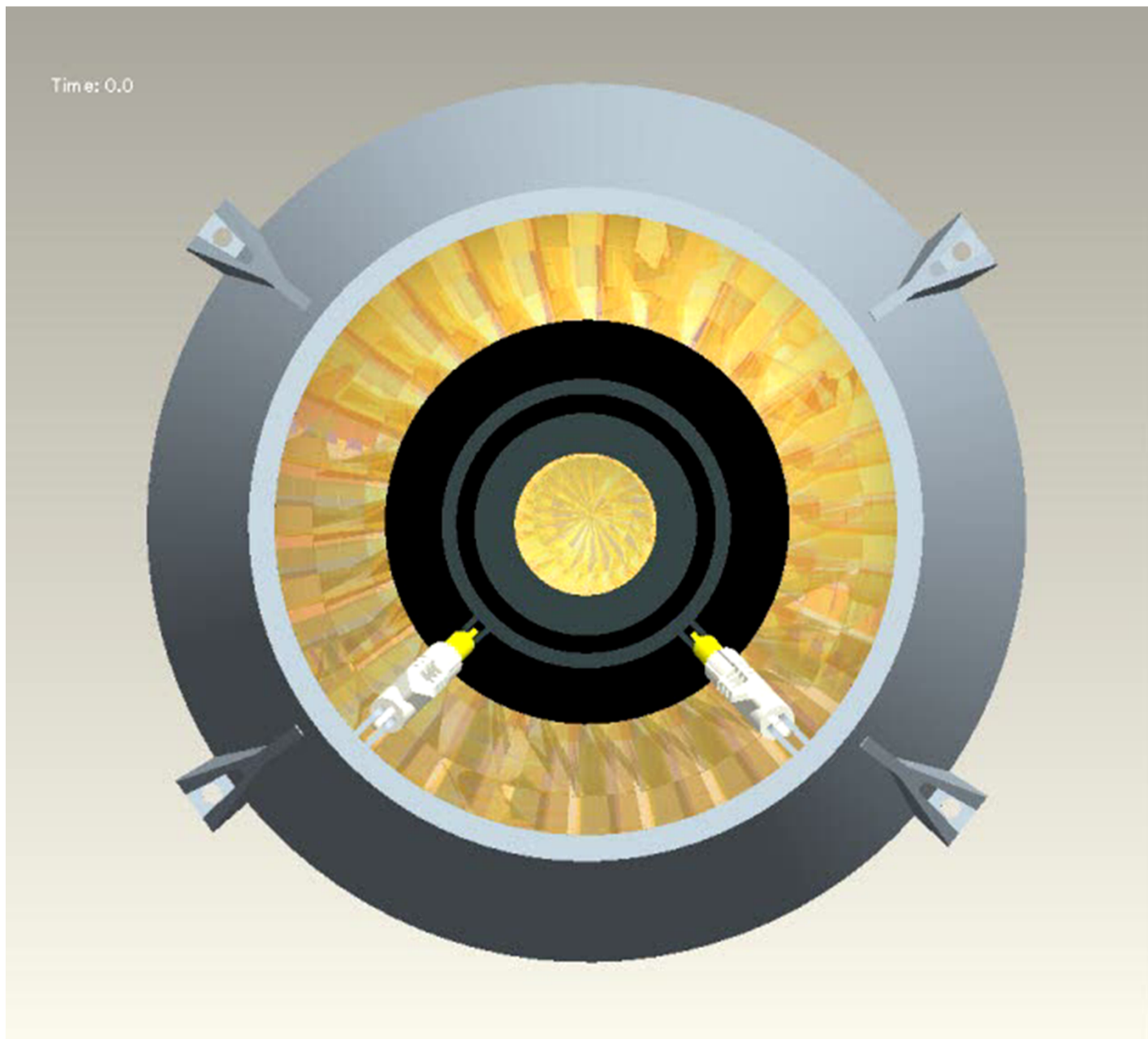
Student Advisor Dr. Brain Landrum, UAHuntsville.

SLS
Space Launch System

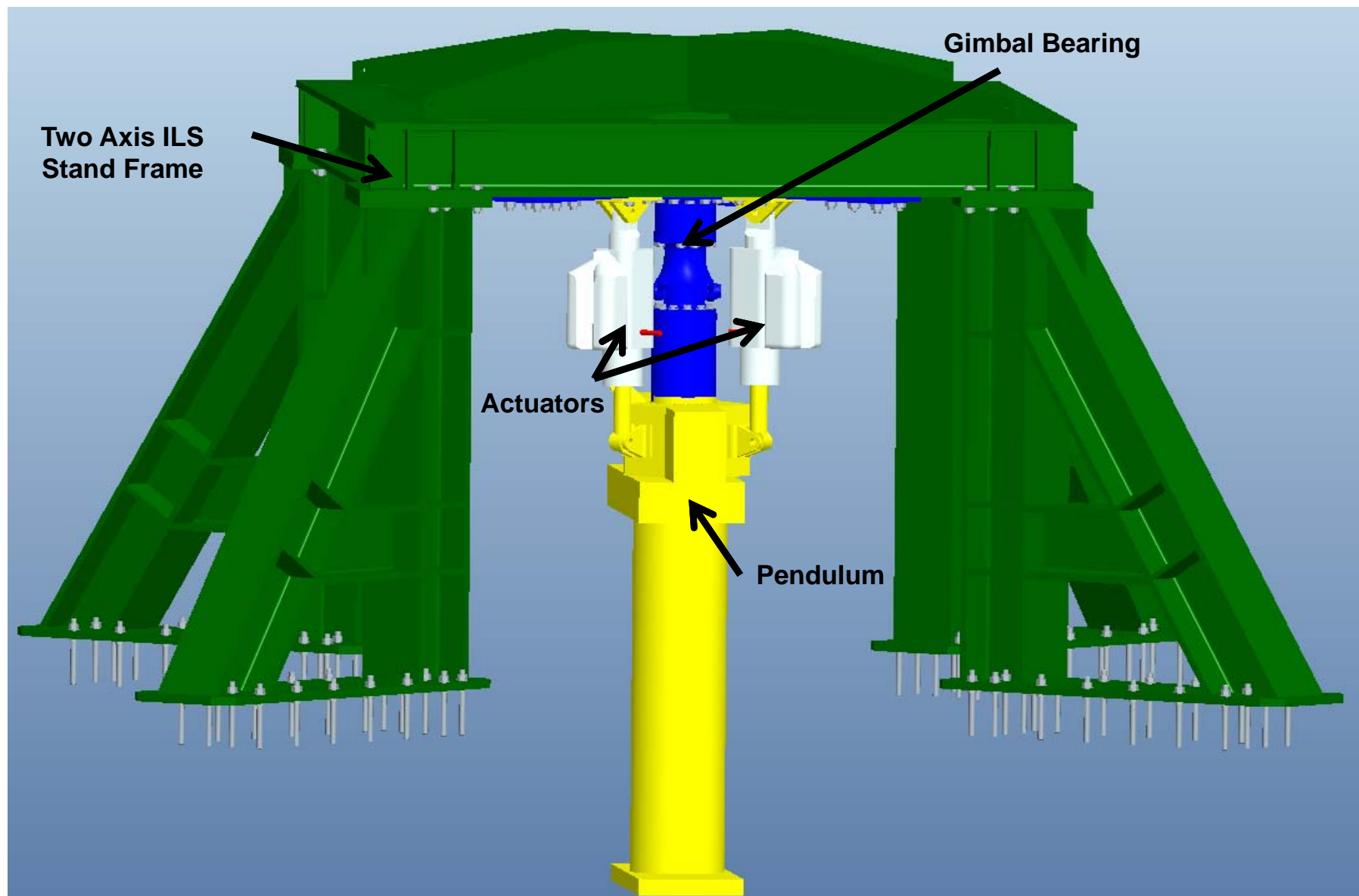


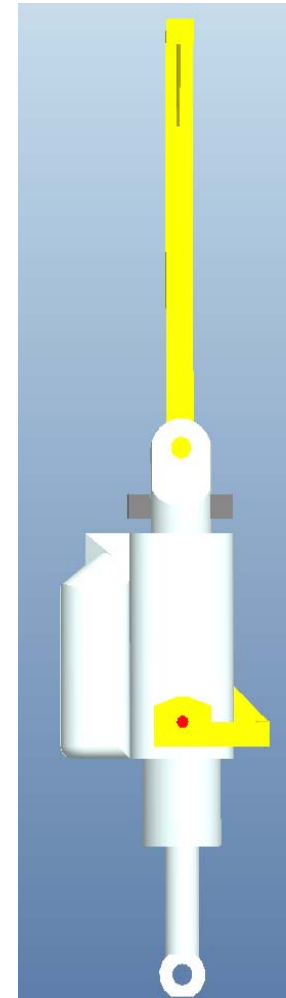
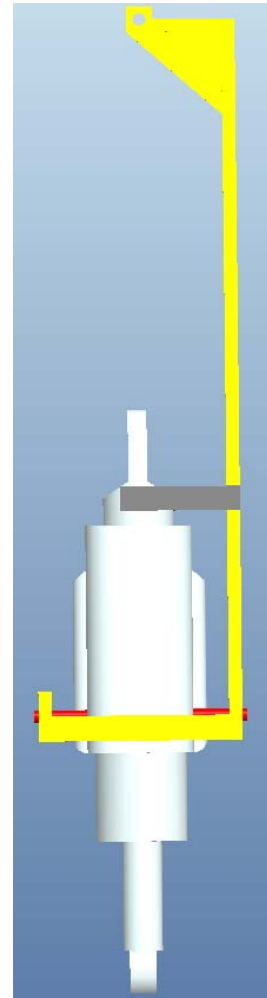
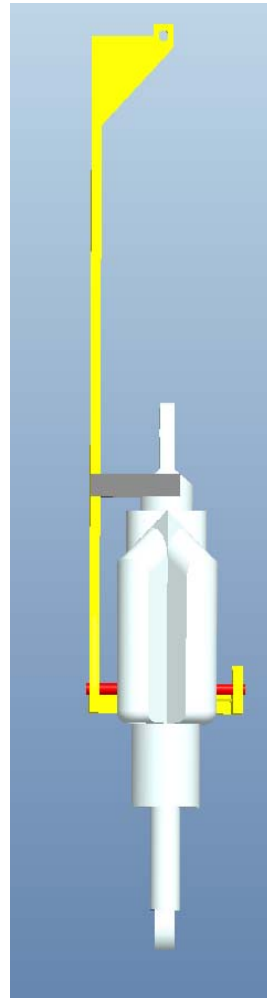
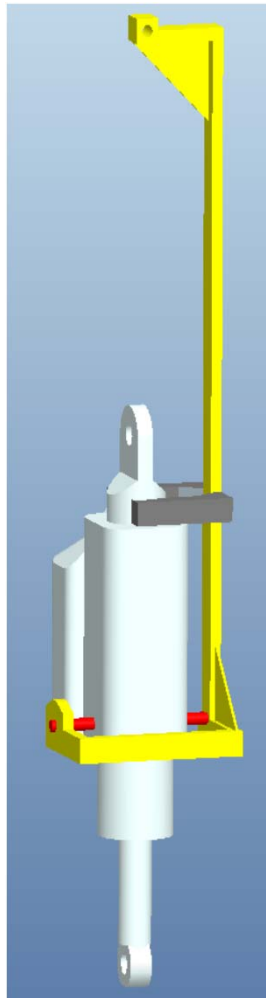
Installation of TVC Actuators in a Two Axis Inertial Load Simulator (ILS) Test Stand

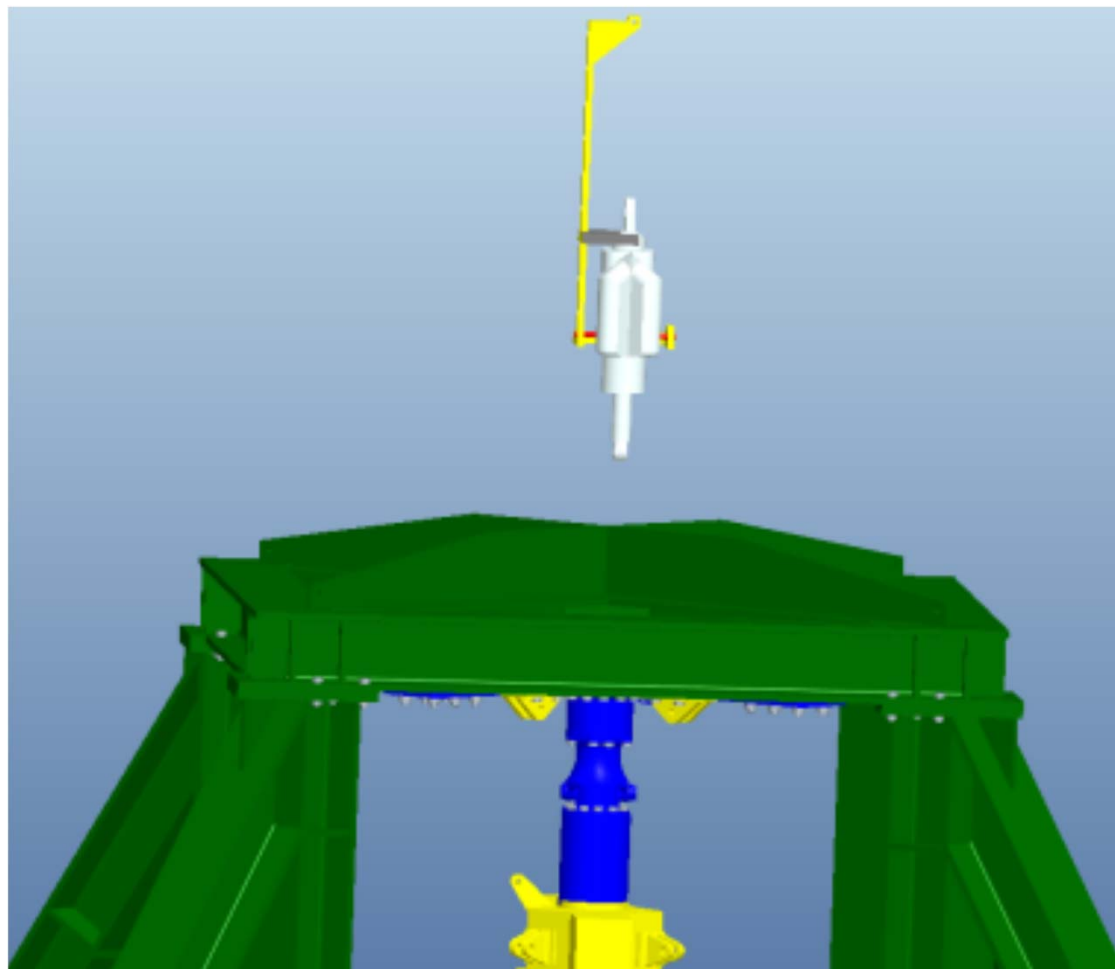
*Adam Dziubanek
University of Alabama in Huntsville
Student Advisor, Dr. Brian Landrum
Marshal Space Flight Center
Thrust Vector Control Systems Integration and Components Branch*

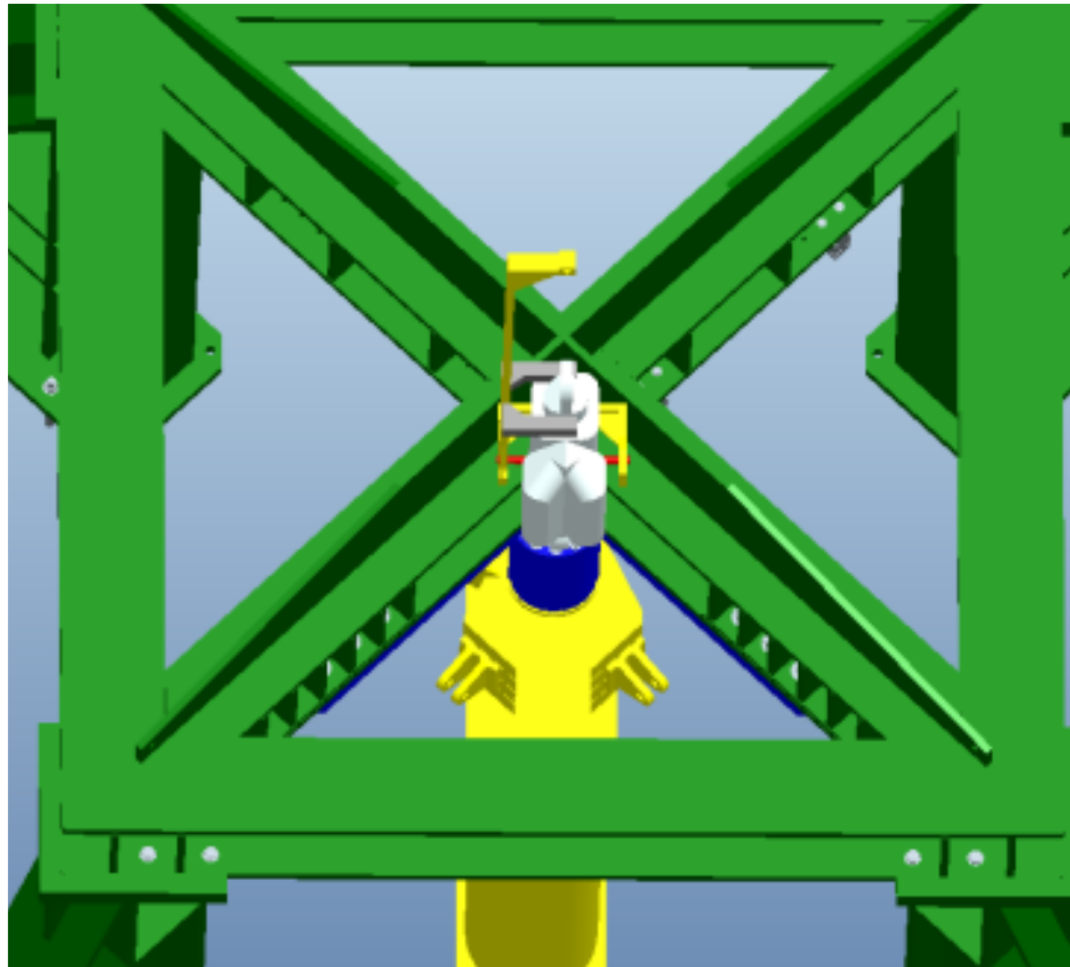


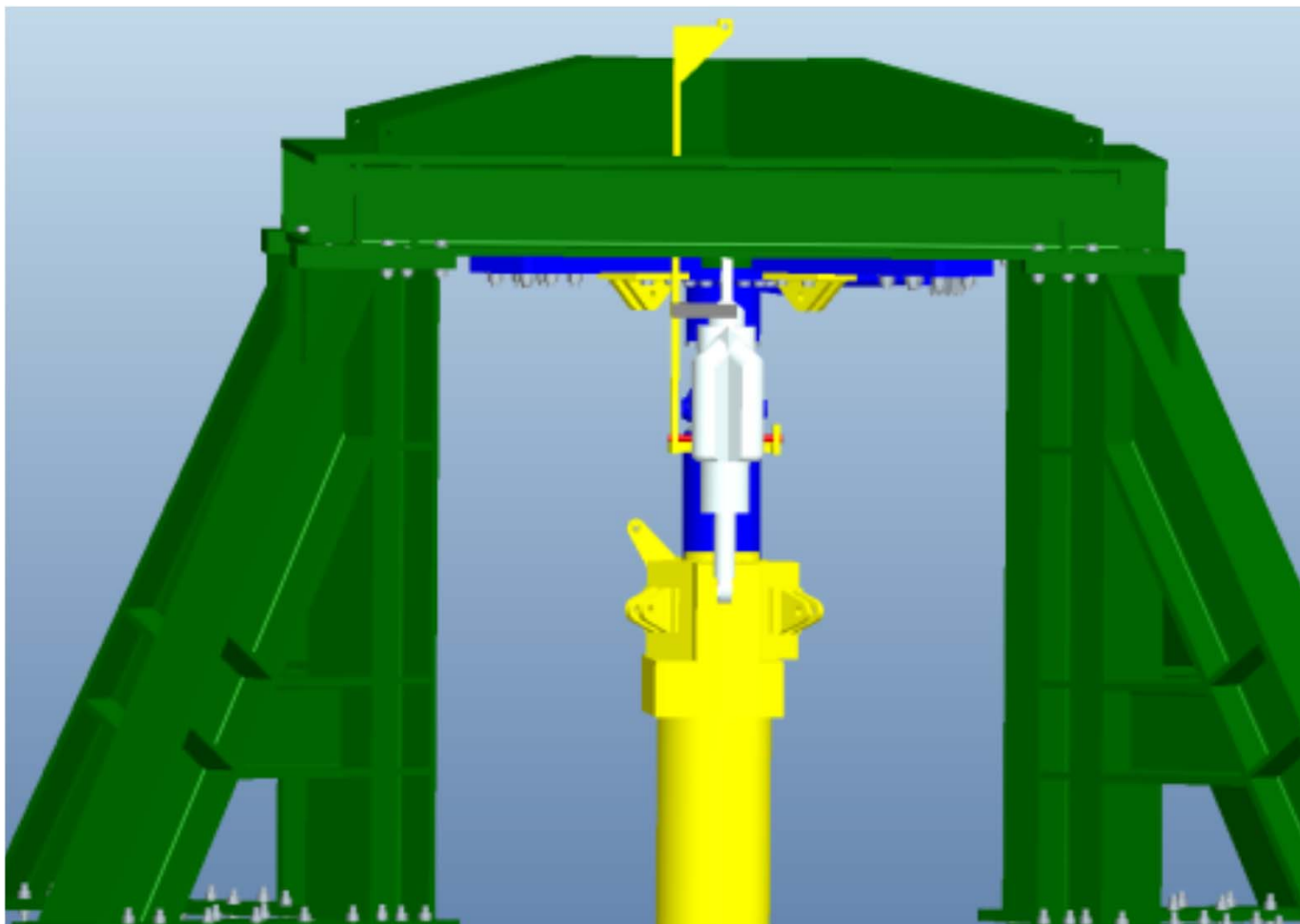


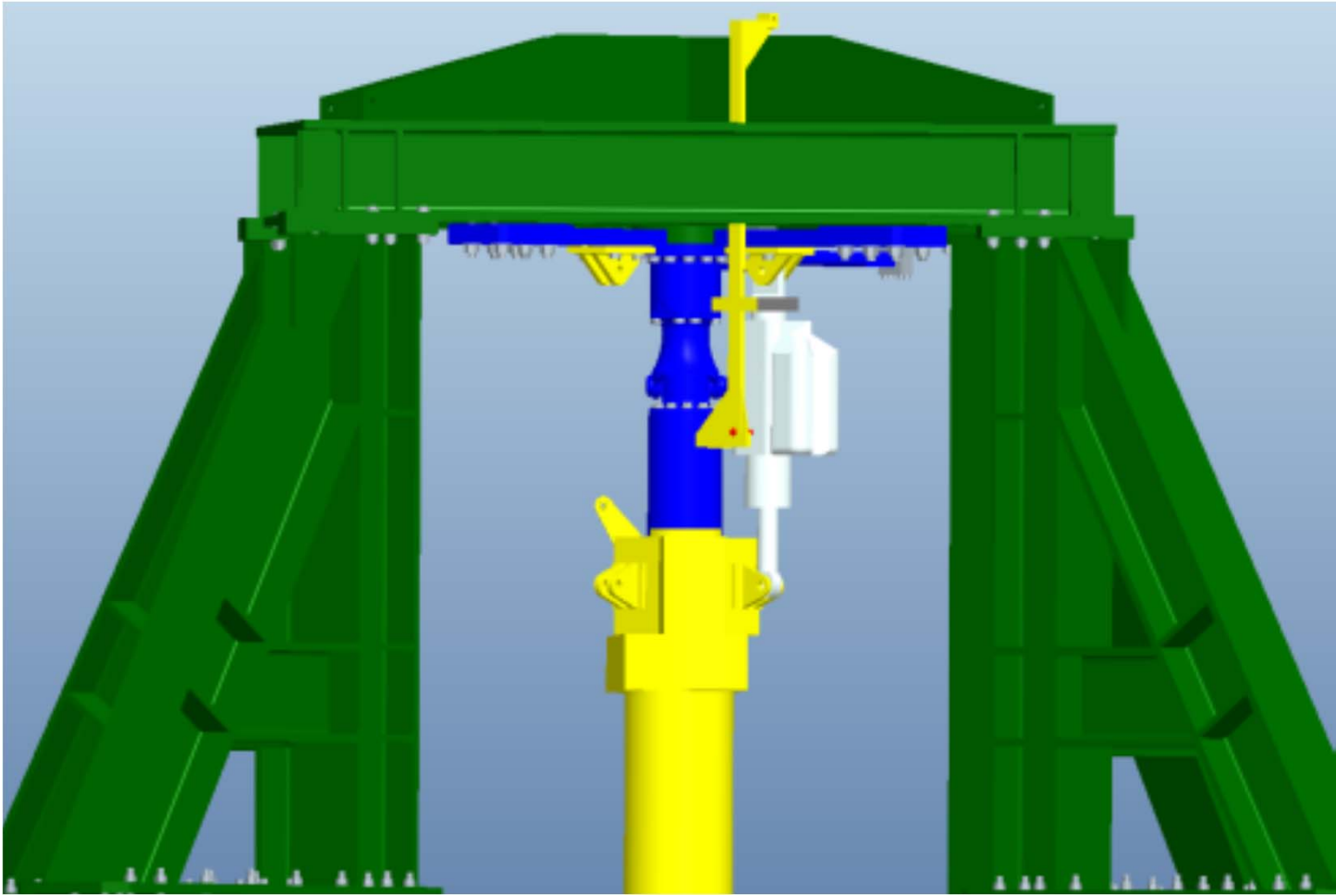


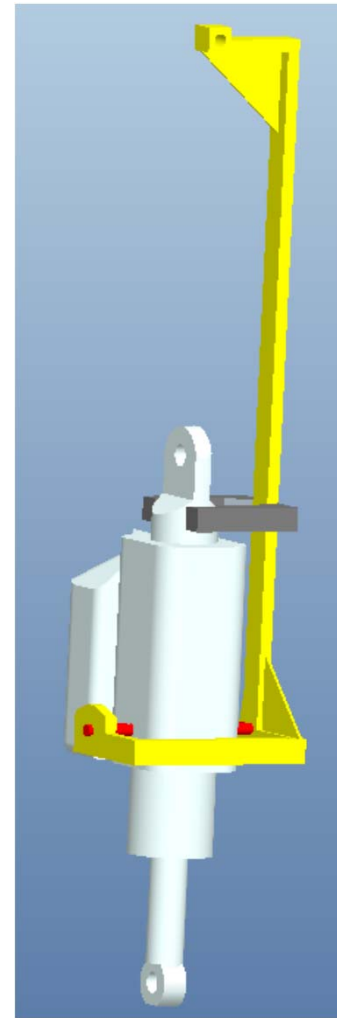
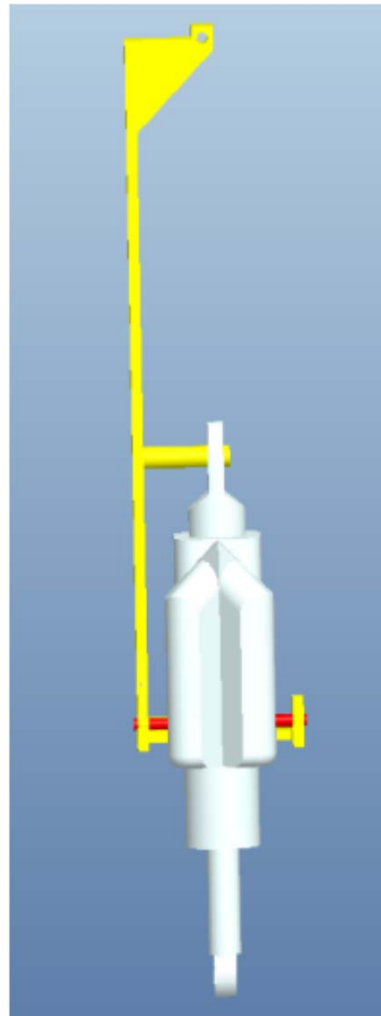
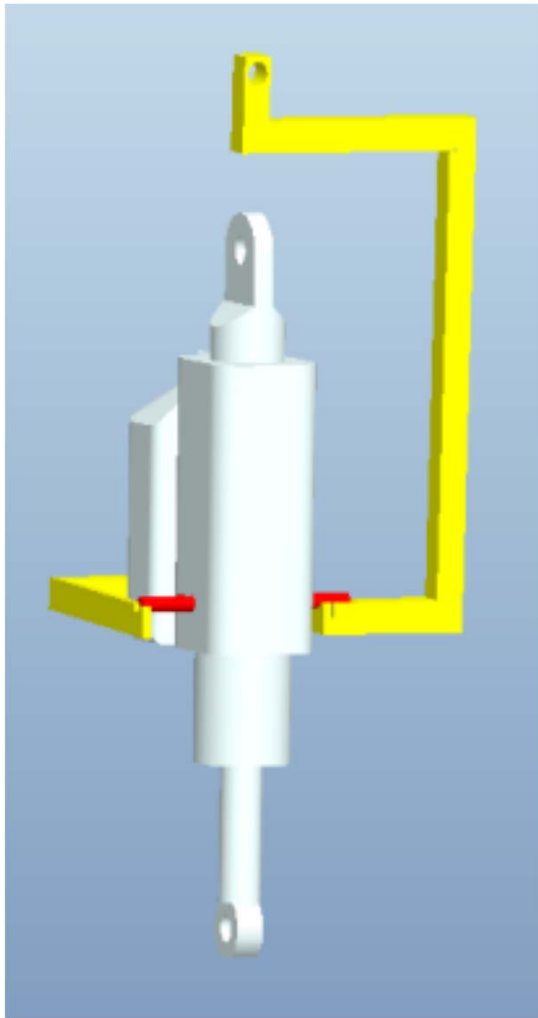




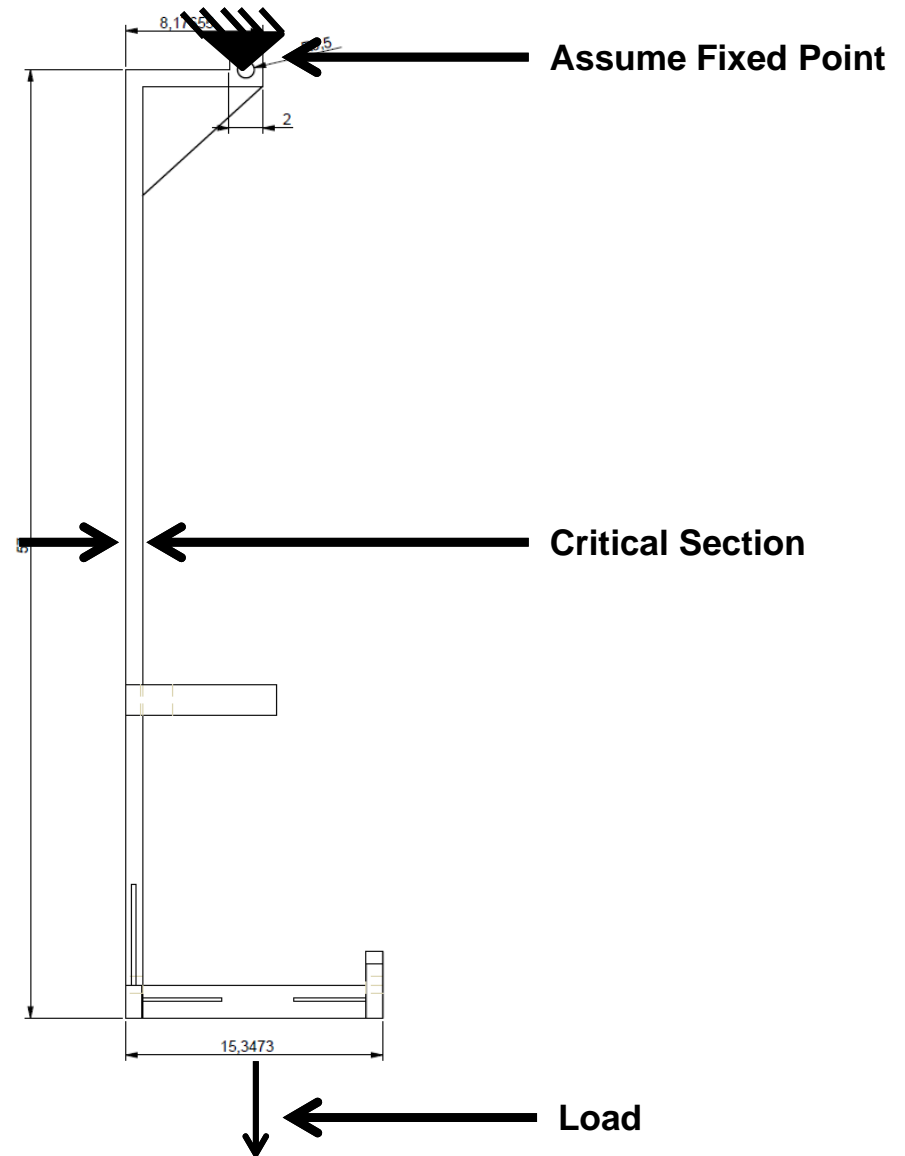




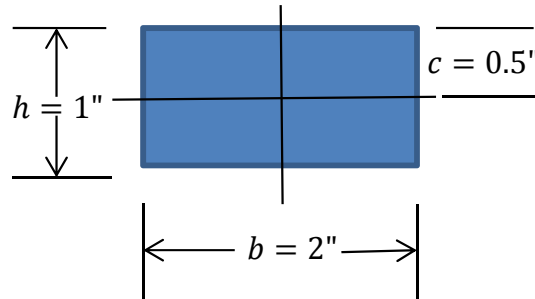




- ◆ Material: A36 Steel
- ◆ Specification: ASTM-A36
- ◆ Ultimate Strength: 58,000psi
- ◆ Yield Strength: 36,000psi



Cross Sectional Area



Area equation

$$\text{base} \times \text{height} = 1\text{in} \times 2\text{in} = 2\text{in}^2$$

Moment of Inertia Equation for a Rectangle

$$I = \frac{1}{12}bh^3 = \frac{1}{12}(2\text{in})(1\text{in})^3 = 0.17\text{in}^4$$

$$\sigma_t = \frac{P}{A} = \frac{400lbs}{2in^2} = 200psi$$

Where,

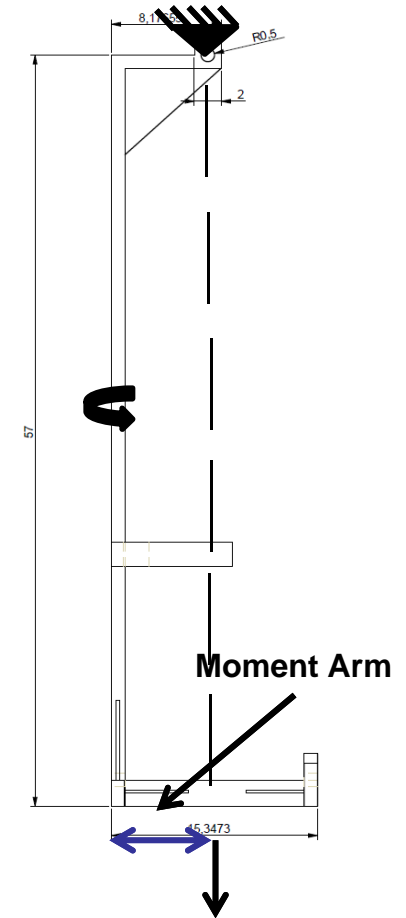
- ◆ σ_t = Tensile stress of beam
- ◆ P = Weight of frame plus actuator
- ◆ A = Area of beam

$$M = (400lbs) \left(\frac{15.35in}{2in} \right) = 3,070in \cdot lb$$

$$\sigma_b = \frac{Mc}{I} = \frac{(3070in \cdot lb)(0.5in)}{0.17in^4} = 9,029psi$$

Where,

- ◆ σ_b = Bending stress of beam
- ◆ M = Load multiplied by the moment arm of the lifting point
- ◆ c = Radius of height



$$\sigma_{tot} = \sigma_t + \sigma_b = 200psi + 9,029psi = 9,229psi$$

Where,

- ◆ σ_{tot} = Total stress
- ◆ σ_t = Tensile stress
- ◆ σ_b = Peakbending stress

$$MS_{ult} = \frac{F_{tu}}{\sigma_{tot}(SF_{ult})} - 1 = \frac{58,000psi}{(9,229psi)(5)} - 1 = +0.25$$

Where,

- ◆ σ_{tot} = Total stress from fixture
- ◆ SF_{ult} = Ultimate safety factor for structural slings
- ◆ F_{tu} = Ultimate material strength of steel

$$MS_{yld} = \frac{F_{ty}}{\sigma_{tot}(SF_{yld})} - 1 = \frac{36,000psi}{(9,229psi)(3)} - 1 = +0.30$$

Where,

- ◆ SF_{yld} = Yield safety factor for structural slings
- ◆ F_{ty} = Yield material strength of steel
- ◆ σ_{tot} = Total stress from fixture

- ◆ This design is a feasible solution to the problem
- ◆ The design could probably be modified with hollow square tubing to reduce the weight of the structure.
- ◆ This fixture could also be modified for different sized actuators