Tiltrotor Test Rig: Model Preparation for First Wind Tunnel Test

Rolizmar N. Vega[1]
University of Puerto Rico, Mayaguez, PR, 00638

The calibration and preparation of the Tiltrotor Test Rig (TTR) prior to wind tunnel testing is examined. A description of the techniques used to complete the preparation process is presented. Upon TTR delivery, the 13 foot long rotor blades wil be checked out and calibrated in the Calibration Rig. The TTR Cal Rig consists of the Aft Frame, which will hold the TTR, and the Forward Frame, which will have eleven actuators; these will be for pitch, roll, torque, lateral shear, vertical shear, and thrust. The TTR and the Aft Frame are manufactured and waiting to be installed in N-246. Prior to the installation of these structures, a stress analysis, lift plan, and other calculations had to be completed. This paper includes a summary of the engineering effort required to prepare building N-246 for both the TTR and the Calibration Rig by providing calculations for structural and mechanical analysis. Lastly, engineering planning for the TTR installed and integrated into the TTR Calibration Rig will be described.

Nomenclature

TTR	=	Tiltrotor Test Rig
RTA	=	Rotor Test Apparatus
LRTA	=	Large Rotor Test Apparatus
NFAC	=	National Full-Scale Aerodynamics Complex
JHL	=	Joint Heavy Lift
Cal Rig	=	TTR Calibration Rig
AFT Frame	=	TTR Calibration Rig Aft Frame
FWD Frame	=	TTR Calibration Rig Forward Frame
WLL	=	Working Load Limit

I. Introduction

The Aeromechanics Branch of the Flight Vehicle Research and Technology Division here at NASA Ames is responsible for aeromechanics research activities that directly support the civil competiveness of the U.S. helicopter industry and the Department of Defense. In order to support the Division's goals, engineers are developing a test capability for the National Full Scale Aerodynamics Facility (NFAC) to support large tilt rotor aircraft. This capability will enable test and evaluation of the prop rotor for the Joint Heavy Lift (JHL) aircraft as well as other rotary concepts. The Tiltrotor Test Rig (TTR) project is a collaborative effort by the Army, NASA and Air Force.
Before the Tilt Rotor Test Rig (TTR), NASA Ames used the Rotor Test Apparatus (RTA) and the Large Rotor Test Apparatus (LRTA) to do tests of rotor and hover performance, wing surface pressure, wing download, etc. "Similar to the Rotor Test Apparatus, the Large Rotor Test Apparatus (LRTA) is a larger rotor test stand available at the National Full-Scale Aerodynamics Complex (NFAC), managed and operated by the U.S. Air Force's Arnold Engineering Development Center. It is a special-purpose drive and support system for operating helicopter rotors up to 52,000 pounds of thrust in the 40- by 80- and 80- by 120-Foot Wind Tunnels". (Peterson & Segall, 2012)

Like the LRTA, the TTR is a large test stand and system and has a balance system included from the beginning. This is because, while testing with the RTA, NASA noticed they needed this kind of system and it was designed and built for a test program in 1985. "The TTR is designed to test advanced prop rotors up to 26 feet in diameter at

[1] Mechanical Engineering Intern, Aeromechanics Branch, NASA Ames Research Center, and University of Puerto Rico.

speeds up to 300 knots. This combination of size and speed is unprecedented and is necessary for research into 21st-century tilt rotors and other advanced rotorcraft concepts. Bell Helicopter Textron and Triumph Aerospace Systems are under contract to NASA to design and manufacture the TTR and supporting equipment, including a calibration rig. The U.S. Army and Air Force are contributing funding and support. Additional funding is provided under the American Recovery and Reinvestment Act". (Peterson & Segall, 2012)

The TTR will be used in both the 40- by 80- and 80- by 120-Foot Wind Tunnels. The TTR is a horizontal axis rig and rotates on the test-section turntable to face the rotor into the wind at high speed (300 knots), or fly edgewise at low speed (100 knots), or at any angle in between. But prior to wind tunnel testing the model has to be properly calibrated and this is the purpose of the Calibration Rig.

There are two main components of the TTR: Calibration Rig, which consists of the Aft Frame and the Forward Frame, and the TTR, which consists of motors, gearboxes and other instruments to support rotorcraft testing. The TTR and the Calibration Rig weighs over 150,000pounds. The Aft Frame and the TTR have been manufactured. These will be installed in building N-246 as planned. To distribute the load that the TTR and the Cal Rig applies to the floor, steel plates have been designed and will be installed prior to assembling the structural frames and TTR.

This paper presents selected information and results from the preparation of the Calibration Test Rig's Aft Frame and the structural analysis for the steel plates installation, and describes the installation of the Cal Rig prior to TTR delivery into building N-246.

II. Preparation prior TTR delivery

A. TTR Calibration Rig

The main purpose of the TTR Calibration Rig is to structurally support the TTR during the calibration process prior to entering the 40x80 Foot Wind Tunnel. In addition, it is needed to support the TTR weight of 60,000 pounds.

The Calibration Rig consists of two main components: the Aft Frame and the Forward Frame. The Aft Frame has been manufactured and ready to be installed onto the steel plates. This frame has three struts that act as supports for the TTR, see Figure 2. It is a 32,000 pound structure which main purpose is just to hold the TTR. Meanwhile, the Forward Frame is under design review and is expected to be manufactured and ready for installation by the end of the year. It will be a 21-foot tall structure that weighs 60,000 pounds, and will have eleven actuators: two for pitch, two for roll, two for torque, two for lateral shear, two for vertical shear, and one for thrust.

B. Floor Plates

The installation of floor plates under the Cal Rig and the TTR is needed to distribute the total load of approximately 150,000 pounds. These are four different sizes of A36 Steel plates: 8ft x 8ft, 8ft x 4ft, 8ft x 4ft 8in, and 8ft x 5ft 8in. These plates are 1in thick, and the heaviest weighs 2,614 pounds. The configuration seen in Figure 2 will be used to place the floor plates.

To execute the installation, a 5-ton crane, 5/8in hoist rings, shackles, and slings will be used to lift the floor plates. Each floor plate will have three hoist rings installed, without an insert. Proper analysis was done to determine proper size of the hoist rings, slings, and shackles. Further analysis was done on the steel plates to determine thread pullout and shear of the threaded hoist rings during the plate lift. As a result no insert was required in the steel plate. The results from these were that three 6-foot long slings with an angle of 70.5° between the sling and the plate at 24 inches from the center of the floor plate, as shown in Figure 3, was the most reliable option. Calculations for 4-foot and 3-foot long slings were done, too.

In addition, safety factor calculations for the 5/8in hoist ring installation were done. Using a torque of 1,100 ft-lb, the resulting safety factor was 2.27. This is still a little bit low, but documents that there is no need for inserts.

C. Aft Frame Installation

The Aft Calibration Frame weights 32,000 lbs, and needs to be installed over the floor plates. A 25-ton crane will be used to execute the installation. The overhead bridge height is 32 feet and the crane will be at a 21.83 feet height from the bottom edge of the Aft Frame. Similar to the floor plate's installation, three 5/8in hoist rings diameter will be used with a 15ft long sling. From the calculations, the resulting percent of WLL for the 15ft sling is 60.3%, the Forward hoist ring is 80.4%, and the Aft hoist rings are 33.5%.

After completing the Aft Frame lift and placing it over the floor plates, sixteen angle brackets have to be installed on the sides of the Aft Frame, see Figures 4 and 5. This will be installed to provide the Cal Rig with seismic restraint. These anchors will be 48in and 20in long, 0.5in thick, and a 7/8in threaded rod with nut will go through the anchors, the floor plates, and the concrete slab to hold the AFT Frame system in place. To drill through all this, a Diamond Core Bit, which can drill through both metal and concrete, will be used. Lastly, after everything is drilled through and before installing the rods, an Epoxy adhesive will be applied to the concrete hole to secure the rod to the concrete floor.

Once the Aft Frame and the seismic restraint system are installed over the floor plates, additional shimming between the plates and the Aft Frame is required to level the AFT Frame. This will be achieved by placing pieces of steel plates or other material between those two structures in every area that has a gap.

D. Pull Test

A pull test is required and implemented to test the structural integrity of the 7/8" threaded rods. The reasons to conduct this test are because we want the Epoxy to fail before the rods or the concrete do, and we calculated a safety factor of 1.96 for it, calculations in the Appendix. This test will be applied to 20% of the bolts. They should each stand up to 7,000 psi. If any bolt fails the test, every installed bolt shall be tested.

FOR CRACKED CONCRETE, SEISMIC (ASD), CONDITION B

NOMINAL ANCHOR DIAMETER	EMBEDMENT DEPTH (inches)	NORMAL – WEIGHT CONCRETE (psi)
7/8"	3.5"	7,003

Table 1. Pull test requirements for cracked concrete, seismic, condition B.

The Engineering Evaluation LAB, will conduct the test. They showed us how they implement it. Two configurations were selected for it. I designed the pull test in Pro/E and made two additional diagrams of the different configurations. Configuration 1 shows how we can complete the test with adequate open space, for example, plates that would be under the Forward Frame that are readily accessible. Configuration 2 will be used if we have to test 100% of the bolts because one from the 20% failed. This will require testing bolts close to the Aft Frame, adjacent to the TTR box beam. See Figures 6, 7 and 8.

E. Prior TTR to delivery into building N-246

Once the plates are placed over the floor, the Aft Frame is sitting over them, the anchors are installed, and the pull test has been implemented, we are ready to receive the Tiltrotor Test Rig (TTR) into Building N-246. The remaining task will be the manufacture and installation of the Forward Frame which is expected to be done by the end of the year. But, in case we cannot complete the floor plate installation prior TTR delivery into N-246, the Mechanical Design Team came up with an alternative way to arrange all the parts in the Building and leave some space for when the truck comes in with the TTR and its stand. See Figure 9 for a better understanding of how the completed installation. This figure also shows the Forward Frame, though it still is under Design Review.

III. Plan B

If the floor plates and Aft Frame installation process does not goes as planned and it is not completed prior TTR delivery into building N-246, adequate calculations and a Plan B arrangement was made to resolve the situation. First, we needed to see if the concrete could hold the weight of the TTR and its transportation stand, which its total weight is approximately 69,347 pounds, without failing.

$$Area_{stand} = A_1 + A_2 + A_3 + A_4$$
$$= 1874.643\ in^2 + 1874.643\ in^2 + 1080.248\ in^2 + 798.33\ in^2 = 5627.864\ in^2$$

$$\sigma_{TTR+stand} = \frac{Weight_{TTR+stand}}{Area_{stand}} = \frac{69347\ pounds}{5627.864\ in^2} = 12.32\ psi$$

$$Safety\ Factor = \frac{\sigma_{concrete\ allowable}}{\sigma_{TTR+stand}} = \frac{2750\ psi}{12.32\ psi} = 223$$

The resulting stress of the stand is 12.32 psi, and it is compared to the 6-in slab concrete allowable design load, which is 2,750 psi, to get the safety factor of 223. This means the concrete can hold up to 223 times the weight of the TTR and its transportation stand. See Appendix pages 7 and 8 for original calculations on the transportation stand drawings.

IV. Conclusions

To check out and calibrate the TTR, the manufacturing of the Calibration Rig, the floor plates, and the anchorage should be completed. By the end of April 2012, the Aft Frame, floor plates, and the anchors should be installed in building N-246 prior to TTR delivery. In addition, the pull test has yet to be implemented. Calculations and analysis were presented in this paper for better understanding of the engineering process that was used. Lastly, in case the schedule doesn't go as planned, a second arrangement was selected in order to complete the installation of the Cal Rig's Aft Frame over the floor plates with the TTR already in building N-246, as a scheduling contingency.

References

[1] R. L. Peterson and M. Segall, "National Aeronautics and Space Administration," NASA Ames Research Center, 9 Abril 2012. [Online]. Available: http://rotorcraft.arc.nasa.gov/Research/Facilities/lrta.html. [Accessed 10 Abril 2012].

[2] NASA Ames Research Center Drawings: N246 TTR Calibration Rig Steel Plate Installation Assembly (A246-1200-M1). 29 March 2012.

[3] Triumph Aerospace Systems: Handling Support Fixture Drawing (1317-800). February 2012.

[4] NASA Ames Research Center Presentation: TTR N246 Steel Plate Design Review. 16 February 2012.

[5] NASA Ames Research Center Presentation: TTR N246 Steel Plate Kickoff Meeting. 29 March 2012.

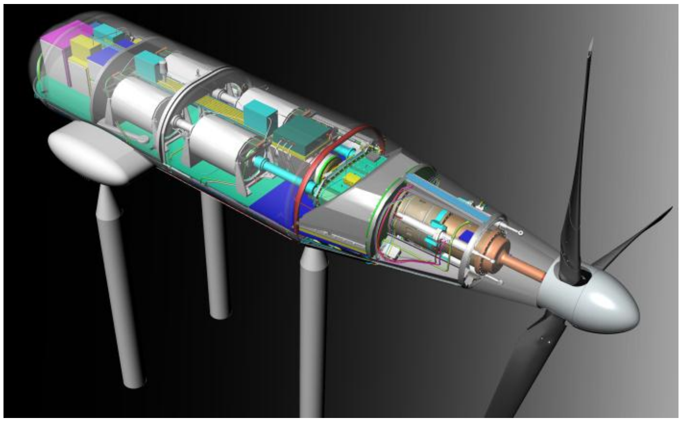


Figure 1. TTR and its subsystems.

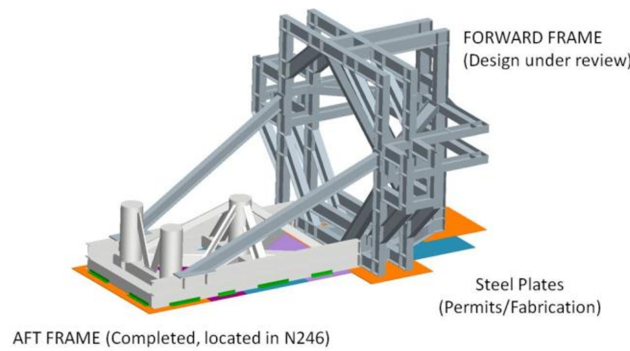


Figure 2. TTR Calibration Rig and steel plates in Building N-246.

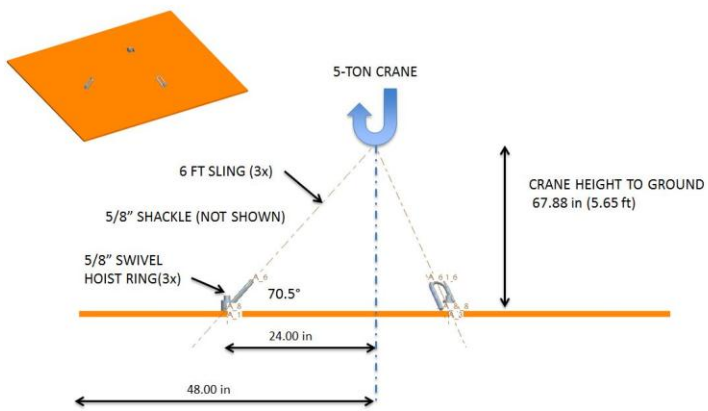


Figure 3. Steel Plates Lift Plan.

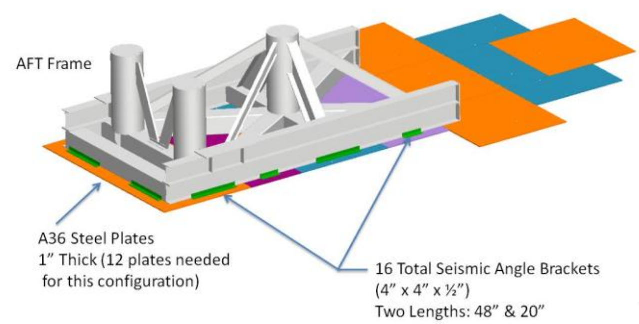


Figure 4. TTR Cal Rig with seismic restraint system.

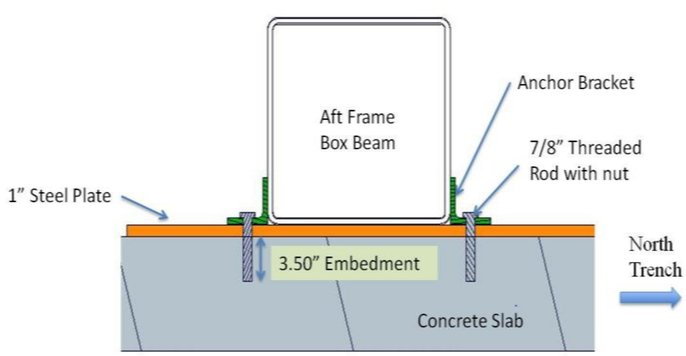


Figure 5. Anchor Design.

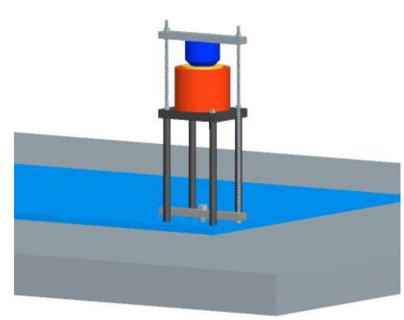


Figure 6. Pull Test Pro/Engineering model.

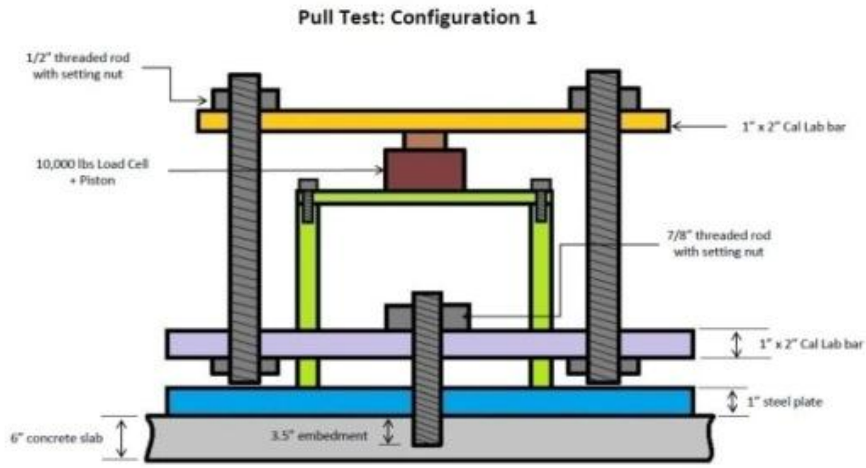


Figure 7. Pull Test Configuration 1.

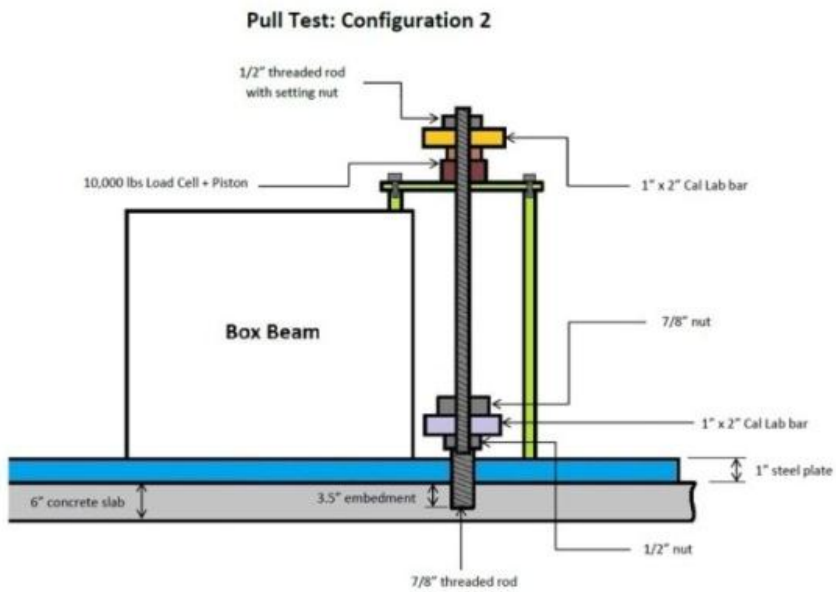


Figure 8. Pull Test Configuration 2.

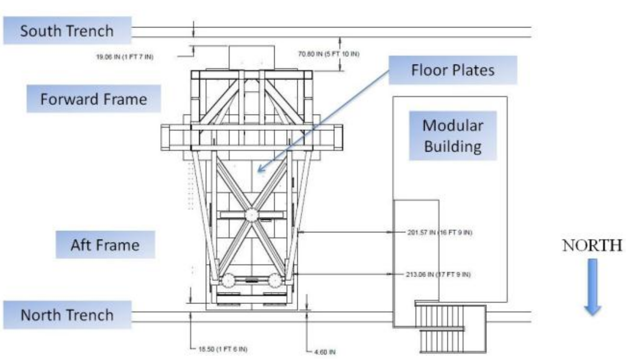


Figure 9. Complete system arrangement in building N-246 without TTR installed in Cal Rig.

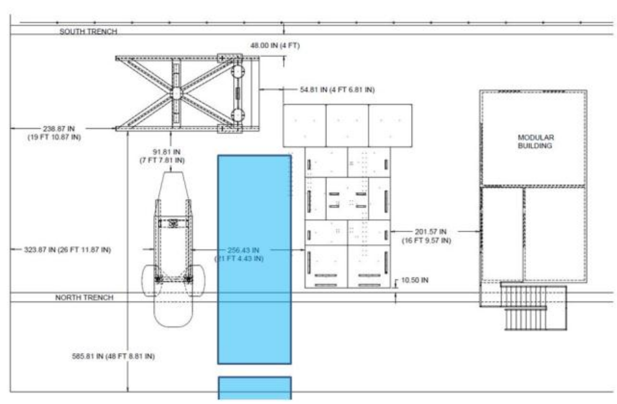


Figure 10. Plan B: Alternative arrangement that shows the configuration of all the parts if the steel plates are not installed in time.

Appendix

R. Vega February 2012

For ≤ 2000 Concrete:

→ Tension 16475 psi
Shear 34780 psi

7000 psi for Pull Test

For ≥ 4000 psi Concrete:

→ Tension 9130 psi
Shear 18535 psi

$x = 2750$ psi → Concrete allowable stress

$$y = y_a + (y_b - y_a)\frac{(x - x_a)}{(x_b - x_a)}$$

where, $x = 2750$ psi, $x_a = 2000$ psi, $x_b = 4000$ psi

$y_a = 16475$ psi, $y_b = 9130$ psi

$$y = 16475\text{ psi} + (9130 - 16475)\text{psi}\ \frac{(2750-2000)\text{psi}}{(4000-2000)\text{psi}}$$

$$y = 16475\text{ psi} + [(-7345\text{ psi})(0.375)]$$

$$y = 16475\text{ psi} - 2754.375\text{ psi}$$

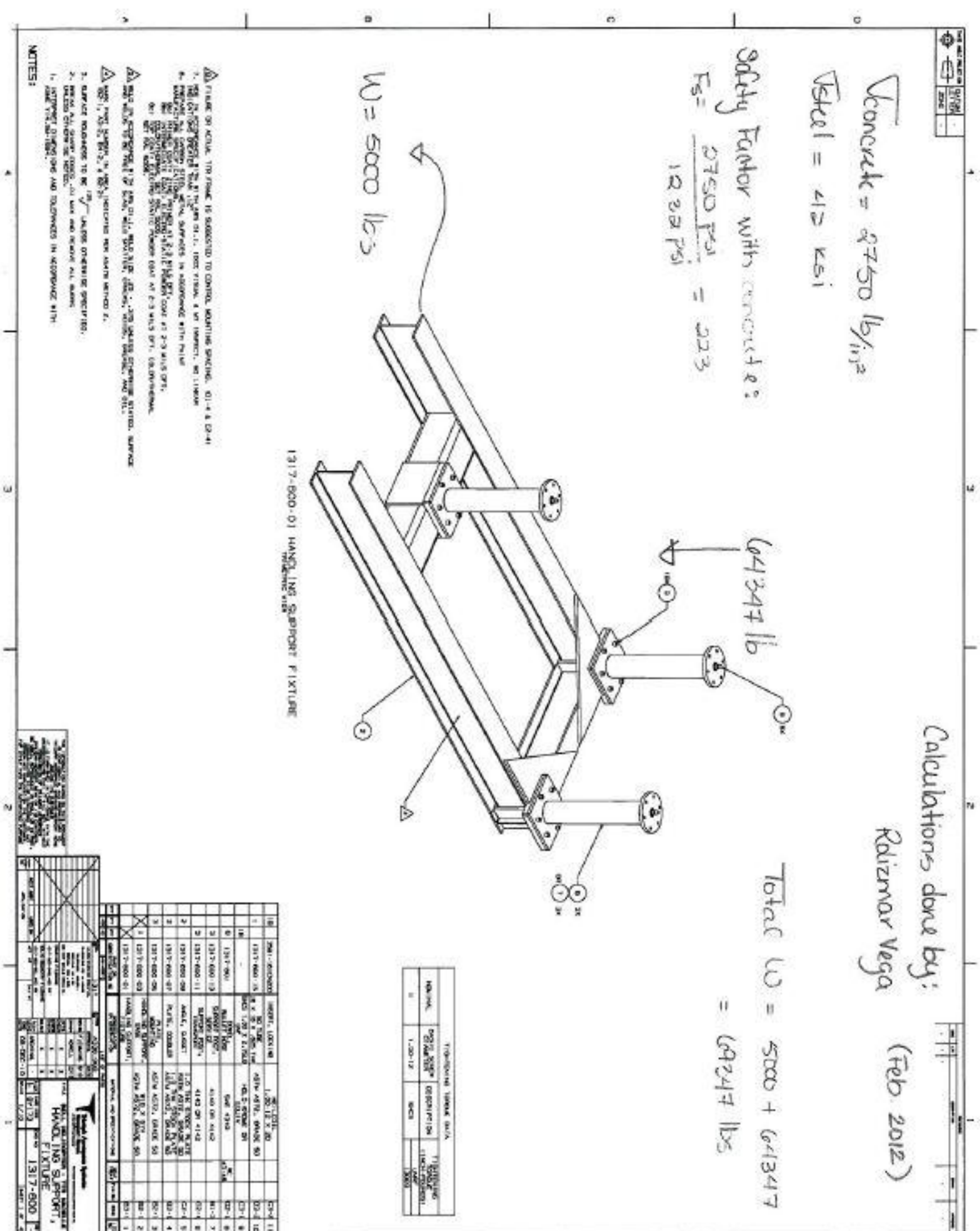
$$y = 13720.625\text{ psi}$$

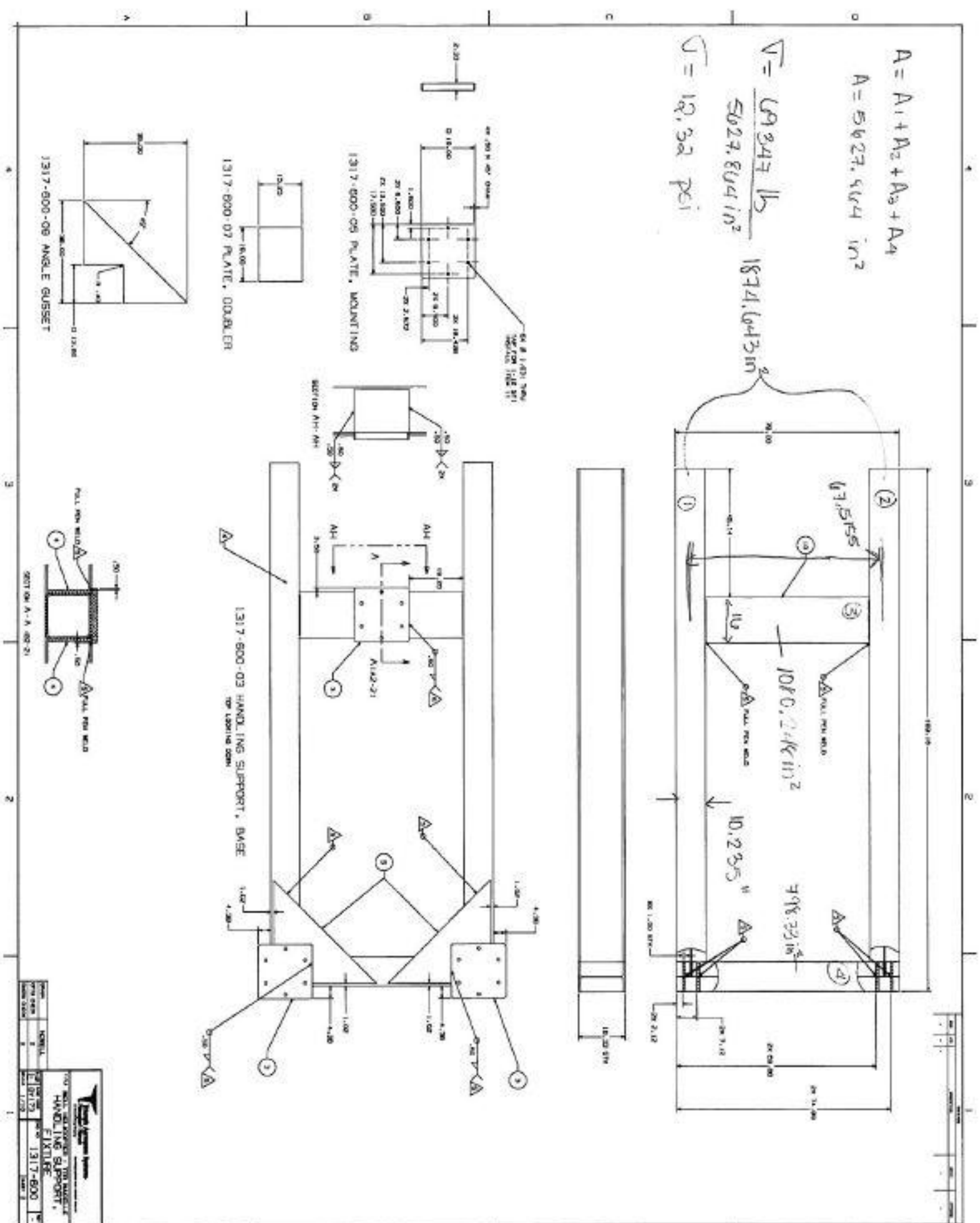
Allowable Tension will be 13720.625 psi

$$F_S = \frac{13720.625\text{ psi}}{7000\text{ psi}} = 1.96$$

↑ Safety Factor for Pull Test

TOPS 35502


Calculations done by:
Raizmar Vega (Feb. 2012)
Total W = 5000 + 64347
= 69347 lbs
64347 lb
W = 5000 lbs
Safety Factor with concrete:
1317-800-01 HANDLING SUPPORT FIXTURE


1317-600-08 ANGLE GUSSET
1317-600-07 PLATE, DOUBLER
1317-600-05 PLATE, MOUNTING
1317-600-03 HANDLING SUPPORT, BASE

Acknowledgments

Puerto Rico Space Grant Consortium for sponsoring my internship. My sincerest gratitude extended to Bill Warmbrodt and Gina Willink for the support, guidance, encouragement, and pleasure of working with them in the Aeromechanics Branch.

In addition, special thanks to all the personnel involved in the Tiltrotor Test Rig Project. This includes but is not limited to Alexander Amy, Alex Sheikman, Brandon Hagerty, Miguel Martinez, Luis Garcia, and Daniel Ponce de León.