## **Introduction**

NASA is a household name in this day and age, known commonly as America's government-run powerhouse of innovation and space exploration. It is a common dream for students to be a part of NASA's workforce, but I did not realize that it was my dream until I found that I could not imagine working anywhere else. From August to December, I had the privilege of a co-op tour with NASA at the Johnson Space Center.

The National Aeronautics and Space Administration (NASA) first formed in the early hysteria of the Cold War, and in its early days it received enormous funding and political support. It was America's response to the Russian *Sputnik*, which was a not only a stark symbol of what was suddenly possible, but also of how far behind the United States had fallen in the race for technology. The political atmosphere in the world has since changed, but NASA's drive to push the boundaries of the impossible has not faded:  NASA's primary mission has been exploration for the betterment of mankind, and it works towards that mission to this day.

The specific NASA site that I worked in was by a coast near Houston, TX, at the Johnson Space Center (Figure 1). I was led on my first day of work to a building dedicated to Structural Engineering (Building 13), which was where I would be spending most of my time in the months to come. It was here that I had my desk and cubicle, and would later do the bulk of my computer modeling and theoretical planning. Later that day we traveled to the Vibrations and Acoustics Test Facility (Building 49), and here I was shown the parts we would use for our technical project and the locations we would work in. I worked in the Loads and Dynamics Branch of the Structural Engineering Division, in the Engineering Directorate.

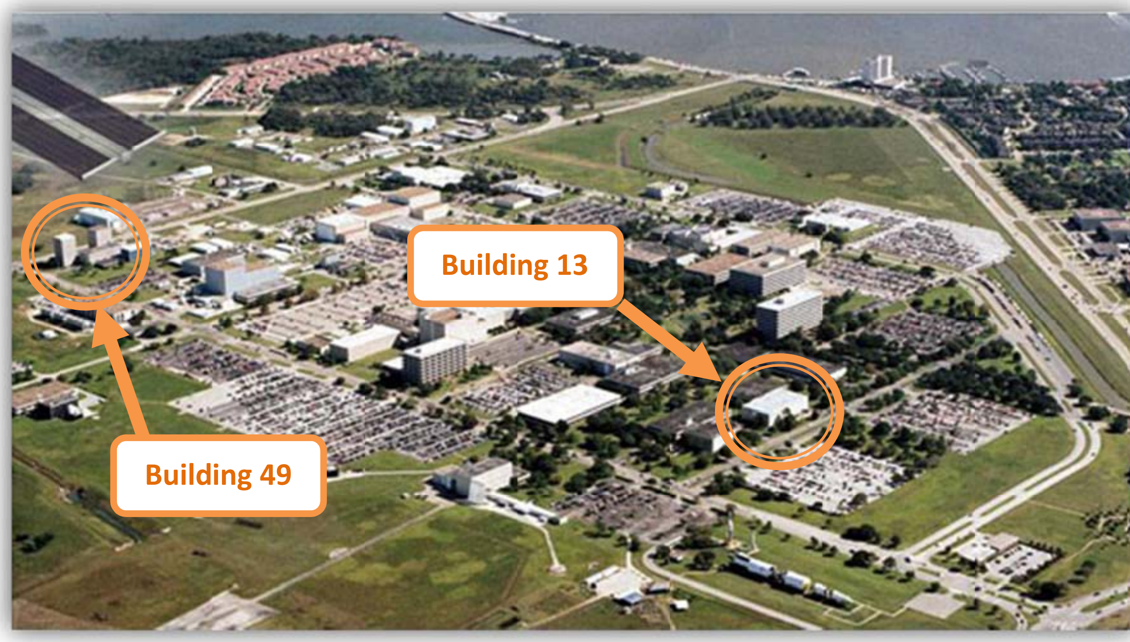


Figure 1: Johnson Space Center, from here. http://www.nasa.gov/recovery/agency-plans/jsc-aerial.html

**Work Environment**

Out of the many people I worked with, I saw Rodney Rocha and Juan C. Lopez most regularly. Mr. Rocha was my mentor, and saw to it that I had all the instruction, materials, and advice that I needed. He has contributed to NASA's Structural Engineering division for 39 years, and in that time he worked with high profile projects, such as the space shuttle orbiter and the International Space Station. He has a bachelor's degree from the University of Texas in Aerospace Engineering and an MS from the University of Houston. Mr. Lopez has not been at NASA for as long as Mr. Rocha (having just completed his six month review), but his lack of experience did nothing to affect his competence and enthusiasm to help. He graduated from the University of Texas at El Paso in 2012 with honors in aerospace engineering, and he was a teacher's assistant for the UTEP Department of Physics. Mr. Lopez has been active participant in outreach activities to Mexican and Hispanic students for years, and was recently elected as an officer in JSC's Hispanic Employee Resource Group.

The three of us attended weekly meetings with the rest of the Loads and Dynamics Branch (ES6), which were led by our Branch Chief, Eli Rayos. There were times when these meetings would be postponed for a week (such as for Holidays and scheduling conflicts), and there were also times where we needed more input from other Branch members than we were obtaining otherwise; this resulted in that other tag-ups and meetings would arise as needed, and I attended these as well.

In addition to the meetings for my main project, I also attended weekly meetings for the Co-op Advanced Planning Team, which was also called CAPT. CAPT is a student association oriented primarily around the professional development of co-ops at JSC, and as the group's Secretary and Historian I kept records from CAPT meetings and worked with a three-person-team to rewrite the organization's by-laws.

## Technical Summary

Due to expense and scheduling constraints, NASA is planning to find alternative approaches to  Experimental Modal Analysis. Operational Modal Analysis (OMA) is an alternative that is being considered, but it is a newer method of gathering modal parameters, and still has uncertain accuracy. My technical project was the Test Article Unit for Rectified Utility Systems Testing (TAURUS-T), and its purpose was to create a database of information that will be used to test-validate OMA. I was involved in a project to accomplish two approaches in gathering this database: experimental and analytical.

The experimental approach involved building a physical structure that could be used to gather experimental data. The structure was shaped like a six foot tall 'T', and was built out of prefabricated aluminum unistruts. The shape was chosen because it would provide easy-to-

visualize mode shapes at low frequencies (<100 Hz for first 10 modes). The material was aluminum due to the material's low weight, which meant that the structure could be assembled and transported without needing special equipment to counter the weight. A picture of the final product is included in Figure 2.

Figure 2: Finished experimental TAURUS-T.

We started the assembly process by taking inventory of the parts that had arrived (one of two deliveries) and making adjustments to the design as our understanding of the structure's needs and deficiencies progressed. There were three main adjustments made as we went through the assembly process. The first adjustment involved removing some plates that had been in the original design, and which would have decreased the primary  modal frequency of the structure beyond what our test sensing equipment would have been able to measure . The second adjustment was that the original model did not have plans for how the structure would be constrained at its base. After three different design iterations, the final product involved three different layers of adapter plates, a 3000+ lb billet, and a bracing grid formed from leftover unistruts. Pictures of this design and the materials involved are shown below, in Figure 3.

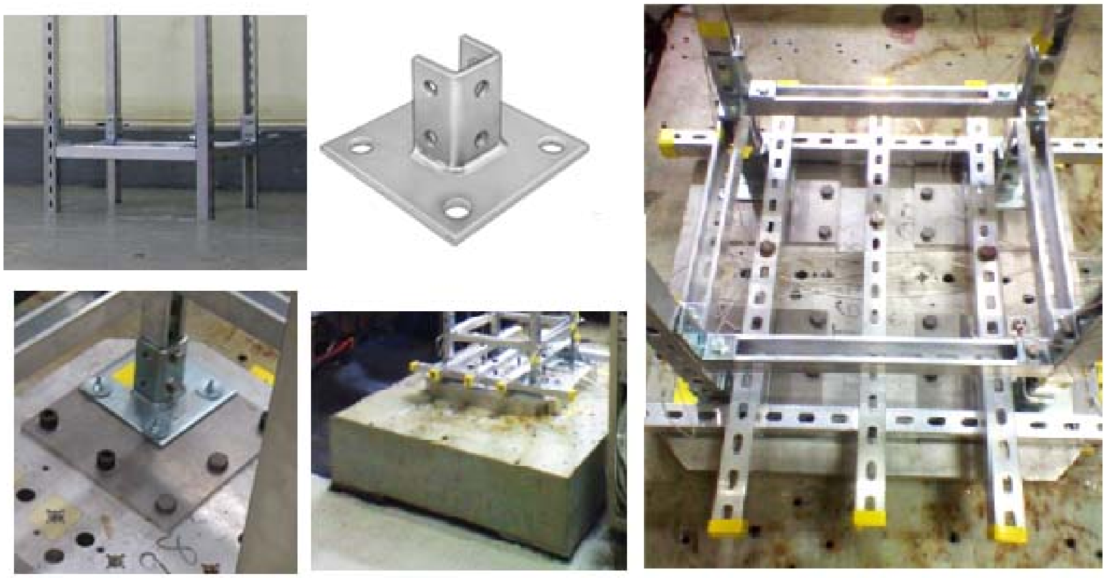

**Figure 3:** Starting in upper left corner, in clockwise order: the Taurus-T's base, the 'foot' adapter plate, the final design of the base constraints, the billet, the constraint design with no unistruts.

The third adjustment was to not use the previously planned diagonal unistrut supports in addition to the orthogonal structure. The original designed included these diagonals to increase the structure's stiffness, but it was later found that we did not have the means to machine these with precise repeatability, but that the added stiffness they would have provided was not needed . Pictures of the original and updated designs are shown in Figure 4 .

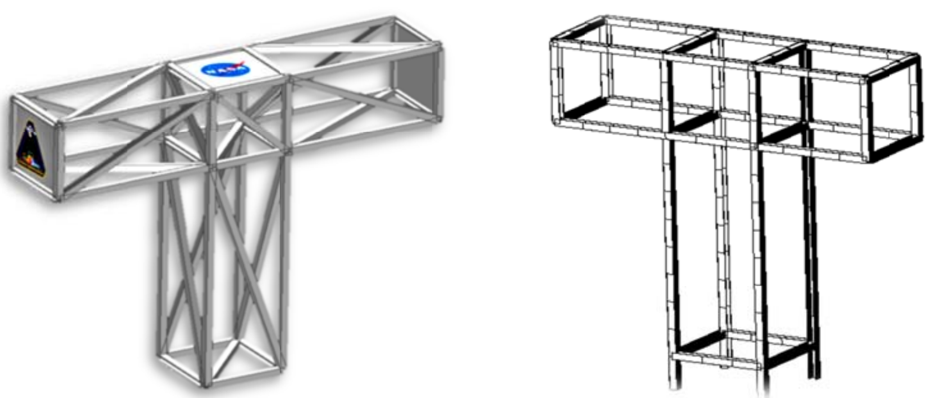

**Figure 4:** From left to right, the original design compared to the final design.

Throughout our work we did not always have the parts in the right dimensions or specifications that we needed, particularly as the changes added up. This eventually required me to gain machine-shop experience with a horizontal and vertical band saw, a drill press, and the facility's safety procedures.

The analytical model was made concurrently with the physical model. Because there were changes to the dimensions from the earliest design adjustments, the first thing done with the analytical model was to redraw it in MSC-Patran with the updated measurements. Patran does not have the option to model beams as unistruts, but it did have C-channels, and these were a close enough approximation that they were used instead. The structure was assigned the material properties of Aluminum 6061-TS. The original analytical model did not account for the added weight that the steel bolts and fasteners provided, and we later found that this was interfering with our model's results. After doing some troubleshooting, we found that the weight of the brackets was significant (20-30 lbs out of 100 lbs), and we accounted for this by adding non-structural masses throughout the design. Another significant adjustment made to the model was that as we worked on the physical model's base constraints, the concern arose that one of our preliminary designs would give the structure spring dynamics at its base. To examine the possible effects of this we added C-BUSH elements to the base, and determined that the effect on the structure's behavior was not negligible. This led to the final iteration of the design, where we added the leftover unistruts to counter any possible dynamics at the base.

Other things that we did with the analytical model included using finite element analysis to complement Patran. We used MSC Nastran to run a normal modes analysis, and through it we were able to obtain animations that were later used for the physical structure's accelerometer

instrumentation. We also used ProCOR for model reduction, because that had been what we were originally planning to use to locate sites for accelerometers.

We placed the accelerometers by analyzing the Nastran simulations visually, and then picking the locations of highest kinetic energy. Our data acquisition system allowed for 120 channels of input, and with this maximum limit I made and executed the plans for us to use 37 triaxial accelerometers, which used three channels each. The particular accelerometers that we used were chosen because they had the frequency and range that we were expecting to need from our Nastran simulations (the others had high frequency sensitivities that were not of our interest). The accelerometers were sensors remaining from the Shuttle Modal Inspection System, and had been used in the past to see where shuttles might be at risk for damage.

Once I finished the pre-test planning, I received training in handling and applying the sensitive equipment to the structure. I cleaned and prepared the surfaces we would attach the accelerometers to by swabbing the areas with rubbing alcohol, laying down aluminum tape, and then sanding the tape so that the surface would be easier to stick to. Before actually attaching the accelerometers, we arranged and attached the microdot cables that they would connect to, making sure that they were oriented in ways that avoided placing strain on either the sensors or the structure. The accelerometers themselves were attached with hot glue, because the alternatives (wax and dental cement) had been decided against for a variety of reasons. Once they were in place, I ensured that the specifications of all the equipment (serial numbers, sensitivities, and locations)  were entered into our data processing system properly. At this point the structure was finally ready to test, so I conducted a basic hammer test.

The hammer test's results came in the form of a frequency response function, which showed the response of the system in relation to frequency. We used this to compare the experimental structure's modal frequencies with the ones found analytically, and found that there were new modal frequencies that the experimental structure was experiencing, and that the analytical was not. We also saw that for the higher frequencies, the experimental system's mode shapes were different to those found analytically. This was all expected  because the physical system had irregularities in its bracket designs that the analytical model did not account for, and will need to be adjusted to simulate in the future. Below is a graph comparing the natural frequencies of both the analytical and experimental models.

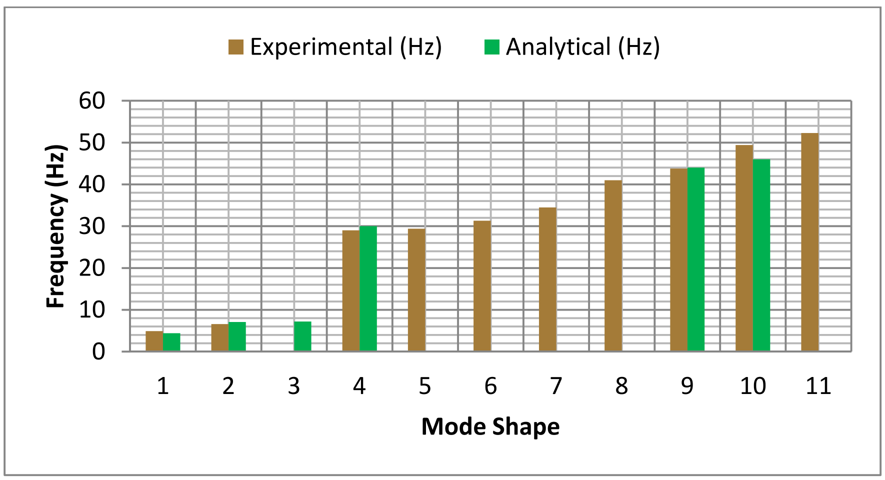


**Figure 5:** Comparison of experimentally and analytically generated modal frequencies.

## **Conclusion**

My project spanned an unusually wide variety of the tasks that go into a physical project's assembly, testing, and result validation. I started with minimal background in finite elements, vibrations and acoustics, and throughout this term I have received an impromptu course in not just these subjects, but in how to apply them in the workplace.

All of these different learning experiences have given me confidence not just as a student, but as a future full-time employee. I know now that taking the time needed to get everything done properly is rewarding, and that the stress of a project decreases when you are not in a rush. Aside from this day-to-day adjustment, I plan to look into courses that I could take that would help me learn more about finite elements and vibrations. My lack of knowledge was fortunately only a minor problem during this tour, since my inexperience in leading a project of this magnitude turned out to be my biggest weaknesses.

If these problems were obstacles, then the increased confidence and experience I obtained were my best gains. These helped me use the skills that I already had in using machine-shop tools, problem solving skills, and team communication to navigate my way through every task and challenge given to me. I even got through learning the model-reduction program ProCOR, which would turn out to be my least immediately useful skill.

I plan to spend three more tours here at NASA, alternating with semesters at the University of Texas. My upcoming Summer will see me working with the Missions Operations Directorate in a branch dedicated to assisting with Extra Vehicular Activity, and the Fall that follows will be with NASA's Engineering Robotics division. My final summer is not planned. After I graduate in the Fall of 2015, I hope to enter NASA's workplace as a full time employee.

Due to the nature of the work that I will be doing, I expect to someday return to school for a graduate degree, but I do not yet have a specific plan.