Space Structure Development

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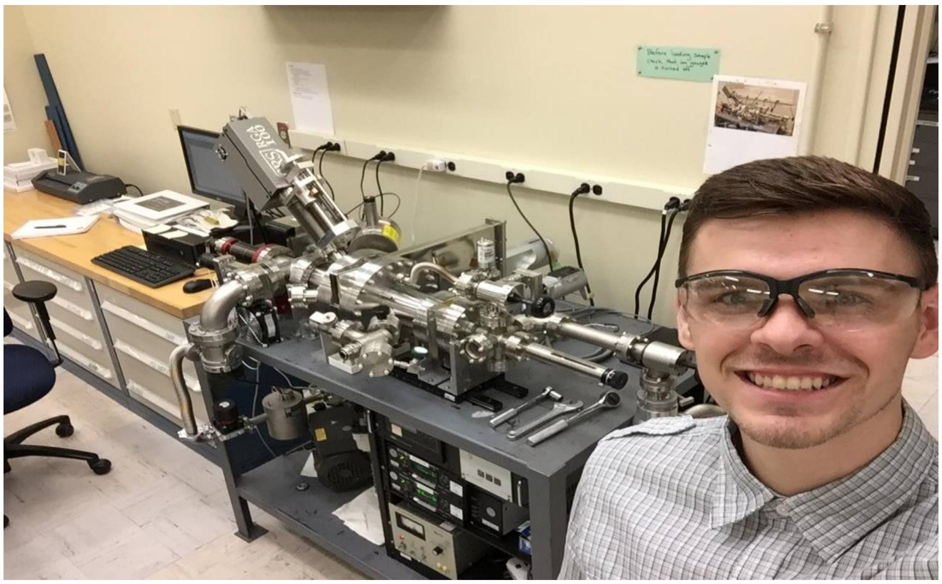

The duration of my Summer 2015 Internship Tour at NASA's Johnson Space Center was spent working in the Structural Engineering Division's Structures Branch. One of the two main roles of the Structures Branch, ES2, is to ensure the structural integrity of spacecraft vehicles and the structural subsystems needed to support those vehicles. The other main objective of this branch is to develop the lightweight structures that are necessary to take humans beyond Low-Earth Orbit. Within ES2, my four projects involved inflatable space structure air bladder material testing; thermal and impact material testing for spacecraft windows; structural analysis on a joint used in the Boeing CST-100 airbag system; and an additive manufacturing design project.

Inflatable Structures Air Bladder Material Cold Flexure Evaluation:

The purpose of the Inflatable Structures Air Bladder Material Cold Flexure Evaluation is to assess how the repeated packing, storage, and deployment of an inflatable material after launch in the extreme environment of space effects the strength of potential bladder materials that could be used in future inflatable space structures. In order to be launched into orbit, inflatable structures are packed and compressed in a small volume and then deployed after a certain time period in space depending on the mission. Therefore, this evaluation and testing will allow ES2 to determine which bladder material is the best candidate for use in inflatable space structures.

The five bladder materials being tested are CadPak HD200, CadPak HD100, CadPak S-Series, CadPak N-Series, and CadPak N-HD. All five of these materials have varying thicknesses and tensile strengths according to their manufacturing specifications. The cold flexure evaluation is initiated with baseline tensile and permeability testing on each of the materials. This is followed by cold-flex testing at room temperature, -30 degrees Fahrenheit, and -50 degrees Fahrenheit, which is concluded with post-flex tensile and permeability testing on the flexed materials. The baseline tensile testing and initial baseline permeability testing was previously completed for each of the bladder materials.

The baseline permeability testing was conducted on each remaining material per the ASTM D1434 Test Standard. From the roll stock material, three 3” by 3” square samples of each bladder material were cut in order to be tested in a custom-designed dual vacuum chamber. The permeability test consisted of loading a square sample between each chamber, then allowing each chamber to pump down to a vacuum of at least $4x10^{-7}$ torr, followed by introducing helium into the upstream chamber, and finally using a residual gas analyzer to measure the change in pressure in the downstream vacuum chamber as the helium permeates through the sample. It takes approximately one and a half hours to load a new sample, one hour to run the test on a new sample, and approximately 18-24 hours to wait for the vacuum chambers to pump down to acceptable total pressures before taking measurements.

After collecting the data for each material’s permeability tests from the residual gas analyzer program, the data is processed and analyzed using an excel spreadsheet to calculate each sample’s, and correspondingly each material’s, average experimental transmission rate and permeability rate. However, the process of importing, formatting, and analyzing the data for all five materials was very tedious and took approximately two hours. Therefore, the previous excel spreadsheet used to analyze the data was updated and automated by writing a Visual Basic for Applications, VBA, program in excel in order to reduce the analysis time down to approximately 15 minutes. The user must import his or her desired text files into excel and then the automated spreadsheet processes, formats, and calculates the desired results. The baseline testing revealed that the material with the lowest permeability rate and therefore the best potential in regards to baseline permeability performance is the CadPak N-Series.

After conducting the baseline permeability testing on three samples of each bladder material, the next phase in the evaluation is to perform cold-flex testing on each material. The cold-flex testing is conducted per the ASTM F392 Test Standard by using a custom-designed Gelbo Flex Machine in the new Lightweight Structures Workshop. Forming a cylinder using an 8” by 11” rectangular sample, the Gelbo Flex Machine simultaneously rotates and compresses the material, and vice versa, in order to perform a twenty-cycle flexure of the test sample. Each material is tested in both the machine and transverse direction dictated by the roll stock material. Initially, the motor powering the Gelbo Flex Machine did not have enough power to overcome the force of friction and drive the rotating shaft through its bearing in order to complete the flex test. Therefore, the shaft was filed down in order to provide a looser fit in the bearing and reduce the amount of friction between the shaft and the bearing. However, the machine was still unable to independently drive the shaft while the material was loaded due to the rigid strength of each bladder material. Another challenge with the flex machine is that the cold chamber used in order to control the temperature at which the test is performed is still under construction.

Consequently, due to these challenges the initial timeline for cold-flex testing has been significantly delayed. However, the room temperature flex testing has been completed for each of the five bladder materials by running the machine's motor and manually assisting the machine's lever arm to ensure full rotation and compression throughout all twenty cycles of each sample's flex test.

The first two weeks of August 2015 will consist of inspecting the room temperature flexed samples using a light table and recording noticeable damage; cutting test samples for post-flex permeability and tensile tests per the ASTM D412 and ASTM D1434 Test Standards respectively; conducting and finishing the post-flex tensile testing for the room temperature samples; and beginning the post-flex permeability testing for the room temperature samples. As post-flex tensile and permeability testing is completed, the baseline results can concurrently be compared to the post-flex tests in order to determine which bladder material experienced the least amount of degradation in regards to tensile strength and permeability performance due to cold flexure.

Orion and ISS Window Material Testing:

The purpose of the Orion and ISS Window Material Testing project was to assess and validate the potential use of different materials for particular panes of each structure's windows. The window of a spacecraft or space structure is a subsystem that adds structural vulnerabilities and complexities to the overall design in order to provide astronauts with the ability to directly view the outside environment as they are traveling through space.

Thermal testing of two potential new window materials for Orion was conducted for approximately one and a half weeks; however, due to program sensitivity testing procedures and results cannot be discussed at this time.

According to the Test Plan for Comparative Impacts of Aluminum Oxynitride, ALON, and Fused Silica, the International Space Station, ISS, Program Office has requested that engineering explore the ceramic material, ALON, in order to potentially replace the bore silica glass currently used in the scratch panes of the windows on the ISS. ALON is being considered because of its toughness and hardness compared to bore silica. More specifically, the test plan is exploring ALON as a candidate that could potentially not require a laminate containment layer while still adequately protecting the astronauts and protecting the primary pressure panes of the windows on the ISS. Therefore, low-velocity impact testing on ALON samples has begun with the end outcome of determining at what level of energy ALON begins to generate particulate, shards, or spall and if it occurs beyond the energy threshold of 6 ft*lbf. The impact testing utilizes a standard NASA defined hardened steel tool impact tip (0.08" diameter) and a sharp tool impact using the standardized impact machine in the JSC Structures Test Laboratory. Impact testing is still currently being conducted and will be completed throughout the first two weeks of August 2015.

Boeing CST-100 Airbag Field Joint Structural Analysis:

The purpose of the Boeing CST-100 Airbag Field Joint Structural Analysis project was to verify whether or not the field joint can withstand the loads placed on it by the airbag straps during landing. The first phase of this analysis started with obtaining a complete understanding of the engineering drawings for the components of the field joint by modeling the joint in ProE. It was also essential to obtain the engineering properties for the materials specified for the field joint's components in order to be able to conduct the analysis. Finally, it was vital to learn how to predict the stresses and deflections of the pin in the field joint by starting with simple assumptions about the pin.

The analysis began with treating the pins of the field joint as straight beams that were either simply supported or had fixed end supports that would experience either a concentrated load or a distributed load. By performing hand calculations using equations and derivations from various structural analysis reference books, the maximum stress, maximum shear stress, and maximum deflection for each load case was calculated. The most realistic load case for the field joint and airbag straps is the fixed end case with a distributed load across the exposed surface of the pin. Therefore, the hand-calculated maximum stress in the pin was verified by using PATRAN to develop a computational model of the pin, but there was a discrepancy between the model's deflection and the hand-calculated deflection of the pin. The reason for this discrepancy is still unclear and is being examined. However, moving forward with the structural analysis, margins of safety were calculated in order to determine whether or not the calculated maximum stresses and shear stresses in the pin during the various load cases could be supported by the material of the field joint based on its yield strength and ultimate tensile strength. Finally, a Mohr's circle analysis was conducted in order to further verify the structural integrity of the field joint when placed under its expected design loads. The final Mohr's circle hand calculations were used to calculate the principal stresses in the field joint during loading and demonstrated that the field joint's pin could withstand the load of the airbag's straps but not within the desired factor of safety.

Additive Manufacturing – Soldering Iron Clamp and Stand:

The purpose of the Additive Manufacturing – Soldering Iron Clamp and Stand project was to design and print a clamp that could hold a soldering iron completely vertical and steady as it is used to melt metal inserts into 3-D printed parts made in the Additive Manufacturing Lab. The initial design phase began with paper and pencil conceptual brainstorming for a clamp and stand system design that would allow the clamp to move freely up and down a vertical shaft. After narrowing down and refining the design, ProE was used to model the initial design consisting of a metal base and shaft with a clamp that fit onto the shaft and extended outward over the base. The clamp further consisted of two separate parts that would "sandwich" the handle of the soldering iron and be held in place with fasteners.

After modeling various iterations of this overall design concept while making small changes from iteration to iteration the final design was ready to be fabricated. An aluminum base and steel shaft was first fabricated using scrap material from NASA's machine shop on site. Then, the Pro-E models of the clamp design were processed and printed out of a durable plastic material, Ultem, using a FORTUS 400mc machine. All of the inserts and fasteners fit perfectly on the first print, which allowed for easy assembly of the clamp. However, the clamp currently does not move up and down the stand's shaft freely enough to be used efficiently when melting inserts into parts. Therefore, throughout the first two weeks of August 2015 the design is being modified in order to use a different bearing for the shaft that will reduce the amount of friction between the clamp's bearing and the stand's shaft.

Lessons Learned and Impact of Experience on Educational and Career Goals:

The experiences and knowledge the human mind is capable of obtaining over the course of ten weeks is remarkable. This summer I have been given the opportunity to work on significant experimental projects that support NASA's high-profile manned spaceflight programs such as Commercial Crew, ISS, and Orion. Furthermore, I have also been given the opportunity to assist with future inflatable space structure development through material testing. Each of my summer projects enabled my development of a brand new set of skills that have been added to my engineering toolbox.

The cold flexure evaluation project provided me with the opportunity to gain immeasurable hands-on experimental testing experience, experience working with various test standards, and the ability to troubleshoot and solve issues with custom-designed machines as they arise either before, during, or after testing. Next, the Orion and ISS window material testing provided me with more hands-on engineering test experience along with the ability to work with only the available resources on hand by adapting and modifying a test plan as needed in order to obtain useful results. The Boeing CST-100 field joint analysis and additive manufacturing project provided me with real-world analysis and design experience. Throughout the Boeing CST-100 field joint project I learned how to read engineering drawings; create a finite element model; perform computational analysis in PATRAN; and finally apply engineering formulas, derivations, and equations to a problem in order to determine whether or not the structure would be able to withstand the loads it is expected to experience during use. This project especially was beneficial in demonstrating how the material learned in the classroom can be directly applied to real-world problems in the aerospace industry. Finally, the additive manufacturing project carried me through the entire design process of a part. I learned how to start developing initial ideas and designs on paper; how to efficiently translate those concepts into a single design modeled on the computer; and finally how to process and fabricate a 3-D CAD model by using additive manufacturing techniques.

My internship at NASA's Johnson Space Center has been an invaluable turning point in my educational and professional career that has re-focused and set a new direction for my future career path. I would like to return to the Johnson Space Center again in the future as a pathways intern with the ultimate goal of working full-time as a civil servant at the center. After finishing my bachelor's degree and before beginning to work full-time, I plan on attending graduate school in order to obtain a M.S. and Ph.D. in aerospace engineering with a specialization in either astrodynamics or aerospace structures.