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Student Paper
Design of Access Platforms for Assembly Tooling on the Payload Attachment Fitting (PAF) for NASA's Space Launch System

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Abstract

This paper reports on the results of a unique undergraduate student internship and research experience conducted at NASA Marshall Space Flight Center, supported by a U.S. Department of Education award. The program specifically aims to engage students from minority servicing institutions in research and internships while enhancing their academic and professional development. The student selected for this experience is from a minority background underrepresented in STEM, and this internship provided hands-on exposure to research in aerospace and mechanical engineering.

The ET50 Special Test Equipment Design Branch at the Marshall Space Flight Center designs and modifies test stands supporting the other test branches: Propulsion, Environmental, Structural, and Dynamics. ET50 supported the Payload Adaptor (PLA), also known as the Payload Attachment Fitting (PAF), which is a part of the Integrated Spacecraft Payload Element for the Space Launch System (SLS) rocket. The Payload Adaptor is the interface between the launch vehicle and the co-manifested payload, and its test stand is currently being modified to begin a series of rigorous tests that will verify its design, analysis, and fabrication. For fabrication, the technicians required a mobile exterior and stationery interior platform to allow them safe and necessary access to the Payload Attachment Fitting assembly stand, and they requested that ET50 design these platforms. Using Creo and other Finite Element Analysis (FEA) packages, ET50 designs 3-dimensional models and paper drawings to carry out manufacturing.

To understand, develop, and integrate the structural design test process, the use of Computer-Aided Design provided an efficient design technique to meet the requirements of stress analysis and fabrication. Beginning with a skeletal structure and items provided by Creo and external vendors, the 3-D CAD models and preliminary drawings were constructed and distributed for a stress report. This report documented the stress analysis of these products, which confirmed the strength and durability of the hardware and ensured that both platforms could withstand the functional loads during the assessment. After stages of review and drawing signatures, the drawing, stress report, and CAD model were released to the fabricators. The production and application of these platforms are specifically designed to ensure that the PLA is built effectively to secure attachment and successful deployment for the SLS mission.

Keywords:

Research experiences for undergraduates, underrepresented groups in STEM, Payload Attachment Fitting (PAF), Space Launch System (SLS), Computer-Aided Design (CAD)

Introduction

In this paper, a student discusses the enriching experience they had interning at the NASA Marshall Space Flight Center (MSFC) in the summer of 2024 under the ET50 Special Test Equipment Design Branch team. The student was chosen for the Minority Science and Engineering Improvement Program (MSEIP), which the U.S. Department of Education funds to promote and increase the number of minorities in STEM. The program requires a specific project/research assignment for the selected student to complete during their time at the internship, allocating the student to a particular branch to successfully carry out this task with the aid of a mentor(s). This student was tasked to complete Project 21: Support Design Analysis Team in Developing Test Hardware Equipment under the supervision and mentorship of the ET50 Branch Chief and the Structural Design Team Lead. The student has always been intrigued by the field of aerospace engineering and to one day work for and help lead a significant company in furthering the exploration and development of the relationship between earth and space. This opportunity was introduced and encouraged by one of her engineering professors after sharing her interest in aerospace and NASA, and the student later became a selectee to participate in the program at the Marshall Space Flight Center in Huntsville, Alabama, during the summer entering her junior academic year as a mechanical engineering student. Upon applying for the NASA internship, the student was given a list of projects to choose from that fit her academic and career goals the best, choosing a project that was described to focus on mechanical engineering majors and design work. The complex task sparked her initiative to grow her design skills in the Department of Test Hardware Equipment and learn how to operate in a professional engineering environment.

The ET50 branch is known for being the MSFC's leading design organization for ground-test hardware, utilizing three teams: piping design, structural design, and stress analysis to ultimately design and modify test stands that support the other test branches of NASA: Propulsion, Environmental, Structural, and Dynamics. With the use of Computer-Aided Design (CAD), Creo in particular, and other Finite Element Analysis (FEA) packages, the branch can create models and drawings and run stress analysis on these models that will eventually be sent to fabrication shops to be manufactured and utilized. Every drawing and model created by the ET50 branch and other design branches is stored in the PTC Windchill database. During the student's time of the internship, the ET50 branch was helping design/re-design the ground test hardware for the Space Launch System (SLS). When the student joined the branch in late May 2024, the branch supported the Payload Attachment Fitting (PAF) in this rocket unit. With the current projects at hand, the student's mentor, the Structural Design team lead, tasked the student to use Creo, the Windchill database, and applicable vendors to design two platforms for the technicians to work on and run tests on PAF's interior and exterior more efficiently than their previous strategy. The student had previous experience in Computer-Aided Design, specifically, Siemens NX10, but had never used Creo. Before the student could start brainstorming ideas for her designs, she was required to take a list of courses offered by PTC to become familiar with the complex CAD software. The student also joined a Geometric dimensioning and tolerancing (GD&T) course to learn how to create engineering drawings for 3D models. Upon completing these courses, the student designed a stationary inner platform and a mobile outer platform model for the technicians working on PAF.

The objectives of the MSEIP and NASA collaboration internship program under the ET50 Special Test Equipment Design Branch team are Design and/or Analysis of Ground Test Hardware, Use of Computer-Aided Design and/or Finite Element Analysis, Understanding Structural Design and Stress Analysis, Development of Collaboration and Professional Skills, and Engagement in Aerospace Engineering Research and Experience.

ET50 Special Test Equipment Design Branch: Overview and Functions

The ET50 Special Test Equipment Design Branch serves as the Marshall Space Flight Center's primary establishment for developing ground test hardware. This hardware is referred to as Special Test Equipment (STE), which includes "Any non-flight*, non-GSE*, or non-Facility** structure, hardware, piping systems, pressure vessels, or equipment intended to be used for testing or simulation, or associated with the manufacturing, process development, and preparation of MSFC facilities for testing or simulation. Designs include...test stands, test beds, load reaction and application structures, load line components,…, flight hardware mockups and simulators, hardware support stands and dollies, personnel access stands, lifting and handling hardware, and tooling used to facilitate the fabrication and/or assembly of flight/non-flight hardware…" [1]. The branch is split up into three teams: Structural Design, Piping Design, and Stress Analysis that each plays a significant role in accomplishing these design collaborative tasks [2].

The structural design team includes a group of mechanical and aerospace engineers who use computer-aided design to design 3-dimensional models. These models are created using a CAD software called Creo, which is a product of PTC, an American computer software company. Unlike other CAD systems, Creo is unique due to its complexity and many capabilities, making it the perfect tool for the aerospace industry. The system is ideal for larger-scale, more complex assemblies with its powerful assembly management and ability to create intricate designs with many parts and assemblies. It also offers data management and collaboration, namely, Windchill, built for larger teams like ET50 [3]. NASA's version of the PTC Windchill tool is called the Integrated Collaboration Environment (ICE) which collects and stores all Creo parts, assemblies, and drawing files created and used by ET50 [4]. To illustrate this complex database, each ET50 member can save their model they designed into Windchill by "checking in" the part or assembly. Then, their colleagues can assess this part or assembly by "checking out" the design, granting them the ability to view and edit the model. This allows the ET50 design team to collaborate and review designs that each member creates when working on complex projects such as designing special test equipment for SLS.

Each Creo part, assembly, and drawing designed by the ET50 Special Design Equipment Branch is given an eight-character name prefixed with '90M' followed by a unique 5-digit number. These 90M documents are solely used for ET50, and they are all uploaded to ICE for viewing and collaboration [4]. After the early design concepts are finished, the stress analysis team first comes into the picture. Before the design team creates a drawing for the model, the stress analysis team runs a preliminary stress analysis on the CAD model using tools such as FEMAP and ANSYS. These are Finite Element Analysis software tools for simulating and analyzing complex engineering problems [5]. These simulations can cover various engineering properties such as fluid dynamics, thermal, structural, and electromagnetic simulations [5]. The CAD and FEA software that the ET50 team uses allows for integration between each other to transfer the CAD models from one program to another. Once this step in the design process is completed, the design team has the green light to start creating the preliminary drawings for the model. The 90M drawings created by ET50 include significant information and unique details on the drawing to give fabricators a step-by-step guide for fabrication. The first sheet of the drawing consists of the final result of what the model should look like after completion and the standard notes for the ET50 branch titled "GENERAL NOTES" required for each 90M drawing. The lower right corner of the sheet includes the unique 90M number, the title of the drawing, the drawing's date (updated upon successful completion), the detailer of the drawing, signatures from the representatives of various reviewing organizations, and a detailed parts list [6]. The parts list itself is also very detailed by giving each part a "FIND NO." starting from the bottom of the column with the number 1, exclusively reserved for the top-level assembly, numbering each consecutive part to the top. The parts list also includes the callout sheet number, detail sheet number (if needed for the specific part), total number of parts required, find number designation (A= Assembly, Sub-assembly, or Installation, F= Fabricated Item, P= Purchased Item, E= Existing Item, and M=Modified Item), the part number (90MXXXXX-Y), the vendor number (if any), and a column of remarks to provide additional information about an item (e.g. vendor part number, reference to general notes, or useful information/instruction on assembly or manufacturing) for each part [6]. The pages that follow the front page call out each part or sub-assembly, providing necessary details on how they should be assembled/how they should be fabricated. For instance, these include dimensions, details of sub-assemblies, tolerances, detailed views for smaller parts/sub-assemblies, section views, drafting elements (e.g., cross-hatching, weldments), etc. [6]. There are many symbols and acronyms that represent these elements.

Nevertheless, these sheets are thoroughly detailed with the use of Geometric Dimensioning and Tolerancing (GD&T) as well as other factors to ensure proper functional performance when fabricated or manufactured. The preliminary drawing is distinguished with a preliminary stamp on the front sheet during the drawing's review process. The drawing is sent in for checking and review for proper approval, technical application, and adherence to the required regulations by an ET50 engineer [1]. Once approved, the drawing is sent to the stress analysis team for the formal stress analysis and review to determine if it meets the minimum engineering design strength requirements for Marshall Space Flight Center's ET50 Special Test Equipment Design Branch. Some of the strength requirements that the stress analysis team checks for are Factor of Safety (FOS, FS, or Safety Factor), Lateral Stability Factor of Safety, Margin of Safety (MS), Tension/Shear Stress, and Torque [7]. The Vendor Supplied Components need to be verified before being incorporated into a design by either the published strength data based on the Safe Working Load of the component or its Ultimate or Breaking Strength [7]. The stress analysis and internal peer check are a vigorous process necessary for the drawing's release and the safety of the fabricated model's usage.

Figure 1 provides an overview of the entire ET50 Design Process and illustrates its length and strategic nature. These processes also give a better understanding of how the design teams and the stress analysis team collaborate to make the ET50 Special Test Equipment Design Branch successful in designing reliable and high-quality ground test hardware.

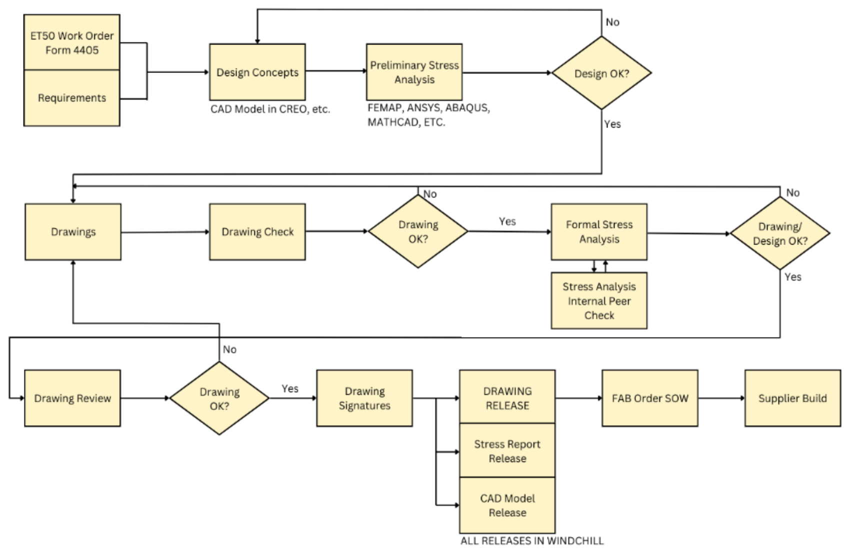

Figure 1. ET50 Design Process Flow Diagram.

Tools and Training

It was vital for the student to gain proficiency in particular engineering tools and programs used by ET50's structural design team to contribute to her assigned project of Designing Access Platforms for Assembly Tooling on the Payload Attachment Fitting. The student had previous experience in Computer-Aided Design, specifically, Siemens NX10, from a design course she was required to take her freshman year called Introduction to Mechanical Engineering Drawing and Design Lab I. This course taught the student basic efficiency and skills using Siemens NX10, giving her general knowledge of 3-D CAD modeling and 2-D Sketching. Despite this previous experience, this brought the student her first challenge facing her project: no previous Creo experience. The student found that Creo is more complicated software than Siemens NX because she was required to create a more complex design than she had ever made with Siemens NX. Comparing the two after becoming more familiar with the Creo software, the student found that Creo had easier usability. The main difference between these two CAD softwares is that Creo offers a more intuitive and organized graphical user interface (GUI), allowing for easier navigation toward parametric modeling tasks by presenting feature options to set up workflows faster and more efficiently [8]. Creo also offers beneficial tools such as cross-section views, hidden line removal, and collision detection to improve productivity and precision [8]. In terms of the products' modeling and simulation functions, Siemens NX provides surfacing and sculpting modeling features to allow for supplemental versatility for complex designs, while PTC Creo offers multifaceted modeling tools such as direct modeling, generative design, and parametric modeling for several engineering tasks [8]. Although Siemens NX has more advanced simulation features, both products carry high-functioning simulation tools such as FEA, a key feature vital to ET50's stress analysis branch. Regarding the products' focuses, Siemens NX stands out with its wide array of capabilities including electrical, electronic, and software engineering, while Creo is proficient in streamlining product design and mechanical engineering workflows.

According to the information in Table 1, the student found that PTC Creo was more suitable for the design project and growth as a mechanical engineering student overall because of its focus on mechanical design and user-friendly interface. The student's method of assessment was through extensive research of articles that showcased the individual qualities of both softwares, the student's own personal experiences throughout their on-the-job training at NASA and from previous collegiate courses, as well as personal opinions from their coworkers in ET50.

Table 1. PTC Creo vs. Siemens NX comparison chart.

PTC Creo (On the job training)	**Siemens NX (Collegiate Experience)**
More intuitive and organized graphical user interface, making it easier to learn	Less intuitive and more complex graphical user interface
Focuses more on product design and mechanical engineering	Has a wide range of capabilities
Has versatile modeling tools to help with several engineering tasks	Has advanced modeling tools to help with complex designs
Offers simulation features like FEA	Offers simulation features like FEA

For the first 4 weeks of the student's internship, she attended weekly face-to-face Creo training sessions as well as took the PTC Creo online training course. The tutorials taught the student how to navigate through Creo, understand how to accomplish different modeling techniques, assemble individual parts together, and access parts (screws, nuts, bolts, beams, ladders, casters, connectors, etc.) of different materials. The student also learned how to use and navigate through the Windchill workplace, although initially difficult and intricate. She learned how to name her designs, create a workspace, check in and out of her own and other peoples' models, and add already-made models in Windchill into an assembly. These pieces of training helped the student become familiarized with the engineering software used by the ET50 branch, but for the remainder of her time while executing her project, she was able to thoroughly understand the ins and outs of these tools by struggling through them and gaining guidance from her mentors. The student was interning under the structural design team, so she was not required to learn how to use any FEA.

Toward the middle of the student's internship, she began an in-person weekly GD&T course to help her understand how to create an engineering drawing for her two platform design models. Although the student did not complete the entirety of the course due to her internship's completion, she gained a helpful understanding of the symbolic language that details the orientation, form, location, and size of a part's features. Despite the student's gain in knowledge, she faced a few struggles in fully comprehending the language of GD&T due to its complex set of rules and various symbols and their applications. Because the student only had to design basic platforms, she was not required to delve deeply into GD&T. However, she learned how it ultimately allows designers to communicate part of design intent.

Project Approach and Results

The ET50 Special Test Equipment Design Branch was tasked with designing and analyzing multiple Special Test Equipment for the Space Launch System Payload Attachment Fitting. A few of the STE hardware needed by the customer were axial, torsion, and shear load line assemblies, starting with a design concept with specific requirements [9]. The ET50 design team used Creo Parametric to create a design schematic view of the load line assemblies, which applies the loads on the tested models, the PAF in this instance. These load line assembly designs are then integrated into the PAF Creo test stand assembly to verify that all the needed equipment fits together seamlessly [9]. These Creo load line models are uploaded into FEMAP by the stress analysis team to run a preliminary stress analysis to affirm that they meet the STE safety factors [9]. These models will then go through the rest of the ET50 design process to ensure proper strength requirements and approval, allowing for the applicable drawings of the load lines to be released for fabrication and installation into the test structure. The Payload Attachment Fitting needed some corrections/changes before testing could continue on the test model structure. While these alterations are being executed by the hired engineers and technicians, the PAF model sits on top of the Payload Adaptor structural test equipment stand. The student's mentor took her to the building that held this piece of equipment to observe and communicate with the technicians about the issue they were faced with working on both the inside and outside of PAF on the PLA structural test equipment stand. The technicians explained that they were only using ladders to work on the PAF test model, and while it was slightly useful at first, it was not allowing them full access to accomplish their full lists of tasks. They said that the ladder was inefficient because they could only reach so far, and only 1-2 people could get on the ladder at a time. Overall, the ladder was unproductive, and they were asking for a more efficient option to be designed by the ET50 team. The student's mentor assigned her to solve this issue by using Creo to design two models: an inner stationary platform to work on the interior of PAF, and an outer mobile platform to work on the exterior of PAF.

Figure 2. Payload Adaptor Structural Test Equipment Stand.

The student started by taking measurements of the PLA structural test equipment stand, as shown in Figure 2. The inner platform would need to be laid in between two horizontal beams in the structure's interior, bolted into the previously made holes in the structure. Each of the inner horizontal beams has two holes on both ends (4 holes in total) of the beam approximately 5 ½"" laterally and 33" longitudinally apart. Considering this, the student brainstormed for the platform to include 4 holes in total, matching up with the outer holes of each horizontal beam. Each hole would measure 0.5" in depth and 0.5625" in diameter. Given that the test equipment stand has a round shape, the inner platform would need a trapezoidal shape to match the precise configuration made from beam to beam. Knowing these details, the student measured the approximations for the height and width (long and short side) of the platform and the longitudinal and lateral distances between each hole. The student also accessed the CAD model of the test equipment stand to measure the angle made between each inner beam from the center point of the structure, measuring 45 degrees. Following the inner platform measurements, the student proceeded to brainstorm ideas for the outer platform. The mobile platform was required to be about 3 ft long and 4 ft wide, with wheels to roll around the circumference of the structural test equipment. The platform itself needed to have an inward curve with a diameter that matched the same as for the test equipment stand. The platform would need to be bolted on top of a light structure made of beams to fit the height of the equipment's ring, so the student proceeded to measure this required height. After gathering the specific requirements and measurements, the student created a few drafts of both designs, correcting the designs over time as she received helpful feedback from her mentors and coworkers throughout the process. Despite the student being able to adjust and adapt to the given feedback, the process over the course of the design and testing processes was not always straightforward. Because the student's branch was carrying out significant projects for SLS, the student was required to think outside the box and use critical thinking skills to solve software and modeling issues she faced when using the Windchill database and the Creo Parametric. Both software include various tools that oftentimes get confusing for the student to access and locate due to their complex interfaces. Therefore, the student used articles and videos to research different ways to carry out specific tasks that would go into her design drafts. For example, the student was not sure how to design and assemble each link for the safety chains on the outer platform. Due to this issue, the student utilized videos as a research tool to resolve the confusion they were facing. This research gave them a tutorial on the assembly process, visualizing that a curved line would need to be drawn from the center-point-edge of the first link. This curved line would be placed exactly down the middle of the link, extending along the required length for the entire chain. Afterward, the student would add another link to begin the assembly, turning the link 180 degrees, aligning the two parts along the curved line created, and finally linking both links together by placing the second link inside the first link of the assembly chain. This problem-solving example is just one of the many instances where the student had to face challenges they were met with during the design process.

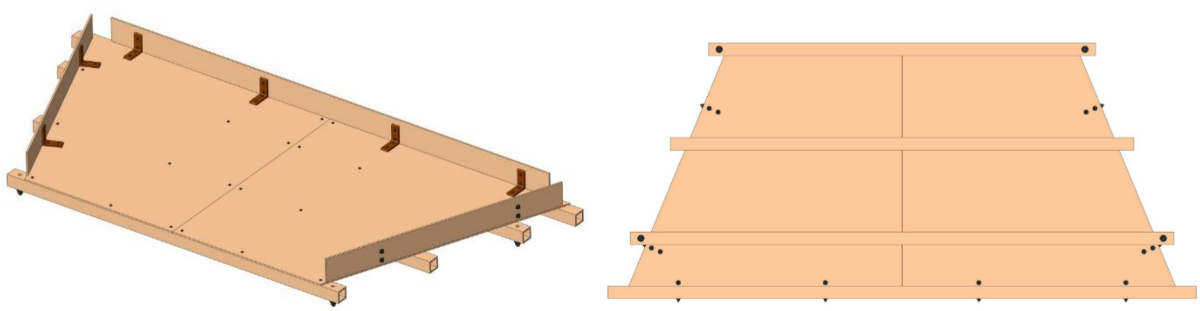

Figure 3. The final draft of the CAD assembly model for the Inner Platform.

Considering the accurate measurements and valuable feedback the student received, the student created a final design of the inner platform model, as shown in Figure 3. Originally, she made both platforms 2 inches thick to allow sturdiness and stability in them, but was corrected by her mentor that it was not necessary. The student changed the thickness to a quarter of an inch and added rectangular Hollow Structural Section (HSS) beams underneath the platform, ensuring that it would be strong enough to hold the weight of the technicians along with the force of gravity. Holes were made in the HSS beams that aligned with the holes of the platform. Bolts, nuts, and washers (1/2" in diameter) were included through the holes of the platform and beams, allowing the platform to be mounted into the PLA Structural Test Equipment Stand. The final dimensions of the trapezoidal shape were 40.5" long, 104.378" wide for the long side, and 70.815" wide for the short side. As requested, the student assigned the material of the parts to be aluminum and symbolized the HSS beams and the platform to be welded together on the engineering drawing. The entire assembly for the inner platform had nine individual parts in total and only needed three pages (the cover page included) to call out the parts and express her design's intentions. The simplicity of the design did not present a need for outside vendor parts or a lengthy process. Nonetheless, the student had to revise the diameter size for the bolts, nuts, and washers, originally sizing them as the same diameter as the holes. She discovered from her mentor that it was vital to make these components slightly smaller in size than the hole they go through to allow for tolerance and prevent friction. This model also did not require elaborate GD&T on its drawing but gave the student practice in creating a Creo preliminary drawing to prepare for the more intricate design of the outer platform.

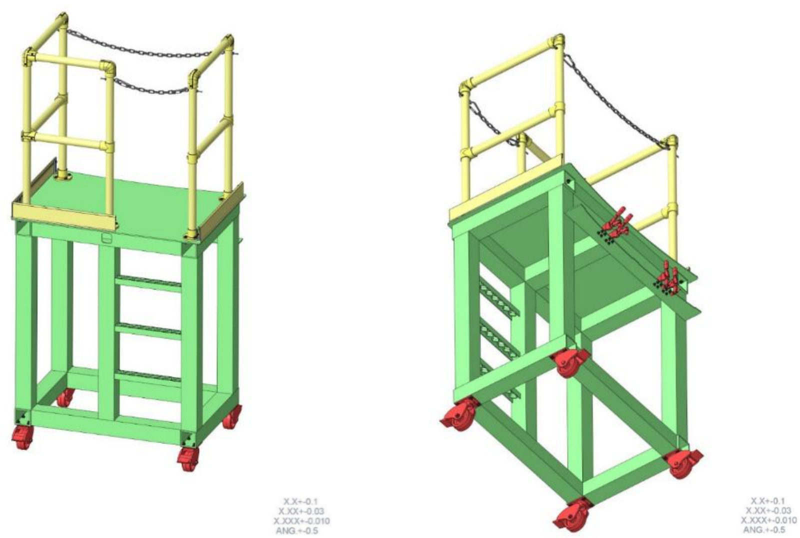

Figure 4. The final draft of the CAD assembly model for the Outer Platform.

Multiple modifications were made to the outer platform's model during the design process. The student created a rough draft of the model to gain useful advice from multiple mentors in her office. The student originally added cross sections to the HSS beams in its structure to ensure stability, but was advised that it was not necessary. The student was told that because the platform sits on top of wheels, a safeguard is required, hence, the safety railings and chains. A ladder was also required for easy access to the top of the platform. Following these suggestions, the student began designing a final draft of the model beginning with a skeleton structure in Creo to outline the placements of the beams and ladder steps. The student inserted the HSS beams onto the skeleton and assembled the ¼" platform piece on top, securing the necessary constraints. Due to the platform's more complex design, the student used an outside vendor, McMaster-Carr, to provide specific parts (casters, ladder rungs, carabiners, eyebolts, and chains) [10]. A few of these parts had CAD files that could be inserted directly and assembled into the model, but the student had to replicate and model the ladder rung, carabiner, and chain piece designs. The student was originally going to use a mount ladder from McMaster, but found that the built-in ladder steps felt more logical. She made sure to find ladder rungs of aluminum material so that they could be welded into the aluminum HSS beams. She used swivel, total lock casters to ensure multidirectional mobility, stability, and safety. The student also found previously made parts (bolts, washers, nuts, square beams, and railings) in the ET50 menu that she implemented into the assembly. When assembling a part into an assembly, you need to constrain it by selecting the reference geometry (the points, faces, or axes), then applying constraints (Align, Insert, Tangent, Parallel, Perpendicular, Point, etc.), allowing correct position and orientation. The student proceeded to assemble each part into the assembly, applying the appropriate constraints. Following the finished Creo model, she started working on the engineering drawing for the design having 29 different parts, defining and controlling them across six pages (including the cover page). The student was unable to fully complete the outer platform's drawing due to the completion of her internship, but she gained various hard and soft skills throughout the process.

Summary of the Internship Experience

As shown in Table 2, the student summarizes the new skills they achieved after completing the entirety of the internship program and their project. As mentioned in the *Introduction* section of the Research paper, the student accomplished the following objectives:

- Design and/or Analysis of Ground Test Hardware
- Use of Computer-Aided Design and/or Finite Element Analysis
- Understanding Structural Design and Stress Analysis
- Development of Collaboration and Professional Skills
- Engagement in Aerospace Engineering Research and Experience

Table 2. Summary table of new skills gained.

Category	New Skills Gained
CAD Modeling (Creo)	Understanding how to access and utilize various modeling tools and techniques using the user-interface
	Using outside vendors to access and incorporate existing parts
	Creating and assembling individual parts into a final assembly
Windchill Database	Creating a workspace
	Naming new parts, assemblies, and drawings
	Accessing and integrating existing parts into a new design or assembly
Geometric Dimensioning & Tolerancing	Understanding the symbolic language of the tool to detail the orientation, form, location, and size of a part's features
Effective Communication & Collaboration	Interacting with mentors, technicians, ET50 engineers, and other interns to gain helpful advice and influence
	Participating in an Exceptional Presentations Workshop to improve presentation skills
	Representing the ET50 Branch at NASA in the Park showcasing necessary knowledge of how ET50 operates
Adaptiveness	Taking feedback from ET50 mentors and coworkers to make necessary changes to refine models or drawings
	Resolving modeling issues and challenges in Creo software
Manufacturing Knowledge	Considering fabrication functionalities when designing models
	Understanding different tolerancing and welding techniques

The student was able to gain a set of valuable skills that they carried into their junior year of collegiate courses, organizations, engineering conferences, networking events, and leadership roles. Even though the student had previous skills in computer-aided design, they were able to further advance these skills at NASA, using them for assigned projects in their Manufacturing Processes and Kinematic Design courses at school. The student's significant development in professional and collaboration skills professionally motivated them to network effectively and receive beneficial opportunities to advance their career even further. These two demonstrations illustrate how the Department of Education Minority Science and Engineering Improvement Program (MSEIP) program and its collaboration with NASA considerably developed and advanced an engineering student's professional and technical skills over the course of a summer internship. The student working directly under the ET50 Special Test Equipment Design Branch taught them how important ground test hardware and the design stress analysis are to aerospace engineering and the continued success of the National Aeronautics and Space Administration. These conclusions demonstrated that there are broader implications that go into the fabrication and launching of rocket ships and that test equipment and particles are one of the first steps in making these successful units possible.

Acknowledgments

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