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Emulating NASA's Structural Strength Test Procedures with the Centaur V-Upper Stage of the ULA Vulcan Rocket: Findings from a Student Internship at NASA Marshall

Taylor St. Fleur, Prairie View A&M University
Dr. Jianren Zhou, Prairie View A&M University

Professor, Department of Mechanical Engineering.

Mr. Minghui Xu, Clemson University

Minghui Xu is currently a Ph.D. student at Clemson University. His research focuses on droplet combustion science and image analysis.

Dr. Yuhao Xu, Clemson University

Yuhao Xu received a Ph.D. in Mechanical Engineering from Cornell University. He is currently an Assistant Professor in the Department of Mechanical Engineering at Clemson University. He was previously with Prairie View A and M University (an HBCU) and ASML-HMI North America Inc.. His current research includes experiments on high-pressure combustion of petroleum-based liquid fuels and bio-derived fuels, digital image processing of experimental data, and studies of microfluidics in energy systems.

Student Paper
Emulating NASA's Structural Strength Test Procedures with the Centaur V-Upper Stage of the ULA Vulcan Rocket: Findings from a Student Internship at NASA Marshall

Taylor St. Fleur[1], Jianren Zhou[1], Minghui Xu[2] and Yuhao Xu[2]

[1]*Department of Mechanical Engineering, Prairie View A&M University, Prairie View, TX 77446*
[2]*Department of Mechanical Engineering, Clemson University, Clemson, SC 29634*

Abstract

This study presents findings from an innovative undergraduate internship and research opportunity at NASA Marshall Space Flight Center, funded by a grant from the Department of Education. The novelty of this initiative is to involve students from minority-serving institutions in meaningful research and internship experiences, thereby fostering their academic and professional growth. The participant in this program comes from an underrepresented minority background in STEM, gaining valuable practical experience in aerospace and mechanical engineering through this internship.

At Marshall Space Flight Center, the ET30 division conducts structural strength testing on articles to find various components and evaluate how they withstand extreme forces that the customer will need to know. This is executed by applying and reacting to extreme loads using compression, tension, and torsion. Many environmental properties (temperature, pressure, and humidity) can be tested by environmental simulations, which are critical in assessing the durability of the components in actual space conditions.

The objective was to gather vital data for customers like the United Launch Alliance (ULA). One of the major projects worked on involves ULA's Vulcan Rocket, for which ET30 tested components of the Centaur V upper stage. The instrumentation on Centaur V is essential to measuring stress, strain, and other mechanical factors during testing to ensure the system can perform as expected during a launch. Most of the testing done follows a general testing process. This process consists of designing, fabricating, instrumenting, creating a test setup, constructing the database, writing a Test Procedure Sheet, and running the actual test. A specific test was a dog bone test, which was designed to focus stress on the middle portion of the sample. This "dog bone" test used methods that correlate directly with larger-scale structural tests, such as those conducted on Centaur V. These smaller tests serve as a cost-effective and reliable method for verifying behavior before committing to large tests on systems like those in Centaur V. Through processes like the ones used in ET30, these systems are ensured to meet flight readiness for demanding conditions of space exploration.

Keywords:
Research Experiences for Undergraduates, Underrepresented Groups in STEM, Structural Strength, Design and Development, Centaur V, Dog bone

Introduction

In this work, a minority female student from Prairie View A&M University (PVAMU) participates in a high-level internship experience at the NASA Marshall Space Flight Center (MSFC) in Huntsville, Alabama. This opportunity provided an integration of professional skills and technical knowledge learned from engineering courses to better her understanding of what a career in mechanical engineering is like. During the spring of her freshman year, the student was endorsed to apply to the internship by one of her professors based on her dedication and merit in his course. With an ultimate career goal to contribute to advancing technology and innovation, particularly in aerospace engineering, this was a stimulating endeavor she was willing to conquer. A total of 21 projects were presented to the student applicants, and Project 20, "Design and Develop Test Equipment for Structural Test," was chosen by her based on her academic and career goals in mechanical engineering. Upon being selected, the internship was executed using funding from the Department of Education (DOE) through the Minority Science and Engineering Improvement Program (MSEIP). The project was conducted under the ET30 Branch-Structural Strength Test Laboratory, led by Branch Chief Mike Lau and Lead Structural Test Engineer Mark White. Upon arrival at MSFC, the student was assigned to be a mentee for Ashlee Bracewell, Alternate Test Engineer, and shadow her through the final stages of the highest priority project for ET30.

The student worked on a project in collaboration with the private aerospace company United Launch Alliance (ULA) and NASA's Marshall Space Flight Center. The project focused on testing a critical component of ULA's Vulcan rocket, specifically the Centaur V upper stage. This stage, a tank designed to hold cryogenic propellants, was undergoing test readiness preparations. The student contributed by coordinating efforts between the NASA and ULA teams to gather and analyze the information required by ULA for the testing process. To accomplish this, the student worked under the guidance of Ashlee Bracewell, who oversaw and managed the flow to flight readiness for the Centaur V upper stage. During this process, the student was also assigned an additional project designed to simulate the NASA process for article readiness. This side project involved designing a test coupon, allowing the student to select the material and dimensions, and then subjecting it to failure using a tensile testing machine to evaluate its mechanical properties and gather data. The purpose of this project was multi-purposed: it aimed to help the student intern build a professional network within the branch by seeking insights from colleagues, applying technical knowledge of mechanical properties learned in school, gaining hands-on experience with instrumentation installation, and producing documentation aligned with NASA standards. This paper outlines what the student learned during this internship and how the experience provided the student with an invaluable opportunity to bridge the gap between academic knowledge and the professional competence required in their career field.

What is ET30?

The overall branch of Test Lab is referred to as ET at MSFC, and test lab facilities accommodate test articles at any technology readiness level [1]. Specifically, the ET30- Structural Strength Test Laboratory is unique to MSFC. The main purpose of this branch is to do structural strength testing on articles to find a variety of variables that NASA or the customer will need to know prior to launching spaceships [2]. This is an imperative role in the aerospace launching process because it ensures that the specific section of a rocket is able to withstand the extreme pressures in outer space [1, 2]. ET30 has multiple buildings/areas that hold these different reaction structures, ranging from small to extremely large. These reaction structures are specifically designed to test the effects of various environmental factors, such as humidity, vacuum conditions, extreme heat, and cryogenic temperatures [2]. This testing process involves applying and withstanding extreme loads through methods like compression, tension, and torsion on a wide range of materials [2]. These rigorous tests ensure the materials' reliability and performance under diverse and demanding conditions. The structure of ET30 can be generalized into two categories: the electrical team and the mechanical team. The two teams work together to distribute workloads and specialize in different parts of a project. Some of the previous projects that ET30 worked on were the Space Launch System (SLS) Engine Section, SLS Intertank, SLS Hydrogen Tank, SLS Oxygen Tank, and many more.

Collaboration with United Launch Alliance

To begin the internship, the student was first required to gain a foundational understanding of how rockets work and the various components that make up a rocket. This initial task ensured she was well-prepared for the more specialized responsibilities to follow. Afterward, she delved into the previous work conducted with ULA on Centaur V, enabling her to catch up to the current state of their test readiness process.

The Vulcan Centaur, a specific rocket design developed by ULA, includes an upper stage known as the Centaur V. This stage is fueled by liquid hydrogen and liquid oxygen, equipped with two engines, and features cryogenic tanks insulated with foam. ET30's primary focus was on Centaur V's upper stage section. The Centaur V test article overview involved several critical objectives: structurally qualifying the internal and external hardware against critical failure modes, design limits, and ultimate load conditions; obtaining strains, deflections, and temperatures for validating analysis models; and ensuring all these elements met rigorous standards.

Collaboration between ET30 and ULA was essential to achieve these goals. Regular meetings were held to discuss instrumentation, documentation, load control, cryogen control, checkpoint statuses, and various other aspects to keep the project on track. Through this collaborative environment, the student gained exposure to different measurement and monitoring tools, such as Linear Variable Differential Transformers (LVDTs), strain gauges, Fiber Optic Strain Sensors (FOSS), and thermocouples. These instruments play a crucial role in monitoring testing processes when loads are applied to rocket components. On occasion, technicians working on the Centaur V would take the student inside the actual test article, demonstrating how to install the instrumentation. This process, which demands precise measurements and meticulous attention to detail, often takes hours to complete. As with any engineering endeavor, unexpected issues arose, such as LVDTs shifting or microphones malfunctioning on Centaur V. When problems occurred, it was the responsibility of the test engineers to diagnose and resolve them. Working closely with Bracewell, technicians, ULA officials, and other test engineers gave the student a solid foundation in the technical aspects of ET30's operations.

Simulating NASA's Structural Strength Test Procedures

Towards the latter part of the internship, the student was assigned a project designed to emulate NASA ET30's structural strength testing procedures. In ET30, these procedures typically involve a sequence of tasks (see Figure 1): collaborating with clients to define objectives, creating a project timeline, designing the test article to meet specific requirements, assembling and instrumenting the article, preparing the test environment, drafting documentation, and ultimately applying loads during testing [2]. For this assignment, the student worked with her mentor, Bracewell, who acted as the "client" to establish the project's objectives. Together, they determined that the test would evaluate the mechanical properties of a coupon by subjecting it to failure using a tensile testing machine.

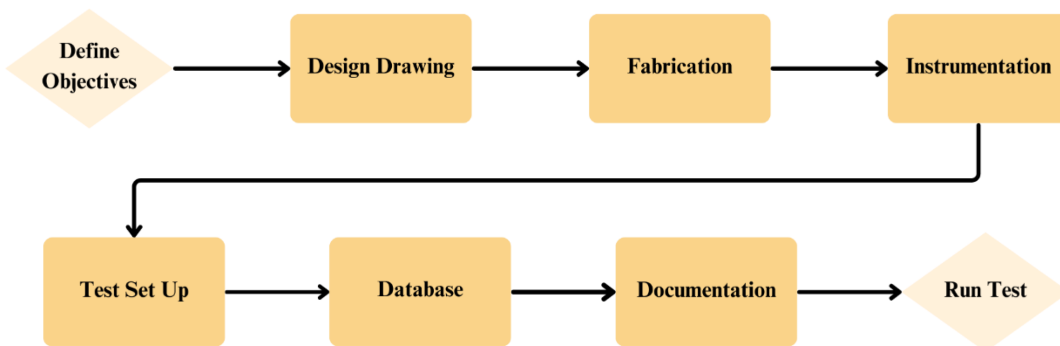


Figure 1. ET30 structural strength testing process: A visual representation of the procedural workflow undertaken by ET30 when preparing for and executing structural testing.

The student began by outlining a timeline and consulting with colleagues to gather insights and guidance. Networking with team members, she scheduled meetings to refine her approach and receive technical support. The design process followed standards set by the American Society for Testing and Materials (ASTM). Initially, the coupon was designed in a dog bone shape with one hole at each end. Recognizing that the holes could act as unintended stress concentration points, she revised the design to focus on the narrowest cross-sectional area at the center, ensuring failure would occur there during testing. Aluminum was selected as the material due to its lower strength, ensuring easier failure, and a detailed draft of the revised design was produced (see Figure 2).

With the design finalized, the student collaborated with a material fabricator to manufacture the coupon and worked closely with a strain gauge specialist to determine the optimal placement and application techniques for instrumentation. She researched strain gauge types, considering factors like size and sensitivity, and practiced installation methods. After resolving challenges with gauge adhesion by using stronger bonding agents and heat curing, the strain gauges were successfully installed.

Next, the student worked with a systems and controls engineer to configure the database for the tensile test. The test setup incorporated multiple components, including the dog bone clamped within a SATEC tensile testing machine. The setup also involved clevis pins, load cells, strain gauge wiring, a Hughes connector, a Remote Data Harvester (RDH), and the control system interface. This test setup was established with significant input from her coworkers, stressing the collaborative nature of the project.

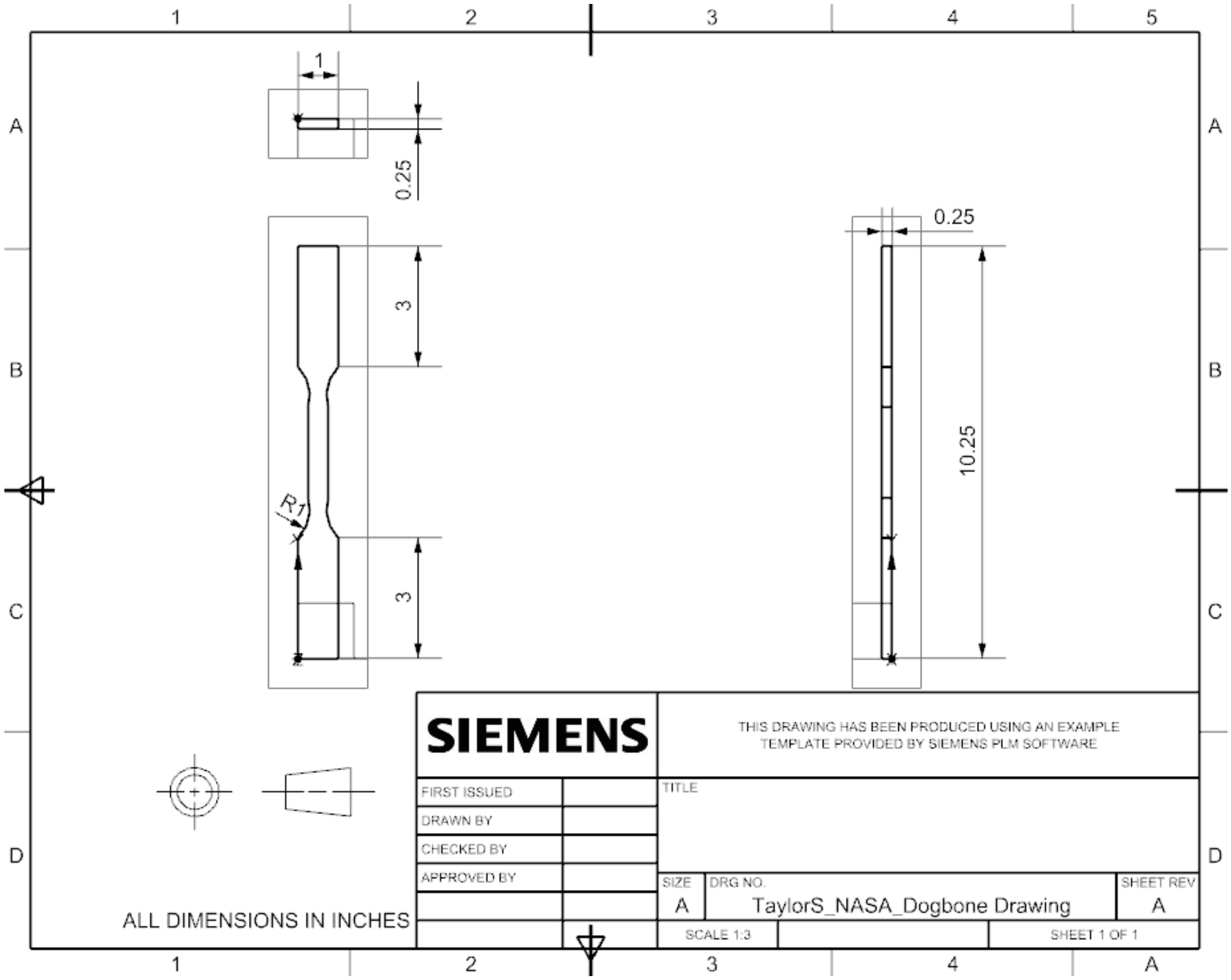
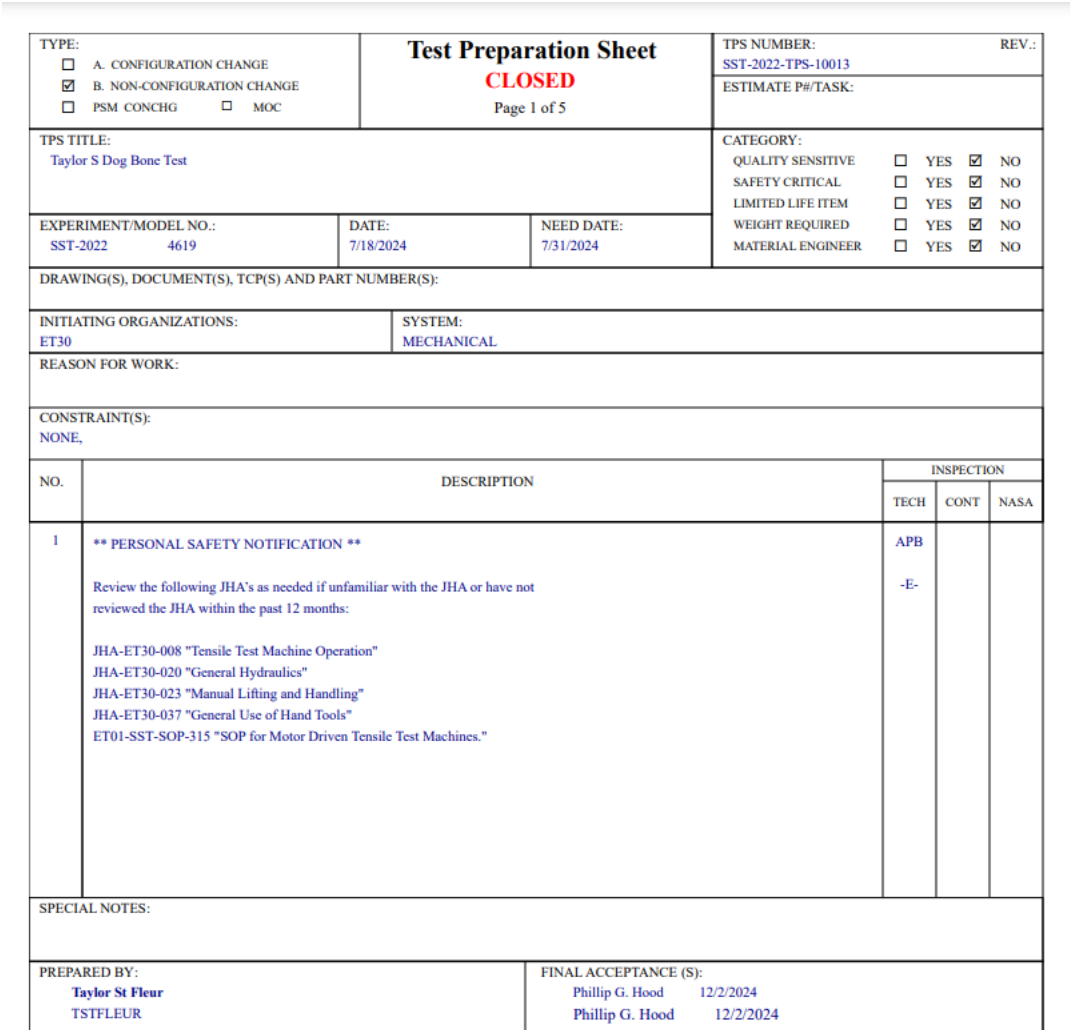


Figure 2. The drawing of the "Dog Bone" draft design.

To document her work, the student prepared a comprehensive Test Preparation Sheet (TPS), a critical component of ET30's standard testing workflow, as shown in Figure 3. The TPS outlined safety considerations, test setup descriptions, hardware configurations, and the tensile testing procedure. Following approval from lead engineers, the student led the actual testing process, instructing a load operator to incrementally apply loads until the coupon reached failure. Once the dog bone fractured at the designated point, she collected and analyzed the data, comparing it to predicted results and documenting the findings in the TPS.



TYPE:
☐ A. CONFIGURATION CHANGE
☑ B. NON-CONFIGURATION CHANGE
☐ PSM CONCHG ☐ MOC

Test Preparation Sheet
CLOSED
Page 1 of 5

TPS NUMBER: SST-2022-TPS-10013
REV.:
ESTIMATE P#/TASK:

TPS TITLE: Taylor S Dog Bone Test

CATEGORY:

QUALITY SENSITIVE	☐ YES	☑ NO
SAFETY CRITICAL	☐ YES	☑ NO
LIMITED LIFE ITEM	☐ YES	☑ NO
WEIGHT REQUIRED	☐ YES	☑ NO
MATERIAL ENGINEER	☐ YES	☑ NO

EXPERIMENT/MODEL NO.: SST-2022 4619
DATE: 7/18/2024
NEED DATE: 7/31/2024

DRAWING(S), DOCUMENT(S), TCP(S) AND PART NUMBER(S):

INITIATING ORGANIZATIONS: ET30
SYSTEM: MECHANICAL

REASON FOR WORK:

CONSTRAINT(S): NONE,

NO.	DESCRIPTION	INSPECTION TECH	INSPECTION CONT	INSPECTION NASA
1	** PERSONAL SAFETY NOTIFICATION ** Review the following JHA's as needed if unfamiliar with the JHA or have not reviewed the JHA within the past 12 months: JHA-ET30-008 "Tensile Test Machine Operation" JHA-ET30-020 "General Hydraulics" JHA-ET30-023 "Manual Lifting and Handling" JHA-ET30-037 "General Use of Hand Tools" ET01-SST-SOP-315 "SOP for Motor Driven Tensile Test Machines."	APB -E-		

SPECIAL NOTES:

PREPARED BY: Taylor St Fleur TSTFLEUR

FINAL ACCEPTANCE (S): Phillip G. Hood 12/2/2024 Phillip G. Hood 12/2/2024

Figure 3. Test Preparation Sheet used in this work to provide technical work instructions for test support personnel.

This project presented several challenges. Initially, the use of steel and overly large coupon dimensions hindered progress, prompting the switch to aluminum and scaled-down dimensions. Additionally, early difficulties with strain gauge bonding were addressed through improved adhesive techniques and heat application. By overcoming these obstacles, the student successfully completed the project, delivering the required results to her "client." This hands-on experience provided valuable insights into NASA's rigorous testing methodologies, highlighting the parallels between her small-scale dog bone project and the high-priority work conducted with United Launch Alliance.

Reflections on the Internship Experience

Internships play a crucial role in bridging academic learning and professional experience, particularly in STEM fields, by providing hands-on training, mentorship, and industry exposure. The collaboration between the U.S. Department of Education and NASA, which effectively integrates structured projects, guided mentorship, and industry collaboration to maximize intern productivity and growth. The NASA internship program began with an overview of the organization's mission, goals, and departmental structure, ensuring that interns gained a clear understanding of the broader framework. Interns were also provided with key contact information, facilitating seamless communication throughout the program.

To enhance the internship experience, NASA offered various professional development opportunities, including presentation workshops, mentorship and personal development classes, and public engagement events. For example, one such event that the student participated in was NASA in the Park, an annual initiative that brings the community together to showcase NASA's divisions, discoveries, projects, and research. During this event, the intern had the opportunity to present demonstrations on behalf of ET30, gaining valuable public speaking and technical communication experience. Expanding similar internship models across NASA's ten centers and other institutions could significantly increase opportunities for minority students, fostering greater diversity in aerospace engineering. Key takeaways from this program emphasize the importance of setting clear goals, establishing mentorship frameworks, and encouraging active participation. Interns are advised to take initiative, engage in networking and professional development opportunities, and seek out tasks rather than passively waiting for assignments.

Ultimately, the effectiveness of an internship depends on both the structure provided by the organization and the intern's proactive engagement. By implementing structured mentorship, diverse learning opportunities, and strong industry connections, internship programs can successfully bridge the gap between academic knowledge and real-world STEM careers.

Technical and Professional Skill Development

The experience working with the ET30 branch at MSFC on the final stages of test readiness for Centaur V profoundly benefited and enhanced the student's technical and professional skill sets. By collaborating closely with skilled technicians, the student gained valuable insights into the intricate components of load control and the complexities of conducting structural tests. Observing and participating in the instrumentation process provided a unique opportunity to witness real-world challenges, such as troubleshooting and resolving issues with Centaur V's test cameras. For instance, the team encountered a problem when the microphones were not performing as expected due to incorrect input connections. The student, under her mentor's guidance, contributed to diagnosing and revising the issue by reconfiguring the camera setup, ensuring that sound could be properly captured during testing. These moments symbolized the importance of adaptability and problem-solving in achieving project goals.

In addition to observing the Centaur V project, the student engaged hands-on with her dog bone project, applying mechanical drawing skills previously developed using Siemens NX. Designing the dog bone required meticulous attention to detail to ensure it could withstand applied pressures while breaking in the designated area. This task reinforced the connection between theoretical knowledge from coursework and practical application, particularly in material science and structural analysis.

The internship also provided exposure to the management side of high-stakes engineering projects. Shadowing Ashlee Bracewell offered an in-depth understanding of project documentation, team coordination, and the strategic planning required to meet critical deadlines.

By observing meetings and reviewing essential documents, the student gained a comprehensive perspective on the framework necessary to execute major projects like Centaur V.

Networking and collaboration were essential to the student's development during this internship. To successfully complete her dog bone project, she actively reached out to colleagues across the ET30 branch, seeking advice and technical support. This proactive approach not only helped her overcome challenges but also promoted professional relationships and deepened her understanding of ET30's mission to contribute to NASA's future achievements. The confidence gained from these interactions emphasized the importance of effective communication and collaboration in professional settings.

A highlight of the student's technical development was working with a load control engineer who introduced her to the foundational principles of load control for structural testing. Through hands-on learning, she became familiar with essential equipment, including hydraulic pumps, actuators, servo manifolds, valves, and load cells. This experience provided an appreciation for the precision and complexity of tools used in structural tests, bridging the gap between classroom theory and real-world application.

Overall, the internship at MSFC was instrumental in bridging the technical concepts learned in university with the professional demands of aerospace engineering. From resolving instrumentation challenges to designing and testing a custom article, the student grasped a better understanding of the technical, managerial, and collaborative aspects of engineering at NASA.

Lessons Learned and Impact on Career Goals

In addition to technical aspects, this project highlighted the importance of applying the technical aspects learned in school, networking, and documentation to allow engineering projects like the ones performed at NASA to go smoothly. The TPS not only guided the testing process but also served as a vital communication tool, ensuring all stakeholders understood the methods being used and safety precautions. By simulating the real-world processes followed by NASA engineers, the student gained a deeper appreciation for the extreme planning and execution required in aerospace engineering. This experience also emphasized the interdisciplinary nature of engineering projects, as the student collaborated with experts in materials science, instrumentation, and data systems to achieve the project's objectives.

The repetitive nature of the project provided valuable lessons in problem-solving and adaptability. For example, revising the coupon design to address potential failure points and selecting appropriate materials demonstrated the importance of critical thinking in engineering. Similarly, troubleshooting instrumentation challenges highlighted the need for persistence and attention to detail. Each stage of the project reinforced the student's ability to integrate academic knowledge with professional practices, bridging the gap between theoretical concepts learned in school and practical application in the real world.

Ultimately, the project exemplified how the internship allowed the student to experience firsthand the problems of structural strength testing. By participating in every step of the process, from conceptual design to final testing, she developed a holistic understanding of the technical and procedural aspects of aerospace engineering. This captivating experience not only enhanced her technical skills but also prepared her for the collaborative and detail-oriented nature of a career in engineering.

Broader Picture of the Internship

The broader impact of this NASA internship reflects a collaborative effort to expand access and opportunity for underrepresented students in STEM. Funded by the U.S. Department of Education, the internship was specifically designed to allow NASA and other sponsors to welcome more interns and expose them to diverse, cutting-edge projects. Uniquely, a minority-serving university played a key role by using its education grant to provide student stipends, enabling greater participation from underrepresented groups. Dr. Bernadette Hence, Program Manager at the U.S. Department of Education, was instrumental in bridging the funding between NASA and participating universities. To ensure strong student alignment with the internship's goals, professors could adopt innovative recruitment strategies by identifying students whose classroom engagement and performance match the program's structure. For students, best practices include arriving with basic knowledge about the company, demonstrating punctuality and reliability, asking thoughtful questions, networking, seeking feedback, and maintaining connections with peers. Beyond the individual experience, interns are encouraged to use their journey to inspire fellow students, particularly in aerospace research. This internship model has the potential to scale nationally through minority-focused organizations like the National Society of Black Engineers (NSBE), the Society of Hispanic Professional Engineers (SHPE), and the Society of Women Engineers (SWE). These organizations host conferences where students share their research, grow in leadership and technical skills, and build valuable networks. With NASA centers located across ten states, universities in those regions could adopt this inclusive framework by securing funding for student organizations, encouraging grant-based student research, and hosting seminars to spark interest in aerospace and STEM careers.

Acknowledgments

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References

[1] R. Shaughnessy, "MSFC Test Capabilities," *prezi.com*, Jun. 06, 2016. https://prezi.com/p9qhquslrkck/msfc-test-capabilities/ (accessed Jan. 12, 2025).
[2] "Structural Strength Test Lab." Available: https://www.nasa.gov/wp-content/uploads/2016/01/et30_sstl_3_1_211.pdf