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Undergraduate Hypersonics Research: The Second Year of the REU Site HYPER

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Training future engineers and scientists for the research-oriented careers necessary to deliver solutions to the challenges of hypersonic flight is important task for the aerospace community at-large. A number of programs and initiatives at the University of Central Florida (UCF) contribute to this need. Among them is the Research Experiences for Undergraduates (REU) site framed on HYpersonic, Propulsive, Energetic, and Reusable Platforms (HYPER) an program housed withing the Center for Advanced Turbomachinery Energy Research (CATER). This residential summer program convening on the UCF main campus prepares a group of undergraduate students to pursue doctoral-level degree programs in aerospace engineering and related disciplines. During the Summer 2021, the second term of the program, HYPER hosted fourteen students. Students conducted intensive research under the guidance of faculty mentors and their graduate student assistants. To support their complete development, HYPER students participated in industry tours, software training, technical seminars, and more. This paper reports the impact of the program in its second year. Data are derived from pre- and post-experience surveys, study groups, and technical assessment activities. Feedback from the first year were implemented in the second year.

I. Introduction

The REU site cultivates and unites multidisciplinary interests to study advanced structures and systems with application to hypersonics, space, propulsion and energy. Participants gain hands on research training in contemporary challenges such as utilizing advanced manufacturing techniques for high-value components, integrating in site monitoring of stress-strain evolution, developing novel methods for improved internal cooling and heat transfer effectiveness, and mitigating flutter through advanced rotor dynamic control. Many of these challenges rely on approaches that cut across disciplines and research techniques. In many ways, the REU site is operated analogously to the research center which is home to the majority of HYPER faculty mentors named the Center for Advanced Turbomachinery and Energy Research (CATER). Central Florida has a unique position in the world as a convergence for Turbine, Energy, and Space technologies. With the presence of Siemens Energy, Pratt & Whitney, Mitsubishi Power Systems, Alstom / Power Systems Manufacturing, Aerojet Rocketdyne, Florida Turbine Technologies, Chromalloy, Boeing, Lockheed Martin, Embraer, Kennedy Space Center in or near Central Florida, UCF's CATER has a unique opportunity and responsibility for taking the leadership in innovation and advanced technology development.

II. Programmatic Overview

A. Research Project Objectives and Accomplishments

Each student conducts research with one of eleven faculty mentors and a graduate student. The research projects relate to hypersonics. The individual research projects available to the prospective students at the time of application are listed on the program's webpage [http://cater.cecs.ucf.edu/hyper]:

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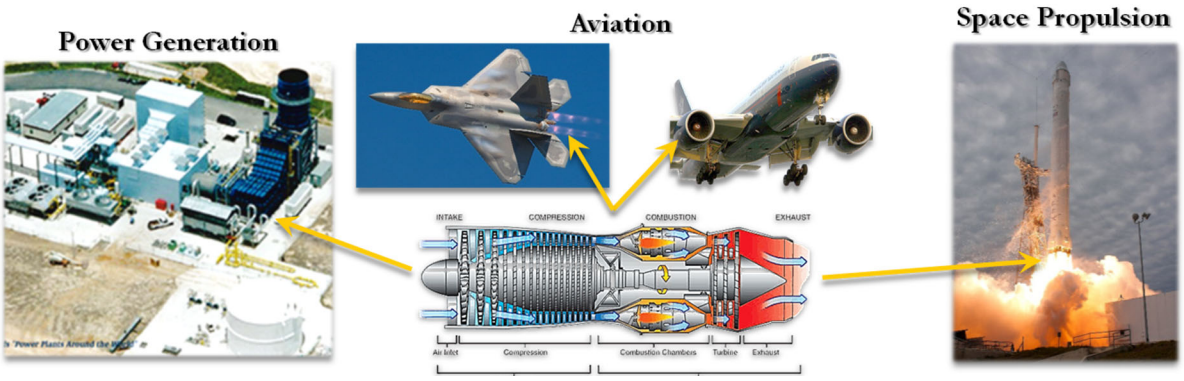

Figure 1: Research topics covered by HYPER and CATER.

- *Continuum-Level Life Prediction of Materials under Combined Extreme Environments*, with a goal to conduct a numerical analysis of thermo-mechanical buckling in combined extreme environments. The project has applications for the stability of fuselage panels in hypersonic vehicles. The participant will learn to conduct finite element analyses (FEA) using ANSYS and simulated the transient response of a long flat plate subjected to high temperatures to assess its stability. The participant will incorporate advanced nonlinear material and constitutive properties/models to the FEA.
- *Damping of Anisotropic Composite Structures Under Extreme Multi-Axial Mechanical and Thermal Loads*, with a goal to establish a testing framework to understand how multi-axial mechanical loads affect the damping of anisotropic composite structures. The project has applications related to the structural dynamics of hypersonic vehicles. The participant will develop and built a test rig that imposes controllable multi-axial loads and can accommodate mixed boundary conditions, characterized the rig using an initial test specimen, and gathered experimental data on the trends of damping based on in-plane loading. The participant will also simulated the effect of boundary conditions to optimize the specimen plate geometry and support mechanisms.
- *Evaluation of CFD Models for Solid-Propellant Rocket-Exhaust Modeling*, with a goal to explore numerical methods relating to solid-laden flows for rocket propulsors. The project has applications relating to rockets, sand blast nozzles, coal processing, and other applications involving flowing particulate. The participant will learn to master research tools such as computational fluid dynamics, multiphase flow, and key concepts of compressible jets. Using these research skills, the participant will evaluate a variety of numerical methods; the work directly pointed to an improved path for nozzle optimization.
- *Atmospheric Entry, Descent and Landing (EDL) for Manned Mars Missions*, with a goal to develop a new method using neural networks for a Mars capsule controller during atmospheric entry. This method utilizes the controller from the Apollo missions as a reference for data when training the neural network. The participant will contribute to on-going research by conducting the simulation with the trained network to replicate the results from Apollo with variations in the initial conditions, e.g. position. The participant will then use the real data from Apollo to evaluate the controller's performance. The controller will then be adapted to the Mars environment where it will satisfy the requirement for landing accuracy.
- *Non-Invasive Inspection of High-Temperature Coatings*, with a goal to develop material systems that can endure the extreme conditions associated with hypersonic flight. The project has applications of material design for hypersonic and extreme environments. The participant will contribute to on-going research by conducting a literature review on possible substrate and coating materials for the candidate samples for testing. The participant will identify the typical X-ray emission peaks for these materials for ease of testing.
- *Transpiration Cooling for Turbine Blades as Enabled by Additive Manufacturing*, with a goal to investigate the effects of applying mechanical loads to auxetic designs that could be used as film-coolant slots. The project has applications in gas turbines, where enhanced cooling could increase the maximum turbine temperature, thus increasing its energy efficiency. The participant will learn to conduct finite element analyses (FEA) using Siemens NX and simulated the behavior of auxetic slotted plates subjected to force and pressure loads. The participant will simulate both flat and cylindrical coupons, and the results indicate specific slot shapes that produce the least deformation and lowest stress concentrations.
- *Additive Manufacturing of Ceramic Turbine Blades*, with a goal to design an experimental testbed for evaluating the performance of carbon fiber reinforced polymer composite gears. The carbon-fiber-reinforced

polymer composite gears have a wide range of applications in lightweight aerospace components. The participant will design and 3D printed several carbon fiber reinforced polymer composite gears as well as designed a health monitoring system for the testbed.

- *Fundamental Combustion Studies of Renewable Fuels for Hypersonic Propulsion and Rocket Engines*, with a goal to develop a Matlab model for an advanced 3D tomographic optical diagnostic technique of flames. The model is used to investigate and measure heat release in premixed hypersonic compressible turbulent flames models for hypersonic propulsion. The student will develop a Matlab code and start the generic image processing.
- *Uncertainty Quantification and Massive Computing in Prognosis and Fleet Health Management*, with a goal to improve the fidelity of inputs used in the physics-informed machine learning model for corrosion fatigue. The project has applications of Python coding and large data analysis. The participant will contribute by a) identifying available data regarding airport corrosivity indices such as salt, CO, and humidity levels across the USA (looking at databases from NOAA, NREL, and others); b) coding computational routines for data curation (dealing with outliers and missing data); and c) performing literature research and coding a model that maps such indices into a corrosivity severity factor. At the end of the summer, the participant will deliver a dataset with five-year of data for ten airports in the USA.
- *Flame Diagnostics Using an Advanced 3D Tomographic Optical Technique*, with a goal to analyze flame speed measurements from constant-volume combustion chamber. The project has applications in design of engines used in hypersonic airbreathing vehicles. The participant will analyze images to obtain flame speeds from high-speed videos.
- *3D-Woven Polymer-Derived All-Oxide Ceramic Matrix Composites (CMCs)*, with a goal to develop high temperature oxide-oxide ceramic matrix composites. The project has applications of hypersonic vehicles, gas turbine blades, and aircraft engines. The participant contributed by processing, characterizing and testing the oxide-oxide CMCs.

Updates presented here extend from those originally reported in a prior article from the authors [1].

B. Training and Professional Development Activities

In addition to participating in mentor-guided research, HYPER participants receive a broad range of experiences. Activities take the form of either site visits, trainings, or leisure activities. Because Florida is home to over 600 aerospace and aviation establishments, site visits related to aerospace engineering are typically plentiful. An ANSYS facility is close to the UCF campus. This collaborator provides software training and access to the cohort of students. During the summer, students participate in field trips to points of interest in the Orlando region. For example, students visit NASA Kennedy Space Center, a gas turbine manufacturer, and an aircraft manufacturer. Tickets are also procured for one of Orlando's major theme parks (i.e., Universal Orlando).

Professional development activities during the summer take the form workshops organized by UCF's Office of Undergraduate Research. Along with other summer research students, HYPER students receive training in each of the following: (1) applying for graduate programs, (2) development a technical poster, (3) writing a conference paper or journal article, (4) giving an oral presentation, (5) applying for graduate-level fellowships, (6) resume development, and more. Each week there is a faculty seminar provided by one of the HYPER mentors. Throughout the course of the summer, students gain a broader perspective of all of the HYPER's research projects as well as their connectivity.

Each of the HYPER participants are required to provide technical deliverables throughout the course of the summer. At the close of weekly faculty seminars, students are expected to provide updates on challenges, advances, and plans for their research. At the fifth week of the summer session, students are expected to prepare a mid-term report that overviews the research, motivation, background, research approach, and expected results. The report is formatted as either an AIAA SciTech or ASME conference manuscript. At the close of the summer, students' final reports are a full conference manuscript. A final oral presentation and poster presentation are also required. Each of these assignments provides students with the opportunity to leverage knowledge that they acquired during the professional development workshops to effectively communicate their research accomplishments. Collectively, these activities help provide the cohort of students with insight into research-oriented careers.

III. Application and Participant Recruitment

Marketing for the second year of the program (2021) commenced in the mid-November 2020 time-frame. A website, a flyer, and a message were updated from year one marketing efforts. The flyer was sent via e-mail and posted

to social media outlets. The e-mail was sent to (1) undergraduate students in Florida's state institutions, (2) chairs of aerospace, mechanical, or materials engineering at US institutions, and (3) various leaders of offices that broaden participation in engineering and computer science. The flyer contains a link to the program website. The website details the program and includes a link to the online application.

The application consists of basic information (e.g., name, school, major, expected graduation date), essay, transcript, resume, and two letters of recommendation. By design, these elements are consistent with the elements needed for admission to many of UCF's graduate program.

The applicant pool was more focused in the second year of the program compared to that of its first year. This resulted in 419 total applications down from 698. A larger fraction of applicants met HYPER criteria (i.e., 352 in year 2 compared to 140 in year one). Participant profiles posted on the program website in the first year were retained during the application window of the second year. First-year participants represented only aerospace, mechanical and materials engineering disciplines. This was noted by prospective students since a larger fraction of the year two students were from these undergraduate programs of study.

Preferred criteria consist of minimum GPA, well aligned major, exposure to junior-level engineering courses, research interests, etc. The HYPER PI and co-PI prepared an initiation selection of 49 preferred applicants. Individual faculty mentors reviewed a subset of the applicants to make final selections. There were 19 students who were offered positions, and fourteen students agreed to participate. The finalists were connected to their faculty mentors via e-mail. Some students elected to participate in training and/or research activities prior to their arrival to UCF's campus.

The marketing effort, applicant pool, and selection process combine to facilitate a diverse cohort. In year two, 7 of 14 participants are female. This represents an increase from year one in which 36% of participants were female. In year two, 5 of the 14 students are from minoritized populations. Recognizing those populations are not unique, 11 of the 14 (78.6%) participants were from URM or female groups. This was a slight drop from year one's 82%. Four year-two students hailed from the UCF undergraduate program. This doubled from year one. The entire cohort represents eight states (FL, OH, MA, VA, NV, CT, NY, and MO). The students' majors were as follows: Mechanical Engineering (8), Aerospace Engineering (3), Computer Science (1), Physics (1), Mathematics (1), and General Engineering (1). The average GPA of the group was 3.7 on a 4.0 scale. The expected graduation dates of the students were: Spring 2022 (10), Spring 2023 (3), and Fall 2022 (1).

An interesting aspect of the selected students is the strong support received via recommendations. Some are excerpts are as follows:

- Among the top students I have ever come across during my 20 years of teaching
- Consistently a hardworking and enthusiastic person
- Hardworking- and high-achieving student with great ambitions
- Any professor would like to have this student in his/her class because of his/her diligence, honesty, self-respect, sincerity, and integrity
- Hard for me to imagine a much better candidate for an REU experience. I have no doubt that they will excel in whatever role they are given
- Has my highest, unqualified recommendation
- Many students in our program have exceptional scholastic abilities and aptitudes. However, the truly exceptional ones combine those skills with common sense, a great work ethic, enthusiasm, and a driven nature to achieve their desired goals. That is exactly where I place this student.
- Was one of the students that I experienced in the program at this stage who was able to grasp both the theory and practical components
- Has demonstrated time and time again a willingness to go above and beyond
- Is an especially bright student and their eagerness to learn and grow is very apparent through their actions
- Always attentive in the classroom, and learns concepts quickly during lectures
- I am convinced that they will succeed in every project
- Always going above and beyond expectations
- Showed a perseverance to learn that I was extremely impressed with
- I was particularly impressed with their efforts to guide their team
- Among the most enthusiastic and positive students I have taught over the past 15 years
- I observed them to be a superb collaborator who did not hesitate to assist and support their colleagues when opportunities presented themselves
- Extremely focused, inquisitive, initiative oriented, and tenacious student...strives for perfection in every endeavor they participate. They possess a scientific mind set

- Never forgot to write down important and relevant technical details in their laboratory notebook while they were designing the experiments and testing
- Aside from being an outstanding student in many conventional ways, they made an impression by being a voracious learner and an extremely adaptive and flexible thinker
- This speaks to their superb ability in time management and balancing their priorities

It should be noted that these excerpts were minimally modified to anonymize the student, her/his gender, and their home institution.

IV. Impact of COVID

The COVID pandemic significantly affected HYPER. In the 2020 summer, the University of Central Florida shifted to remote operation. Access to dormitories and laboratory spaces became more restricted as the summer progressed. The conditions did not facilitate the launching of a site which could meet its program objectives and maintain health and safety. The summer 2020 site were consequently postponed by a year even though a cohort of students had applied. Summer 2020 applicants eligible to participate in the 2021 session were allowed to shift their applications to consideration in 2021.

Figure 1: *Selected group activities of HYPER 2021 participants: (a) visit to NAS Kennedy Space Center Visitor Complex, (b) bioluminescent kayaking, and (c) ice skating.*

Although COVID was on the decline at the outset of the summer 2021 session, many restrictions remained. Most notably social distancing was required in university laboratories. It was also expected that individuals would wear masks while on UCF's campus. Partners such as NASA KSC, Blue Origin, etc. were not open to site visits from non-essential groups. Most of the group activities during the summer were informal activities such as those shown in Figure 1. Professional development workshops organized by UCF's Office of Undergraduate Research were virtual instead of being offered in-person. The poster presentation was also transitioned to being fully virtual.

The final group meeting was conducted in person. Each student summarized their research activities and fielded questions from other participants. Faculty and graduate mentors were also in attendance. Many students showed results that they expected would appear in either a conference or journal publication in the near future. Several pictures from the final meeting are shown in Figure 2. As a part of the final week, the group met for dinner at a restaurant.

Figure 2: *Final group meeting for HYPER 2021.*

Finally, some HYPER research projects were conducted virtually. This meant that several students working on projects lacking a hands-on element were more than likely expected to conduct their research from a dormitory, library, or other location away from a conventional engineering laboratory space.

V. Assessment

Assessment ultimately centers on the six core objectives. External assessment remains in progress, but initial findings and internal results are available. Toward Objective 1, all HYPER participants said the experience better prepared them for graduate school or a career in research, with significant gains over the course of the experience in several categories. Seen in Figure 3, participants self-rated their abilities and experience in these categories both at the start and conclusion of the HYPER experience. Based on a rating scale of 1 (low) to 5 (high), participants reported the largest pre- to post-experience jumps in "Research Self Efficacy" (from 3.46/5 to 4.47/5), "Research Skills and Knowledge" (from 3.39/5 to 4.26/5), and "Scientific Identity" (from 3.15/5 to 3.85/5). To Objective 2, participants significantly improved technical skills including with finite element analysis, improving from 50% to 90% on pre- and post-experience quizzes related to each participant's specific project. HYPER participants reported improved communication proficiency, from 3.40/5 to 4.09/5. Aerospace attitudes increased slightly throughout the research experience, with skills and attitudes about contemporary and futuristic technologies increasing from 2.97/5 to 3.86/5.

Figure 3: Pre- and post-experience self-rated skills of HYPER participants.

VI. Conclusions and Enhancements

Participants were presented with exciting research endeavors in which faculty mentors, as well as associated graduate students, offered multidisciplinary experiences rooted in areas of Aerospace and Mechanical Engineering. While students felt positive about their experiences, limitations by COVID posed as a barrier in allowing 2021 student participants to gain the full experience afforded to HYPER 2019 students. Students still demonstrated the ability not only to present research after short-term exposure, but also to apply newly learned software packages. Professional development was also valuable to the students.

Areas that HYPER will be improved in the future relate to scaling. Firstly, resources outside of NSF and DoD will be identified to subsidize the participation of additional students. Many HYPER faculty work with large groups of research students (i.e., greater than 10 students). Several have expressed a desire to mentor multiple HYPER students were additional students available. HYPER students develop significant research momentum over the 10 weeks of the program. Despite some students being enrolled at institutions distance from UCF, several students continue to work with their HYPER mentors beyond the context of the summer program.

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References

[1] Kauffman, J. L., & Gordon, A. (2021). Undergraduate Hypersonics Research: The First Year of the REU Site HYPER. In AIAA Scitech 2021 Forum (p. 0354).