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

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The University of Central Florida (UCF) recently began hosting a Research Experiences for Undergraduates (REU) site based on next-generaion transportation and energy. The site unites eleven multi-disciplinary research projects around HYpersonic, Propulsive, Energetic, and Reusable Platforms (HYPER). A key goal of HYPER is to equip and motivate undergraduate students to pursue graduate school and/or a research-oriented career, particularly across a diverse student participant cohort. In this first year, eleven students engaged in a ten-week intensive experience, conducting research under the guidance of faculty mentors and graduate students. Students explored career options through industry tours, professional development seminars, and mentor-led research seminars. This paper reports the program impact on the eleven students, including through pre- and post-experience surveys, study groups, and assessment activities.

I. Introduction and Background

The REU Site HYPER 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: (1) utilizing advanced manufacturing techniques for high-value components, (2) integrating in situ monitoring of stress- strain evolution, (3) developing novel methods for improved internal cooling and heat transfer effectiveness, (4) mitigating flutter through advanced rotor dynamic control, etc. Eleven research projects are crafted to engage students in PhD-level topics. Many of these challenges rely on approaches that cut across disciplines and research techniques (e.g., experiments and simulations), as depicted in Figure 1.

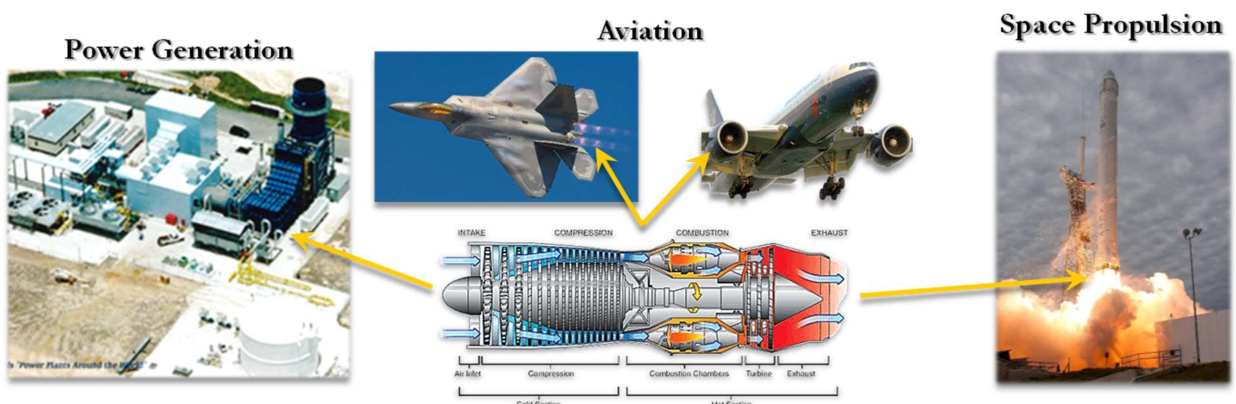

Fig. 1 HYPER addresses multidisciplinary research related to hypersonics, space, propulsion, and energy. Many of the research projects involve advanced turbomachinery technology.

HYPER has six core objectives: (1) technically prepare students for graduate school and/or research-oriented careers; (2) escalate students' abilities to simulate phenomena using multi- physics based finite element analysis; (3) improve participants' communication skills through repeated oral and written technical research reporting; (4) enhance participants' research skills and attitudes about contemporary and futuristic technologies for power generation, hypersonic flight and space propulsion; (5) present an REU site that is diverse in terms of student participation (e.g.,

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prior research experience, age) and (6) provide high-quality mentoring to prepare the students in the program for research-related careers. We assess HYPER outcomes according to these objectives, with data gathered after one year included below. Additional and longer-term assessment will continue in subsequent years of HYPER offerings.

This REU site seeks to achieve these objectives through intensive multi-disciplinary research experiences centered on next-generation transportation and energy. Recent and renewed interest in advanced transportation modes, increased propulsion efficiency, and decreased travel cost has led to the need for advanced platforms for transportation and electric power generation [1, 2]. Research in the past decade has identified challenges and assessed the business cases surrounding these next-generation technologies [3, 4]. More recently, researchers seeks to close the performance gaps that inhibit their use and create the transformative technologies that will bring about new transportation and energy systems [5–7]. Reusability and efficiency of propulsion systems in current-generation platforms have steadily improved, but transformative advances to turbomachinery and propulsion systems, materials, and manufacturing is vital to reduce both the costs and emissions associated with manufacture and operation [8].

The key thrusts of the program are technologies for advanced transportation systems (e.g., launch systems and hypersonic flight) and turbomachinery-based power generation, as in Fig. 1. HYPER seeks not only to advance the fundamental technology, but also to ignite and inspire current students to pursue research-oriented careers and carry on the innovation for decades to come. Systems needing research to solve contemporary challenges and fill fundamental knowledge gaps include propulsion systems, hot structures durability, big data analytics of propulsion models and multi-disciplinary optimization. This REU site facilitates related multidisciplinary research experiences for HYPER participants.

II. Programmatic Overview

A. Research Project Objectives and Accomplishments

The first year's cohort consisted of eleven students; each conducted research directly with a faculty mentor and a graduate student. These eleven participants engaged in the following hypersonics-related research projects:

- **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 learned how 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 incorporated 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 developed 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 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 learned how to master research tools such as computational fluid dynamics, multiphase flow, and key concepts of compressible jets. Using these research skills the participant evaluated 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 contributed 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 then used the real data from Apollo to evaluate the controller's performance. The controller is then 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 take extreme conditions associated with hypersonic flight. The project has applications of material design for

hypersonic and extreme environments. The participant contributed by doing a literature search on possible substrate and coating materials for the candidate samples for testing. The participant identified 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 learned 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 simulated 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 designed 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 wrote the Matlab code and started the generic image processing.
- **Uncertainty Quantification and Massive Computing in Prognosis and Fleet Health Management**, with a goal to 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 contributed 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 delivered 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 analyzed 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.

B. Training and Professional Development Activities

HYPER students spent the vast majority of their time conducting research; however, they also enjoyed professional development activities, ANSYS training sessions, weekly research seminars, outreach activities, and planned social activities to foster a stronger cohort. In addition, the participants frequently enjoyed more informal and organic gatherings, for example to go see the Falcon Heavy Launch in mid-June. These opportunities allowed the participants to hear and learn from the group's shared experiences, as well as from other UCF-hosted REU participants. The next section describes many of these activities in greater detail, as well as their impacts. Table 1 displays a nominal schedule; note that students also conducted research on days such as "Training" and "(Item) Due."

C. Recruitment and Program Logistics

Broad recruitment for Year 1 participants commenced following award notification in March 2019. HYPER sought excellent applicants using a variety of online media, including the HYPER website, direct emails to engineering departments at US universities, distribution of a HYPER flyer to each project mentor's technical community, and social media through the home engineering department. Recruitment concluded with evaluation of selection of final participants on April 16. The HYPER experience commenced on May 27 and concluded ten weeks later on August 2.

Table 1 HYPER participants engaged in research and related activities to encourage a research-oriented career.

Week	Monday	Tuesday	Wednesday	Thursday	Friday
1	Orientation/Lab Tour/Seminar	Training	Training	Training	Site Visit/BBQ
Even Weeks (2, 4, 6, and 8)	Seminar/ANSYS Training	Research	Research	Research	Development
Odd Weeks (3, 5, and 7)	Seminar/Focus Group	Research	Research	Research	Site Visit
9	Seminar/Focus Group	Research	Research	Poster Presentation Due	Site Visit
10	Written Technical Report Due	Presentation Preparation	Oral Presentations (Small Group)	Closing Banquet/Posters	Exit Interview

III. First-Year Cohort and Activities

A. Participant Recruitment

The applicant pool included 698 total applications, of which 140 met HYPER criteria. Given the short application window to recruit a sufficient applicant pool, the program had advertised widely and identified only minimum eligibility standards. Subsequently, the large applicant pool demonstrated evaluation could incorporate preferred criteria such as a minimum GPA, well aligned major, research interests, etc. The HYPER PI and co-PI prepared an initial selection to 29 preferred applicants based on the 11 specific research projects; individual faculty mentors then reviewed several applicants each to make final HYPER participant selections. The students and faculty mentors were connected via email prior to the commencement of the program. Some students even began training prior to their arrival to campus. Students met their faculty and graduate mentors on the first formal day of the program to begin getting acquainted with their laboratory placements.

The diverse applicant pool led to a diverse HYPER cohort: four of the eleven participants were female (36%) and seven (64%) were from under-represented minority groups (URMs). Recognizing those populations are not unique, 9 of the 11 participants (82%) were from URMs, students with disabilities, or female. Only two students were from UCF; the entire cohort hailed from 9 universities across 6 states. Five students (45%) hailed from Florida, which broadly aligns with the applicant pool: 40% of all applicants attended a university in Florida. The 11 participants had an average GPA of 3.71 with a relatively even mix of student standing: 4 planned to graduate in Spring 2020, 1 in Fall 2020, and 6 in Spring 2021.

B. Professional Development Activities

While students devoted most of their time to working on research projects, other HYPER activities were geared towards developing a holistic view of the subject matter and preparing them for careers beyond their undergraduate programs. Figure 2 and the following paragraphs describe some of the specific activities; the final paper will include follow-up responses and impressions from the participants on the utility and importance of these elements.

Each week, students participated in Graduate School Preparation Workshops conducted with the aid of UCF's Office of Undergraduate Research (OUR) and UCF's Advanced Academic Programs (AAP). Presented topics included exploring the library and foundational literature reviews, resume development, graduate application preparation, technical writing, developing poster presentations, and giving a technical seminar, among others. Students also attended a research seminar each week given by one of the faculty mentors. In this way, students saw all aspects of the multidisciplinary problem. Moreover, these seminars helped students to understand the context and motivation for their fellow students' research projects.

Every other week, students participated in ANSYS training sessions with ANSYS personnel. These sessions alternately addressed computational solutions to structural (e.g., finite elements) and thermal/fluid (e.g., heat transfer or CFD) problems. Many of the students directly incorporated this new knowledge into their research projects, running simulations for comparison with experimental data, design of experimental/test components, or validation of numerical models.

Fig. 2 HYPER participants engaged in a variety of activities for professional development.

Perhaps the highlight of these professional development activities were the industry site tours. The students' favorite was a backstage tour of the NASA Kennedy Space Center, including visits to SWAMP Works, the Veggie lab, and the Space Station Processing Facility (SSPF). The semi-weekly tours also provided significant time for students to interact in a more casual setting. With most sites located near the "Space Coast"—a one-hour drive from campus—students enjoyed ample time to learn more about each other. Several social activities were connected to these visits as well; for example, students completed a ropes course in the morning before touring Embraer's facilities in the afternoon. (The students made their own impromptu beach visit as well!)

C. Research Dissemination, Outreach, and Social Events

Twice over the summer, students disseminated their research to the campus community. First, a campus-wide REU poster symposium was held at UCF, in which students from all UCF's REU programs presented their final research posters. Second, HYPER students gave brief final presentations using PowerPoint slides in a final research symposium. Students also completed a final technical report in the form of a conference paper suitable for either AIAA SciTech or an ASME technical conference. Many of these publications remain in revision for journal and conference submission.

Approximately halfway through the experience, the eleven students also conducted an outreach activity through UCF's Camp Connect. This program brings local high school students to campus for weeklong STEM-based enrichment camps. HYPER students informally shared some of the research they were conducting and then demonstrated aerodynamics concepts by way of tabletop wind tunnels, as shown in Fig. 3.

Finally, not all HYPER events were technical. Like the aforementioned ropes course, some social activities were organized to introduce the cohort and provide ample time for non-technical interaction. These activities included a Memorial Day introductory BBQ, local museum trips, a virtual reality experience, cross-REU birthday celebration at a local state park, a formal dinner, and, the most popular, a day at Universal Orlando. Of course, students organized their own activities as well, including an evening trip to observe the night launch of the SpaceX Falcon Heavy.

Fig. 3 HYPER participants engage local high school students in STEM

IV. Impacts

The Program Evaluation and Educational Research Group (PEER) performs an annual independent evaluation of the REU site HYPER [9]. The evaluation process gathers data through several methods including questionnaires and a focus group to assess HYPER's impact on participants' intentions toward graduate school, attitude toward mechanical and aerospace engineering, research skills and knowledge, student self-efficacy, research self-efficacy, teamwork and leadership, scientific identity, communication skills. Participants provided pre-, mid-, and post-experience feedback; mentors provided post-experience feedback. Participation in these feedback mechanisms was voluntary, and all participants and mentors completed the questionnaires.

One of the key goals in conducting these types of research experiences is to prepare students for graduate school and research-oriented careers. The participants displayed a significant increase in technical knowledge of and interest in next-generation platforms and technologies for advanced transportation and energy generation systems. Pre- and post-experience quizzes of technical skills were administered; the cohort's average score increased from 50% to 90% over that time. Research skills and attitudes about contemporary and futuristic technologies improved as well, with self-reported assessment of ability and interest increasing from 2.97/5 to 3.86/5. Figure 4 displays pre- to post-experience self-assessed skills and attitudes across several project-related areas.

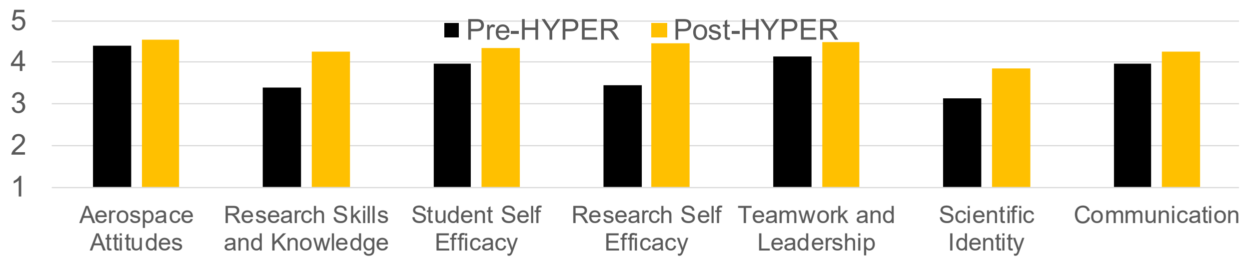

Fig. 4 Self-reported skills and attitudes improved over the course of the research experience.

The REU site seeks to escalate students' abilities to simulate phenomena using multi-physics-based finite element analysis. This objective relied heavily on the ANSYS training seminars offered through the experience. Following the research experience, a majority (73%) of participants expressed confidence they could demonstrate such an ability. A majority of mentors assessed the mentee's growth in technical skills as "much improved."

A third REU site objective centered on effective communication of research through oral and written technical reporting. Participants self-reported an increase in communication skills from pre- to post-experience. Of note, students self-reported strong communication skills even before beginning the research experience, so the increase is comparatively small. In subsequent years of HYPER, mentors and non-participant UCF faculty/staff will be engaged to help score student posters and research papers to better assess this objective.

HYPER also seeks to enhance participants' research skills and attitude about contemporary and futuristic technologies for power generation, hypersonic flight, and space propulsion. In addition to the above increase in self-reported research skills and attitudes (from 2.97/5 to 3.86/5), PEER evaluators also observed significant increases in participants' "Research Skills and Knowledge" and a positive change in participants' "Attitudes toward Mechanical and Aerospace Engineering."

Another element in preparing students for research-oriented careers is high-quality mentoring. Participants unanimously described their partnership with their mentors as effective and an overwhelming majority indicated they received effective support from their assigned graduate student. The participants also engaged in a number of industry site tours and professional development seminars, including on CV preparation, poster design, library resources and literature reviews, elevator "pitching," and graduate fellowship/funding opportunities. Participants found high value in these activities and strongly recommended retaining similar opportunities for subsequent HYPER cohorts. Of particular interest were the CV preparation, graduate school funding, and presentation coaching, demonstrating strong student interest in advancing their research careers.

V. Conclusions and Lessons Learned

The REU site HYPER addresses challenges in next-generation modes of transportation and energy generation. HYPER participants' research will play a part in developing high-speed terrestrial and space transportation modes and breaking the associated cost barriers. The REU site actively recruits and partners a diverse group of eleven participants with leading faculty and graduate students. HYPER participants reported a significant increase in technical knowledge of and interest in next-generation platforms and technologies for advanced transportation and energy generation systems following the research experience. Each year's cohort returns to their home universities better prepared for graduate school and research-oriented careers regardless of their long-term contributions to next-generation modes of transportation and energy generation.

This first year of HYPER emphasized the importance of active and early recruitment. The REU site was awarded in mid-March 2019, a time when some previously established sites had stopped taking new applications or were even wrapping up their participant selection process. However, HYPER was fortunate to receive a large pool of applications. Institutional support played a key role in this area: assistance from offices focused on undergraduate research, academic advancement, and even the graduate college enabled wide advertisement of the REU. Indeed, HYPER received almost 700 applications, yet only 20% met the preferred selection criteria. Earlier recruitment should allow more targeted advertisements that still provide a large applicant pool. Institutional support played another key role here: department and college communications staff rapidly crafted the actual advertisements and established the web site housing HYPER-specific information. Anecdotally, it appears that the later recruitment window may have skewed the participant pool: many participants indicated they were primarily interested in securing an internship before they applied for HYPER. After the experience, however, participants almost uniformly expressed a strong desire to attend graduate school; quantifying these preferences in future assessments may provide insight into better recruitment approaches. In any case, the authors look forward to recruiting in a more focused effort that commences even in the Fall semester.

A key element to HYPER's success is the close collaboration of the mentors. Many of the mentors have collaborated previously in some capacity or have been connected through UCF's Center for Advanced Turbomachinery and Energy Research. With this background familiarity, mentors were able to help mentees see a more holistic view of the project focus. Mentor research talks help with that, too, but two participants who work in labs that already collaborate with each other will experience a more dynamic research effort. The REU site intentionally partnered each participant with both a faculty mentor and a graduate student in that lab. This multi-level support, along with cross-lab interaction, provided several avenues for each participant to seek help when needed in their research, especially when faculty were traveling. Along those lines, many faculty traveled for a conference during the experience. In a few cases, the supporting graduate student also attended the conference, leaving the REU participant with less direct contact during that time.

In structuring the REU site, the authors selected a graduating undergraduate student to assist in administering the program. This student was completing an undergraduate degree at UCF and had accepted admission to graduate school at UCF following the research experience. This student could handle basic logistics and assist in weekly seminars/activities while also relating to the participant cohort as a peer. (Indeed, the authors included this student in professional development, social, and outreach events.) As such, this student also served as an ombudsperson who could anonymously relay participant concerns to the program directors. Interestingly, both participants and mentors expressed some dissatisfaction with the research expectations and productivity: some participants felt faculty mentors prioritized specific research objectives too heavily, while some mentors felt participants prioritized the professional development, industry tour, etc. opportunities too heavily. In reality, this tension likely means there is a good balance of core research and student development activities, though the authors hope to communicate the program expectations to the participants and faculty mentors more efficiently in subsequent summers.

This REU site is fortunate to be at a university that with large summer undergraduate research activity. HYPER was able to partner with several other REU sites at UCF for cross-REU technical and social activities. Institutional support again plays a key role. The UCF Office of Undergraduate Research and Advanced Academic Programs office held weekly Graduate School Preparation Workshops for all undergraduate summer researchers on campus. HYPER partnered with several other REUs to host a kick-off picnic the evening before REU activities began. Subsequent social events included a "summer birthday celebration" and a trip to a local state park. While the eleven HYPER participants formed friendships among the cohort and did not exhibit any friction between each other, the opportunity for additional social interactions could be a good option for supporting participants' social needs in those cases. Perhaps most significantly, institutional funding for these events was critical – even a tiny amount (relative to a typical PI's research lab budget, for example) enabled HYPER to provide a variety of social activities for HYPER participants.

Acknowledgments

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