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Fundamental Detonation Physics Research for Rocket Propulsion and Hypersonics

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RCEU 2023 Project Proposal

Project Title

Fundamental Detonation Physics Research for Rocket Propulsion and Hypersonics

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I. Project Description

Acoustically coupled combustion instabilities have been a major challenge in the development of liquid rocket engines (LRE's) and gas turbine engines over many decades. Large scale combustion instabilities are generally associated with a feedback cycle among temporal velocity oscillations *u'*, pressure oscillations *p'*, and oscillatory heat release *q'* in the reactive system, resulting in enhancement of the instability when the latter two parameters are in phase, or nearly so, per the well-known Rayleigh criterion. Similarly, detonations are characterized by even more severe coupling between pressure of the leading shock and heat release of the reaction zone. These two oscillatory-coupling phenomena share extremely similar characteristics, as notably, high amplitude traveling combustion instabilities have even been noted to encompass "detonation-like" qualities (Ar'kov et al., *JAMTP 1972*). In reality, these phenomena are representative limiting cases, with combustion instabilities being of lower amplitude and closer to the linear regime compared to high strength non-linear detonation modes. During operation, rotating detonation rocket engine (RDRE) modes tend to establish somewhere in between the linear acoustic instability modes and highly non-linear detonation modes (Bennewitz et al. *IJEMCP 2019*), and can spontaneously breakdown to low amplitude modes for certain flow conditions (Bennewitz et al., *Energies 2021*). Therefore, further work is required to understand the fundamental coupling that occurs between flames and traveling wave forcing. This experiment will expose a continuously-fed liquid fuel droplet to traveling wave acoustic forcing and quantify the flame-acoustic coupling through a combination of high-frequency pressure measurements and OH* chemiluminescence. In a previous study (Bennewitz et al, *CNF 2018*), the PI Bennewitz investigated acoustically-coupled droplet combustion for standing wave acoustic forcing. Since that time, the PI has developed an acoustic model to determine the required acoustic forcing conditions to generate traveling acoustic wave forcing spanning a variety of frequencies in a two-speaker waveguide, which currently has been left unexplored. Traveling wave forcing is inherently different from standing wave forcing, as the phase difference between the pressure and transverse velocity shifts from 90^o in a standing wave to 0^o (in-phase) for a traveling wave. This project will entail the design, fabrication and initial testing of the acoustic waveguide facility to characterize individual droplet combustion under traveling wave acoustic forcing. This experiment involves a small combustion volume and low-pressure environments, making it ideal for an undergraduate student project within a laboratory environment with supervision from graduate students and the PI. This project has dual applications to both RDRE's and thermo-acoustic instabilities for liquid rockets.

II. Student Duties, Contributions, and Outcomes

a. Specific Student Duties

This research project will entail the undergraduate researcher assisting with the laboratory work for the acoustically-coupled combustion experiment, encompassing the following tasks: (1) facility/diagnostic design and construction, (2) data collection and processing, and (3) archival (i.e., publication) of the work.

b. Tangible Contributions by the Student to the Project *(10% of Review)*

Tangible contributions for the undergraduate student will be the finalized waveguide design, constructed facility and the experimental data collected from the initial testing. This will provide the student a well-rounded experience in scientific research, and these contributions will be key towards growing the laboratory capabilities and research pathways. There is a realistic expectation that successful execution of this research plan will enable the undergraduate to participate in follow-on archival publications associated with this research.

c. Specific Outcomes Provided by the Project to the Student *(30% of Review)*

The major objectives of this RCEU proposal contribute to providing a well-rounded undergraduate research experience, encapsulating the entirety of a project lifetime from conceptual design to facility construction, and then initial testing. The expectation is for the undergraduate student to actively participate in relevant hypersonic propulsion research that will serve as significant work force development in an area of high national interest. This will provide experience that will bolster their ability to make an early impact in hypersonics upon graduation, either in graduate school or the aerospace industry.

III. Student Selection Criteria

Interested applicants should be upper-level undergraduates pursuing a degree in science or engineering. Previous experience performing research in a laboratory environment in combustion/propulsion related areas is desired, but not necessarily required. As this project will integrate both conceptual understanding and hands-on laboratory work, other previous relevant experiences including design, fabrication and system-level automation will contribute to the applicant rankings in the event there are multiple interested students.

IV. Project Mentorship *(30% of Review)*

Mentorship for this undergraduate research program will employ a dual approach from both graduate students and the PI Bennewitz. Daily laboratory mentoring will be carried out by the graduate research assistants to advise the undergraduate with facility construction and data acquisition. The graduate students are familiar with the program objectives for the acoustically-forced combustion experiment and measurement techniques (e.g., high-speed chemiluminescence, high-frequency pressure), which will enable the undergraduate to make steady progress under their direction. This approach has proven effective with previous undergraduate researchers. In addition, the PI will regularly (2-3 times/week) participate in laboratory activity over the summer to work directly with all students for further guidance and direction. Finally, the PI's laboratory is affiliated with the Propulsion Research Center, with access to two dedicated research staff with 20+ years of experience. The undergraduate student will regularly interact with PRC staff to ensure laboratory operations are performed safely and efficiently.