

Fiscal Year:	FY 2021	Task Last Updated:	FY 01/10/2021
PI Name:	Dunn-Rankin, Derek Ph.D.		
Project Title:	ACME: EFIELD – Electric Field Effects On Laminar Diffusion Flames		
Division Name:	Physical Sciences		
Program/Discipline:			
Program/Discipline--Element/Subdiscipline:	COMBUSTION SCIENCE--Combustion science		
Joint Agency Name:	TechPort:	No	
Human Research Program Elements:	None		
Human Research Program Risks:	None		
Space Biology Element:	None		
Space Biology Cross-Element Discipline:	None		
Space Biology Special Category:	None		
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Zip Code:	92697-3975	Congressional District:	48
Comments:			
Project Type:	FLIGHT	Solicitation / Funding Source:	NOT AVAILABLE
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No. of Post Docs:	1	No. of PhD Degrees:	
No. of PhD Candidates:	1	No. of Master' Degrees:	
No. of Master's Candidates:	0	No. of Bachelor's Degrees:	
No. of Bachelor's Candidates:	0	Monitoring Center:	NASA GRC
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Flight Program:			
Flight Assignment:	NOTE: End date changed to 11/17/2020 per NSSC information (Ed., 11/7/19)		
Key Personnel Changes/Previous PI:			
COI Name (Institution):	Karnani, Sunny Ph.D. (Army Research Labs)		
Grant/Contract No.:	NNX17AC51A		
Performance Goal No.:			
Performance Goal Text:	<p>NOTE this is a successor agreement to “Electric Field Control of Flames (NNX11AP42A)” with the same Principal Investigator Dr. Derek Dunn-Rankin, in Microgravity Combustion Science per D. Stocker, NASA Glenn Research Center.</p> <p>This final project year at the University of California, Irvine completed the provision of microgravity experimental data to be used in the exploration of using electric fields in combustion for improving the performance of energy conversion systems. The year was a no-cost extension with the hope of obtaining a third phase of experiments on the International Space Station (ISS); this third phase did not occur so we completed our project. As an actuator, electric fields can improve flame stability and soot formation, while, as a sensing device, the electrical response at saturation is an inherent flame characteristic. In addition to completing the proposed Advanced Combustion via Microgravity Experiments (ACME) E-FIELD experiments aboard the ISS, we have continued to enhance our understanding of the</p>		

	<p>experimental methods and the dynamic interaction between the flame and chemi-ions. We have finalized the methodology for extracting time-stamped experimental results of ion current and images, and we have made progress in our implementation of computational models to predict chemi-ion concentrations in flames, including a comparison between enhanced body forces from electric fields and those from enhanced gravity. This final annual report (following a no-cost extension) summarizes our findings in 2 main areas:</p> <p>1.) Experimental – There are two major components of our experimental progress: (a) the extraction and analysis of the first phase of E-FIELD Flames microgravity combustion experiments aboard the ISS. These experiments were with the co-flow burner, with positive and negative polarities, methane and ethylene as fuels, different fuel dilutions, different flow velocities, and cases with and without a small coflow of air. These were the first electric field experiments completed in the combustion integrated rack (CIR). And (b) the second phase of E-FIELD Flames microgravity combustion experiments aboard the ISS were completed and all data verified and submitted for inclusion in the Physical Sciences Informatics (PSI) database. These experiments were with a simple jet burner, with positive and negative polarities, methane and ethylene as fuels, different fuel dilutions, and different flow velocities. These were the first jet diffusion flame experiments under the influence of an electric field in zero gravity. Although the experiments had been completed in the prior year, the additional no-cost extension permitted more intensive evaluation of the subtleties contained in the results.</p> <p>2.) Developing a computational model to predict ion concentrations in flames and the effects of ion driven winds in coflow and jet flames. A focus has been on a full Computational Fluid Dynamics (CFD) simulation with appropriate reduced chemistry using the Open Foam Optics And Mechanics (FOAM) platform of computation. This final year completed a study confirming a potentially appropriate reduced chemical mechanism that provides accurate chemi-ion concentrations with a sufficiently small number of reactions to allow a comprehensive CFD model that includes electrical forces. The complete CFD was not accomplished, but the current simplified modeling approach where ion production is tuned via experimental results was employed and provided some insights regarding the relative value of electric versus gravitational body forces. The configuration for these computations was the coflow geometry but without coflowing gas. The comparisons were accomplished against 1-g flame data available in the literature. Future work will enhance the modeling to a full CFD and then compare the results to the newly acquired ISS E-FIELD Flames data.</p> <p>Because this year was a no-cost extension used for refining the results already reported last year, we refer to the prior annual report for most of the details. Only salient summary information of outcomes beyond those reported last year are included. In addition, details of all the work will appear in the publications and conference proceedings identified in the Bibliography section (Ed. note: use the Cumulative Bibliography link). The COVID-19 pandemic interrupted substantially the dissemination of our findings, but in the past year we have produced: 1 PhD dissertation; 2 invited technical presentations, and a public presentation.</p>
Rationale for HRP Directed Research:	
Research Impact/Earth Benefits:	<p>The control of combustion has the potential to improve efficiency and reduce emissions from burning fuels. Since high power density often requires combustion, these improvements will be important no matter what the fuel source. Electric fields acting on flames have the potential to aid in combustion control both for sensing and actuation. For example, electrical properties of flames can identify poor performing boiler flames that release poisonous carbon monoxide. Our studies show that a flame's electric signature can capture incipient quenching before dangerous emissions result. Electrically driven ions can produce local convection that changes combustion behavior. Understanding the links between electrical character and flame behavior may allow improved sensing of poor performing combustion systems.</p>
	<p>The project includes both experimental and computational parts. The experiments employ a coflow burner and a jet burner that are aboard the ISS. The computational work employs the OpenFOAM framework.</p> <p>1. ISS Experiments. The major accomplishment of the prior year was the extraction and evaluation of the data from the first and second phase set of tests from the ACME E-FIELD Flames experiment. The raw results were reported in the last annual technical report (Ed. note: available to NASA management). The first phase employed the same co-flow burner aboard the ISS as was used for the CLD Flames experiments, but an electrode mesh was installed downstream of the burner. The second phase set of tests used a jet flame burner with the electrode mesh downstream of the jet tip.</p> <p>No report can be comprehensive since the ISS experiments covered a wide range of conditions and outcomes, with 131 different tests run, and more than 120 of them successful in phase I with the coflow burner and 104 different tests run in phase II with the single-jet burner for a total of 235 testpoints. There are, therefore, too many conditions to share fully, though the data is available on the Physical Sciences Informatics website. Color camera images, intensified camera images, total flame luminosity, and ion current, along with all test parameters and flow monitoring, were recorded in all cases.</p> <p>The most significant results from the past year are the understanding and evaluation of the subtleties of the data collected, including limitations driven by the experimental hardware, and there are then important data analysis and manipulation developments and details needed to bring the experimental information to the conditions appropriate for comparison with theory or numerical simulation. E-FIELD Flames data were recorded with the Greenwich Mean Time Zone (GMT) up to the millisecond, and the data acquisition capability of the voltage output (i.e., electric field strength), ion current, and the voltage signal of the Photomultiplier Tubes (PMT) collecting the flame illumination in different wavelength regions, are stored at 100 Hz (10 ms/data point). The image data requires variation based on the exposure time driven by the luminosity of the flame, and so the image data is not at regular intervals, and is at most recorded at video rates (30 Hz). This means that the image data and the quantitative data are not synchronized, which requires special attention for uniformity.</p> <p>This experimental work reports the initial flame appearance and voltage-current (V-I) plots for the unique condition of a nonpremixed flame under the influence of an electric field in microgravity conditions using a coflow burner (without turning on coflow) and a jet burner. The flame images in microgravity are distinct in the change of size and reaction zone location while there are relatively small differences observed in normal-gravity laboratory experiments. The ion current results at low gravity do not exhibit the typical sub-saturation, saturation, and supersaturation trend as recorded in terrestrial tests, suggesting that buoyancy driven flows play an important role in this characteristic ion current behavior. This work will continue and further compare with similar carbon content at different fuel flow rates in 0g as a marker to research how the soot, ion current and flame luminosity vary with each other.</p>

Task Progress:	<p>2. OpenFOAM Simulations. Electric fields can affect flame shape, burning velocity, temperature profile, speed of propagation, lift-off distance, species diffusion, stabilization, and extinction. The primary reason is that combustion of hydrocarbon fuels involves chemi-ionization, which generates ions and electrons that can be manipulated by the field producing a body force also referred to as an ion wind. To fully explore the links between these various aspects, a comprehensive computational model is needed. We have made some progress towards this goal, but there remain some significant challenges (that we hope to address in proposed future research).</p> <p>There are four major parts in the computational study. The first one relates to the chemical kinetic model for the flame chemistry with charged and excited species; the second looks into the effects that two different jet burner geometries have on a flame that is exposed to different gravity environments; the third explores the implementation of applied electric fields in the simulations and how this affects a non-premixed flame at 1g; and the last aspect carries out a comparison between the effects on flame behavior when body forces of different nature, buoyancy and electric field force, are present. The first 3 parts were already described in some detail in the prior annual report, and so this report includes only on the last part. This last component also provides insight into the possible similarities and regimes when both forces could be equivalent. The final goal is to fully understand how flame behavior is altered by different electric fields and to compare those effects to the behaviors generated by gravitational body forces.</p> <p>Part 4 – Comparing Buoyancy and Electric Body Forces. An analogy between body forces (buoyancy and electric) and the possible similarities among them is examined. This comparison corroborates previous literature mentioning that, even though electric and buoyancy forces are from a different nature, they can be considered equivalent when applying an electric field in a 1g flame to achieve an equivalent supergravity flame. It is concluded that the 2g flame resembles the 1g flame with 0.5kV/cm applied. However, a large regime of supergravity conditions where both forces are equivalent is yet to be explored.</p> <p>The results of the computations show that, in fact, electric field magnitude predominates in comparison to buoyancy forces in the center axis of symmetry. Buoyancy forces are larger than the electric field moving further from the center line. These results reinforce the fact that the influence of small electric fields applied to a 1g flame – when the electric field is applied in the same direction as the buoyant plume – is often masked by the buoyant convection since both body forces have very similar values.</p> <p>Promising work in electric field forces computational studies has been performed. The electric field simulations still need to be developed to acquire more reliable results that match before and after the saturation point (i.e., the saturation plateau) in order to assure and assume that the fluid dynamics, chemistry, and body forces phenomena that are happening in the flame and are changing its behavior are well captured by the simulation. In addition, while the global ion current results align with the literature, the detailed distribution of the ions and the local forces they produce requires additional work. Once 1g flame simulations show comprehensible results matching with the literature for all the burner geometries, these simulations can be run for comparison with the experimental results obtained on the ISS.</p>
Bibliography Type:	Description: (Last Updated: 02/12/2024)
Abstracts for Journals and Proceedings	<p>Chien Y-C, Stocker D, Hegde U, Dunn-Rankin D. "Microgravity Experiments Examining Electric Field Effects on Laminar Methane Gas-Jet Diffusion Flames." 35th Annual Meeting of the American Society for Gravitational and Space Research, Denver, CO, November 20-23, 2019.</p> <p>Abstracts. 35th Annual Meeting of the American Society for Gravitational and Space Research, Denver, CO, November 20-23, 2019. , Nov-2019</p>
Dissertations and Theses	<p>Lopez-Camara C. "Numerical Study of Non-Premixed Methane/Air Flames Behavior under Different Body Forces: Buoyancy and Electric Field." Dissertation, University of California, Irvine, December 2020. , Dec-2020</p>