Fiscal Year:	FY 2020	**Task Last Updated:**	FY 02/25/2020
PI Name:	Bhattacharjee, Subrata Ph.D.		
Project Title:	Residence Time Driven Flame Spread Over Solid Fuels		
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:	92182-0001	**Congressional District:**	53
Comments:			
Project Type:	Flight	**Solicitation / Funding Source:**	2009 Combustion Science NNH09ZTT001N
Start Date:	04/06/2015	**End Date:**	04/05/2021
No. of Post Docs:	0	**No. of PhD Degrees:**	1
No. of PhD Candidates:	0	**No. of Master' Degrees:**	5
No. of Master's Candidates:	3	**No. of Bachelor's Degrees:**	2
No. of Bachelor's Candidates:	7	**Monitoring Center:**	NASA GRC
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Flight Program:	ISS		
Flight Assignment:	ISS NOTE: End date changed to 4/5/2021 per NSSC information (Ed., 5/12/2020) NOTE: End date changed to 4/30/2022 per S. Olson/GRC (Ed., 1/9/2020)		
Key Personnel Changes/Previous PI:			
COI Name (Institution):	Miller, Fletcher Ph.D. (San Diego State University) Paolini, Christopher Ph.D. (San Diego State University) Takahashi, Shuhei Ph.D. (Gifu University, Japan) Wakai , Kazunori Ph.D. (Gifu University, Japan)		
Grant/Contract No.:	NNX15AG11G		
Performance Goal No.:			
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Task Description:	NOTE: Continuation of "Residence Time Driven Flame Spread Over Solid Fuels," grant # NNX10AE03G, with the same Principal Investigator Subrata Bhattacharjee, PhD. Flame spread over solid fuels in an opposed-flow environment has been investigated for over four decades for understanding the fundamental nature of hazardous fire spread. The appeal for this configuration stems from the fact that flame spread rate remains steady, even if the flame itself may grow in size. For practical fire safety issues, however, wind-assisted flame spread is more relevant. However, these two regimes have always been studied in isolation without much effort to establish a connection, even though the underlying mechanism of flame spread is the same in all regimes. Sitting between the two regimes are high-residence time flames, as found in a low-velocity or quiescent microgravity environment. Residence time is the time spent by an oxidizer in the combustion zone. Such flames, which are of interest on their own merit due to fire safety issues in spacecraft, offer some unique characteristics because of the high residence time. Radiation becomes dominant and, based on previous space experiments and analysis, we contend that a vigorously spreading flame on Earth becomes self-extinguishing in a microgravity environment under certain conditions such as the fuel thickness being greater than a critical value. The proposed research uses a comprehensive approach-- a novel experimental set up and a theoretical framework based on scaling and numerical modeling-- to investigate flame spread driven by varying residence time, from blow-off extinction in an opposed-flow configuration through high residence time flame to blow-off extinction in a concurrent-flow configuration. At the heart of this proposal is a novel but simple experiment where the residence time of the oxidizer can be controlled and high residence time flames can be established for a long duration (compared to drop towers). As a proof of concept, we have constructed a flame tower at San Diego State University (SDSU) in which, after a sample is ignited, the sample holder, placed in an open moveable cart, can be traversed at any desired speed upward or downward, creating an external flow that can augment or mitigate the buoyancy-induced flow. Preliminary results show that we can control the residence time and create flames in different regimes, including a transition between a wind-aided and wind-opposed configuration. At Gifu University in Japan, we have been developing an interferometry based imaging system which we intend to enhance to capture the thermal footprint of a flame's leading edge. The leading edge is central to our understanding of mechanism of flame extinction. Further development of this technology will enable us to integrate diagnostics in future space based experiments and provide validation data to a comprehensive numerical model. The comprehensive model, to be built upon our existing two-dimensional model, will solve an unsteady, three-dimensional, Navier stokes equation with finite rate kinetics in the gas and solid phases and radiation in the gas phase. The software implementation will be object-oriented and utilize a new technology called Web Services that will decouple various sub-models and enhance parallel execution. The radiation model will also be refined by including the equilibrium composition of species for finding radiative properties in high residence-time flames. The comprehensive model, tested against available theory, data in literature, and data generated at SDSU and Gifu, was applied to test the three hypotheses presented in the preceding grant regarding flame extinguishment in a microgravity environment. A successful outcome of that project is leading to a well thought out space-based experiment on the mechanism of flame extinction in a gravity free environment. We have received authority to proceed to Preliminary Design Review.
Rationale for HRP Directed Research:	
Research Impact/Earth Benefits:	Our research has four components. (a) We have built three experimental setups at SDSU: Flame Tower where a test sample can be traversed up or down at any desired velocity; Flame Stabilizer where the motion of the flame can be arrested by moving the sample exactly at the speed of the flame spread in the opposite direction; and a rotating Flame Tunnel where a combustion tunnel can be oriented at any desired angle to study the interaction of buoyancy and forced flow; (b) Theoretical and computational work that explores the similarity and differences between the mechanisms flame spread in a zero gravity space environment and on Earth; (c) Support the space based experiment (in the SoFIE project) to establish extinction mechanism of flames; (d) Develop software tools for data analysis and share those with the research community. The data that we are acquiring in the experiments provide the research community with a comprehensive set of results for testing different theories of flame spread in a normal gravity environment. Moreover, by controlling the residence time, various regimes of flame spread, including the microgravity regime, can be explored in the Flame Tower. Our theoretical work predicts a fuel thickness beyond which steady flame spread is unsustainable in a gravity free environment. If we are successful in establishing a critical thickness, this will have a powerful impact on making fire resistant environment for humans in space. As part of this project, we are developing thermodynamic calculators for combustion and equilibrium calculations, which has a significant educational component. These are available to the community through http://www.thermofluids.net . We have also developed a MATLAB based image processing tool named FIAT (Flame Image Analysis Tool), which is now available to the community from http://flame.sdsu.edu .
Task Progress:	We have completed a very productive year with vigorous experimental, theoretical, and numerical research in support of the Residence Time Driven Flame Spread (RTDFS) module of the Solid Fuel Ignition and Extinction (SoFIE) project. The major achievements of this period include publication of archival journal papers, several conference papers, further development of the radiation model, ground based experiments at San Diego State, and preparations for analysis of the expected data from the SoFIE experiments. Luca Carmignani has defended his Ph.D. dissertation and joined the Fernandez-Pello research group at University of California (UC) Berkeley in January, 2020. Several Masters students, undergraduate students, and visiting research students from Germany have contributed to our research effort during this reporting period.
Bibliography Type:	Description: (Last Updated: 06/13/2025)

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