Fiscal Year:	FY 2017	**Task Last Updated:**	FY 01/31/2017
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
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No. of PhD Candidates:	1	**No. of Master' Degrees:**	2
No. of Master's Candidates:	4	**No. of Bachelor's Degrees:**	8
No. of Bachelor's Candidates:	6	**Monitoring Center:**	NASA GRC
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Flight Program:	ISS		
Flight Assignment:	ISS		
Key Personnel Changes/Previous PI:			
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Grant/Contract No.:	NNX15AG11G		
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Task Description:	NOTE: Continuation of "Residence Time Driven Flame Spread Over Solid Fuels," grant # NNX10AE03G. 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.
Task Progress:	Significant progress has been made during this period of the project. The major highlight of this period is further analysis of BASS-II experimental results (obtained from experiments aboard International Space Station-ISS) and publication of two archival journal articles based on these results. We also presented several conference papers. In this period we have significantly expanded the capabilities of our Flame Stabilizer apparatus for automated data acquisition. One of our major accomplishment is the publication in the 36th International Symposium on Combustion, the abstract of which is highlighted below (see also Bibliography section): The three regimes of opposed-flow flame spread – radiative, thermal, and kinetic regimes – are well known. For thermally thin fuels, the spread rate is independent of opposing flow velocity in the thermal regime. It decreases with an increase in the flow velocity in the kinetic regime, leading to blow off extinction. In the radiative regime which occurs mostly in a buoyancy-free environment of microgravity, the spread rate decreases with a decrease in flow velocity leading to radiative extinction unless the oxygen level is very high. In a recent experiment aboard the International Space Station, thin sheets of (Poly(methyl methacrylate) (PMMA) were ignited in a flow tunnel with the opposing flow varying over a wide range. All three regimes of flame spread were captured in a single set of experiments for the first time. Instantaneous spread rates were obtained from digital video processing and compared with a computational model in all three regimes along with the evolution of flame shapes. Spread rates in the radiative and thermal regimes are also compared with existing theories of flame spread in the thermal and the radiative regime producing remarkable qualitative agreement.
Bibliography Type:	Description: (Last Updated: 06/13/2025)

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