Fiscal Year:	FY 2022	**Task Last Updated:**	FY 03/13/2022
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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City:	San Diego	**State:**	CA
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:**	09/30/2021
No. of Post Docs:	0	**No. of PhD Degrees:**	0
No. of PhD Candidates:	0	**No. of Master' Degrees:**	0
No. of Master's Candidates:	0	**No. of Bachelor's Degrees:**	0
No. of Bachelor's Candidates:	3	**Monitoring Center:**	NASA GRC
Contact Monitor:	Olson, Sandra	**Contact Phone:**	216-433-2859
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Flight Program:	ISS		
Flight Assignment:	ISS NOTE: End date changed to 9/30/2021 per NSSC information (Ed., 4/23/21) 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:	Ed. Note (4/15/22): Per the PI, Dr. Kazunori Wakai has left the project and is no longer a CoInvestigator on this task.		
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)		
Grant/Contract No.:	NNX15AG11G		
Performance Goal No.:			
Performance Goal Text:			

Task Description:	NOTE: Continuation of "Residence Time Driven Flame Spread Over Solid Fuels," grant # NNX10AE03G, with the same Principal Investigator (PI) 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 goal of the RTDFS (Residence Time Driven Flame Spread) experiments as part of the SoFIE (Solid Fuel Ignition and Extinction) program is to experimentally test the hypothesis that radiative quenching of a flame in a low gravity environment is caused by the asymmetry between how the species field and temperature field evolve. While the radiation loss, enhanced due to higher residence time, restricts the size of the reaction zone, the combustion products field keeps expanding around the flame, displacing the oxidizer, in effect choking the flame. Using results from BASS-II (Burning and Suppression of Solids) experiments, part of our hypothesis that under a critical flow velocity flames will extinguish in a microgravity environment has already been tested successfully, resulting in a number of publications. The RTDFS experiments will provide us with much more comprehensive measurements on the species and temperature distribution around the flame, leading to a better understanding of the mechanism of flame quenching. Moreover, flame spread experiments over samples covering a range of thicknesses will help us experimentally establish the critical fuel thickness above which flames become self extinguishing, a phenomenon predicted by theoretical and computational analysis. One of the significant works we have carried out this year is to explore the similarities between flame spread in a microgravity environment with that in a low-pressure terrestrial environment. We have identified the non-dimensional numbers that capture the radiative and chemical kinetics effects, which are both affected by gravity and pressure. The work, published in the 38th Proceedings of the Combustion Institute, shows that while the a reduction in pressure or gravity affects the radiation number in a similar manner, their effect on the kinetics number (Damkohler number) is just the opposite. Therefore, a low-pressure experiment cannot be a substitute for a low-gravity experiment. Another key work involved a comprehensive comparison of different radiation sub-models to evaluate the importance of (i) surface radiation loss, (ii) gas radiation loss; and (iii) radiation feedback on flame spread rate and flame structure in different regimes of opposed-flow flame spread. In preparation to the RTDFS experiments we will focus our work on: (i) Comprehensive numerical modeling of the entire experimental matrix; (ii) Improving the pyrolysis kinetics model; (iii) Investigating effect of solid conductivity on radiative quenching of flames; (iv) Predicting of flame length; (v) Expanding our work to cylindrical geometry.
Rationale for HRP Directed Research:	
Research Impact/Earth Benefits:	Our research has four components. (a) We have built three experimental setups at San Diego State University (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:	With the difficulties accessing SDSU laboratories due to COVID related restrictions, our research focus for this period has been mostly theoretical. To understand the mechanism of opposed-flow flame spread and to develop predictive abilities, the flame was divided into three zones: preheat zone, pyrolysis zone, and the plume region. Our work on the pyrolysis zone led to an ASGSR presentation and submission of two manuscripts, one to the 39th International Symposium on Combustion and another to the ICES 2022 conference. Another theoretical work we undertook – developing flame spread rate expressions for cylindrical sample – led to two conference presentations and submission of a manuscript to the 39th International Symposium on Combustion. We also continued our collaborative research work with our Japanese colleagues, which led to a third manuscript for the 39th International Symposium on Combustion. Now that the pandemic related restrictions are easing, we have restarted our experimental effort, recruited new students, and looking forward to a productive research year ahead. [Ed. Note: see investigation under new grant number: Residence Time Driven Flame Spread: The Final Phase, grant number 80NSSC21K1126, with same PI Bhattacharjee.]

Bibliography Type:	Description: (Last Updated: 06/13/2025)
Abstracts for Journals and Proceedings	Bhattacharjee S. "Expressions for flame spread rate over cylindrical fuels I opposed-flow configuration using a scale modeling approach." 9th International Symposium on Scale Modeling, Napoli, Italy, March 2-4, 2022. Abstracts. 9th International Symposium on Scale Modeling, Napoli, Italy, March 2-4, 2022. , Mar-2022
Papers from Meeting Proceedings	Bhattacharjee S. "Predicting the vaporization temperature and pyrolysis length: A comparison of simplified analysis, numerical experiments, and available experimental data." 37th Annual Meeting of the American Society for Gravitational and Space Research, Baltimore, MD, November 3-6, 2021. Abstracts. 37th Annual Meeting of the American Society for Gravitational and Space Research, Baltimore, MD, November 3-6, 2021 (Paper #2021137). , Nov-2021
Papers from Meeting Proceedings	Chiba Y, Okuno S, Matsuoka T, Bhattacharjee S, Yamazaki T, Torikai H, Nakamura Y. "Effect of angle on flame spread over folded plate." The 59th Symposium (Japanese) on Combustion, Virtual, Nov. 22-24, 2021. The 59th Symposium (Japanese) on Combustion, Virtual, Nov. 22-24, 2021 (Paper #234). , Nov-2021