Fiscal Year:	FY 2021	**Task Last Updated:**	FY 10/10/2020
PI Name:	Fernandez-Pello, Carlos Ph.D.		
Project Title:	Wire Combustion with External Radiation in Support of the JAXA Project Fundamental Research on International Standard of Fire Safety in Space		
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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Comments:			
Project Type:	Flight,Ground	**Solicitation / Funding Source:**	2012 Japanese Space Agency (JAXA) AO for Fundamental Research on an International Standard of Fire Safety in Space
Start Date:	01/01/2019	**End Date:**	12/31/2021
No. of Post Docs:	0	**No. of PhD Degrees:**	0
No. of PhD Candidates:	1	**No. of Master' Degrees:**	0
No. of Master's Candidates:	0	**No. of Bachelor's Degrees:**	0
No. of Bachelor's Candidates:	1	**Monitoring Center:**	NASA GRC
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Flight Program:			
Flight Assignment:			
Key Personnel Changes/Previous PI:	Prof. Carlos Fernandez-Pello is U.S. Co-Investigator on Japan Aerospace Exploration Agency (JAXA)-sponsored project, “Flammability Limits At Reduced-g Experiment (FLARE)." JAXA Principal Investigator is Prof. Osamu Fujita, Hokkaido University. Co-PI Investigator is Professor Van Carey.		
COI Name (Institution):	Carey, Van Ph.D. (University of California, Berkeley)		
Grant/Contract No.:	80NSSC19K0331		
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Performance Goal Text:			

Task Description:	NOTE this is continuation of "Fundamental Research on International Standard of Fire Safety in Space - Subteam 2: Wire Combustion with External Radiation in Support of the JAXA Project Fundamental Research on International Standard of Fire Safety in Space," grant NNX14AF01G with the same principal investigator Prof. Carlos Fernandez-Pello. Funding is for Prof. Fernandez-Pello's role as U.S. Co-Investigator for the Japan Aerospace Exploration Agency (JAXA)-sponsored project, "Flammability Limits At Reduced-g Experiment (FLARE)." JAXA International Announcement of Opportunity (AO) to fund experiments to be conducted aboard the Japanese Experiment Module, Kibo, 2012. The objective of the proposed research program is to continue the experimental study of the flammability of wire materials in space exploration atmospheres and associated computational/theoretical tools to aid interpretation of test results.
Rationale for HRP Directed Research:	
Research Impact/Earth Benefits:	Studying materials flammability in spacecraft allows us to accurately elucidate the effect of the environment parameters on the ignition and flame spread over combustible material, and through them their potential fire hazard. Particularly important is the determination of the Limiting Oxygen Concentration (LOC) on flame extinction under spacecraft environments. The anticipated improved methodology should reduce time and cost for the spacecraft material screening. Another important aspect of the research is the effect of melting and dripping of plastic insulation in normal gravity in comparison with microgravity. The results are relevant because dripping will not occur in microgravity and consequently could impact their burning and methodology to screen. The investigation and results have also benefits for terrestrial fire safety by providing further information about the flammability of materials under a variety of environments.
	Reporting period: January 1, 2019–December 31, 2020 A program to study the flammability characteristics of electrical wire insulations that will complement the existing JAXA project entitled "Fundamental Research on International Standard of Fire Safety in Space" (FLARE) is being carried out at University of California Berkeley (UCB) under NASA sponsorship. The final objective of the project is to provide an assessment of wire materials flammability in the conditions expected in "Space Exploration Atmospheres" (SEA), i.e., low velocity flow, external radiant heating, reduced ambient pressure, elevated oxygen concentration, and microgravity. The near-term objective of the research is to develop and conduct tests in a ground-based FLARE/UCB apparatus that reflects the environments that are expected in space-based facilities, and that supports the International Space Station (ISS)/Kibo experiments to be conducted under the FLARE project. The apparatus is used to study the flammability of electrical wires, specifically ignition and flame spread. Tests are being conducted with laboratory type wires consisting of a conducting core and PE insulation. A summary of the research conducted during this period is reported here. The research has one primary goal: to understand the changes in electrical wire flammability in the environment expected in space-based facilities, particularly those at exploration atmospheres. To date, flammability testing has focused mostly on atmospheric conditions. Work conducted at NASA Glenn Research Center (GRC) and at the combustion laboratories at UC Berkeley indicate that combustible materials are in some cases more flammable in SEA atmospheres than in Earth atmospheres. Also, if the insulation material melts during the wire burning, major differences in flammability may occur between normal and micro-gravity, because the molten material will not drip in microgravity. Thus, considerable work remains to be done to understand how the new spacecraft cabin environment influences material flammability, particularly that of wires. The overall project experimental methodology consists of obtaining flame spread flammability characteristics of electrical wires and wire insulation materials (primarily those being studied in Hokkaido University) under external radiation and in SEA environments. Experiments were conducted primarily in normal gravity to observe the effect of melting and dripping on the flame spread over wire insulation. Effects, such as gas flow velocity and direction, external radiation, ambient oxygen concentration and pressure, were analyzed for different laboratory type wires. The research primarily support the above mentioned JAXA program but also could lead to better determination and ranking of the fire hazard characteristics of potential wire materials to be used in spacecraft for long term exploration missions. Research Progress: A summary of the research progress during this reporting period is presented in this section. The summary is divided into five sections, corresponding to different aspects of the work conducted during this period. 1. Effect of Flow Velocity on Flame Spread along Insulated Electrical Wires. The work reported in this section was presented at the 11th U. S. National Combustion Meeting, Western States Section of the Combustion Institute, March 24–27, 2019, Pasadena, CA. The goal of this study was to examine how the burning, in terms of flame spread rate is affected by the flow conditions (opposed/concurrent and flow speed) and characteristics of the wire (insulation thickness, metal core size, and material) for relatively small to intermediate sized wires. The mass loss due to dripping was also recorded and assessed. Then, these results were combined with others' results and compared against one another to determine larger trends that could not be observed from the scope of this study alone. "Laboratory" wire samples with cores of either solid copper (2.5 mm or 0.64 mm diameters) or stainless-steel tubing (2.413 mm outer-diameter) with surrounding low density polyethylene (LDPE) insulation sheaths (4 mm outer-diameter) were burned subject to various airflow conditions. Concurrent, opposed, and no flow flame spread rate as well as mass loss due to dripping were determined. The flame spread rate was found to vary linearly with the airflow velocity, increasing for concurrent flame spread and decreasing for opposed flame spread, and the mass loss due to dripping was found to remain approximately constant for all airflow velocities. When compared to the literature, there was not a clear trend between flame spread rate and airflow velocity; however, a very clear relationship between flame spread rate and insulation thickness was observed, where, as the insulation thickness decreased, flame spread rate increased. When comparing mass loss due to insulation dripping from the current study with the literature, it was found that core diameter as well as heat transfer properties had the largest influence on insulation dripping, with larger cores and more conductive cores exhibiting fewer dripping effects and smaller cores dipping in excess. These experiments and comparisons with

Task Progress:

prior studies provide further understanding of the complex flame spread mechanisms along electrical wiring and serve as a baseline for a larger set of ongoing experiments in a 1g environment to study the effect of lower ambient pressures and higher oxygen concentrations on flame spread along electrical wires.

2. Effect of Ambient Pressure on the Piloted Ignition and Subsequent Flame Spread Across Simulated Electrical Wires. The work presented in this section was presented at the 2019 Fall Meeting of the Western States Section of the Combustion Institute, October 14-15, 2019, Albuquerque, NM.

The goal of the present study is to investigate whether utilizing different lengths of igniter exposure times to ignite various types of "laboratory" wire samples subject to multiple pressure environments and exposed to a constant opposed airflow will influence flame spread results. These results are relevant for comparison with future similar experiments planned in the International Space Station.

Due to electrical wires being potential sources of fire ignition in spacecrafts and with the cabin environments of NASA's next generation of spacecrafts planned to operate under reduced pressure and increased oxygen concentration conditions, it is highly important to understand the burning behavior of electrical wires in their operating environments. To begin understanding the potential effect these environmental conditions may have on material flammability, experiments examining ignition delay and flame spread rate in both an atmospheric and low-pressure, 60 kPa environments were performed. In these experiments, "laboratory" wire samples containing cores of various materials, including copper, nichrome, and stainless steel, where surrounded with either 4 mm- or 3 mm-outer diameter LDPE insulation sheaths and ignited with an electrically-heated nichrome coil placed around one end of the wire. Experiments utilizing various lengths of time for which the igniter was applied were performed in both the described environments with horizontally aligned wire samples and opposing airflows of 10 cm/s.

In the environment exposed to atmospheric pressure, it was found that for wire samples with thin copper rod cores or other less conductive cores (nichrome rods and stainless-steel tubes), the length of igniter exposure had practically no effect on the flame spread rate. For the more conductive wire samples containing thicker copper rod cores, an effect was observed in which longer lengths of exposure to the igniter produced faster flame spread. Repeating these experiments in the low-pressure environment caused delays in ignition and enhanced the effect of igniter exposure length on flame spread rate. As in the atmospheric pressure environment, tests in the low-pressure environment showed samples with cores considered here to have low conductivity (thin copper rods, nichrome rods, and stainless-steel tubes) had negligible changes in flame spread rate as the length of igniter exposure increased. The remaining sample types, having thicker copper rod cores and being more conductive, showed similar trends to one another of drastic increase in flame spread rate with increased exposure to the igniter.

While further research and analysis are needed to further quantify the effect of igniter exposure length on flame spread rate, the current results clearly show that in environments at and below atmospheric pressure, an effect is observed for certain wire types that are highly conductive where increased igniter exposure times result in faster flame spread. It is important to fully understand these results to develop a ignition method that allows for consistent results across environments with various pressures in order to more accurately describe the flammability and flame spread of materials subject to these conditions, especially because these results are relevant for comparison with future similar experiments planned in the International Space Station.

3. Effect of Reduced Ambient Pressures and Opposed Airflows on the Flame Spread and Dripping of LDPE Insulated Copper Wires. The work reported in this section has been published online ahead of print in the Fire Safety Journal (see Bibliography section).

The goal of the present study was to examine the combined effect of sub-atmospheric, ambient pressure, and opposed airflows on flame spread over wires with a high conductivity core such as copper. The insulation dripping off these wires was also analyzed under these conditions, since it has been shown that it affects the rate of flame spread and burning of insulated wires. The results of the present work are also relevant for comparison with future experiments planned in the International Space Station (ISS) with similar wire, which is the primary objective of this work.

The combined effect of reducing the ambient pressure and increasing the opposed flow speed on horizontal flame spread and dripping of copper-cored, LDPE-insulated wires was examined through experiments to increase understanding of the fire hazard electrical wires pose in spacecraft environments, and to provide data for comparison with future microgravity experiments. Results showed that the flame spread rate as well as the molten, burning insulation drip frequency were found to decrease both with decreasing pressure as well as increasing opposed flow speeds. Contrarily, it was found that the total mass dripped increased both with decreasing pressure and increasing opposed flow speeds. It is thought that these results are due to the wire core acting as a heat sink and drawing a significant amount of heat out of the flame, which affects both the rate of flame spread and the rate of insulation burning. Comparison with results from other studies with wires of different core material or dimensions show that the effect of the environmental parameters on the flame spread and mass burning of insulated wires depends strongly on the core conductivity as well as core and insulation diameters. Consequently, data obtained from specific wire tests should not be extended to other wires without justification.

4. Concurrent Flame Spread over LDPE Insulated Copper Wires in Reduced Ambient Pressures. The work presented in this section has been published in Fire Technology.

The goal of the present study is to examine the combined effect of sub- atmospheric or ambient pressures and low air flow speeds on concurrent flame spread over copper wires. The insulation dripping off these wires was also analyzed under these conditions, since it has been shown that it affects the rate of flame spread and burning of insulated wires. Furthermore, since dripping does not occur in the absence of gravity, these results are relevant for comparison with future similar experiments planned in the International Space Station (ISS) [R. Friedman, "Fire Safety in the Low-Gravity Spacecraft Environment," Denver, Colorado, 1999].

The combined effect of reducing the ambient pressure and increasing the flow speed on horizontal concurrent flame spread and dripping of copper-cored, LDPE-insulated wires was examined through experiments to increase understanding of the fire hazard electrical wires pose in spacecraft environments. Results showed that the flame spread rate as well as the molten, burning insulation drip frequency both decrease with decreasing pressure as well as decreasing flow speeds. As well, it was found that the total mass dripped increased with decreasing pressure. It is thought that these results are due to variations in the heat transfer to the insulation from the flame as well as from the insulation to the environment via the wire core acting as a heat sink and drawing a significant amount of heat out of the flame, which affects both the rate of concurrent flame spread and the rate of insulation burning. Comparison with results from other studies with wires of different core material or dimensions show that the effect of the environmental parameters on the flame spread and mass burning of insulated wires depends strongly on the core conductivity as well as core and insulation diameters. Consequently, data obtained from specific wire tests should not be extended to other wires without physical justification.

5. Modeling Flame Spread over Insulated Wires using Neural Network and Genetic Algorithm. The objective of this task is to use neural network to further understand how certain variables in the present problem relate to one another and affect dripping/flame spread. This information will be used to be able to model/predict both flame spread rate and dripping. In addition, it will be used to determine predictive equation of the problem as a whole.

Bibliography Type:	Description: (Last Updated: 03/19/2025)
Articles in Peer-reviewed Journals	Lu Y, Huang X, Hu L, Fernandez-Pello C. "Concurrent flame spread and blow-off over horizontal thin electrical wires." Fire Technology. 2019 Jan;55(1):193-209. https://doi.org/10.1007/s10694-018-0785-0 , Jan-2019
Articles in Peer-reviewed Journals	Gagnon L, Urban J, Fernandez-Pello C, Carey V, Konno Y, Fujita O. "Effect of reduced ambient pressures and opposed airflows on the flame spread and dripping of LDPE insulated copper wires." Fire Safety Journal. 2021 Mar;120:103171. Available online 18 July 2020. https://doi.org/10.1016/j.firesaf.2020.103171 , Mar-2021
Articles in Peer-reviewed Journals	Kobayashi Y, Konno Y, Huang X, Nakaya M, Tsue M, Hashimoto N, Fujita O, Fernandez-Pello C. "Laser piloted ignition of polyethylene insulated wire in microgravity." Proceedings of the Combustion Institute. 2019;37(3):4211-9. https://doi.org/10.1016/j.proci.2018.06.089 , Jan-2019