Fiscal Year:	FY 2023	**Task Last Updated:**	FY 11/14/2022
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		
PI Email:	ferpello@me.berkeley.edu	**Fax:**	FY 510 642-6163
PI Organization Type:	UNIVERSITY	**Phone:**	510 642-6554
Organization Name:	University of California, Berkeley		
PI Address 1:	Department of Mechanical Engineering		
PI Address 2:	6105A Etcheverry Hall		
PI Web Page:			
City:	Berkeley	**State:**	CA
Zip Code:	94720-1740	**Congressional District:**	9
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:	1	**No. of PhD Degrees:**	1
No. of PhD Candidates:	0	**No. of Master' Degrees:**	0
No. of Master's Candidates:		**No. of Bachelor's Degrees:**	0
No. of Bachelor's Candidates:		**Monitoring Center:**	NASA GRC
Contact Monitor:	Olson, Sandra	**Contact Phone:**	216-433-2859
Contact Email:	Sandra.Olson@nasa.gov		
Flight Program:	ISS		
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 (PI) is Prof. Osamu Fujita, Hokkaido University. Co-PI is Professor Van Carey.		
COI Name (Institution):	Carey, Van Ph.D. (University of California, Berkeley)		
Grant/Contract No.:	80NSSC19K0331		
Performance Goal No.:			
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.
Task Progress:	A summary of relevant research progress during this reporting period (January 1, 2022 - December 31, 2022) is presented here. The research consisted primarily in modeling the available experimental data of the flame spread over insulated wires using Neural Networks and Genetic Algorithms. Modeling Flame Spread over Insulated Wires using Neural Networks and Genetic Algorithms The objective of this theoretical task is to use artificial neural networks (ANN) and genetic algorithms (GA) to further understand how certain variables in the problem of flame spread over insulated wires relate to one another and affect the insulation melting and dripping from the flame spread. The information will be used to model both flame spread rate and dripping of insulated electrical wires and to develop predictive equations of the problem as a whole. The equations will be applied to predict burning behavior of wires in normal and microgravity environments. The research primarily supports the above-mentioned Japan Aerospace Exploration Agency (JAXA) program but also could lead to a better determination and ranking of the fire hazard characteristics of potential wire materials to be used in spacecraft for long-term exploration missions. Here a summary of the work conducted during this reporting period is summarized. More detailed description of the work can be found in the references provided. 1. Comprehensive Database To develop an artificial neural network that can predict flame spread rate along electrical wires under various environmental parameters, a comprehensive database of experimental flame spread rate results was first compiled from the current existing work in the field. Altogether, the database consists of approximately 1200 data points, with approximately one third (400) coming from internal experiments and two thirds (800) coming from external sources. 2. Artificial Neural Network Structure and Training To develop the ANN model of this comprehensive database, an ANN was trained to predict the flame spread rate along wires of different sizes and compositions under various ambient conditions. Using the data from the database, a procedure was implemented of data preparation, then training of the ANN, and finally validation of the ANN. The first stage, data preparation, involves transforming the data corresponding to the input parameters, as well as experimentally gathered output data (in this case, flame spread rate), into normalized values. This calculation is carried out by taking each data point of a specific parameter and dividing it by the corresponding mean of that parameter. Next, half of this data is taken for use in training the ANN, while the remaining half is reserved for validation of the ANN. The basics of the ANN training can first be thought of in terms of a single node in a matrix. Each of these nodes are in a position and take in various inputs, multiplies them by weights, linearly combines those products along with a bias value, and inputs the result into an activation function to determine the node output. This calculation is then carried out for all nodes in the ANN which are typically arranged in layers, so the outputs from every node in one layer become the inputs for each node in the next. Once the calculations have been iterated through the entire ANN, one epoch is considered to have passed. This process can then be repeated for multiple epochs with the weights and biases being adjusted each time through backpropagation to refine the ANN output, leading to more accurate predictions. The basic structure of the ANN utilized here was created with the open-source Python package, Keras (Chollet, 2015). The input layer consists of 15 nodes, corresponding to the 12 selected input parameters, two of which were vectors with multiple components, with each assigned its own node. Based on the number of input parameters, it was determined that there should be two dense hidden layers with 12 nodes each, and an output layer consisting of only one node, corresponding to the single output parameter of interest, the flame spread rate. The chosen activation function was a hyperbolic tangent, and the weight and bias values were refined over approximately 5,000 epochs. 3. Validation and Training Results After training, validation of the ANN is carried out using the reserved half of the data that was not put through the training process. Because the ANN has never seen this data before, it is able to validate the training of the ANN and show that it is actually able to make predictions and has not just memorized the patterns found in the training data. The results from the validation dataset are obtained by running the corresponding input parameters through the fully trained ANN for one epoch. The results from the ANN's training show a very strong agreement between the ANN's predictions and the experimentally measured values, with an average error of 12%. The results of the ANN's validation, with datasets divided by reference origin, also show strong agreement between the ANN's predictions and the experimentally measured values, with an average error of 16% for data the ANN had never encountered before. It should be emphasized that experiments with opposed and concurrent flame spread rates, different wire orientations, and varying strengths of gravity are all represented within these ANN predictive results. The initial results from the ANN are exceedingly promising. However, it must be remembered that there are also still

improvements that can be made to the ANN to increase the accuracy of its predictions. With further training using a wider variety and more accurate input data, as well as greater insight into influential parameters, predictions may become even better with future iterations of the ANN.

4. Parametric Trends While there is room for improvement in the ANN model, that is not to say that nothing further can be learned from it in its current state. Examining some of the parametric trends predicted by the ANN can give further insight into the flame spread rate along electrical wire insulation problem. This can be done by plotting the results as prediction surfaces in function of different input parameters. As an example, this approach shows a parametric surface that demonstrates the ANN's predictions for flame spread rate's dependence on oxygen concentration and ambient pressure. The surface clearly displays the well-known trend for flame spread rate to increase both with increasing oxygen concentration and increasing pressure; however, it also shows that even at extremely low oxygen concentrations or pressures, a high value of the other parameter can still result in a moderately fast flame spread rate. Each of the other parameter surfaces can be examined similarly to gain insight to the flame spread rate over electrical wire problem.

One of the developed surfaces shows the predicted flame spread dependence on ambient oxygen concentration and pressure for a wire with constant 2.9 mm core diameter and 1.2 mm insulation thickness, and another wire with constant 0.64 mm core diameter and 1.7 mm insulation thickness. Another, with constant 0.64 mm core diameter and with 1.7 mm insulation thickness, and varying core thermal conductivities with wire core properties averaged for copper, iron, and nichrome; unless otherwise stated, parameters are held constant with copper core.

5. Neural Networks and Genetic Algorithms using Dimensional Parameters To improve the generality of the predictions and to assist with an equation formulation of the problem as a whole, an additional neural network model was trained using a selection of non-dimensional parameters. To determine the parameters to use in the model, a large set of possible non-dimensional combinations were generated and selected based on the optimal and lowest quantity of inputs. The selection was based on a set of generated neural network models generated by a combination of nondimensional parameters. The highest precision was selected based on predictive/measured deviation by root mean square of the error for a given quantity of inputs.

The results show that the artificial neural network provides good predictive performance with the experimentally measured flame spread rates. The final artificial neural network model used 3 layers, 13 non-dimensionalized input parameters, and up to 10,000 epochs. The selected non-dimensionalized neural network model successfully maintained a low root mean square error of the predictive performance compared to the reported values. This performance was achieved with the more generalized non-dimensional input parameters, while also reducing the over-fitting of the data. The large reduction in the fitting parameters was a result of the reduced number of input parameters. This work will be continued in the extension of the present grant.

Bibliography Type:	Description: (Last Updated: 12/29/2023)
Abstracts for Journals and Proceedings	Scudiere C, Gagnon L, Fernandez-Pello C, Carey V. "Modeling analysis of experimental results of flame spread over insulated wires using an artificial neural network." The 8th International Workshop for ISS Material Flammability Standard Project: FLARE, Virtual, September 2022. Abstracts. The 8th International Workshop for ISS Material Flammability Standard Project: FLARE, Virtual, September 2022. , Sep-2022
Articles in Other Journals or Periodicals	Gagnon L, Urban JL, Fernandez-Pello C, Urban J, Carey V, Konno Y, Fujita O. "Analyzing and predicting effects of low flow velocity and reduced ambient pressure on the horizontal flame spread rate across electrical wires and dripping of molten insulation." Fire Technology. In review as of November 2022. , Jan-2023
Articles in Peer-reviewed Journals	Rivera J, San Martin D, Gollner M, Torres CE, Fernandez-Pello C. "A machine learning approach to predict the critical heat flux for ignition of solid fuels." Fire Safety Journal. 2023 Dec 1;141:103968. https://doi.org/10.1016/j.firesaf.2023.103968 , Dec-2023