

Fiscal Year:	FY 2023	Task Last Updated:	FY 11/03/2023
PI Name:	Mudawar, Issam Ph.D.		
Project Title:	Analysis of ISS Data from the Flow Boiling and Condensation Experiment (FBCE)		
Division Name:	Physical Sciences		
Program/Discipline:			
Program/Discipline--Element/Subdiscipline:	FLUID PHYSICS--Fluid physics		
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:	47907-1288	Congressional District:	4
Comments:			
Project Type:	GROUND	Solicitation / Funding Source:	Physical Sciences Unsolicited
Start Date:	01/01/2022	End Date:	12/31/2024
No. of Post Docs:	2	No. of PhD Degrees:	0
No. of PhD Candidates:	3	No. of Master' Degrees:	0
No. of Master's Candidates:	0	No. of Bachelor's Degrees:	0
No. of Bachelor's Candidates:	0	Monitoring Center:	NASA GRC
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Flight Program:			
Flight Assignment:			
Key Personnel Changes/Previous PI:	N/A		
COI Name (Institution):	Hasan, Mohammad Mujibul M.Sc. (NASA Glenn Research Center)		
Grant/Contract No.:	80NSSC22K0328		
Performance Goal No.:			
Performance Goal Text:	<p>As space missions increase in scope, size, complexity, and duration, so do both power and heat dissipation demands. This is particularly the case for future manned missions to Mars. Paramount to the success of these missions is the ability to reduce size and weight, including those of thermal management sub-systems. One means to achieving this goal is to transition from single-phase to two-phase thermal management. By capitalizing upon the merits of both latent and sensible heat exchange rather than sensible exchange alone, two-phase systems can yield orders of magnitude enhancement in evaporation and condensation heat transfer coefficients compared to single-phase systems. These improvements are evident from recent NASA workshops that culminated in critical recommendations concerning the implementation of flow boiling and condensation in a variety of space applications such as Rankine cycle power conversion, thermal control systems, and advanced life support systems. The Flow Boiling and Condensation Experiment (FBCE) was conceived in 2011 with the intent of developing an integrated two-phase flow</p>		

Task Description:	<p>boiling/condensation facility for the International Space Station (ISS) to serve as a primary platform for obtaining two-phase flow and heat transfer data in microgravity. By comparing the microgravity data against those obtained in Earth's gravity, it will be possible to ascertain the influence of body force on two-phase transport phenomena in pursuit of predictive design tools, and to help determine minimum flow criteria that would ensure gravity independent flow boiling and condensation. FBCE is a joint effort between the Purdue University Boiling and Two-Phase Flow Laboratory (PU-BTPFL) and the NASA Glenn Research Center.</p> <p>Key objectives of the proposed project will be to acquire information from the ISS microgravity heat transfer data and video records as well as assess validity and accuracy of recorded data for different operating conditions. The ISS data will be used to (1) assess and retrofit available empirical correlations and demonstrate validity for different gravities, (2) assess and retrofit available theoretical models and demonstrate validity for different gravities, (3) assess and retrofit models for minimum velocity that would ensure gravity independent heat transfer, and (4) develop computational fluid dynamics (CFD) models for both flow boiling and flow condensation.</p>
Rationale for HRP Directed Research:	
Research Impact/Earth Benefits:	1. Advanced cooling methods for electric vehicles. 2. Cooling of fusion reactors. 3. Cooling of avionics. 4. Cooling of hybrid vehicle power electronics 5. Design of industrial heat exchangers.
Task Progress:	<p>This study examines data collected as part of the "Flow Boiling and Condensation Experiment" (FBCE), which collected microgravity flow boiling data on board the International Space Station (ISS) between February 2022 and July 2022. This study focusses on detailed analysis of critical heat flux (CHF) data for microgravity flow boiling experiments with a two-phase mixture inlet, which is unavailable in the literature. n-Perfluorohexane is used in a rectangular channel with a heated length of 114.6 mm, heated width of 2.5 mm, and adiabatic height of 5.0 mm, with either single- or double-sided heating. The database covers parametric ranges never before studied in long-term microgravity: mass velocity of 249.8 – 1999.9 kg/m²s, inlet thermodynamic equilibrium quality of 0.02 – 0.86, and inlet pressure of 120.4 – 200.4 kPa. Image sequences recorded surrounding CHF reveal the passing of high-density fronts plays a key role in rewetting the wall and facilitating boiling. Trends show CHF is weakly affected by inlet pressure and mass velocity at high mass velocity, and, at low mass velocity, strongly affected by both inlet quality and mass velocity. Upon comparing the new microgravity CHF data with prior Earth-gravity vertical-upflow CHF data, the relatively weak influence of gravity on CHF during flow boiling with two-phase inlet, contrary to subcooled inlet, is established. Intricate observations of flow features suggest a wavy liquid-vapor interface, with a central vapor core and boiling within the liquid sub-layer, is the primary mechanism of CHF, and the Interfacial Lift-off Model for flow boiling CHF well predicts the present unique database, evidenced by 29.2% mean absolute error. The predictive capability of select prior correlations for flow boiling CHF is assessed for the present operating conditions, and one previously proposed by the present authors performed the best with an overall 22.4% mean absolute error, suggesting its applicability for this unique data.</p>
Bibliography Type:	Description: (Last Updated: 11/24/2023)
Abstracts for Journals and Proceedings	<p>Mudawar I, Devahdhanush VS, Darges SJ, Lee J, Kim S, Hasan MM, Nagra HK, Balasubramaniam R, Hall NR, Mackey J. "Flow Boiling and Condensation Experiment (FBCE): Summary of findings for flow boiling based on completed ISS experiments." 39th Annual Meeting of the American Society for Gravitational and Space Research, Washington, DC, November 13-18, 2023.</p> <p>Abstracts. 39th Annual Meeting of the American Society for Gravitational and Space Research, Washington, DC, November 13-18, 2023. , Nov-2023</p>
Articles in Peer-reviewed Journals	<p>Lee J, Kim S, Mudawar I. "Assessment of computational method for highly subcooled flow boiling in a horizontal channel with one-sided heating and improvement of bubble dispersion." International Journal of Thermal Sciences. 2023 Feb 1;184:107963. https://doi.org/10.1016/j.ijthermalsci.2022.107963 , Feb-2023</p>
Articles in Peer-reviewed Journals	<p>Mudawar I, Lee J. "Experimental and computational investigation into hydrodynamic and heat transfer characteristics of subcooled flow boiling on the International Space Station." International Journal of Heat and Mass Transfer. 2023 Jun 15;207:124000. https://doi.org/10.1016/j.jheatmasstransfer.2023.124000 , Jun-2023</p>
Articles in Peer-reviewed Journals	<p>Mudawar I, Devahdhanush VS, Darges SJ, Hasan MM, Nagra HK, Balasubramaniam R, Mackey JR. "Heat transfer and interfacial flow physics of microgravity flow boiling in single-side-heated rectangular channel with subcooled inlet conditions – Experiments onboard the International Space Station." International Journal of Heat and Mass Transfer. 2023 Jun 15;207:123998. https://doi.org/10.1016/j.jheatmasstransfer.2023.123998 , Jun-2023</p>
Articles in Peer-reviewed Journals	<p>Mudawar I, Darges SJ, Devahdhanush VS. "Parametric experimental trends, interfacial behavior, correlation assessment, and interfacial lift-off model predictions of critical heat flux for microgravity flow boiling with subcooled inlet conditions—Experiments onboard the International Space Station." International Journal of Heat and Mass Transfer. 2023 Oct 1;213:124296. https://doi.org/10.1016/j.jheatmasstransfer.2023.124296 , Oct-2023</p>
Articles in Peer-reviewed Journals	<p>Mudawar I, Kim S, Lee J. "A coupled level-set and volume-of-fluid (CLSVOF) method for prediction of microgravity flow boiling with low inlet subcooling on the international space station." International Journal of Heat and Mass Transfer. 2023 Dec 15;217:124644. https://doi.org/10.1016/j.jheatmasstransfer.2023.124644 , Dec-2023</p>
Articles in Peer-reviewed Journals	<p>Chang S, Suh Y, Shingote C, Huang CN, Mudawar I, Kharangate C, Won Y. "BubbleMask: Autonomous visualization of digital flow bubbles for predicting critical heat flux." International Journal of Heat and Mass Transfer. 2023 Dec 15;217:124656. https://doi.org/10.1016/j.jheatmasstransfer.2023.124656 , Dec-2023</p>
Articles in Peer-reviewed Journals	<p>Mudawar, I., Devahdhanush, V.S., Darges, S.J., Hasan, M., Nagra, H., Balasubramaniam, R., Mackey, J.R. "Effects of Heating Configuration and Operating Parameters on Heat Transfer and Interfacial Physics of Microgravity Flow Boiling with Subcooled inlet Conditions – Experiments Onboard the International Spec Station" International Journal of Heat and Mass Transfer, Vol. 217, 124732 , Jan-2023</p>