Fiscal Year:	FY 2023	**Task Last Updated:**	FY 09/28/2022
PI Name:	Miljkovic, Nenad Ph.D.		
Project Title:	High-Fidelity Experiments and Computations of Transient Two-Phase Flow for Understanding Cryogenic Propellant Tank Transfer		
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:	61801-2924	**Congressional District:**	13
Comments:			
Project Type:	FLIGHT,GROUND	**Solicitation / Funding Source:**	2020 Physical Sciences NNH20ZDA012N: Fluid Physics. Appendix A
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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:**	1
No. of Bachelor's Candidates:	2	**Monitoring Center:**	NASA GRC
Contact Monitor:	Chao, David	**Contact Phone:**	216-433-8320
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Flight Program:	ISS		
Flight Assignment:	ISS		
Key Personnel Changes/Previous PI:	None to report.		
COI Name (Institution):	Yazdani, Miad Ph.D. (United Technologies Corporation)		
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Task Description:	Cryogenic chilldown governs initial stages of cryogen transport. Chilldown involves complicated hydrodynamic and thermal interactions between the liquid, vapor, and channel wall. Large initial temperature differences between the walls and the cryogen create rapid evaporation and large pressure and temperature fluctuation. Although work has attempted to identify transient flow boiling regimes, local surface temperatures, and heat fluxes, chilldown remains poorly understood due to the lack of experimental techniques capable of attaining high spatio-temporal resolution in both optical and infrared (IR) spectra. Furthermore, a lack of computational methods exists which can predict transient flow boiling and chilldown for a variety of length and time scales, and working fluid and system geometries. Here, we propose a collaborative effort between the University of Illinois, Urbana-Champaign (UIUC) and Raytheon Technologies (RTX) to develop fundamental understanding of chilldown using complementary high-fidelity experiments and computations. Internal flow pattern variations ranging from the film, transition, nucleate, to convection flow boiling using FC-72 and liquid nitrogen (LN2) in NASA relevant aluminum and stainless steel tubes, will be studied. We will use in-liquid endoscopy to study in-situ quench front propagation during FC-72 and LN2 flow boiling. The synchronous use of internal optical and external IR visualization will enable the gaining of a rigorous understanding of the thermal-fluidic behavior occurring in the near-wall region during chilldown and transient flow boiling. The obtained parameters, such as the quench front propagation rate and the temperature and heat flux distributions near the quench front, will then be used to validate high-fidelity computations. The computational framework at RTX leverages the established foundation that is capable of predicting the thermal and hydrodynamic behavior of multiphase flows in convective boiling and condensation regimes. The multiple scales associated with chilldown and two-phase flow boiling will be addressed through a combination of the previously developed Direct Numerical Simulation (DNS) approach for the nucleation near the wall, the Large Eddy Simulation (LES) formulation for the macroscopic transport in the core, and a novel coupling scheme for transporting the information across these scales. While the inherent transient phenomena such as solid condition, nucleation, and regime transition are an integral part of this framework, the model will be modified to allow transient boundary and operating conditions due to the operation of the tank during chilldown. The simulation will provide highly resolved information on the thermal and flow characteristics of two-phase cryogenic flow during the chilldown process and particularly the transient evolution of the flow regime during boiling. The model predictions will continually be validated against the high-fidelity experimental measurements over a range of test conditions. The work is broken down into tasks, which are briefly defined by: 1) Experimental analysis of transient heat transfer and pressure fluctuation during chilldown in Earth gravity with FC-72; 2) Integration of synchronous optical and IR visualization of chilldown with FC-72 and LN2 in Earth gravity for a variety of conditions including tube material, tube size, pressure difference, initial system temperature, and cryogen flow rate; 3) Simulations of transient flow boiling and chilldown in Earth gravity with FC-72 in order to provide physical insight on how the flow regime and boiling regime evolve over the course of chilldown; and 4) FC-72 flow boiling tests in microgravity with simulation validation. The outcomes of the on-Earth experiments will guide testing in microgravity on the Flow Boiling and Condensation Experiment (FBCE) on the International Space Station (ISS) to better understand the time-varying system pressure and temperatures during the cryogenic propellant transfer process.
Rationale for HRP Directed Research:	
Research Impact/Earth Benefits:	Cryogenic chilldown governs initial stages of cryogen transport. Flow pattern variation and quench front propagation are crucial for analyzing and understanding the mechanism of chilldown.
Task Progress:	Our project is a joint University of Illinois, Urbana-Champaign (UIUC) and Raytheon Technologies (RTX) - NASA project that aims to develop an understanding of chilldown using high-fidelity experiments and simulations on highly-transient quench front propagation for the purpose of ensuring the efficient and safe utilization of cryogenic fluids during transfer under microgravity conditions. The specific tasks are: Year 1: FC-72 Experiments and Simulations in Earth Gravity Year 2: Synchronous Optical and Infrared (IR) Visualization using FC-72 in Earth Gravity Year 3: Liquid nitrogen (LN2) Chilldown Experiments and Simulations in Earth Gravity Year 4: FC-72 Experiments and Simulations in Microgravity (International Space Station - Flow Boiling and Condensation Experiment / ISS - FBCE) Year 5: FBCE Data Analysis, Model Validation, and Computational Framework Editing The summary of the Year 1 contributions from the Principal Investigator Institution and Co-Investigator Institution are stated below. In this reporting year, the work on terrestrial experiments and microgravity experiments moved forward as planned. We designed the flow boiling setup for terrestrial chilldown experiments with FC-72 and LN2. This was done based on the scientific problem and the test matrices in the proposed proposal and we have completed the assembly of the loop for FC-72 so far. In addition, we have confirmed our collaboration with Case Western Reserve University (CWRU) on the science requirement document (SRD) in May 2022 and have submitted the summary list and the first draft of the SRD in July 2022. The first phase of the computational portion of this work focused on validation of the convective boiling model against previously obtained experimental data obtained at UIUC. The multiscale approach developed and integrated into the high-fidelity convective boiling framework exploits the separation of length and time scales associated with nucleation and convection with the use of coupling between the nucleation and convection frameworks. The approach provides a practical path towards predictive simulation of convective flow boiling due to the fact that Large Eddy Simulation (LES) models are more amenable in terms of resolution requirement. The convection characteristics, hydrodynamics and thermal, are resolved in what is henceforth referred to as the LES model. However, the reduced resolution and inability of LES models to properly capture the near-wall physics prohibit a full representation of nucleation at the wall, and therefore, a coupling strategy will be used to model the interaction of nucleation at the wall and convection in the core. In this approach, the nucleation behavior is characterized in what is henceforth referred to as the Direct Numerical Simulation (DNS) model of pool boiling. This approach allows for the prediction of hydrodynamic and thermal characteristics of convective flow boiling at large Reynolds numbers at a modest computational cost.
Bibliography Type:	Description: (Last Updated: 09/29/2022)

Abstracts for Journals and Proceedings	Zhang J, Li J, Miljkovic N. "Effects of tube thermal properties on FC-72 line chilldown during low Reynolds number flows." 38th Annual Meeting of the American Society for Gravitational and Space Research, Houston, TX, November 9-12, 2022. Abstracts. 38th Annual Meeting of the American Society for Gravitational and Space Research, Houston, TX, November 9-12, 2022. , Nov-2022