Fiscal Year:	FY 2022	**Task Last Updated:**	FY 12/22/2021
PI Name:	Beckermann, Christoph Ph.D.		
Project Title:	Effect of Convection on Columnar-to-Equiaxed Transition in Alloy Solidification		
Division Name:	Physical Sciences		
Program/Discipline:			
Program/Discipline--Element/Subdiscipline:	MATERIALS SCIENCE--Materials 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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Zip Code:	52242-1527	**Congressional District:**	2
Comments:			
Project Type:	Flight,Ground	**Solicitation / Funding Source:**	2010 Materials Science NNH10ZTT001N
Start Date:	03/01/2014	**End Date:**	07/31/2022
No. of Post Docs:	0	**No. of PhD Degrees:**	2
No. of PhD Candidates:	1	**No. of Master' Degrees:**	
No. of Master's Candidates:		**No. of Bachelor's Degrees:**	
No. of Bachelor's Candidates:		**Monitoring Center:**	NASA MSFC
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Flight Program:	ISS		
Flight Assignment:	ISS NOTE: End date changed to 7/31/2022 per NSSC information (Ed., 12/28/21) NOTE: End date changed to 9/30/2021 with new grant number awarded (80NSSC20K0828) (Ed., 9/9/20) NOTE: End date changed to 2/29/2020 per NSSC information (Ed., 2/12/19) NOTE: End date is now 2/28/2019 per NSSC information (Ed., 12/1/15)		
Key Personnel Changes/Previous PI:			
COI Name (Institution):			
Grant/Contract No.:	80NSSC20K0828 ; NNX14AD69G		
Performance Goal No.:			
Performance Goal Text:			

Task Description:	ED. NOTE (7/14/2014): Project continues "Effect of Convection on Columnar-to-Equiaxed Transition in Alloy Solidification," grant #NNX10AV35G with period of performance 10/1/2010-2/28/2014. See that project for previous reporting. The project examines the mechanisms giving rise to the columnar-to-equiaxed grain structure transition (CET) during alloy solidification. On Earth, experimental investigations of the CET are affected by thermosolutal buoyant convection and grain sedimentation/flotation, making it impossible to separate these effects from the effects of solidification shrinkage and diffusive processes in determining mechanisms for the CET. Long duration microgravity experiments suppress the convective effects and grain movement, thus isolating the shrinkage and diffusive phenomena. The project increases the base of knowledge relevant to the development of solidification microstructure/grain structure of metals and alloys. Therefore, this topic is of high interest from a fundamental science point of view and it is important to those engineers practicing casting and other solidification processes. Open scientific questions include the role played by melt convection, fragmentation of dendrite arms, and the transport of fragments and equiaxed crystals in the melt. The research utilizes computational models at three different length scales: phase-field, mesoscopic, and volume-averaged models. The phase-field model is needed to resolve the growth and transport processes at the scale of the microstructure, the mesoscopic model allows for simulations at the scale of individual grains, while the volume-averaged model is used to perform simulations of entire experiments. The models help to define and interpret previous and future microgravity and ground-based experiments.
Rationale for HRP Directed Research:	
Research Impact/Earth Benefits:	The columnar-to-equiaxed transition (CET) in the grain structure of metal alloy castings has fascinated researchers in the solidification area for more than 50 years. The CET refers to the transition between the elongated grains in the outer portions of a casting and the more rounded grains in the center. Understanding this transition is fundamental to determining what type of grain structure forms in castings of most metal alloys (steel, aluminum, copper, etc.). Often, a fully equiaxed structure is preferred, but the fully columnar structures of many turbine blades are an important exception. In addition to its high practical significance, the CET represents a “holy grail” in the area of modeling and simulation of casting. This is because in order to realistically predict the CET, almost every physical phenomenon at every length scale must be taken into account simultaneously: heat transfer, solute transport, melt flow, and the transport of small dendrite fragments and equiaxed grains on the scale of the casting; the thermal/solutal/mechanical interactions between the growing grains/dendrites; and the nucleation of grains (especially in the presence of grain refiners) and fragmentation of existing dendrites. The research will not only provide an improved understanding of the CET, but also models and computer simulations of the grain structure formation in metal castings that can be used by industry to better understand and optimize their casting processes.
Task Progress:	Microgravity samples of Aluminum 4, 10, and 18 wt.% Copper and Aluminum 7 wt.% Silicon were tested in the Solidification Using a Baffle in Sealed Ampoules (SUBSA) furnace on board the International Space Station (ISS) in February 2021. Corresponding ground samples were tested in April 2021 at Techshot, Inc. Temperature results measured for the alloys solidified in microgravity and on Earth are practically identical. Microgravity samples were returned to the University of Iowa in July 2021. Terrestrial and microgravity samples were sectioned, mounted in epoxy, polished, and electropolished using the Struers LectroPol-5 machine at the NASA Marshall Space Flight Center in November 2021. After electropolishing, micrographs of the samples were taken using a polarized light optical microscope. The electropolishing, combined with polarized light, allows for clear visualization of the grains due to orientation contrast. The microstructures may then be straightforwardly characterized. It is immediately apparent that all Aluminum-Copper (Al-Cu) alloys exhibit purely equiaxed microstructures in the microgravity experiments. This is contrasted with the terrestrial experiments where these alloys exhibit clearly columnar or mixed columnar-equiaxed microstructures. The 4 and 10 wt.% Cu alloys exhibit obvious columnar grains near the bottom while the 18 wt.% Cu alloy exhibits elongated but not clearly columnar grains near its bottom. Grain characteristics have not yet been quantified. Qualitatively however, Al-Cu alloys solidified in microgravity appear to have a uniformly fine grain size. Terrestrial samples show an initially fine grain size near the transition from columnar or elongated grains to equiaxed grains. The grains appear to become coarser near the top of these samples. The Aluminum-Silicon (Al-Si) alloys, on the other hand, display almost purely columnar microstructures. There appears to be some grain competition near the bottoms of these alloys, resulting in shorter grains in that region. However, grains whose growth aligns with the temperature gradient eventually win out, resulting in relatively few grains near the top. Further analysis of the samples will include Scanning Electron Microscopy (SEM) imaging and Energy Dispersive X-Ray Spectroscopy (EDX). These analyses are currently being performed at NASA Marshall Space Flight Center as time allows. Upon completion of these analyses, the samples will be returned to the University of Iowa. Thermal simulations of the experiments were performed using the software codes MAGMA and OpenFOAM. Excellent agreement was achieved between measured and predicted temperatures. Currently the OpenFOAM code is being expanded to allow for fully temperature-dependent thermophysical properties. From these simulations, spatio-temporally varying heat flux boundary conditions describing the experiments will be calculated, validated, and published.
Bibliography Type:	Description: (Last Updated: 12/29/2023)
Abstracts for Journals and Proceedings	Beckermann C, Neumann-Heyme H, Eckert K. "A model for dendrite fragmentation in alloy solidification." TMS 2021. 150th Annual Meeting and Exhibition, The Minerals, Metals and Materials Society, Virtual Meeting, March 15-18, 2021. TMS 2021. 150th Annual Meeting and Exhibition, The Minerals, Metals and Materials Society, Virtual Meeting, March 15-18, 2021. Conference Program, p. 14. , Mar-2021