Fiscal Year:	FY 2023	**Task Last Updated:**	FY 12/30/2022
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:**	07/31/2023
No. of Post Docs:	1	**No. of PhD Degrees:**	3
No. of PhD Candidates:	0	**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 07/31/2023 per NSSC information (Ed., 12/6/22) NOTE: End date changed to 07/31/2022 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:	Corresponding benchmark solidification experiments were performed in terrestrial and microgravity settings for end-cooled cylindrical samples of three Aluminum-Copper (Al-Cu) alloys with negatively, neutrally, and positively buoyant primary solid. All samples solidified in microgravity were entirely equiaxed while the samples solidified on Earth exhibited columnar growth near the chill surface. Columnar growth in the terrestrial samples was attributed to melt convection. In the terrestrially solidified alloy samples, the Al-4 and 18 wt pct Cu samples showed evidence of grain sedimentation and flotation, respectively, while the Al-10 wt pct Cu sample did not exhibit any effects of transport of unattached grains. All samples exhibited inverse segregation due to shrinkage driven flow, as demonstrated by the eutectic fraction and macrosegregation measurements. Samples solidified on Earth showed pockets of high solute concentration and eutectic percentage that were evidence of melt convection. The terrestrially solidified Al-18 wt pct Cu sample exhibited negative solute segregation and low eutectic percentage at the top, which was attributed to solute-poor primary solid grains floating to and accumulating there. Eutectic and macrosegregation measurements showed excellent agreement with each other except for the Al-4 wt pct Cu alloy. The high level of agreement in general indicates that the macrosegregation and eutectic fraction data can be confidently used as benchmarks, except in the case of the Al-4 wt pct Cu samples where only the macrosegregation measurements should be used. Temperatures on the exterior surface of the ampoule were successfully predicted by a thermal model of the entire furnace. Heat flux boundary conditions on the sample surface were determined from the furnace model and validated using a second sample-only heat diffusion model. The boundary conditions are necessary for future modeling efforts. Selected predicted temperatures along the sample axis were presented as benchmark temperature data for the sample interior. In all samples, the liquidus isotherm passed through the full sample length before the eutectic isotherm began to traverse the samples. Thermal process parameters calculated at the liquidus isotherm along the sample axis, including the isotherm velocity, axial temperature gradient, and cooling rate, were similar in all samples. The benchmark solidification data obtained in this work are valuable for future modeling efforts. The data give the ability to validate combined models for grain structure and macrosegregation development in the presence of melt convection and transport of unattached solid. Models considering only diffusive processes and shrinkage can be validated using results from the microgravity experiments. The inclusion of the neutrally buoyant Al-10 wt pct Cu experiment allows for modeling solidification in the presence of gravity with minimal concern for buoyancy of the solid. The Al-4 and 18 wt pct Cu cases can then be used to validate models that account for transport of unattached grains.
Bibliography Type:	Description: (Last Updated: 12/29/2023)
Abstracts for Journals and Proceedings	Williams TJ, Beckermann C. "Measurement of the columnar to equiaxed transition in aluminum alloys solidified in terrestrial and microgravity environments." 6th International Conference on Advances in Solidification Processes, Le Bischenberg, France, June 20-24, 2022. Abstracts. 6th International Conference on Advances in Solidification Processes, Le Bischenberg, France, June 20-24, 2022. , Jun-2022
Articles in Peer-reviewed Journals	Neumann-Heyme H, Shevchenko N, Grenzer J, Eckert K, Beckermann C, Eckert S. "In-situ measurements of dendrite tip shape selection in a metallic alloy." Phys. Rev. Materials. 2022 June 6;6:063401. https://doi.org/10.1103/PhysRevMaterials.6.063401 , Jun-2022
Articles in Peer-reviewed Journals	Williams TJ, Beckermann C. "Benchmark Al-Cu solidification experiments in microgravity and on Earth." Metall Mater Trans A. 2022 Nov 24. https://doi.org/10.1007/s11661-022-06909-6 , Nov-2022

Dissertations and Theses	Williams TJ. "Benchmark aluminum alloy solidification experiments in microgravity and on Earth." Dissertation, University of Iowa, December 2022. , Dec-2022