Fiscal Year:	FY 2021	**Task Last Updated:**	FY 12/30/2020
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:**	09/30/2021
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 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:	Previous experiment showed large amounts of porosity in the sample. Initially, this was attributed to leakage from the bottom of the ampoule. However, further analysis showed that the porosity was due to the cold shutting phenomenon. In this phenomenon, some of the hot metal expands outside the actively heated zone of the Solidification Using a Baffle in Sealed Ampoules (SUBSA) furnace. It then cools and solidifies there, while the metal in the actively heated area remains liquid. The solidified metal prevents the spring from keeping the sample under compression, and solidification shrinkage pores develop within the sample. In order to alleviate this occurrence, the sample was shortened so that all of the liquid metal would remain within the actively heated zone. The top spacer configuration was also redesigned. Deadlines surrounding the submission of plans and samples for launch, as well as the COVID-19 pandemic, severely limited the possibility of testing the new configuration. However, an “ampoule of opportunity” was constructed using an Al-4%Cu alloy sample and tested in the SUBSA furnace. The single test showed an elimination of the large amounts of porosity. However, the top spring was located within the heated zone. Post-experiment analysis showed the spring was heavily affected by the heat. The top spacer configuration was re-arranged and a second ampoule of opportunity was constructed and tested within the SUBSA furnace. There were no issues with the thermocouples and all porosity was eliminated. Clear columnar growth appears to end at about 3.41 cm from the sample bottom. After that point, it is not clear that equiaxed grains begin to dominate. After testing and approval, samples of Al-4, 10, and 18% Cu and Al-7%Si were constructed by Techshot, Inc. These samples are intended for microgravity experiments. On October 2, 2020, the samples were successfully sent to the International Space Station on board the Cygnus Northrup-Grumman 14 resupply flight. The samples are currently awaiting testing. Numerical simulation models were again recalibrated for the new configuration. Other than the necessary geometric adjustments, only small interfacial heat transfer coefficient adjustments were necessary. Excellent agreement between measured and predicted temperature was achieved. Simulations were first performed without flow and only for columnar solidification. The effects of undercooling nucleation temperature and nucleation grain density on the location of the columnar-to-equiaxed transition (CET) within the sample was investigated. Beginning with 0 K nucleation undercooling temperature, the grain density was varied between 102 and 1010 grains/m3. A value of 60 mm, the sample length, indicates that CET did not occur. At 0 K undercooling, there is a sharp transition between no CET, CET at halfway along the sample, and at CET occurring effectively at the sample bottom. Further investigation using other nucleation undercooling values is ongoing.
Bibliography Type:	Description: (Last Updated: 12/29/2023)