Fiscal Year:	FY 2020	**Task Last Updated:**	FY 02/07/2020
PI Name:	Hayman née Anderson, Allison Ph.D.		
Project Title:	Interactive Space Vehicle Design Tool with Virtual Reality		
Division Name:	Human Research		
Program/Discipline:			
Program/Discipline--Element/Subdiscipline:	HUMAN RESEARCH--Space Human Factors Engineering		
Joint Agency Name:		**TechPort:**	No
Human Research Program Elements:	(1) **HFBP**:Human Factors & Behavioral Performance (IRP Rev H)		
Human Research Program Risks:	(1) **HSIA**:Risk of Adverse Outcomes Due to Inadequate Human Systems Integration Architecture		
Space Biology Element:	None		
Space Biology Cross-Element Discipline:	None		
Space Biology Special Category:	None		
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Zip Code:	80309-5004	**Congressional District:**	2
Comments:	NOTE: name change to Hayman née Anderson (Ed., March 2025). PI moved to University of Colorado from Dartmouth College in early 2017.		
Project Type:	Ground	**Solicitation / Funding Source:**	2016-2017 HERO NNJ16ZSA001N-Crew Health (FLAGSHIP, OMNIBUS). Appendix A-Omnibus, Appendix B-Flagship
Start Date:	11/09/2017	**End Date:**	11/09/2019
No. of Post Docs:	0	**No. of PhD Degrees:**	0
No. of PhD Candidates:	2	**No. of Master' Degrees:**	0
No. of Master's Candidates:	1	**No. of Bachelor's Degrees:**	1
No. of Bachelor's Candidates:	4	**Monitoring Center:**	NASA JSC
Contact Monitor:	Williams, Thomas	**Contact Phone:**	281-483-8773
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Flight Program:			
Flight Assignment:	NOTE: End date changed to 11/9/2019; grant number changed sometime in late 2018 per NSSC information (Ed., 1/31/19)		
Key Personnel Changes/Previous PI:	February 2020 report: There are no Key Personnel changes.		
COI Name (Institution):	Klaus, David Ph.D. (University of Colorado - Boulder)		
Grant/Contract No.:	80NSSC18K1734 ; 80NSSC18K0198		
Performance Goal No.:			
Performance Goal Text:			

Task Description:	Objective: To evaluate the spectrum of visualization tools (i.e., virtual reality, hybrid reality, augmented reality, physical reality) in their ability to facilitate rapid mock-up and flexible design of microgravity vehicles and habitats. Research Product Description: To enable efficient and rapid mock-up of vehicle concepts, the spectrum of visualization tools can be used earlier in the design process to achieve improved system design. We define, characterize, and establish metrics by which these tools can be used, with focus applications in early-stage spacecraft habitat design. From the results of this initial definition phase, an experimental evaluation of the proposed methodologies was performed. Specific Aim 1: We characterize and define the four categories of design tools noted above (physical, augmented, hybrid, and virtual) and establish a set of high-level guidelines from the literature for how each approach is typically used. This was documented as a table of advantages, disadvantages, and comments. This characterization included specific definitions of these categories, metrics by which to evaluate them, and system requirements. We also projected into future technology development on the horizon from interaction with experts in academia, government, and industry, such that this benchmark assessment is not limited to current state-of-the-art. Specific Aim 2: We experimentally investigated alternative reality for spacecraft habitat design assessment. We performed two experiments: one on fundamental perception in virtual, hybrid, augmented, and physical reality. We also asked subjects to perform a spacecraft habitat design evaluation in each of those environments (each person only experienced one environment) that involved a translation in the space, stowage of a large object, and manipulation of a fine control. We identified differences in how people evaluate spacecraft in these environments. NASA Relevance: This proposal addresses the Risk of Incompatible Vehicle/Habitat Design. Specifically, it addresses the Gap HAB – 05 to identify technologies and create a tool to enable the design and assessment of space vehicles. Our findings inform how habitat designers understand all the tools available to them in their toolbox of evaluation capabilities.
Rationale for HRP Directed Research:	
Research Impact/Earth Benefits:	Alternative reality technologies have been used successfully in other engineering and design fields and are rapidly advancing commercially. In the automotive industry, many companies continue to adopt new paradigms for design visualization and assessment. Virtual reality for product design and assembly has been widely studied, with virtual versions of physical hardware demonstrating high utility. It has been used successfully in psychological training, military applications, and entertainment. In building design and construction, architects have adopted Building Information Management and virtual visualizations of designed spaces as a means by which to capture all elements of the design evaluation. This research is the first to performs a side-by-side assessment of technology implementations across the full spectrum of alternative reality technologies. We evaluate the benefits and potential pitfalls of virtual, hybrid, augmented, and physical reality.
	Habitable spacecraft designs are critical to achieve mission success in human spaceflight. As NASA's priorities shift toward longer duration flights in deep space microgravity or on the surface of the Moon or Mars, the impact of insufficient spacecraft habitat design is exacerbated. Longer duration missions farther from the Earth reduce the total amount of volume available, thus leading to smaller crew sizes and increasing the level of isolation and confinement. In recent years, alternative reality technologies (e.g., virtual reality, augmented reality) have experienced rapid development and adoption as design tools in other industries. For spacecraft design and evaluation, though, many of these tools have yet to be adopted. This may be due to the long design cycles associated with building spacecraft and the unknown risks to improper designs associated with performing evaluations using these tools. The objective of this work is to evaluate the spectrum of alternative reality tools and their ability to facilitate the evaluation of spacecraft habitat designs. The specific aims of this study are: Specific Aim 1: We characterized and defined the four categories of design tools (physical, augmented, hybrid and virtual realities) and established a set of high-level guidelines from the literature for how each approach is typically used. This was documented as a table of advantages, disadvantages, and comments. This characterization included specific definitions of these categories, metrics by which to evaluate them, and system requirements. We also project into future technology development on the horizon from interaction with experts in academia, government, and industry, such that this benchmark assessment is not limited to current state-of-the-art. Specific Aim 2: We conducted experimental evaluations to investigate volumetric perception and task performance in volumetric assessment of a spacecraft habitat environment. These tasks were determined in conjunction with NASA personnel to be the highest utility to achieve NASA objectives. The experiments investigated the advantages and limitations of each aforementioned environment for the application of spacecraft habitat design evaluation. Aim 1 was delivered to NASA as a technical report, and is currently under revision as a journal publication in Virtual Reality. The findings from Aim 2 have been written into one journal publication on the environment development, which is under review in Virtual Reality, and a second publication on the experimental findings is currently in preparation. We present a framework for using alternative reality technologies in spacecraft habitat design. From a literature review of existing taxonomies, we identified the characteristics of alternative reality technologies and their most relevant Spectrums for use in spacecraft habitat design and evaluation. The spectrums identified are: 1. Superposition – the extent to which knowledge of the environment is virtualized; 2. Causality – the degree of interaction the user experiences with the environment; 3. Presence – the extent to which the user feels he or she is occupying the environment; 4. Augmentation – the method by which information about the user and environment is captured and transmitted; and 5. Fidelity – the degree of accuracy with which the environment captures a true desired representation. Within each Spectrum, there are anchor points that define the degree to which the environment is altered by changing its features. From our framework, four specific XR Classifications were identified as a defined set of terms that could be used in common vernacular. The identified classifications lie along Milgram and Kishino's Continuum of Virtuality and are defined as: 1. Physical Reality (PR), 2. Augmented Reality (AR), 3. Hybrid Reality (HR), and 4. Virtual Reality (VR). PR is defined as an environment with objective existence, perceived in a traditional manner. It may contain digital content, but only if that content is reflective of true implementation. AR has an increased amount of virtualized and simulated content in an otherwise real environment. That content is integrated into the environment but does not dominate it. HR is a nearly virtual environment, but it incorporates elements with objective physical existence. Finally,

Task Progress:	VR is a fully virtualized environment simulating relevant aspects across sensing modalities. Alternative realities are achieved by influencing human sensing Modalities. Three Modalities were investigated: Visual, Auditory, and Tactile. In this context, we include an individual's perception of motion, orientation, and proprioception within the Tactile modality. Within each sensing Modality, sub-dimensions were identified comprising the technical elements by which the Modality is altered within XR environments. Some sub-dimensions lie along a continuum, while others are discrete technology choices the user may make. The technical requirements of a sub-dimension can be linked to the Spectrums outlined above. In this way, the framework provides a mapping between different sensing Modalities and the environmental aspects influenced by a given technology choice. The objective of this framework is to allow users to transition between Spectrums and Modalities more easily and to identify areas in which to focus development based on their specific needs. From the detailed framework, high-level guidelines were provided to assist stakeholders within spacecraft habitat design (SHD) in choosing an XR category to suit their evaluation objectives. The stakeholders identified were evaluators in Program Management, Human Systems Integration, Operations and Training, Engineering, and Manufacturing and Assembly. Information for the stakeholder groups on their evaluation needs was acquired by reviewing the evaluation criteria against which stakeholders perform SHD evaluations, from documentation provided by NASA personnel, and interviews with subject matter experts. These data were then aggregated into a series of tables incorporating the anticipated advantages, disadvantages, and applicable phases in the design process. A list of tools that can be used by evaluators within an XR classification was also compiled. These guidelines and tool lists should continue to be expanded and adapted as hardware and technology development continues, in order to ensure it remains contemporary. This research provides a functional set of practices that can be used to help SHD evaluators achieve their mission to reduce the risk of incompatible spacecraft habitat design. We defined a framework that links theoretical Spectrums to technical requirements within a sensing Modality and define four XR Classification groups. We converted the detailed framework developed into a functional set of guidelines and potential practice cases for stakeholders in spacecraft habitat and design, with a focus on design evaluation. From these findings, we experimentally investigated the ability of subjects to perceive volume in spacecraft habitats across the XR spectrum. One of the most important aspects of SHD evaluation is to understand the spacecraft's volume, layout, and its impact on the crew. It was noted across the literature, interviews, and NASA documents that virtual representations of interiors, while instructive, are not realistic enough to provide a true evaluation of volume considerations. This mismatch may be due to the 2D projection of a 3D space, the capacity of the human eye and brain to integrate information, or the lack of personal sense within a virtual volume when not visualized. To investigate this, we experimentally evaluated what scaling difference across volume representations were present in VR, HR, and AR as compared to PR. Further, we performed a side-by-side comparison of the four XR environments for volumetric evaluation purposes. Across the literature, comparisons of PR and VR are widely documented, particularly at early stages of design. The comparison of PR and VR with AR and HR, though, are less well documented. This was also reflected in the reduced familiarity our subject matter experts had with these technologies and how they could best be implemented in their SHD evaluations. We performed direct performance comparisons across all four XR Classifications, in a manner similar to that has been done previously. Equal-fidelity mockups were made in each XR environment, depicting a single, common interior vehicle layout. We detailed the steps taken to construct all four environments and highlighted the various advantages and limitations of each alternative reality approach. Moreover, a novel hybrid reality setup that includes intuitive interactions, realistic haptics, and a fully virtual audiovisual scene was implemented. Our experimental results indicate that VR is the most likely to produce results consistent with a real physical mock-up. Each of our metrics was internally consistent and many results were consistent even across experiments. There remain challenges merging physical and virtualized content, perhaps contributing to the poorer overall performance of HR and AR. These environments show promise, though, particularly as the state-of-the-art in XR technology advances. This research contributes to the understanding of alternative reality technologies and their application in all stages of spacecraft habitat design and evaluation. This research will assist in evaluating requirements and can be used to improve habitability, ergonomics and space allocation, and to meet engineering constraints. This work addresses Gap HAB – 05: We need to identify technologies, tools, and methods for data collection, modeling, and analysis that are appropriate for design and assessment of vehicles/habitats… for predetermined mission attributes, and for refinement and validation of level of acceptable risk. This research identifies how emerging and existing alternative reality technologies can be incorporated by SHD stakeholders across various phases of design evaluation to reduce the risk of incompatible spacecraft habitat environments.
Bibliography Type:	Description: (Last Updated: 03/26/2025)
Articles in Peer-reviewed Journals	Banerjee NT, Baughman A, Lin S, Witte Z, Klaus DM, Anderson AP. "Development of alternative reality environments for spacecraft habitat design evaluation." Virtual Reality. 2021 Jun;25:399-408. Published online August 3, 2020. https://doi.org/10.1007/s10055-020-00462-6 , Jun-2021
Articles in Peer-reviewed Journals	Anderson A, Boppana A, Wall R, Acemyan CZ, Adolf J, Klaus D. "Framework for developing alternative reality environments to engineer large, complex systems." Virtual Reality. 2021 Mar;25:147–63. Available online May 23, 2020. https://doi.org/10.1007/s10055-020-00448-4 , Mar-2021
NASA Technical Documents	Anderson A, Wall R, Boppana A, Acemyan C, Adolf J, Klaus D. "Interactive Space Vehicle Design Tool with Virtual Reality: Phase 1 Report - Framework for Spacecraft Habitat Design Evaluation using Alternative Reality Technologies." Houston, Tex.: NASA Lyndon B. Johnson Space Center, 2018. , May-2018