Fiscal Year:	FY 2019	**Task Last Updated:**	FY 06/25/2019
PI Name:	Somers, Jeffrey M.S.		
Project Title:	ATD (Anthropomorphic Test Dummy) Injury Metric Sensitivity and Extensibility Study		
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) **Dynamic Loads**:Risk of Injury from Dynamic Loads		
Space Biology Element:	None		
Space Biology Cross-Element Discipline:	None		
Space Biology Special Category:	None		
PI Email:	jeff.somers@nasa.gov	**Fax:**	FY
PI Organization Type:	NASA CENTER	**Phone:**	281-483-6010
Organization Name:	KBR/NASA Johnson Space Center		
PI Address 1:	2400 NASA Parklway		
PI Address 2:	MAILCODE: WYLE/HAC/37C		
PI Web Page:			
City:	Houston	**State:**	TX
Zip Code:	77058	**Congressional District:**	36
Comments:			
Project Type:	GROUND	**Solicitation / Funding Source:**	Directed Research
Start Date:	01/01/2016	**End Date:**	03/31/2019
No. of Post Docs:	0	**No. of PhD Degrees:**	5
No. of PhD Candidates:	5	**No. of Master' Degrees:**	0
No. of Master's Candidates:	0	**No. of Bachelor's Degrees:**	1
No. of Bachelor's Candidates:	1	**Monitoring Center:**	NASA JSC
Contact Monitor:	Williams, Thomas	**Contact Phone:**	281-483-8773
Contact Email:	thomas.j.will1@nasa.gov		
Flight Program:			
Flight Assignment:	NOTE: End date corrected to 3/31/2019 per B. Gore/HRP and PI (Ed., 6/26/19) NOTE: End date changed to 10/1/2019 (actually 9/30/2019; using 10/1/2019 for reporting purposes) per PI (Ed., 11/6/18) NOTE: Element change to Human Factors & Behavioral Performance; previously Space Human Factors & Habitability (Ed., 1/10/17) NOTE: End date changed to 9/30/2018 (original end date 3/31/2016 and then 1/3/2018) per E. Connell/HFBP/HRP/JSC (Ed., 11/17/17) NOTE: Period of performance changed to 1/1/2016-1/3/2018 due to refinement of and delays in starting this task (original period of performance was 7/2/2015-3/31/2016), per E. Connell/JSC HRP (Ed., 5/24/16) NOTE: End date changed to 1/3/2018 (original end date 3/31/2016) per PI (Ed., 2/16/16)		
Key Personnel Changes/Previous PI:	November 2017 report: PI information=Jeffrey T. Somers, MS, KBRwyle, 2400 NASA Pkwy., Houston, TX 77058 ; Co-I(s) Name(s), Affiliation, Contact Information: Ashley Weaver, Ph.D., Virginia Tech-Wake Forest University Center for Injury Biomechanics, Wake Forest University Health Sciences, Winston-Salem, NC 27101, asweaver@wakehealth.edu, 336.716.0944. Derek Jones, MS, Virginia Tech-Wake Forest University Center for Injury Biomechanics, Wake Forest University Health Sciences, Winston-Salem, NC 27101, derjones@wakehealth.edu, 336.713.1247. Jacob B. Putnam, MS, KBRwyle, 2400 E NASA Pkwy., Houston, TX 77058, 281.244.6938, jacob.b.putnam@nasa.gov. Nathaniel Newby, MS, KBRwyle, 2400 E NASA Pkwy., Houston, TX 77058, 281.483.7749, nathaniel.newby@nasa.gov.		
COI Name (Institution):	Newby, Nathaniel M.S. (KBRwyle/NASA Johnson Space Center) Putnam, Jacob M.S. (KBRwyle/NASA Johnson Space Center) Jones, Derek M.S. (Wake Forest University) Weaver, Ashley Ph.D. (Wake Forest University)		
Grant/Contract No.:	Directed Research		

Performance Goal No.:	
Performance Goal Text:	
Task Description:	Currently, injury assessment reference values (IARV) are based on volunteer and post-mortem human subjects tested in non-spaceflight setups specific to the environment of interest. In automotive research, the occupant is put in the "super-slouched" position and is subjected to either frontal or side impacts at specific velocities with a 3-point restraint and airbags. In military research, test configurations are commonly based on ejection seats. These tests employ seating geometries, restraint, and loading directions that are not consistent with spaceflight configurations. Acute seat pan angles, non-extended legs (fetal position), combined axis loading, as well as other seat, restraint, and loading conditions may induce unforeseen changes in injury risk. Because the current data available do not account for these variations, a sensitivity and extensibility study is needed. Aims: 1. Validate the response of each finite element model against matched physical Anthropomorphic Test Dummy (ATD) tests in the baseline seat from existing datasets. 2. Quantify ATD and human numerical model response variance and sensitivity to a limited set of small perturbations in seat, and restraint initial conditions. 3. Quantify the effects of spacecraft-specific seating and restraint configurations on ATD and human numerical model responses.
Rationale for HRP Directed Research:	This task meets the criteria for a Directed Task because of insufficient schedule available to solicit this work. Based on the approved Path to Risk Reduction, this task is required to be completed by the end of FY16 in order to meet the Orion CDR date.
Research Impact/Earth Benefits:	This research directly impacts life on Earth by improving analytical tools for developing safer vehicles.
Task Progress:	Validate the response of each finite element (FE) model against matched physical ATD tests in the baseline seat from existing datasets. In Phase I, 35 Hybrid III, 26 THOR, and 212 human volunteer tests were chosen to validate the Humanetics 50th percentile Hybrid III, NASA version of the 50th percentile THOR-K, and the Global Human Body Models Consortium (GHBMC) simplified 50th percentile male (GHBMC M50-OS) finite element (FE) models, respectively. Seat and restraint configuration models matching chosen test configurations were developed. Each unique test condition was simulated and model response was evaluated. The sled pulse from each configuration was applied to the appropriate model and instrumented acceleration and force signals were extracted. Each simulated metric was compared to the matched physical responses of the ATD or human volunteer to quantitatively compare physical and simulated signals. The CORA (CORrelation and Analysis) comprehensive score metric was used to evaluate the model response against the matched physical test across several signals and ranged from 0 to 1, with unity being a perfect match, and 0 representing no correlation. The average comprehensive score and standard deviations of the Hybrid III, THOR, and GHBMC M50-OS models across all of their loading conditions were 0.831±0.081, 0.848±0.070, and 0.769±0.109, respectively. In respect to the overall average comprehensive CORA score, both the Hybrid III and THOR models had a CORA score of at least 0.8, as hypothesized for this phase. The THOR had the highest score of the 3 models with all directional average scores scoring at least 0.8; however, the THOR lacked data for the +X-direction. The Hybrid III had the second highest overall average comprehensive CORA score, with only the +X-direction loading group scoring under 0.8. On the other hand, the GHBMC model had only a single direction group, +Z, that scored above 0.8. Active bracing of the human volunteers may have contributed to the low CORA scoring. Quantify ATD and human-numerical model-response sensitivity to a limited set of perturbations in seat and restraint initial conditions. In Phase II, the Humanetics 50th percentile Hybrid III, NASA version of the 50th percentile THOR-K, and the Global Human Body Models Consortium simplified 50th percentile male (GHBMC M50-OS) FE models were used to examine the effects of loading condition and environmental parameters on injury metric response. Boundary conditions were parameterized and categorized as loading condition variables or environmental variables, the latter of which are expected to be less controllable than the former. Loading condition parameters included acceleration pulse shape, relative magnitude, and peak resultant acceleration. Environmental variables included belt forces, seat orientation with respect to gravity at impact time, and initial positioning on the model with respect to the seat vertex. Parameters were varied using a Latin Hypercube Design of Experiments to generate 455 simulations per model. A total of 1365 simulations were developed for this study, 97.9% of which reached termination without error. Ten injury metrics were compared using statistical methods detailed above. It was determined for each region that the loading condition variables generally were more predictive of injury metric outcome compared the environmental variables. In some regions, including the neck, lumbar spine, and lower extremities, the GHBMC response more closely resembled the THOR. In the head, thorax, and pelvis, the GHBMC had results closer to that of the Hybrid III. It was determined that discrepancies exist in injury prediction fidelity of both ATDs when comparing to human volunteer response that vary by body region and specific metrics. Further work should examine these potential differences using more vehicle-specific seats, harnesses, and helmets. Quantify the degree to which ATD and human numerical model responses track each other over a range of spaceflight-relevant loading conditions in conjunction with several spacecraft-specific seat and restraint configurations. In Phase III, the Humanetics 50th percentile Hybrid III, NASA version of the 50th percentile THOR-K, and the Global Human Body Models Consortium simplified 50th percentile male (GHBMC M50-OS) FE models were positioned and belted in FE representations of 3 spacecraft-like seat and restraint systems as well as the simplified seat model from Phase I and II. The LHD (Latin hypercube design) designed in Phase II of this study was developed based on a factorial matrix of loading direction, and acceleration pulse rise time, consisting of 20 unique acceleration profiles. However, these profiles were never directly simulated. As one aim of this study was to determine the differences between modern vehicle seat-restraint systems and the simplified seat model previously used, these 20 acceleration profiles were used. Thus, the first series (Series I) of simulations in Phase III numbered 240 in total (3 occupants × 4 seats × 20 acceleration profiles). The second aim of this study was to quantify the difference in injury metric response in matched simulation between modern vehicle seat-restraint systems. In Phase II of this study it was determined that the magnitudes of the directional acceleration magnitudes were most deterministic on injury metric outcome, followed by peak resultant acceleration magnitude, and finally time to peak (TTP) on individual directional acceleration pulses. The environmental variables (seated position perturbation, belt force, and gravity direction) did not have large effects on injury metric response. Therefore, the 3 variables carried forward for designing simulations in this Phase were 1) relative acceleration direction contribution, 2) TTP, and 3) peak resultant acceleration. Thus, the second series of simulations were created using an LHD approach, with 75 total acceleration profiles applied to the modern vehicle seats. In total, Series II accounted for 675 simulations (3 occupants × 3 seats × 75 acceleration profiles). A total of 915 simulations were run for this study, 97% of which reached termination without error. The Hybrid III and GHBMC exhibited higher rotational head injury metric distributions when equipped with a helmet compared to the simplified seat model. However, for the THOR, median BrIC decreased compared to the simplified seat. For each occupant model, pelvis acceleration tended to be pretty similar across the loading seat models. With the Hybrid III model, there was no statistically significant difference in matched pelvis accelerations between any of the spaceflight-like configurations and the simplified seat. However, with GHBMC the pelvis acceleration in each seat model was decreased compared to the simplified seat. In terms of models, the Hybrid III model saw the highest injury risk in BrIC and Nij, the GHBMC model had the highest BrIC, and the THOR model had the highest Lumbar injury risk (the GHBMC was not scored using Nij). THOR had the lowest injury risk for HIC and Nij, and the GHBMC model had the lowest BrIC and lumbar injury risk. Discussion The results for this work provide critical information to inform the Risk of Injury Due to Dynamic Loads. In Phase I, the results show that the models can accurately predict physical testing, giving confidence to the results presented in the follow-on Phases. In Phase II, the results show that both the Hybrid III and THOR ATDs are sensitive to the loading condition variables (desired sensitivity) and not sensitive to environmental variables (undesired sensitivity),

meaning that the analytical tools respond to changes in loading conditions but are not sensitive to changes in ATD positioning and belting. These results are encouraging as sensitivity to the environmental variables would imply injury prediction would not be reliable because of these sensitivities. In Phase III, spaceflight-like seat designs were used to provide direct evidence of how different designs can affect injury risk and where current and future tools are and are not capable of predicting injury. Specifically, the ATDs had variable success in predicting injury risk for all 3 seat designs.

Future Work

Recommended future work would include collecting seat acceleration pulses directly from all human-tended spacecraft landing events. Additionally, the focus of this project was the 50th percentile male, and does not directly address other body anthropometrics including small females, or larger males.

Bibliography Type:	Description: (Last Updated: 12/29/2020)
Abstracts for Journals and Proceedings	Gaewsky J, Jones D, Ye X, Koya B, Saffarzadeh M, McNamara K., Gayzik F, Weaver A, Stitzel J. "Chest and Lumbar Injury Metric Sensitivity to Spaceflight Landing Conditions." Presented at the 2018 BMES (Biomedical Engineering Society) Annual Meeting, Atlanta, GA, October 17-20, 2018. 2018 BMES (Biomedical Engineering Society) Annual Meeting, Atlanta, GA, October 17-20, 2018. , Oct-2018
Abstracts for Journals and Proceedings	Jones D, Gaewsky J, Weaver A, Gayzik F, Stitzel J. "Injury Metric Sensitivity in FE ATDs and a Simplified HBM to Spaceflight Boundary Condition Perturbations." Presented at the 2018 BMES (Biomedical Engineering Society) Annual Meeting, Atlanta, GA, October 17-20, 2018. 2018 BMES (Biomedical Engineering Society) Annual Meeting, Atlanta, GA, October 17-20, 2018. , Oct-2018
Abstracts for Journals and Proceedings	Jones D, Gaesky J, Somers J, Gayzik F, Weaver A, Stitzel J. "Head Injury Metric Response in Finite Element ATDs and a Human Body Model in Multidirectional Loading Regimes." Presented at the Association for the Advancement of Automotive Medicine (AAAM) 62nd Annual Scientific Conference, Nashville, TN, October 7-10, 2018. Program. Association for the Advancement of Automotive Medicine (AAAM) 62nd Annual Scientific Conference, Nashville, TN, October 7-10, 2018. , Oct-2018
Articles in Peer-reviewed Journals	Ye X, Jones D, Gaewsky J, Koya B, McNamara K, Saffarzadeh M, Putnam J, Somers J, Gayzik F, Stitzel J, Weaver A. "Lumbar spine response of computational finite element models in multidirectional spaceflight landing conditions." J Biomech Eng. May 2020, 142(5):051007. https://doi.org/10.1115/1.4045401 ; PubMed PMID: 31701120 [NOTE previously reported in June 2019 as "In Press as of March 2019.'] , May-2020
Articles in Peer-reviewed Journals	Jones DA, Gaewsky JP, Saffarzadeh M, Putnam JB, Weaver AA, Somers JT, Stitzel JD. "Multi-direction validation of a finite element 50th percentile male hybrid III anthropomorphic test device for spaceflight applications." J Biomech Eng. 2019 Jan 18;141(3):031004. https://doi.org/10.1115/1.4041906 ; PubMed PMID: 30383185 , Jan-2019
Articles in Peer-reviewed Journals	McNamara KP, Jones DA, Gaewsky JP, Putnam JB, Somers JT, Weaver AA, Stitzel JD. "Validation of a finite element 50th percentile THOR anthropomorphic test device in multiple sled test configurations." Stapp Car Crash J. 2018 Nov;62:415-42. https://read.qxmd.com/read/30609003/validation-of-a-finite-element-50th-percentile-thor-anthropomorphic-test-device-in-multiple-sled-test-configurations ; PubMed PMID: 30609003 , Nov-2018
Articles in Peer-reviewed Journals	Gaewsky JP, Jones DA, Ye X, Koya B, McNamara KP, Gayzik FS, Weaver AA, Putnam JB, Somers JT, Stitzel JD. "Modeling human volunteers in multidirectional, uni-axial sled tests using a finite element human body model." Ann Biomed Eng. 2019 Feb;47(2):487-511. Epub 2018 Oct 11. https://doi.org/10.1007/s10439-018-02147-3 ; PMID: 30311040 , Feb-2019
Articles in Peer-reviewed Journals	Jones DA, Gaewsky JP, Somers JT, Gayzik FS, Weaver AA, Stitzel JD. "Head injury metric response in finite element ATDs and a human body model in multidirectional loading regimes." Traffic Inj Prev. 2019;20(Sup 2):S96-S102. Published online: 17 Jan 2020. https://doi.org/10.1080/15389588.2019.1707193 ; PMID: 31951749 , Jan-2020
Dissertations and Theses	Ye X. "Computational Modeling of Lower Extremity and Thoracolumbar Spine Response in Automotive and Spaceflight Landing." Dissertation, Wake Forest University, Winston Salem, NC, January 2019. , Jan-2019
Papers from Meeting Proceedings	Gaewsky J, Jones D, Ye X, Koya B, McNamara K, Saffarzadeh M, Gayzik S, Weaver A, Stitzel J. "Human Surrogate Finite Element Models under Multi-directional Loading: Applications of Aerospace Data for the Future of Automotive Environments." 62nd Stapp Car Crash Conference, San Diego, CA, November 12-14, 2018. 62nd Stapp Car Crash Conference Proceedings. Short Communication (November 2018), p. 23-25. , Nov-2018