

DYNAMICS OF A VIBRATION ISOLATION SYSTEM INCLUDING INERTIA OF THE HUMAN BODY

D. Frenkel¹, R. K. Huffman², L. J. Quioco³, K. H. Lostroscio³

¹CACI, Inc., 2100 Space Park Dr., Houston, TX 77058

²Metecs, Inc., 1030 Hercules Ave., Houston, TX 77058

³NASA Johnson Space Center, 2101 E NASA Parkway, Houston, TX 77058

Using an exercise device in a spacecraft is liable to transmit an unacceptable amount of vibration to that vehicle. This is commonly mitigated by a Vibration Isolation System (VIS), whose dynamics must be analyzed to confirm that the oscillatory forces on the spacecraft remain within allowed range, both from a structural and microgravity perspective (see, e.g., [1]). When modeling a VIS for countermeasures devices, one common approach is to record forces and moments applied on the floor while exercising, and then drive the VIS simulation by applying these recorded loads to the exercise platform part of the VIS mechanical model. This approach misses the fact that when exercising on a moving platform, the force and moment on it will differ from that on the stationary floor due to inertial effects involving the human body. For example, standing up on a platform as it gives under the subject's feet reduces the foot force on it, and such inertial effects are especially complex for rotational motion.

In principle, one could model both the motion of the human body and dynamics of the VIS mechanism in a single combined simulation, e.g., employing a tool such as the commonly used biomechanical simulation OpenSim. Here, the joints of the human body would be driven kinematically along prescribed exercise trajectories while the dynamics engine computed the response of the VIS degrees of freedom. However, mechanism designers and biomechanics experts have their own established tools, making it very desirable to have a way of decoupling the biomechanics from the VIS modeling, simulation, and analyses. We have derived a set of equations that rigorously accomplishes this goal, and have implemented them as an interface function that provides an alternative driving mechanism for an existing force-based VIS analysis simulation. When enabled, the simulated human/VIS system dynamics is now driven by this function, instead of the recorded force methodology described above. The function is designed to accept input from a data file containing the required time-stamped human motion and inertia terms corresponding to the specific exercise in question. This data file is generated by an OpenSim plugin written for that purpose. The existing VIS analytical simulation is developed using NASA's Trick Simulation Environment [2], as well as its MBDyn multibody dynamics [3] package.

The presentation will provide a detailed overview of the mathematical formulation, assumptions, plugin implementation, software interfaces, and results for a sample set of representative exercises. The results from this work aim to better inform VIS design efforts, as well as countermeasure device/protocol designs with respect to exercise type and frequency effects on vehicle structural and microgravity restrictions.

[1] Niebuhr, J.H. and Hagen, R.A. (2012) "Development of the Vibration Isolation System for the Advanced Resistive Exercise Device", Proceedings of the 41st Aerospace Mechanisms Symposium, Jet Propulsion Laboratory, May 16-18, 2012

[2] Paddock, E.J., Lin, A., Vetter, K., and Crues, E.Z. (2003) "Trick: A Simulation Development Toolkit", AIAA Modeling and Simulation Technologies Conference and Exhibit, AIAA 2003-5809, Austin, TX.

[3] Huynh, A., Brain, T., MacLean, J. R., and Quioco, L.J. (2016) "Evolution of Flexible Multibody Dynamics for Simulation Applications Supporting Human Spaceflight", 12th International Conference on Multibody Systems, Nonlinear Dynamics, and Control (MSNDC), ASME DETC 2016-60108, Charlotte, NC.