EXERCISE COUNTERMEASURES LABORATORY AT NASA GLENN RESEARCH CENTER – A NEW GROUND-BASED CAPABILITY FOR ADVANCING HUMAN HEALTH AND PERFORMANCE IN SPACE

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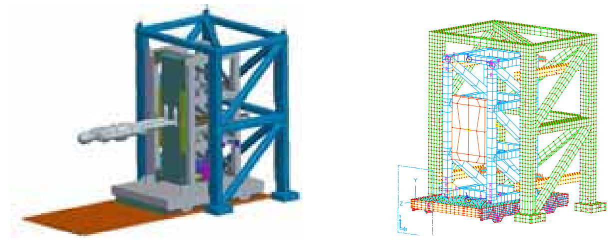
INTRODUCTION

To mitigate the detrimental effects of microgravity on the human musculoskeletal system, astronauts on the International Space Station (ISS) currently exercise on three exercise countermeasures devices (TVIS, CEVIS, and iRED). However, it is known that astronauts on the first 6 Expeditions to the ISS lost lower-extremity bone mass despite exercising on these devices. Peak magnitude and rate-of-change of force elicited under the feet (F and dF/dt, respectively) are widely believed to be important criteria for efficacy of countermeasures against loss of bone mass, but there is no information in the literature to demonstrate F and dF/dt imposed on the lower extremities during exercise throughout the range of available gravity-replacement loads imposed on the subject during exercise on ISS. To address these issues, NASA Glenn Research Center and The Cleveland Clinic Foundation Center for Space Medicine have developed the Exercise Countermeasures Laboratory (ECL), a new ground-based test capability, for providing a more flight-like simulation of exercise and reduced-gravity locomotion. Finite element analysis (FEA) of crucial system components was used to verify structural modes of vibration do not couple with ground reaction force measurements in the simulator.

METHODS

The ECL incorporates an enhanced Zero-g Locomotion Simulator (eZLS) which includes interface dynamics of those seen on the ISS, and the ability to provide variable structural dynamic interdependence to mimic variable interface configurations as seen on the ISS and other possible vehicle carriers. To allow interface forces to be accurately measured, non rigid-body structural modes of the ground-based testbed were analyzed using FEA, to ensure that the forcing function induced by the subject and subject load device are decoupled from non-rigid body modes of the simulator (Figure 1). Components of the simulator that were modeled included (i) the inertial ground frame reference, or ground reaction frame, (ii) the exercise device, and (iii) the 1 DOF off-loading and translation system for the exercise device. Target modes were set at 1.7 times the highest bandwidth of interest in the ground reaction force Z-axis component. The Z-axis is oriented normal to the running surface. Frequency content of human ground reaction force has been shown to be below 25Hz [1]. Acceptable non-rigid body structural modes were established to be 43 Hz or higher, to minimize structural interactions with the foot force measurements.



a.) **b.)**

Figure 1: (a) Solid model of test subject in enhanced Zero-g Locomotion Simulator (eZLS). Subject suspension system not shown. (b) Finite element model of simulator components.

RESULTS AND DISCUSSION

The inertial ground frame reference, or ground reaction frame, is a carbon steel box-tubing welded framework with grouted base pads which accept concrete anchors. Modes of vibration of this structure were found to meet the established criterion, with the first mode in the Z-axis direction at 70 Hz. The treadmill frame, which accommodates treadmill mechanical and electrical components, forceplate, and subject load device system, is an aluminum box-tubing welded framework. The treadmill base mounts to the 1 DOF linear translation system, or "Z-slide", which offloads the weight of the treadmill system and allows frictionless movement in the Z-axis via air bearings. The treadmill frame and Z- slide assembly modes were also found to be acceptable, with the first Z-axis mode at 45 Hz.

CONCLUSIONS

Interface forces to the subject, as well as to the exercise equipment and ground reaction frame, will be measured in the eZLS for various exercise modalities to develop a more detailed understanding of the human, subject load device, and exercise countermeasure equipment interactions, without interference from unwanted non-rigid body modes of the structural components in the system. FEA informed the design decisions for the system components and their interfaces, including the attachment method to ground for the ground reaction frame. The outcome will be that an integrated load (duration, intensity, frequency, time rate of change) may be identified for maximum benefit of counteracting the degenerative effects of space flight.

REFERENCES

1. Kram R, et al.. *J Appl Physiol* **85**(2), 764-769, 1998.

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