MODELING AND SIMULATION OF REACTION FORCES IN A REDUCED GRAVITY EXERCISE SYSTEM

[1]Marcus L. Just, [1]Carlos Grodsinsky, [2]Gail Perusek, [3]Brian Davis, [3]Peter Cavanagh
[1]Zin Technologies, Inc., Brookpark, OH; email: marcus.just@zin-tech.com; web: www.zin-tech.com
[2]NASA, Glenn Research Center, Cleveland, OH
[3]Cleveland Clinic Foundation, Cleveland, OH

INTRODUCTION

NASA Glenn Research Center (GRC) and the Cleveland Clinic Foundation (CCF) are collaborating to study aspects of exercise as a mitigating countermeasure to the phenomenon of bone density loss experienced by astronauts in extended space missions, despite implementing a rigorous exercise regimen. It is suspected that the reduction of reactive forces introduced by necessary vibration isolation systems make the workout less effective, thus contributing to the persistence of the phenomenon. Isolators are needed at the exercise system interface to attenuate forces that are transmitted into the space vehicle. A 1-Degree of Freedom (1-DOF) ground-based treadmill test bed known as the Enhanced Zero-g Locomotion Simulator (eZLS) has been designed which will allow researchers the ability to simulate an on-orbit reduced gravity environment in one axis. A dynamic model of the eZLS has been built to understand system dynamics and their affect on foot-treadmill reaction forces. One of the goals of the project is to experiment with isolators of different properties and determine their effect on foot reaction forces.

METHODS

The exercise system has six distinct elements that were included in the simulation (see Fig. 1).

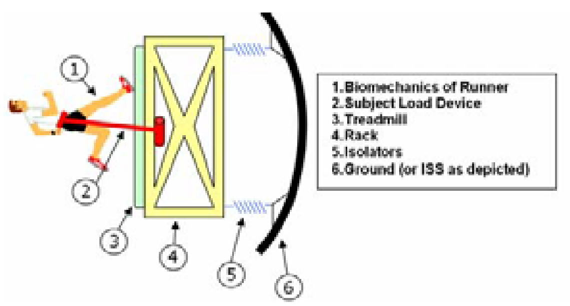

Figure 1: Zero-g Exercise Schematic

The model aimed to simulate rigid body dynamics of the treadmill and rack (items 3 and 4 in Fig. 1) as the runner foot forces (1) excited the dynamics of the isolator elements (5). The isolators were assumed to be grounded at (6). Foot forces were approximated as a sinusoidal, displacement driven body load into the runner's legs. Leg stiffness and damping values were chosen to obtain foot force input loads of 2.5 BW peak force [Ref. 1] into solid ground. The cadence was set to a frequency of 3 Hz. The input signal was half-wave rectified since the foot force could only be directed into the treadmill surface. The treadmill and rack were modeled as a rigid body, the position of which was subtracted from the displacement driven runner load. Isolator stiffness and damping properties were calculated so that certain desired resonances could be studied. Since the position of the treadmill was driven by the runner, depending on isolator stiffness and damping, the treadmill surface tended to dynamically yield against the foot. Output from the model was treadmill deflection, foot reaction forces, and ground reaction forces.

RESULTS AND DISCUSSION

The model was used to gage the potential effect that various isolator designs may have on foot reaction forces. Four simulated isolators were set to resonances of 1 Hz, 3 Hz, 10 Hz, and 25 Hz. Model output is presented in Table 1. The 1 Hz isolator set naturally produced the best attenuation of forces transmitted into the ground, however at the expense of 8.7% less total foot reaction forces compared to the baseline 25 Hz case, which is nearly hard-mounted. While the 1 Hz case peak forces only dropped by about 4.7%, the sum of the forces, which is a way of measuring total workout, increased in a non-linear fashion. Also, the model showed that a 3 Hz isolator resonance will of course couple with the cadence frequency and cause many undesirable effects such as amplified ground interface forces and treadmill oscillations, and a 43.5% reduction in summed foot reaction forces.

CONCLUSIONS

The initial rigid body model provides a good illustration of the effects that the eZLS project is setting out to study and serves as a starting point for building more sophisticated models of exercise systems for use in long duration manned spaceflight. Adding more detail regarding bio-mechanical simulation of the runner, higher-order treadmill and rack dynamics, and an active subject loading device will greatly enhance the model. The model can then be validated against tests performed on the eZLS in normal earth gravity and modified for use in 6-DOF in order to simulate performance of astronaut exercise aboard the International Space Station, or Long Duration Lunar and Mars Exploration Missions.

REFERENCES

1. Cavanagh P, et al. J Biomechanics **13**, 397-406, 1980.

Table 1. Effect of Isolator Stiffness on Foot Reaction Force

	Isolator Design Frequency			
	1 Hz	*3 Hz*	*10 Hz*	*25 Hz*
K_{total} (lbf/in)	178	1690	18e3	112e3
b_{total} (lbf/(in/s))	2	2	2	2
Max dZ of Treadmill (in)	0.699	2.629	0.026	0.003
Max Foot Force (lbs) *[% from Baseline]*	343 *[4.7% drop]*	206 *[42.7% drop]*	359 *[0.3% drop]*	360 *[baseline]*
Max Treadmill Force into Ground (lbs)	125	4232	470	382
Sum of Foot Forces *[% of Baseline]*	8.4e5 *[8.7% drop]*	5.2e5 *[43.5% drop]*	9.2e5 *[0% drop]*	9.2e5 *[baseline]*