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Author: Ms. Neeki Ashari
University of California, San Diego, United States, neekiashari7@gmail.com

Dr. Alan Hargens
University of California, United States, ahargens@ucsd.edu
Dr. Lonnie Petersen
University of California, San Diego, United States, lgpetersen@ucsd.edu

MODELING FORCES OF THE MOBILE GRAVITY SUIT FOR LONG-DURATION SPACEFLIGHT

Abstract

Spaceflight Associated Neuro-ocular Syndrome, bone decalcification, and muscle atrophy are amongst the most prevalent risks associated with long-duration spaceflight. Implementing the lower body negative pressure (LBNP) technique is a potential countermeasure for these risks. LBNP counteracts fluid shifts and generates a ground-reaction force (GRF). GRFs are beneficial for maintaining bones and muscles by mimicking gravitational loads on Earth. Currently, LBNP devices are large/bulky and require the subject to maintain a stationary position. However, a mobile Gravity Suit (G-Suit) is small, untethered, and flexible. By developing a mathematical model for a mobile G-Suit, we can predict the GRF generated underneath the subject's feet. Static LBNP chambers achieve only three forces on the subject. This can be expressed as F1 + F2 + F3= GRF, where F1 = A_W(LBNP) (axial force), F2 = spinal loading force, F3 = waist shear force, where A_W = cross-sectional area of subject's waist. However, the mobile G-Suit suit achieves four forces on the subject. The following model is expressed as (A_F + A_W)LBNP = GRF, where A_F = cross-sectional area of subject's feet. The additional force (A_F) can be further expressed as (F2 + F3 = A_F(LBNP)), where A_F is the total downward force exerted by the feet. Thus, this new G-Suit concept demonstrates higher GRF underneath the subject's feet, due to the suit's flexible exoskeletal membrane. GRF data were recorded using foot sole sensors underneath the subject's feet, while lying supine. Negative pressures ranged incrementally from 5 to 45 mmHg. The data documented that the subject generated 176% of their total bodyweight at 45 mmHg LBNP. This model predicted forces that were within an average 20% value of the experimental values collected. To measure flow rate, we applied the CFM ($ft.^3$/min) equation (($V_{Initial}$ − V_{Final})/t), where $V_{Initial}$ = volume of suit without negative pressure, V_{Final} = volume of suit at final negative pressure, and t = time from zero to final negative pressure. Results demonstrate a flow rate of 10 CFM at 5 mmHg LBNP and reached 1.83 CFM at 45 mmHg LBNP. This substantial decrease causes the exoskeletal membrane of the suit to axially contract, which generates the additional force. Our novel concept of a mobile G-Suit simulates gravitational stress by reversing the head-ward fluid-shift and maintain musculoskeletal health, without sacrificing crew time. This study is funded by NASA grants 80NSSC19K0020 and NNX13AJ12G.