Report submitted to:

Ashton Prat
Commercial Operations Manager
Lapeyre Stair

(504) 470-9723
ashton.prat@lapeyrestair.com

Project name/description:

Comparative Evaluation of Lapeyre Alternating Tread Stair & Ship's Ladder

Prepared by:

Murray Gibson, PE, CPE
Founder & Consultant
Saturn Ergonomics Consulting, LLC
311 North College Street
Auburn, AL 36830
(334) 502-3562
murray@saturnergonomics.com

Richard (Rich) Sesek, PhD, CPE, CSP
Tim Cook Associate Professor
Auburn University
(334) 728-1438
sesek@auburn.edu

Date:

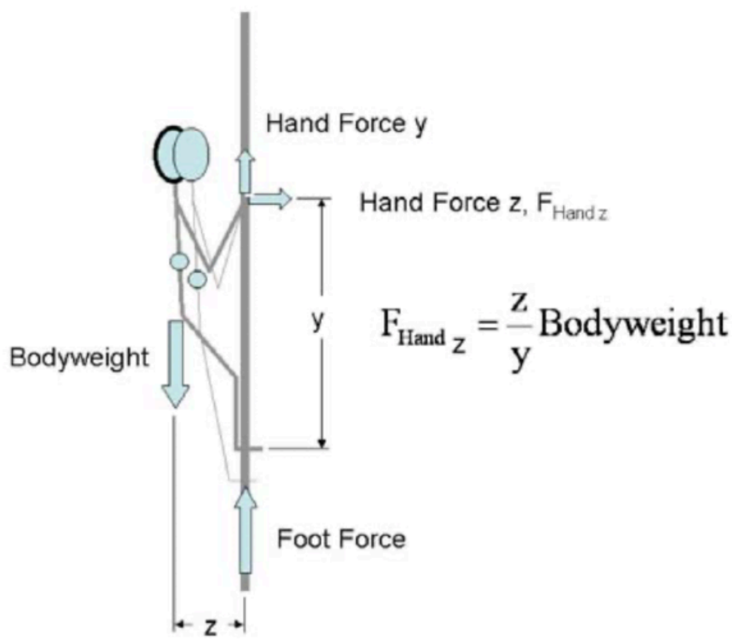
September 2, 2022

2. Balance

INTRODUCTION

The primary metric for assessing balance is Center of Mass (C.O.M.). Center of mass is a point representing the mean (average, concentration, etc.) of the mass of the matter of a body or system. In our case, we are concerned with the human body. The human body is comprised of segments including the arms, legs, torso, head, etc. The design (Lapeyre Stair or ship's ladder) having the average or worst-case C.O.M. closest to the stair/ladder should demonstrate a superior design from a "balance" perspective.

A useful balance-related metric is to calculate the hand force require to keep a static (non-moving) human model from falling. See figure and equation below. This is defined as Hand Force Z. Hand Force Z can be expressed by the equation below where Z is the horizontal distance from the ladder step to the body's C.O.M., Y is the vertical distance from the step to the hand on the ladder, and Bodyweight is the worker's bodyweight.



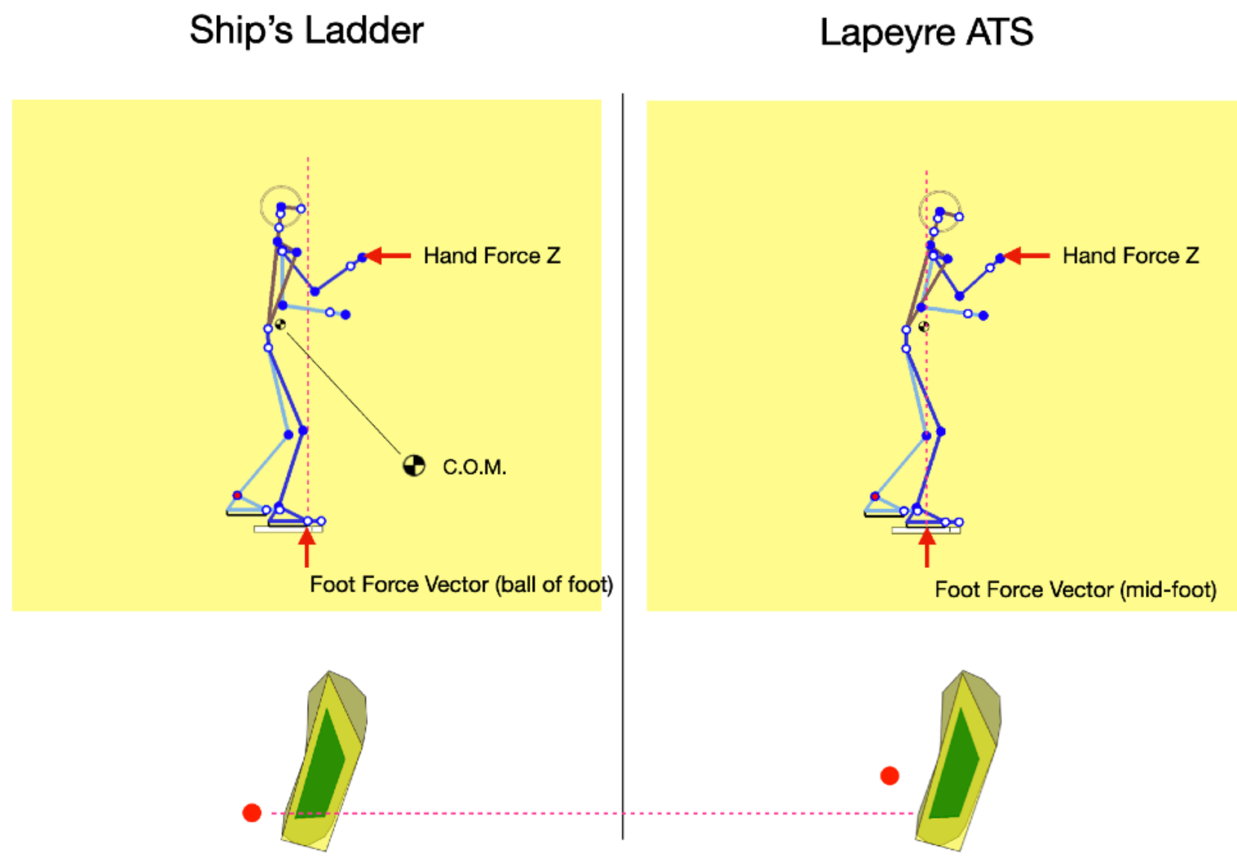
PILOT DATA COLLECTION

Initial Comparative Analysis

An initial comparative analysis was conducted using still images from similar frames of reference, making a comparison between the subject ascending the Lapeyre ATS and Ship's Ladder. Both images consist of the subject with the right foot on the stair/step, and the left foot moving upward. And both images are made with the feet somewhat near mid-height of the steps of each device. The red dot represents an estimate/approximation of the subject's C.O.M., and the purple/pink line represents a vertical axis. See graphic below.

A visually noticeable difference between the designs is the subject's torso being more upright (yellow line above-left = 88º) on the Ship's Ladder, compared to the Lapeyre ATS (yellow line above-right = 83.5º). The subject's torso is tilted forward approximately 4.5º on the Lapeyre ATS than on the Ship's Ladder. Leaning forward moves the body's C.O.M. forward.

On the Ship's Ladder, the subject's bodyweight is supported more under the ball of the foot. See image below-left. While on the Lapeyre ATS (see image below-right), the subject's weight is supported by a larger surface area of the foot, and positioned more mid-foot, somewhat closer to the heel. With the Lapeyre ATS, the body's C.O.M. appears to be positioned more over the Foot Force Vector, rather behind it. University of Michigan's 3DSSPP (3 Dimensional Static Strength Prediction Program) was used to model these forces. See graphic below.



Note how with the Ship's Ladder (above-left) the Force Force Vector is positioned at the ball (front) of the foot. This, along with the torso being more "upright", results in a noticeable horizontal distance between the vertical path of the force vector (vertical dashed line) and the C.O.M. With the Lapeyre ATS (above-right), the subject is leaning forward a few degrees, and the Foot Force Vector is positioned more mid-foot. Note that these two changes result in the digital human's C.O.M. being positioned much closer to the path of the Foot Force Vector than with the Ship's Ladder. Also, note in the graphics above how the red circle (representing the C.O.M. from an overhead perspective) is positioned farther forward - from an overhead perspective - for the Lapeyre ATS than for the Ship's Ladder.

This initial comparative analysis appears to provide observational (possibly subjective?) evidence of the Lapeyre ATS having more advantageous "balance" than the Ship's Ladder. To better quantify this notion, data were collected using Xsens digital motion capture technology.

Quantitative Comparison Using Xsens

For the motion capture project component, a subject performed trials (once) on both the Lapeyre ATS and the ship's ladder.

Subject Preparation

Anthropometric measurements were taken, including height, weight, and the lengths and circumferences of several major body links, following established guidelines (Haslegrave & Pheasant, 2018). Subjects were fitted with 17 IMU sensors (MVN Awinda, Xsens Technologies B.V., Enschede, the Netherlands). Each IMU is a small wireless, battery-powered unit that measures and stores acceleration, angular velocity, and magnetic field information. The sensors were secured using a combination of elastic neoprene straps and/or hypoallergenic athletic tape.

System Calibration

Segment calibration on the IMC system is necessary to align the motion trackers to the subject segments (Xsens®, 2021). The procedure consists of the subject holding a neutral posture for a few seconds (N-pose), then walking straight forward and back to the point where they started.

Data Sampling and Biomechanical Model

Inertial motion capture data was sampled at 60Hz. The biomechanical model used for the IMC system was the one developed by Visual3D to use within their software (C-Motion®, 2020). The 3D position of the body center of mass, feet and hands was obtained in for both trials. See biomechanical model on Figure 1.

Figure 1. Subject, avatar from IMU software and biomechanical model

References:

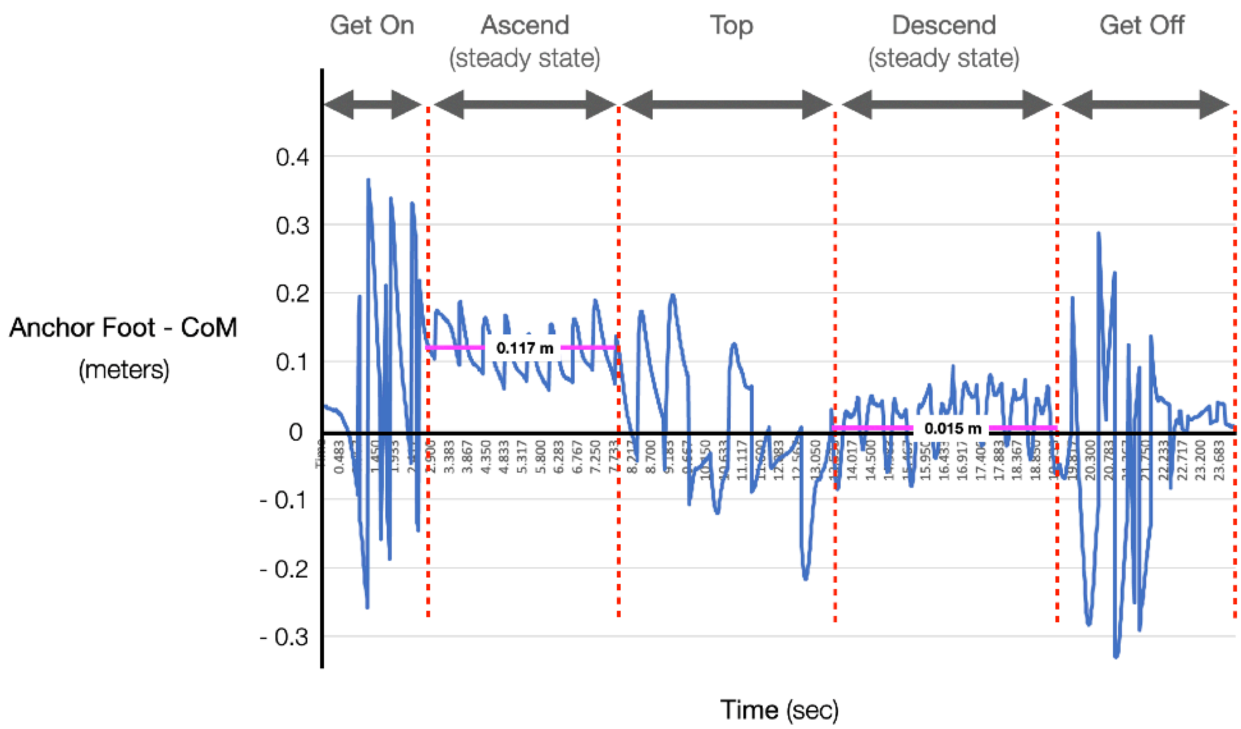
C-Motion®. (2020). Xsens. - Visual3D Wiki Documentation. https://c- motion.com/v3dwiki/index.php/Xsens.

Pheasant, S., & Haslegrave, C. M. (2018). Bodyspace. In Bodyspace. CRC Press. https://doi.org/10.1201/9781315375212

Xsens®. (2021). MVN User Manual. https://www.xsens.com/hubfs/Downloads/usermanual/MVN_User_Manual.pdf

The Xsens data was evaluated in detail to better understand the subject's balance during use of the Ship's Ladder and Lapeyre ATS. See **Figure 2, Ship's Ladder (Anchor Foot - CoM)** below.

Figure 2, Ship's Ladder (Anchor Foot - CoM)



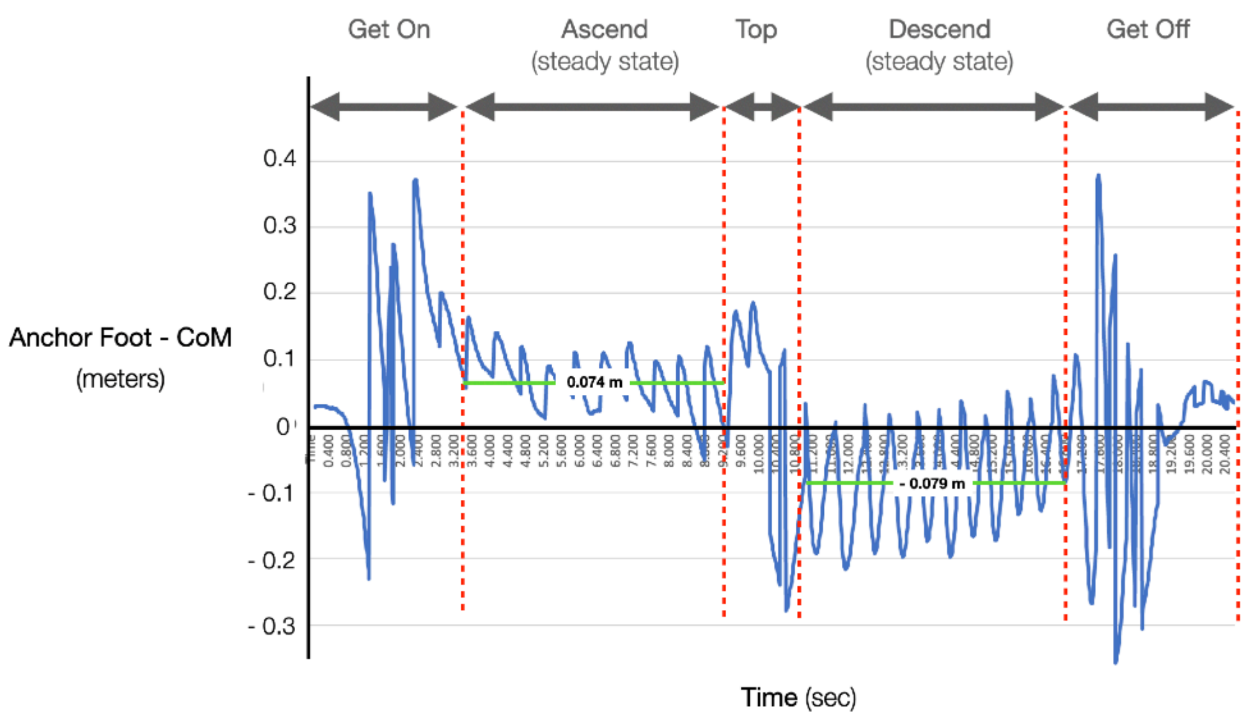
Looking at Figure 2 above, the x-axis is Time (sec) and the y-axis is the horizontal distance between the subject's CoM (Center of Mass) and the Anchor Foot (foot stationary on the rung/step). A positive value on the y-axis indicates that the Anchor Foot is in front of the CoM, resulting in an unbalanced position, where the subject has a propensity to fall backward away from the device. Conversely, a negative value on the y-axis would be indicate of the subject's Anchor Foot being behind the CoM. In this situation the subject has a propensity to fall forward, into the device. Falling forward into the device would appear to be somewhat of a "failsafe" condition.

The pattern of the y-axis value is cyclical in nature, going up/down in a sine wave pattern. This sine wave pattern corresponding with the alternating stepping pattern (gait) of the subject ascending or descending the device. Note that during the Get On, Top, and Get Off regions, the y-axis value varies wildly and exhibits very high peaks and valleys. Whereas during the Ascend and Descend regions the y-axis value is somewhat "steady", having smaller high/low amplitudes. For the purpose of comparing balance characteristics of the Ship's Ladder and Lapeyre ATS, this steady state region appears to be a logical place to focus.

The horizontal pink lines in Figure 2 represent the average "balance metric" within these two steady state regions. This is where the subject is in a steady, predictable rhythm ascending and descending the device. Note that due to the y-axis values being positive in the steady state regions, the balance metric is indicative of the subject having a greater propensity to fall away from the device than to fall into it, particularly in the Ascend region where the average y-xis value = 0.117 meters. During the Descend region, the average y-axis value is 0.015 meters, closer to zero. A positive balance metric indicates that the climber must exert force with the hands to avoid falling backwards. A negative balance metric value would indicate that the climber is leaning into/onto the handrail.

Xsens data were summarized for the subject using the Lapeyre ATS. See **Figure 3, Lapeyre ATS (Anchor Foot - CoM)** below. A noticeable difference between this graphic and Figure 2 is at the top of the device, where the subject spends less time than on the Ship's Ladder. As in Figure 2, there is a high variation in the y-axis value at the transition points (Get On, Top, and Get Off). But as with Figure 2, the steady state ascend and descend regions can readily be identified in the graphic. Horizontal green lines were superimposed upon the graphic to represent the average y-axis value within these steady state regions. Compared to Figure 2 (similar graphic for Ship's Ladder) the green lines in the two steady state regions of Figure 3, Lapeyre ATS, are "lower" (better from a balance perspective) than those in Figure 2, Ship's Ladder. In the descend steady state region the value is actually negative, indicating that the horizontal position of the body's CoM being behind the Anchor Foot. This is due to the subject walking down the Lapeyre ATS facing away from the device, and often the Anchor foot is "out front". These negative values indicate that the subject would have a propensity to fall backward, into the device, rather than falling forward away from the device. See Figure 3 below.

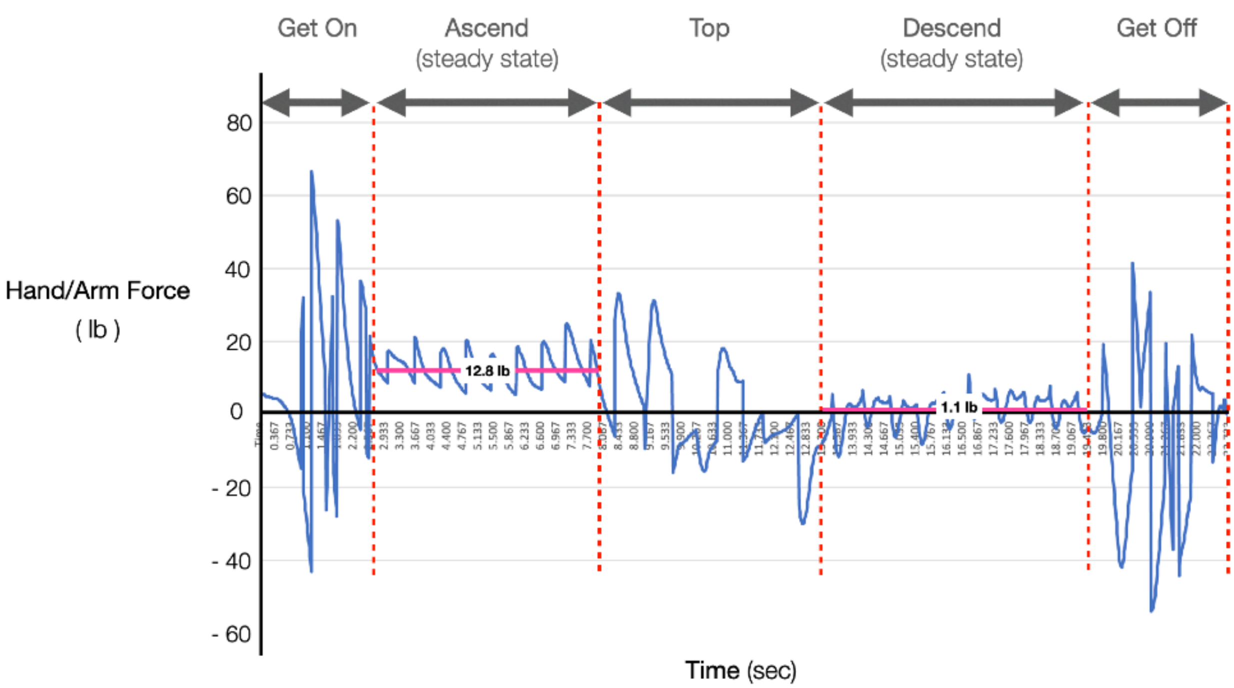
Figure 3, Lapeyre ATS (Anchor Foot - CoM)



Next, the Xsens data set was evaluated to to estimate the horizontal hand/arm force required to achieve a balanced state (prevent the subject from falling forward or backward). Hand forces were estimated based on a 200 lb subject with the assumption that each hand was exerting the same force. Positive hand forces indicate gripping the rails to prevent backward rotation (falling away from the ladder). A negative hand force would indicate that the climber is leaning into or against the rail.

For the Ship's Ladder, the hand/arm force estimated for maintaining balance is presented below in Figure 4, **Ship's Ladder - Hand/Arm Horizontal Force**. Similar to the y-axis values in the prior graphics (Figure 2 and Figure 3), there is high variability during the transition points (Get On, Top, and Get Off), but the values stabilize during steady state periods of Ascend and Descend. In this graphic, positive y-axis values indicate a "pull" Hand/Arm Force required to prevent the body from falling away from the ladder/stair, while negative values indicate a "push" (direction of force toward the device). Positive forces indicate balance such that if the subject were to let go, they would fall away from the ladder/stair, while a negative force indicates that the subject would fall towards or into the ladder/stair if they were to remove their hands (let go) from the rails. See Figure 4 below.

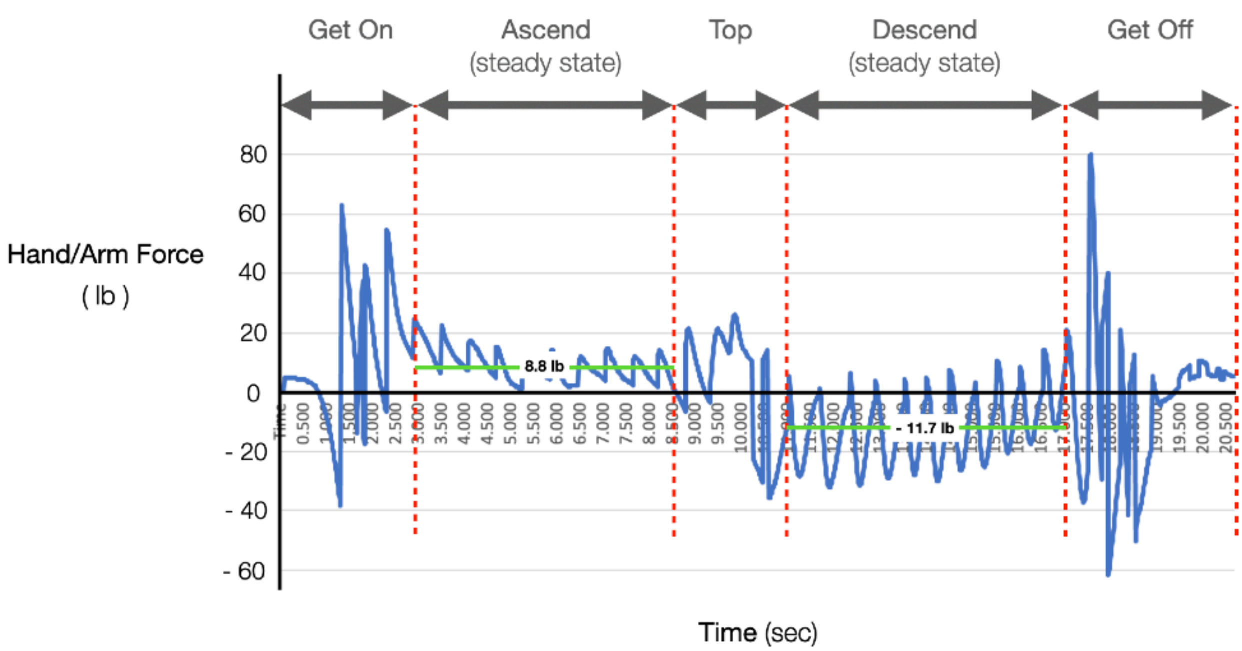
Figure 4, Ship's Ladder - Horizontal Hand/Arm Force



During the subject’s steady state Ascend period on the Ship’s Ladder, the average Hand/Arm Force was 12.8 lb per hand, indicating a balance such that the subject would tend to fall away if they let go of the rails. During the steady state Descend period the average Hand/Arm Force was very small, just 1.1 lbs per hand. However, removing one’s hand from the rails would still result in a tendency to fall away from the ladder.

For the Lapeyre ATS, see **Figure 5, Lapeyre ATS - Horizontal Hand/Arm Force**, during the Ascend period, the Hand/Arm Force was 8.8 lbs per hand, indicating the tendency to fall away from the stairs if the hands were not gripping the rails. During the Descend period, the Hand/Arm Force was actually negative (-11.7 lb per hand). This indicates a tendency to fall backwards towards the device, rather than forward towards the ground. Unlike the positive value during ascent, this negative value represents a safer condition in the event that the climber loses hand contact. See Figure 5 below.

Figure 5, Lapeyre ATS - Horizontal Hand/Arm Force



PROPOSED FUTURE RESEARCH

The CoM data suggest that the Lapeyre ATS may be superior to the traditional ship's ladder with respect to climber balance and tendency to rotate away or towards the ladder/stairs. Given the relatively large differences between the ATS and ladder, albeit for a single climber, it appears that a study with multiple climbers over several trials would be able demonstrate statistically significant and important distinctions between the devices. Additionally, dynamic evaluation of the motion capture data might illuminate further differences. Using Xsens to capture subject positional data is highly recommended for subsequent human-subject research experiments.