Exer-Genie® Exercise Device

Hardware Evaluation

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Summary and Operational Relevance

An engineering evaluation was performed on the Exer-Genie® exercise device to quantify its capabilities and limitations to address questions from the Constellation Program. Three subjects performed rowing and circuit-training sessions to assess the suitability of the device for aerobic exercise. Three subjects performed a resistive exercise session to assess the suitability of the device for resistive exercise. Since 1 subject performed both aerobic and resistive exercise sessions, a total of 5 subjects participated.

During the aerobic exercise sessions, subjects were unable to elevate their sustained or peak heart rate to 70% of maximum, and VO_2 measures demonstrated an exertion level less than that required to walk or jog at 5 miles per hour on a horizontal flat surface. During rapid-cycle use, the central core of the device heated up to as much as 140 degrees Celsius, thus precluding bare-handed manipulation of the device for load adjustment or reconfiguration.

Load characterization testing was performed on three separate Exer-Genie® units for comparison. Results revealed that for the vast majority of load settings, the actual load provided, in terms of average and peak force, differed greatly from the predicted load scale printed on the device. The load disparity ratio was as high as 11:1 for the 1-lb setting on one device and the load differential was as high as 436 lb for the 110-lb setting on another device.

While the Exer-Genie® is capable of providing a wide range of resistive loads and resistance levels suitable for aerobic exercise, and while it allows the user to do multiple exercises conducive to sustained aerobic and circuit-type programming as well as strength training, severe limitations in the human interface with the device, load consistency, and heat output make it unable to meet the load demands of a physically diverse crew and the hardware restrictions for space flight utilization.

Introduction

The Exercise Countermeasures Project (ECP) performed a functional engineering evaluation of the commercial off-the-shelf Exer-Genie® exercise device (currently marketed as "the Trainer," http://www.exergenie.com/) (1). The device was evaluated quantitatively and subjectively to quantify its capabilities and limitations to address questions from the Constellation Program regarding possible use on board the Crew Exploration Vehicle (CEV/Orion), Lunar Habitat, or Small Pressurized Rover (SPR).

The Exer-Genie® was previously used in space flight, when crewmembers used it during the Apollo and Skylab missions of the 1960s and 1970s. Anecdotal evidence suggests that the device provided some exercise stimulus and that the crews found it psychologically beneficial in reducing stress during the multiple-day voyages to and from the Moon (NASA/TM-2147-55). However, some concern was expressed about the extent to which the device heated up during high cycle, rapid movement use.

Motivation for assessing the device stemmed from its previous spaceflight use and the fact that it fits within the current CEV exercise hardware constraints (limited mass and volume and no power), and the Constellation Program has asked ECP about this device's capabilities.

The device has a relatively simple, compact design (Figure 1) and consists of 3 primary components: an outer shell with printed scale (Figure 1-a1), a central core rod (Figure 1-a2), and a synthetic rope (Figure 1-a3). In addition, handles (Figure 1-a4) and straps are provided to facilitate the user's manipulation of the rope ends.
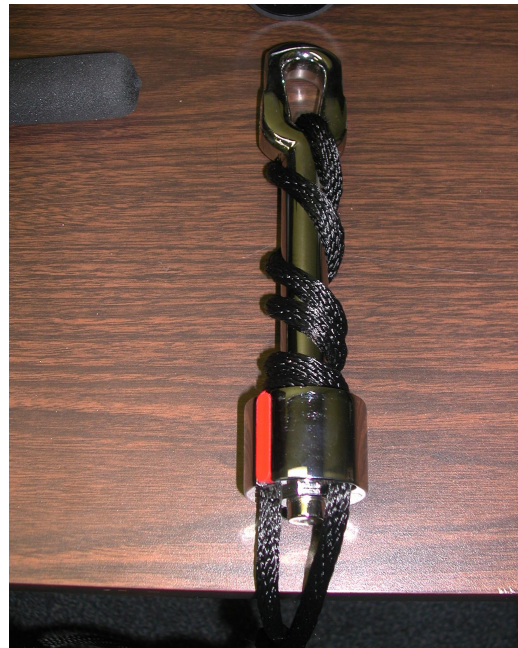
a)
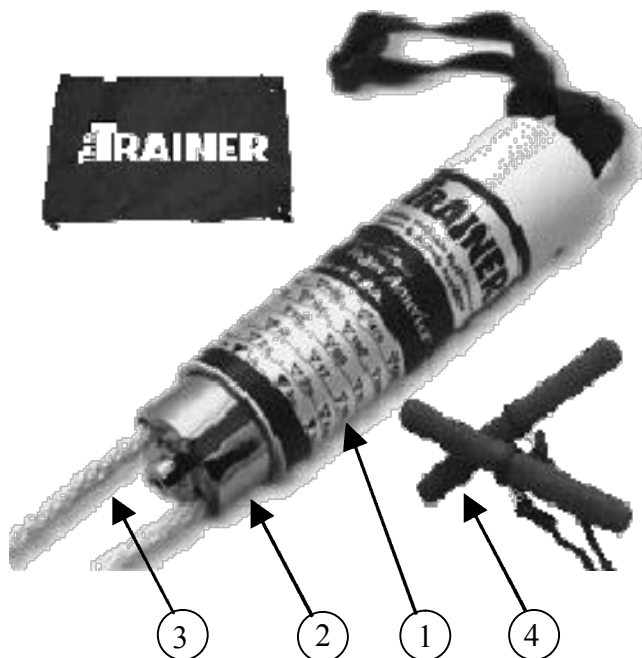
b)

Figure 1.   Components of Exer-Genie® exercise device: a) assembled device in operational use
configuration, b) device partially disassembled to show inner working. a1, printed scale;
a2, central core rod; a3, synthetic rope; a4, handles and straps.

The rope enters through a hole in the cylindrical base of the core, wraps around the core shaft, passes
through an eyelet at the top of the core, wraps back around the shaft, and exits through a second hole
in the core base. The device is operated by pulling one or the other end of the rope to advance it out
of the hole at the base of the core. The resistance is provided by the friction between the rope and the
central shaft and eyelet as the rope is advanced through the device. The base can be rotated relative
to the central shaft and locked in position, thereby changing the amount of wrapping of the rope
around the shaft. The amount of resistance is proportional to the extent of wrapping. A numerical
scale (Figure 1, a1) is provided on the outer shell to indicate the expected resistance.

Assessment Objectives

- Determine the aerobic conditioning stimulus achieved with the device in terms of average
  and peak heart rate, oxygen consumption, and respiratory exchange ratio (the ratio of the
  amount of carbon dioxide produced by the body to the amount of oxygen consumed).
- Determine the actual resistance provided by the device during resistive exercise in terms of
  average and peak force.
- Obtain a subjective assessment of the device's performance through a questionnaire.

Methods

Subjects

The engineering evaluation was performed using 5 subjects of different sizes and fitness levels,
representative of the variations seen in the astronaut corps (Table 1).

Table 1 – Test subjects: various age and fitness levels with gender and body
size distribution as shown below (sorted by height percentile).

Subject	Gender		Age	Height		Weight	
	M	**F**	**(years)**	**(cm)**	**%**	**(kg)**	**%**
1		F	27	162	45	54	50
2	M		31	175	50	80	45
3		F	37	153	5	48	5
4	M		53	188	95	101	95
5	M		31	190	95	93	70
Mean			**35.8**	**173.7**	**58.0**	**75.3**	**53.0**
SD			**10.3**	**16.0**	**38.0**	**23.6**	**33.3**

%, Current Astronaut Corps percentile; SD, standard deviation.

Testing included both aerobic and resistive exercise evaluations with 3 subjects in each evaluation
(subject 2 completed all evaluations).

Aerobic Exercise Protocol

Two separate total-body aerobic exercise protocols were conducted. The first aerobic exercise protocol was a circuit training model in which the subjects performed one exercise for 2 minutes before immediately starting the next exercise (Table 2). This is a commonly employed protocol in commercial gymnasiums. The second aerobic protocol required sustained rowing on a stationary ergometer for 20 minutes. This exercise required the assistance of a "spotter" to hand the Exer-Genie® handles to the subject at the start of each stroke; otherwise, the subject fell on the ground and was difficult or impossible to pick up while remaining in the ergometer seat. It would also have been difficult for the subjects to maintain aerobic exertion levels if they had had to pick up the handles from the ground each time. The total exercise time for each session was about 20 minutes. Slightly more time (about 3 minutes total) was required for the circuit session to allow subjects to move rapidly from one exercise to the next.

Table 2 – Exer-Genie® first aerobic exercise protocol.

Type of exercise	Time
Alternating chest press	2 minutes
Alternating back row	2 minutes
Rowing	2 minutes
Squat with upright row	2 minutes
Rowing	2 minutes
Repeat above sequence	10 minutes
Total time	**20 minutes**

During the aerobic sessions the subject's oxygen uptake (VO_2) and carbon dioxide expiration (VCO_2) were measured continuously using a COSMED K4b2 (COSMED USA, Chicago) portable gas analyzer, and heart rate was measured using a Polar heart rate monitor (Polar USA, Lake Success, NY). For baseline purposes, subjects recruited for the aerobic evaluation had had a VO_2max test in a Johnson Space Center Exercise Physiology Lab study within 1 year before the aerobic exercise sessions in this study.

Device Temperature Measurement

Device temperature readings were obtained using a Fluke Model 52 II (Fluke Corporation, Everett, WA) which has an operating range of –250 to +400 degrees Celsius and an accuracy of ± 0.3 degrees Celsius. One thermocouple was placed on the core metal rod at the top anchor point (contains the eye that the rope passes through) and the other was placed on the outer plastic shell. Both thermocouples were adhered to the device using an adhesive thermal tape. Readings were taken from the digital display every 2 minutes at the start of aerobic exercise and every minute toward the end of exercise.

Load Characterization

Load characterization was performed to objectively determine to what extent the actual load delivered to the subject matched the predicted load as presented on the numerical scale attached to the exterior of the outer housing. The Exer-Genie® was anchored to the footplate support frame (Figure 2) of the Horizontal Exercise Fixture (HEF). One rope end was attached to a single axis load

cell (Entran, Inc., Fairfield, NJ) via a carabiner clip, and the load cell was in turn attached to the right side eyebolt on the shoulder support sled of the HEF via a carabiner clip. Three Exer-Genie® units were tested. For convenience, the units were named Exer-Genie® A, B, and C. Each unit was successively configured to a predetermined setting on the printed scale: 1, 3, 5, 7, 9, 10, 32, 50, 80, 110, 190, 250, and 310 pounds of force for unit A; 10, 32, 50, 80, and 110 pounds force on unit B; and 10, 32, 50, 80, 110, and 190 pounds of force on unit C. The lower load range settings were used on unit A, as this was the only unit used for subsequent aerobic exercise sessions. The highest setting reached varied between units because the subject performing the movement was unable to complete all load levels due to substantial disparity in resistance among the units.
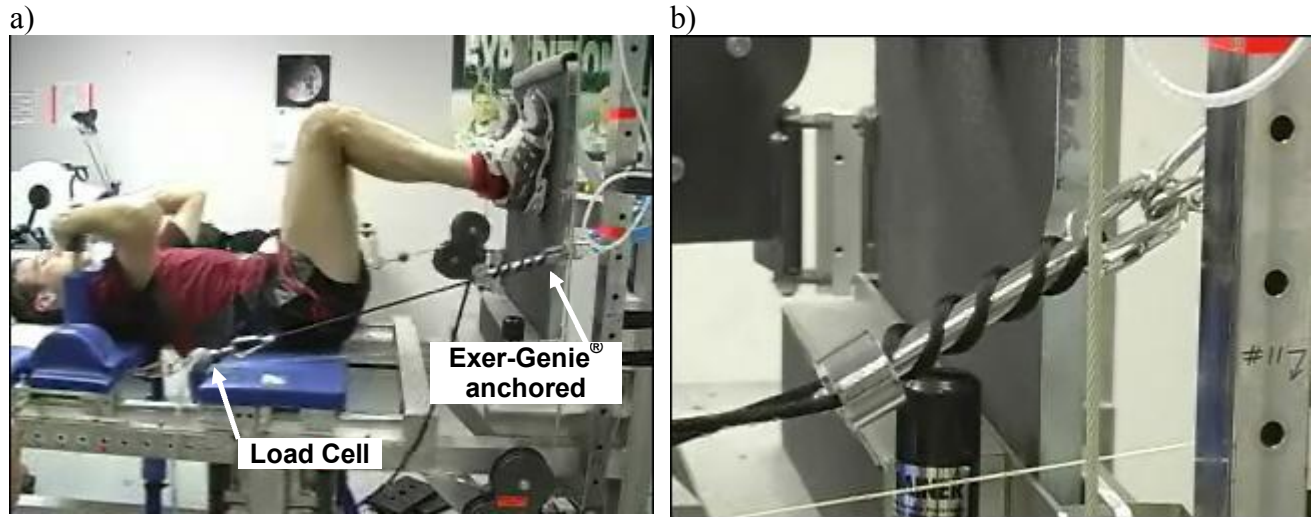
a)

b)

Figure 2.   Test setup for load characterization: a) subject, load cell, and anchor point on HEF frame; b) close-up of test article.

For each load setting, a single subject performed a slow leg press extension, starting with his knees bent at 90 degrees, and then extending until his legs were close to full extension. The movement was performed slowly (3 seconds or more per extension) to minimize the influence of inertial or other dynamic effects. The opposite (free) rope end was supported by an operator and guided into the rope opening at the base of the Exer-Genie®, while care was taken to not apply tension and to guide the rope into the hole smoothly so that it did not wrap around the hole edges and create additional friction. Once the extension was completed, the subject returned to the 90-degree knee-flexed position and the operator switched the rope ends attached to the load cell at the shoulder support sled. The extension movement was repeated while pulling the opposite rope end through the Exer-Genie® and completing the cycle. During the movement, the load measured by the load cell was recorded by a laptop computer using LabView (National Instruments, Austin, Texas) data acquisition software at a sample rate of 120 Hz.

Resistive Exercise Protocol

The resistive exercise protocol is listed in Table 3. All exercises consisted of 2 sets of 10 sub-maximal repetitions per muscle group. The one-repetition-maximum (1-RM) values for each subject (on which all testing values were based) were obtained in a related study, the Horizontal Exercise Fixture (HEF) hardware evaluation, conducted by ECP within the 6 months preceding the resistive

exercise sessions in this study. Most exercises entailed the subject performing an initial warm-up set at 50% of 1 RM and a subsequent set at 75% of 1 RM. The resistances for the squat exercise were intentionally lower (40% and 60% 1 RM) for comfort and safety reasons. In this exercise, the subject was required to hold onto the Exer-Genie® handles, whereas in the original 1-RM assessment on the HEF, the load was applied at the subject's shoulders. Thus, in the case of the Exer-Genie® squat, the maximum load lifted was limited to 60% of 1 RM to avoid encountering limitations in handgrip strength.

Table 3 – Exer-Genie® resistive exercise protocol.

Type of Exercise	Sets	Repetitions	Resistance
Squat with upright row	2	10	40% and 60% 1 RM*
Alternating chest press	2	10 per arm	50% and 70% 1 RM*
Alternating back row	2	10 per arm	50% and 70% 1 RM*
Alternating hip flexion	2	10 per leg	50% and 70% 1 RM*
Alternating hip extension	2	10 per leg	50% and 70% 1 RM*

* 1 RM = one-repetition maximum, based on previous testing in a related study.

Subject Questionnaire

After completing the exercise sessions, the subjects completed a questionnaire containing 11 statements related to the device's performance and handling qualities. The subjects rated their agreement with each statement in accordance with the following scale:

1- Strongly Disagree   2- Disagree   3- Neither   4- Agree   5- Strongly Agree

The specific statements are provided in Table 4 in the next section.

Results

Aerobic Exercise

Cardiovascular aerobic capacity measurement results from both aerobic sessions are shown in Figure 3 (a-c). These results illustrate that subjects were able to achieve a peak heart rate of approximately 70% of maximum with both protocols, although average heart rate was approximately 60%. VO_2 measures reflect this observation, with peak oxygen consumption of 65 ± 6 and 62 ± 4 % for continuous rowing and circuit training respectively and average VO_2 values of 50 ± 5 and 41 ± 3% of maximum. These values again demonstrate that these sessions were in the aerobic training range but lower than would be desirable for maximum adaptation stimulus. In contrast, the peak and average respiratory exchange ratio (RER) for both continuous rowing and circuit training were greater than would be expected for an aerobic exercise session (i.e., RER = 0.85). The effects of local muscular fatigue may have contributed to this finding, as subjects complained of this during and after exercise.
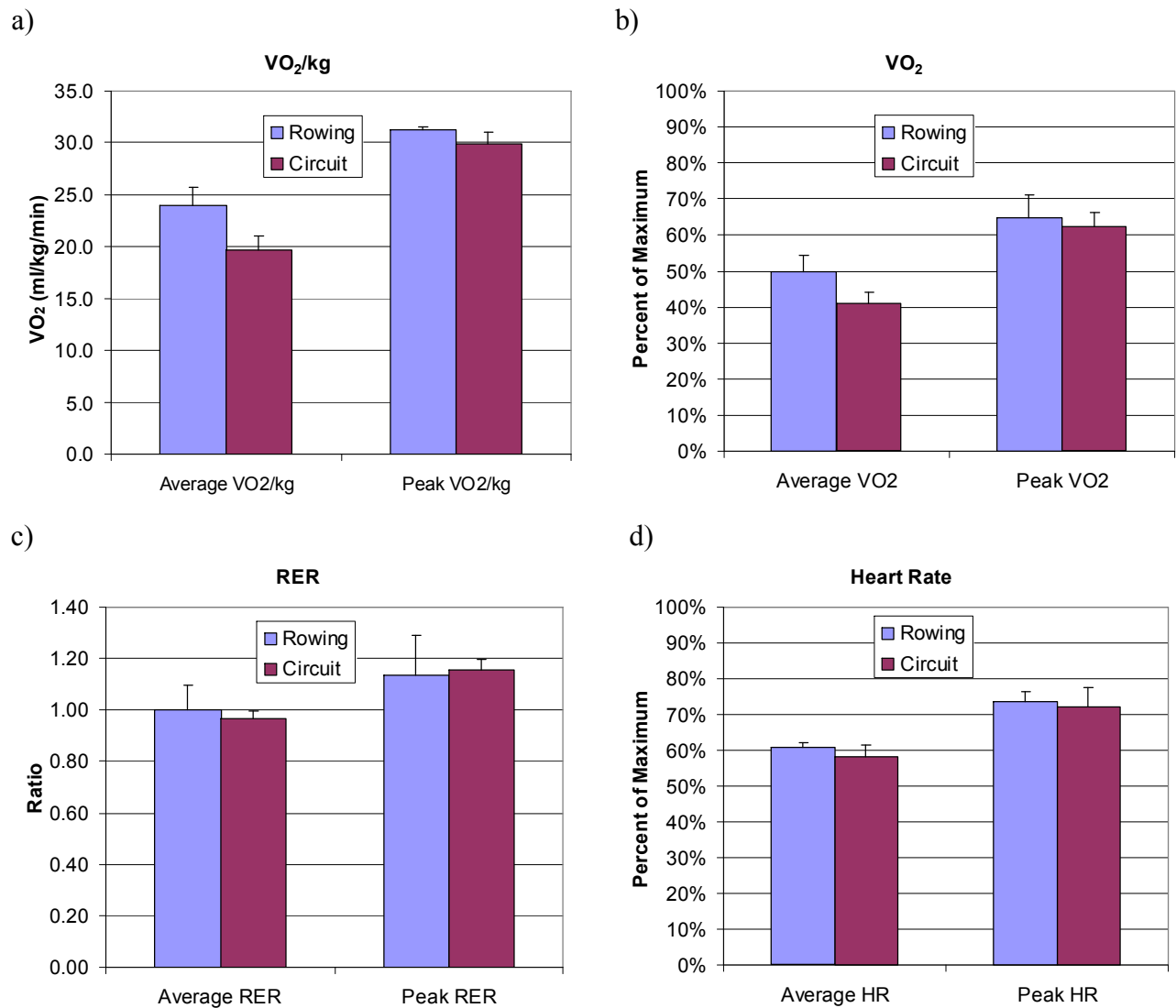
a)

VO$_2$/kg

b)

VO$_2$

c)

RER

d)

Heart Rate

Figure 3.   Oxygen consumption (ml/kg/min and percentage of VO$_{2max}$), respiratory exchange ratio (RER), and heart rate for the two aerobic conditioning sessions (rowing and circuit training) using the Exer-Genie®.

Limitations on work capacity with the device are largely attributed to local muscular fatigue (obtained by subjective feedback from all subjects), which diminished sustained exercise workloads. The inconsistent resistance within and between the same movements required a lower-than-optimal resistance setting that also contributed to a low workload. Throughout an exercise session the device became warm, which changed the friction-based resistance and thus necessitated changing the device's resistance settings. To change the settings, however, the subject or operator would have to hold on to parts of the device that had temperatures in excess of 100 degrees Celsius. Workloads were not subsequently altered at these times because of the risk of injury, which ultimately contributed to workloads being lower than optimal for the subject.

These lower workloads resulted in a sub-optimal aerobic stimulus. The integral design of the resistance (i.e., based on friction) portion of the device precludes it from being redesigned for future optimal aerobic exercise prescriptions.

Device Temperature Measurement

Device temperatures during the rowing session are shown in Figure 4. The metal core reached a peak temperature of just over 140 degrees Celsius. The outer shell reached a temperature of about 50 degrees Celsius.
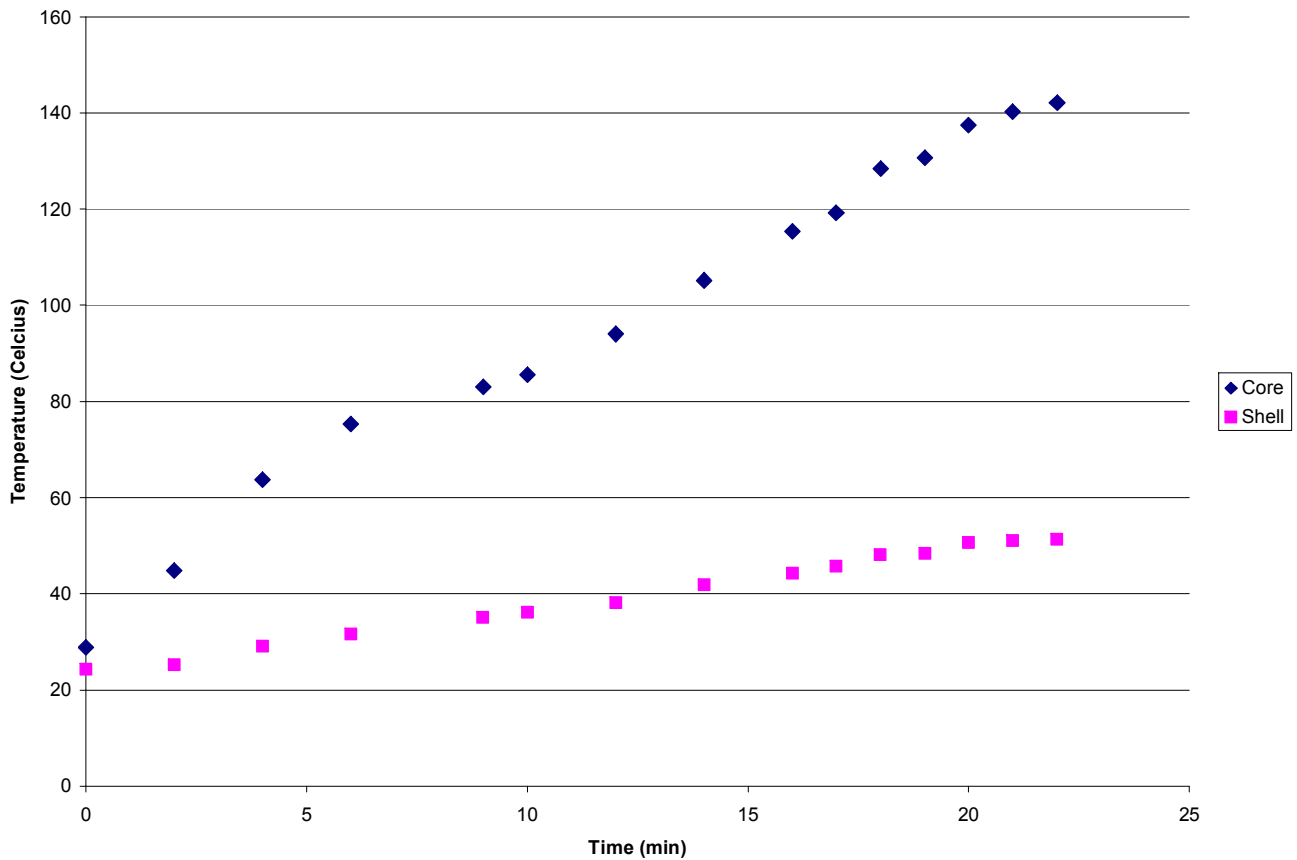

Figure 4.   Temperature profile for the Exer-Genie® device during the rowing exercise session.

Load Characterization

A typical load and displacement plot is provided in Figure 5 for a single representative load characterization trial.
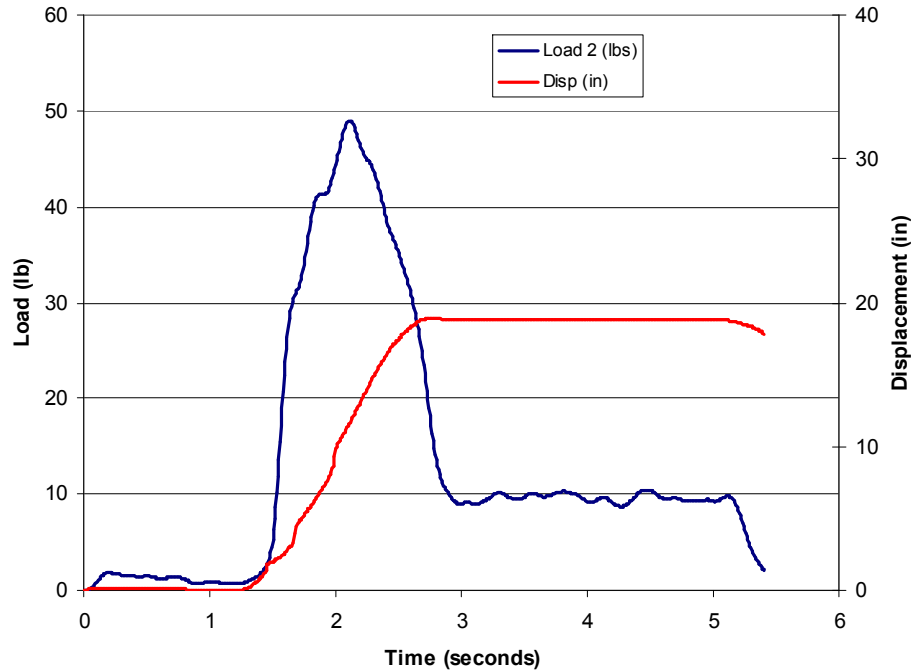
Figure 5.   Typical load (blue line) and displacement (red line) plot, in this case for the 10-lb load setting on Exer-Genie® A.

The load curve was truncated to the portion during which displacement was occurring as indicated by the displacement curve (Figure 6). This portion was then processed to obtain the average value (green line) and peak value (red circle).
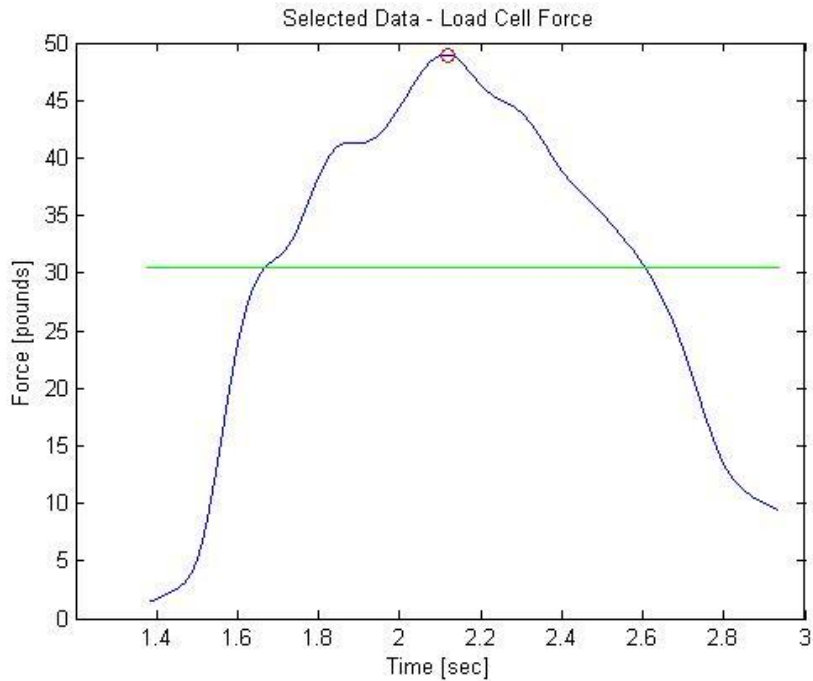

Figure 6.   Processed load curve showing average value (green line) and peak value (red circle).

Average and peak load values for the three units are shown in Figure 7. The average load values for each setting for each device are connected by dashed lines while the peak load values at each setting are connected by solid lines. The predicted load at each setting is represented by the solid red line. Only two average load values fell within one standard deviation of the predicted load. These occurred at the 250-lb and 310-lb settings for Exer-Genie® A. All remaining average and peak values were above the predicted load value. The smallest measured load to predicted load ratio was 0.9 for the 310 lb setting on Exer-Genie® A, while the greatest measured load to predicted load ratio was 11.0 for the 1-lb setting on Exer-Genie® A. The smallest absolute difference in load was 4 lb for the 10-lb setting on Exer-Genie® C, while the greatest absolute difference in load was 436 lb for the 110-lb setting on Exer-Genie® B.
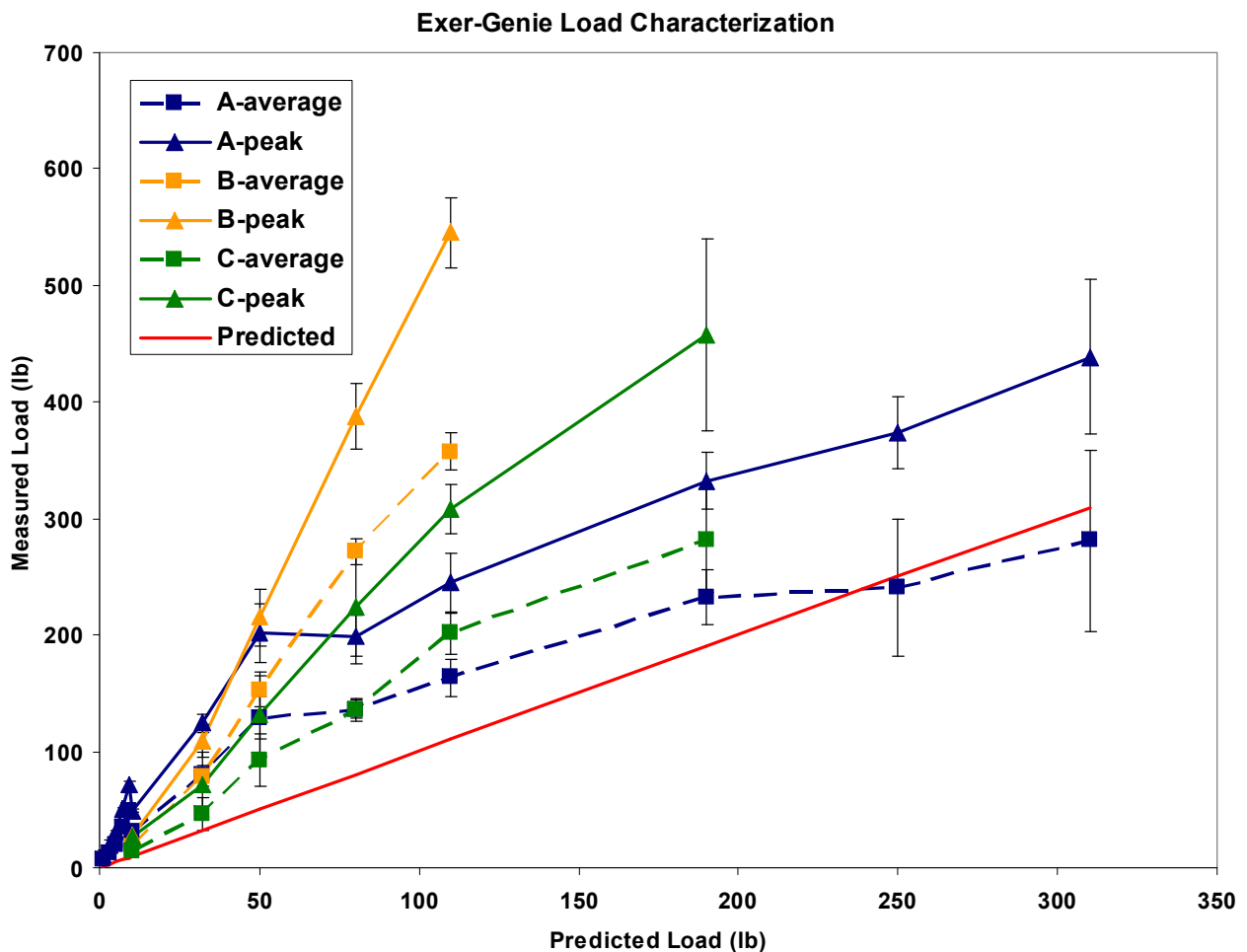

Figure 7.   Average and peak load values compared to scale values for the three units.

Resistive Exercise

All three subjects were able to complete all of the exercises in the resistive exercise protocol. Subjective evaluation of the resistive exercise performance of the device was captured using the subject questionnaire (next section) and additional subject comments (Appendix A). The subjects found that all exercises had some level of awkwardness compared to free-weight or gym-machine exercise. The least awkward exercise was the alternating back row and the most awkward were the hip flexion and hip extension exercises.

Subject Questionnaire

Subjects were asked to express their degree of agreement or disagreement with the statements shown in Table 4. The results are summarized in Figure 8. In general, the subjects disagreed with all statements, except for statement 11 (loads used were appropriate), which was neutral. The subjects strongly disagreed with the statements that the exercise closely resembled standard gym-type exercises or exercise equipment, that circuit training with the device provided effective aerobic exercise, and that the device felt comfortable and smooth to operate. The subjects disagreed with the statements that the rowing exercise resembled a rowing ergometer, that the rowing exercise provided an effective aerobic conditioning stimulus, that the resistive exercise provided an effective strength training stimulus, that it was easy to maintain proper form, and that the resistance felt consistent from one repetition to the next. Feelings of frustration were commonly reported.

Table 4 – List of statements provided to subjects in subjective evaluation questionnaire.

Statement 1	Rowing exercise closely resembled a standard rowing ergometer.
Statement 2	Circuit training session closely resembled a circuit training session w/ free-weights or standard gym resistance machines.
Statement 3	Resistive training session closely resembled resistive training w/ free weights or standard gym resistance machines
Statement 4	Rowing exercise provided an effective aerobic conditioning stimulus.
Statement 5	Circuit training session provided an effective aerobic conditioning stimulus.
Statement 6	Resistive training session provided an effective strength training stimulus.
Statement 7	I felt comfortable performing the exercise on the Exer-Genie®.
Statement 8	I found it easy to maintain proper form during the exercise.
Statement 9	Device felt smooth throughout the motion (resistance felt constant, little sticking or jerkiness).
Statement 10	Resistance felt consistent from one repetition to the next.
Statement 11	Loads that were used during the test were appropriate.

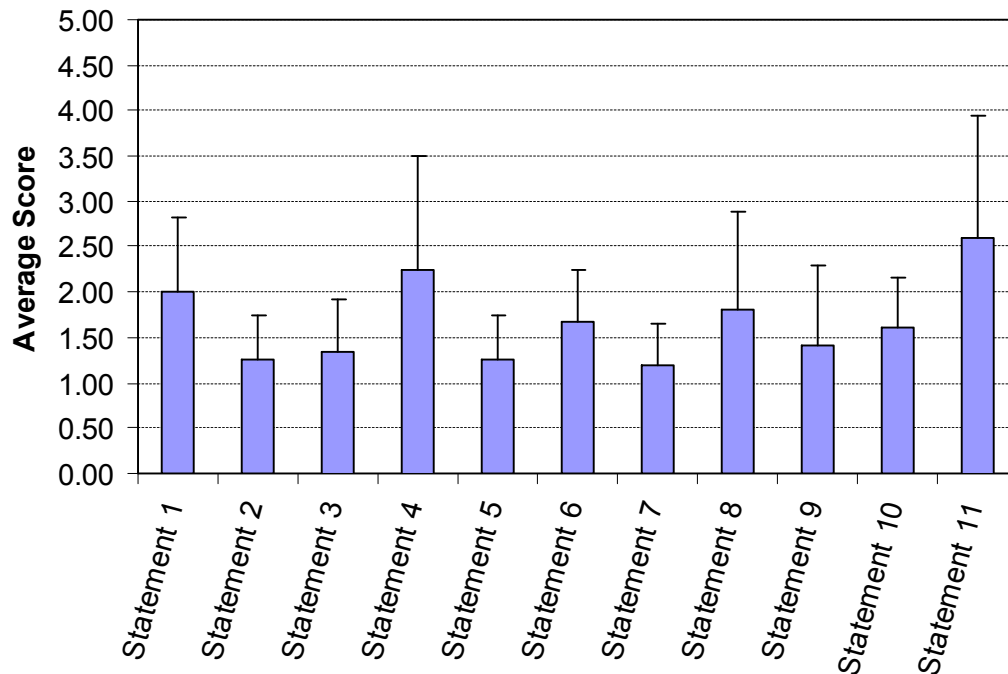**1 − Strongly Disagree   2 − Disagree   3 − Neither   4 − Agree   5 − Strongly Agree**

Figure 8. Summary of responses to Exer-Genie® subjective performance evaluation questionnaire.

Discussion

Aerobic exercise using the Exer-Genie® resulted in an elevated heart rate and increased oxygen consumption above resting levels and within expected aerobic training ranges. However, subject exertion did not reach levels considered by many to be optimal for providing an effective aerobic conditioning stimulus (2). In fact, recent studies demonstrate that intensities greater than 85% of maximum require less time per session and yield higher gains in aerobic performance (3). Furthermore, sustained rapid cyclic use resulted in the device core heating up to temperatures well above the boiling point of water, making it impossible to manipulate the device, or adjust the load, with unprotected hands since significant scalding would occur. Device manipulation with cotton- or polyester-based cloth was also not undertaken due to ignition safety concerns. This limitation was further compounded by the fact that the resistance at a given setting changed as the device heated up, thereby necessitating a change in load setting to maintain the same level of resistance throughout the same session.

The Exer-Genie® was shown to be capable of producing low and high levels of resistance, and a range of adjustability with several intermediate load levels. However, the resistance provided was greatly inconsistent with the printed scale on the device, in terms of both average resistance and peak resistance. In general, for the vast majority of load settings tested, the actual resistance was much higher than that predicted by the scale. Furthermore, the resistance differed greatly from device to device and even from one repetition to the next. A great limitation of the device is its inability to produce eccentric loading (muscle tension during elongation) since this has been shown to be of great importance during resistive training aimed at strength maintenance.

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The subjective evaluation and subject comments further underscored the limitations of the device. Subjects did not believe the device provided effective aerobic or resistive exercise. They were dissatisfied with the jerkiness of the rope movement, the inconsistency of load levels, and the awkwardness of device manipulation, especially exercises requiring frequent handovers from one rope handle to another, which in most cases required a spotter so that the subject could perform the exercise with relatively consistent timing. Subjects also did not believe that they could maintain appropriate form when completing the exercises, because of the awkwardness of the user interfaces and the inconsistent nature of the resistance.

Conclusion

The inherent resistance design of the Exer-Genie® device, which depends on friction, makes using it a safety and health risk from burn and possible musculoskeletal injury (through jerking movements and inconsistent loading between repetitions). This design also precludes it from being reconfigured to a more suitable device for future space flight use. For these reasons, the authors recommend the Exer-Genie® not be viewed as a potential aerobic or resistive exercise device for Constellation missions.

References

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Acknowledgements

Appendix A: Additional Comments

The following additional comments were provided by subjects:

- As resistive subject, movements had to be very slow and often with spotter holding the other rope in order for movement to be somewhat smooth, with out stops due to kinks in rope. Could not effectively perform hip flexion and extension while laying down (to simulate microgravity).
- As a resistive exercise device it is inconvenient. I had to put a lot of effort into it to get my heart rate up and that friction caused high heat so that it was dangerous to change the resistance for a new series. The ropes are awkward, cause rope burn, bind up and drop to the floor, and have a jerky movement. The resistance varied greatly, even while showing constant. The resistance was inaccurate when checked against other measurements. Overall grade is "not acceptable".
- The rowing exercise did provide a decent stimulus, but was just totally unrealistic because of the hand-off stuff. Chest press was difficult because the cords rubbed on your arms. Overall, you could piece together a semblance of a real workout, but not much more. It's not user friendly or practical in most cases.
- Even though I tried, it didn't feel like I was working very hard aerobically. I got blisters on my heels (while rowing). Also, it was awkward to row and then have to get the next handle from someone else. Squats were awkward.