MATH AND SCIENCE @ WORK

AP* PHYSICS Student Edition

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ARED – RESISTIVE EXERCISE IN SPACE

Background

Exploration provides the foundation of our knowledge, technology, resources, and inspiration. It seeks answers to fundamental questions about our existence, responds to recent discoveries, and puts in place revolutionary techniques and capabilities to inspire our nation, the world, and the next generation. Through NASA, we touch the unknown, we learn and we understand. As we take our first steps toward sustaining a human presence in the solar system, we can look forward to far-off visions of the past becoming realities of the future.

The International Space Station (ISS) is a research laboratory that has helped us expand our knowledge of human space exploration since 1998 when its construction began. Astronauts aboard the ISS do not feel the effects of gravity as we do on Earth. As the ISS orbits the Earth, both the vehicle and crew members are in a constant state of free-fall causing astronauts to experience a feeling of weightlessness. In this reduced-gravity state, it is easier to accomplish routine physical activities because they require less use of muscles. Since minimal to no exercise would result in muscle deterioration and bone density loss, astronauts are prescribed exercise routines by exercise and rehabilitation specialists and medical doctors. Astronauts are scheduled to exercise approximately two hours per day to maintain their health while on the ISS.

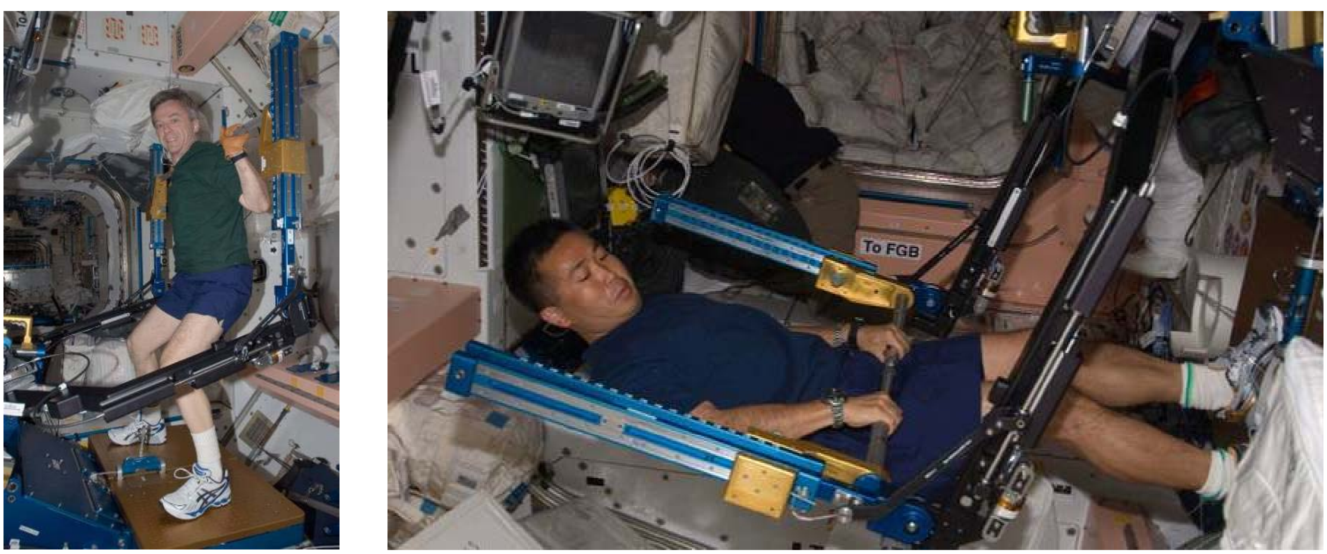


Figure 1: Canadian Astronaut Robert Thirsk (left) and Japanese Astronaut Koichi Wakata (right) use ARED onboard the ISS.

Numerous types of exercise equipment have been used in reduced gravity to evaluate and maintain astronaut fitness. The Advanced Resistive Exercise Device (ARED) allows the crew to engage in resistive exercise onboard the ISS by simulating the use of free weights. This device is used to maintain muscle strength, bone strength, and endurance. The resistive force is generated by two piston/cylinder assemblies with an adjustable load. For bar exercises, the load can be adjusted from 0 to approximately 2,670 N (0 to 600 lbs on Earth or in a 1 g environment). For cable exercises, it can be loaded up to approximately 670 N (150 lbs in a 1 g environment). Astronauts can perform 29 different free-weight style exercises including dead lifts, squats, heel raises, hip abduction and adduction, bench press, bicep curls, tricep extension, and upright rows.

The ARED is attached to the structure of the ISS with a Vibration Isolation System (VIS) installed between ARED and the ISS to limit forces transmitted to the ISS when astronauts are exercising. Springs, dampers, and shock absorbers in the VIS keep ARED centered in its operational volume and minimize the forces transmitted to the ISS to maintain an environment conducive to science.

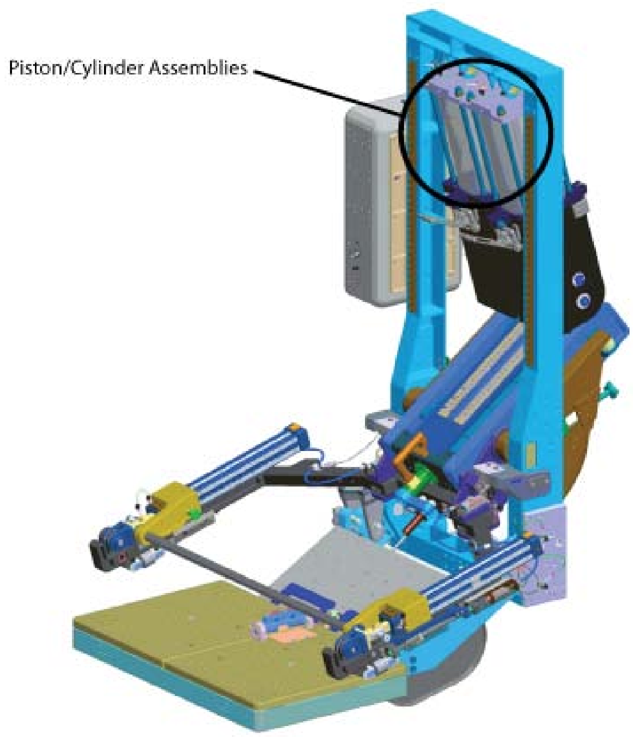


Figure 2: A model of ARED showing the piston/cylinder assemblies

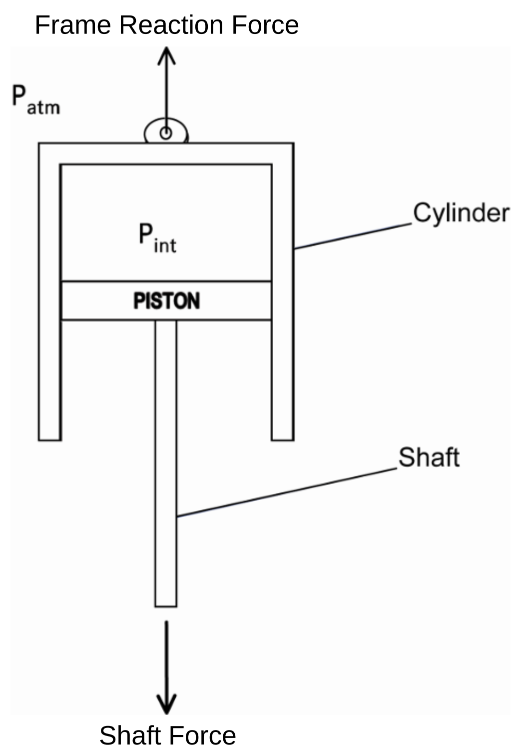


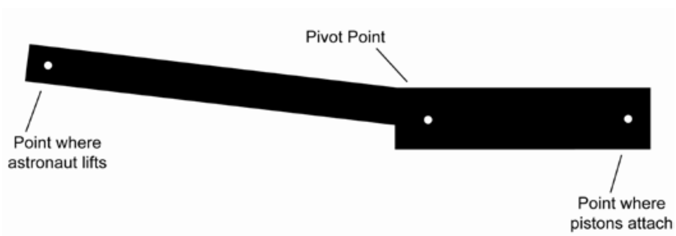
Figure 3: Cross-sectional force diagram of one ARED piston/cylinder assembly

Problem

The Advanced Resistive Exercise Device (ARED) uses two piston/cylinder assemblies of 20.3 cm diameter to provide a constant load which simulates the use of free weights in the microgravity environment of the International Space Station (ISS). The pressure inside the cylinder is essentially zero Pa (or vacuum) and the atmospheric pressure inside the ISS is 101 kPa.

A. Calculate the total force on the pistons.

B. Draw and label the forces acting on the lever arm below based on Figure 4. Assume that the angle formed by the bent lever arm and the pistons is 90°.



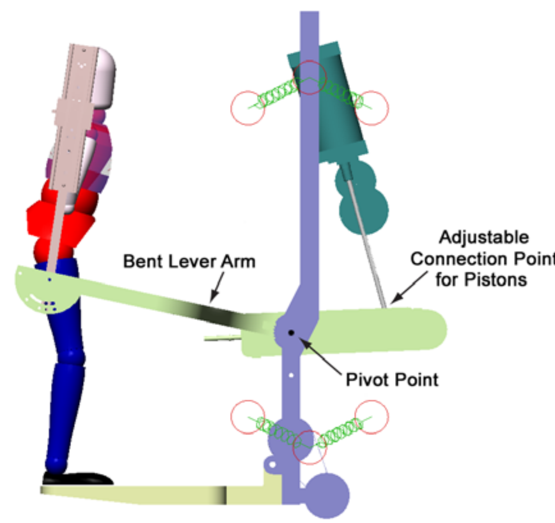


Figure 4: Side-view illustration of ARED showing bent lever arm

Refer to Figure 4. The distance of the astronaut to the pivot point is 1.22 m. The distance from the pivot point to the piston shaft connection point can be varied to adjust the exercise load for the astronaut. The maximum load available for the astronaut is 2,670 N.

C. As the distance increases between the pivot point and the piston shaft connection point, what is the effect on the force the astronaut experiences?

D. Determine the distance from the pivot point to the piston shaft connection point when the maximum load available for the astronaut is used.

E. The ARED is attached to the International Space Station (ISS) at a point on each side of the device with a Vibration Isolation System (VIS). While ARED is in use, the VIS isolates the energy created by the astronaut exercising from the space station structure. When the astronaut completes a workout, the VIS is manually locked to prevent inadvertent motion of ARED.

I. Suppose an astronaut forgets to lock out the VIS on ARED after completing a workout. While moving from one module to another on the ISS, one of the astronauts accidentally kicks ARED, displacing it 3.70 cm from equilibrium. The resulting force exerted by the 650. kg ARED through the VIS into the ISS structure is 4.50 N. Calculate ARED's resulting period of oscillation.

II. Explain why the ARED cannot be bolted to the structure of the ISS without the VIS. Hint: It is similar to the reason that a large group of people cannot walk across a bridge in step.