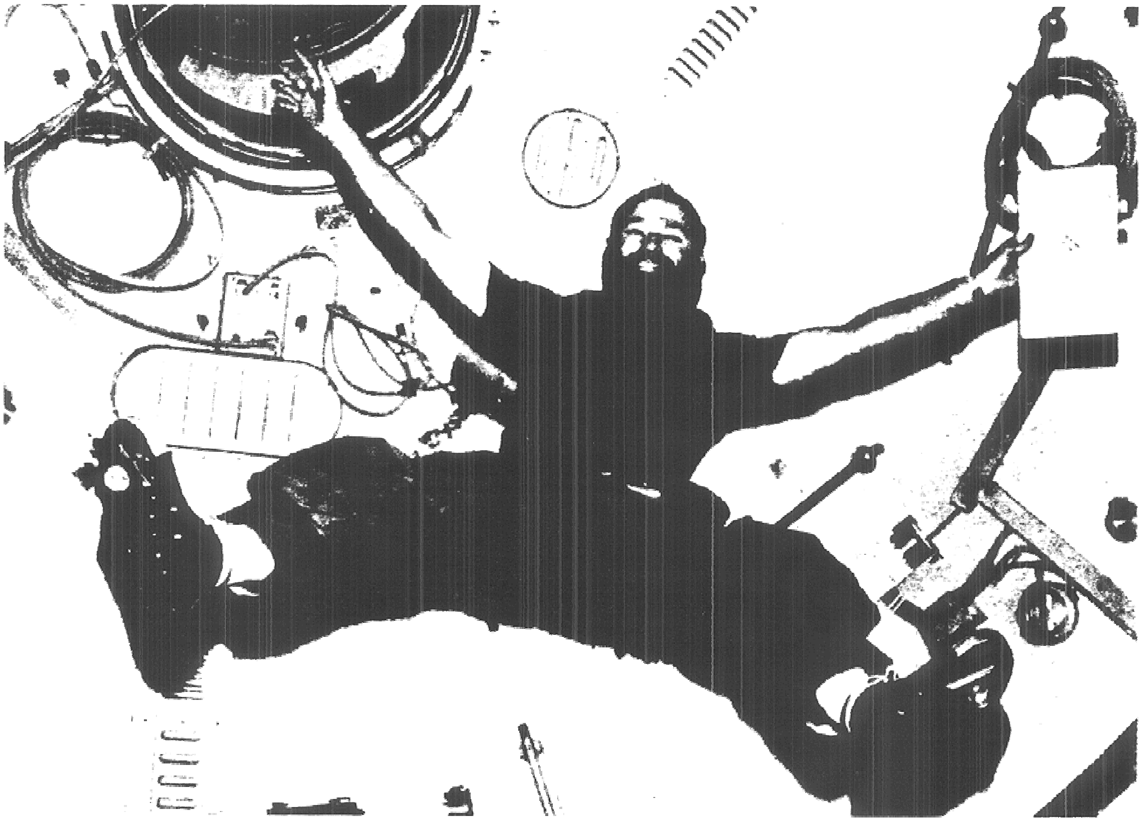
A Teachers Guide for the Videotape Segment 6

Starts at 10:19.0
Run Time 02:07:1

HUMAN MOMENTA



NASA
National
Aeronautics and
Space
Administration

FILM FOOTAGE FROM NASA SKYLAB MISSIONS

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I. Introduction

Since the time man first imagined what it might be like to be in space and have the ability to travel to other planets, he has been fascinated with the prospect. Even now that man has finally experienced space flight, the concept of weightlessness remains something which his body can accept but which his mind cannot stop testing.

On earth we live constantly in a gravitational field which supplies a force we call our weight. In many ways, this gravitational force confines our motion and the motion of objects about us. What would it be like in a reference frame where we were weightless?

At first we might be clumsy, finding difficulty in controlling our limb and body motion much like a newborn colt has difficulty in standing for the first time. Then we would learn through experience to move about slowly and to control our body motion. Before long we would be moving about in a normal manner having adjusted to our new environment through trial-and-error experimentation.

The films of the Skylab Missions show this adaptive procedure for each of the three crews that inhabitated the laboratory. But the adaptation did not end with a mastery of body movements through the orbital workshop; it included many let's-see-what-would-happen-if experiments. The astronauts, as they try to get a better feel for their new environment, express the delight they experience.

As the Skylab spacecraft orbited the earth in a nearly circular orbit 240 miles above the surface, it provided a roomy laboratory for scientific investigations of all types. Although the astronauts were primarily interested in research programs concerned with astronomy and the weightless effects on biological, chemical, physical, and metallurgical processes, they could not resist the temptation to exploit their weightless environment and in doing so illustrated many of the basic principles of physics in a most convincing way. Two of these principles, The Conservation of Linear Momentum and the Conservation of Angular Momentum, are dramatically demonstrated in the movement of the astronauts as they tumble, rotate, twist, and translate in the weightless and nearly frictionless confines of Skylab.

II. Background Physics

Three concepts from physics can be discussed in connection with this film.

1. The Conservation of Linear Momentum - This physical principle states that "In the absence of any net external forces (like weight, friction, force from a wall, etc.) the momentum (product of mass and velocity) of a body will remain constant or unchanged."

2. The Conservation of Angular Momentum - This physical principle states that "In the absence of any net external torques, the angular momentum (product of the moment of inertia and angular velocity) of a body will remain constant or unchanged."

3. The Center of Mass - This is a unique point located within or near a body such that the body as a whole behaves as if all the mass were concentrated at that point. When a body is moving and rotating through space with no forces acting, its motion may be described simply by saying:

    a. Its translation through space is identical with that of the center of mass.
    b. Its rotation occurs about an axis passing through the center of mass.

III. Film Synopsis

The film opens with scenes of astronauts moving in the direction of the long axis of the Skylab.

Film Section 1. Title -

"Initial Conditions: a. Translation--Yes
b. Rotation--Yes."

This film section illustrates the most complex motion shown in the film. In short sequence, the astronaut starts (initial conditions) with a movement of his center of mass through space (translation) and a rotation about the center of mass (rotation). These two degrees of movement are, in this case, quite independent of one another and may be considered separately.

As the motion of the astronaut proceeds, the movement of his center of mass through space (translation) is along a straight line and his linear momentum is constant, even though he may be rotating, as illustrated in Figure 1.

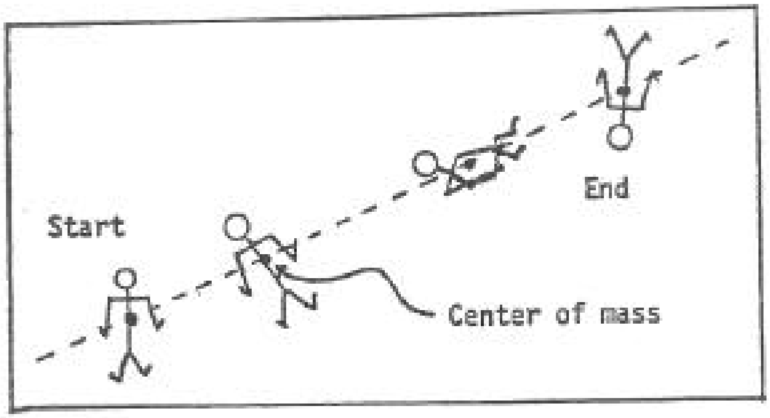

Figure 1. TRANSLATING Astronaut showing straight line motion of his center of mass.

Likewise, the rotation of the astronaut may be considered without regard for the translation as discussed above. The rotation, however, is more complicated because the angular momentum of a rotating body is the product of a moment of inertia and an angular speed. Considering the astronaut to be rotating at the start, he will have angular momentum and this angular momentum will remain constant as he moves through space if he does not encounter forces from surrounding objects. You will note changes in rotation rate as the astronaut changes his moment of inertia by tucking, bending, or making other changes in body limb orientations, as illustrated in Figure 2, but his angular momentum is constant.

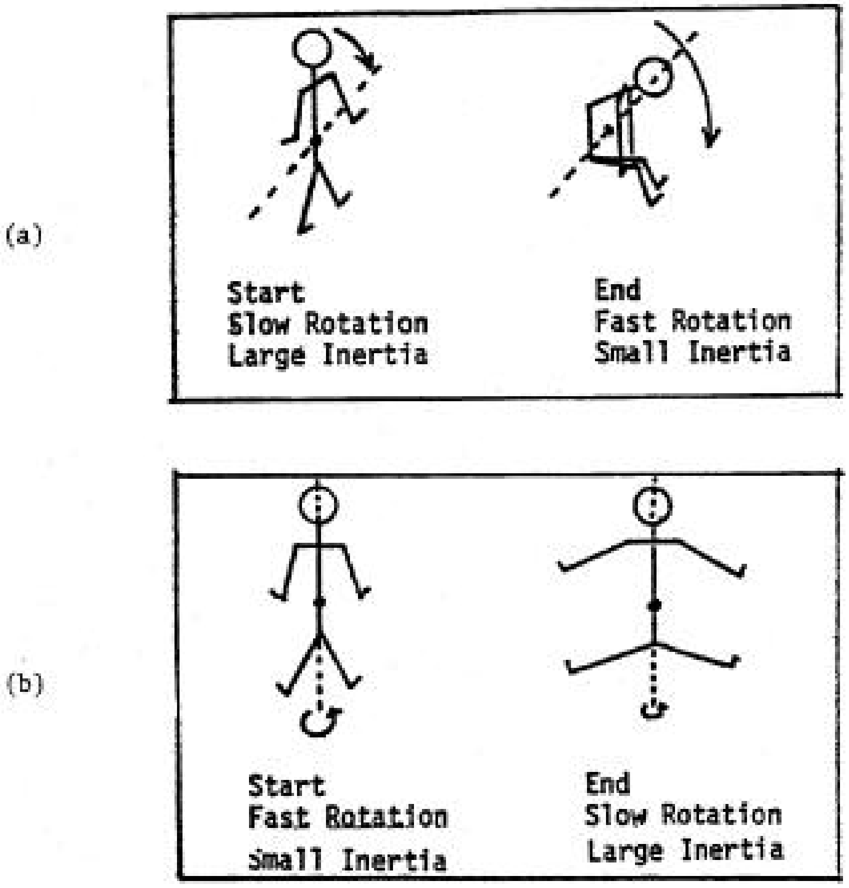

Figure 2. Astronaut with constant angular momentum (a) somersaulting about his short axis and (b) rotating about his long axis.

This section of the film includes the following scenes:

1. Astronaut Allen Bean somersaults, spins and twists from the dome of orbital workshop (OWS) to the grid floor.
2. Astronaut Jack Lousma somersaults from the dome of the OWS.
3. Astronaut Owen Garriott somersaults towards the dome of the OWS.

4. Astronaut Garriott pushes off from the right side and spins across the OWS. He decreases his spin rate by extending his arms and legs.

5. Astronaut Garriott pushes off from the left and spins across the OWS. He decreases his spin rate by extending his arms and legs.

<u>Film Section 2</u>. Title -

"Initial Conditions: a. Translation--Yes
b. Rotation--No."

In this film sequence, the astronaut's center of mass is initially moving and will continue to move along a straight line throughout the sequence.

The astronaut, however, is not rotating initially and therefore has no angular momentum. As you observe him twisting and turning this time, note that each attempt to twist will leave him with no net rotation. For example, with no initial rotation, an attempt to twist his arms one way will result in his lower body twisting in the opposite direction. The net result will be <u>no rotation</u>, although some reorientation may occur. Two possible reorientation maneuvers are illustrated in Figures 3 and 4.

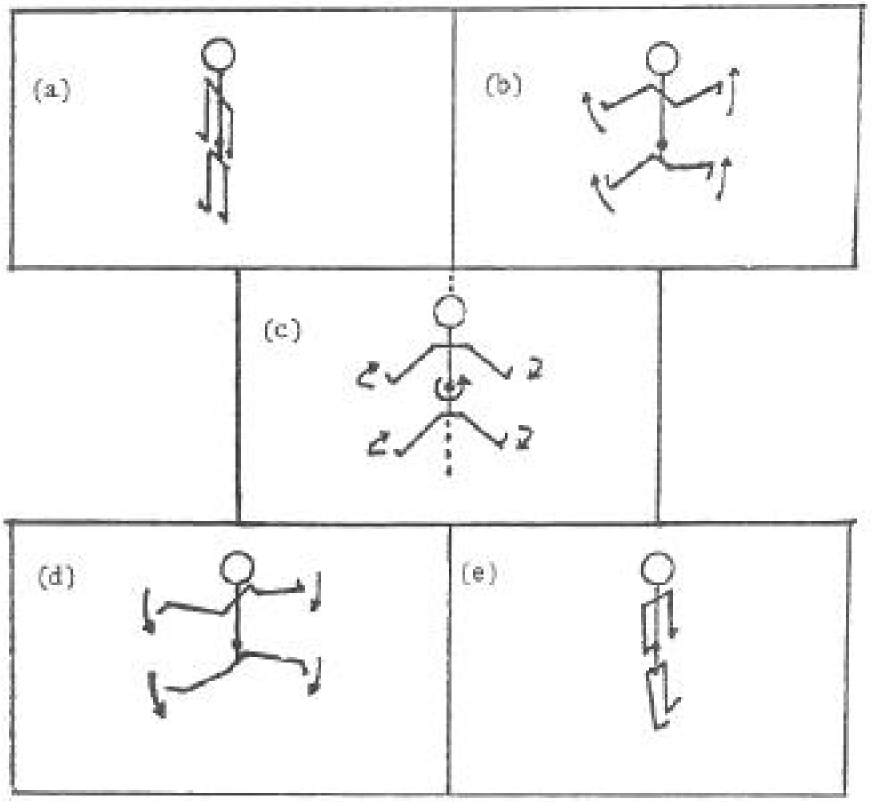

Figure 3. Astronaut with no initial rotation changing his orientation about his long axis. (a) Start; no rotation. (b) Arms and legs move straight out and back. (c) Arms and legs rotate one way; body rotates in opposite direction. (d) Rotation stops and arms and legs move straight down. (e) Body has no rotation but a new orientation.

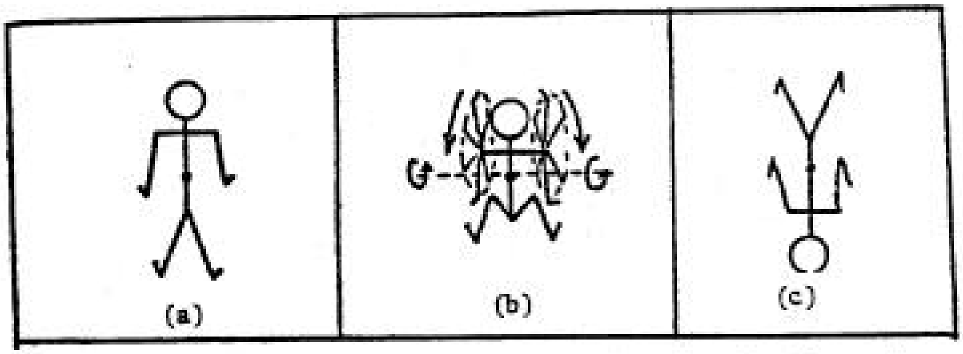

Figure 4. Astronaut with no initial rotation changing his orientation about his short axis. (a) Start. (b) Arms rotate one way, body and legs rotate in opposite direction. (c) End; no rotation but new orientation.

The section of the film shows Astronaut Garriott gently pushing off from the dome of the OWS with no initial rotation. Notice how any rotation of one part of his body is compensated by counter-rotation of another part of his body.

Film Section 3. Title -

"Initial Conditions: a. Translation--No
b. Rotation--No."

In this final sequence, the astronaut will be perfectly at rest at the beginning, and his linear momentum and the angular momentum will remain zero throughout. The center of mass will remain stationary, and no movement by the astronaut will result in any net translation of his center of mass.

This section of the film shows Astronaut Joseph Kerwin being very carefully placed near the center of the OWS by his fellow Astronaut, Conrad. You will see the care that must be used to get Joe Kerwin completely at rest at the beginning of this sequence. Then Astronaut Kerwin performs a series of body maneuvers. At the end of these maneuvers he is rescued from his isolated position by a helping hand from Conrad.

IV. Suggested Activities

The following activities will prove meaningful for students studying the three physical principles outlined previously in these film notes.

TO ASSIST IN THE CHOICE OF ACTIVITY, THEY HAVE BEEN PLACED IN ORDER OF INCREASING DIFFICULTY.

Equipment necessary for these activities includes the following:

1. Projector with "stop-action" and film
2. Sheets of white paper, approximately 12" x 18"
3. Stop clock, 1/10 second accuracy
4. Metric or English ruler

A. Activity One - DESCRIBING THE MOTION OF THE CENTER OF MASS.

Instructions

1. Using masking tape, tape the paper to a wall to use as a screen and allow the film to run through to the end. As the film runs, make special note of section 1, scenes one through five, showing body translation and rotation. As the translation continues, make note of the center of mass motion. (For assistance in locatin the center of mass, see page 2 of these film notes.) Make special note of scene two showing Astronaut Allan Bean slowly translating and rotating downward from the dome hatch.

2. As the film runs through for the second time, still frame the translating and rotating astronaut in scene two at least four times. During the first still frame, select and carefully mark a reference point (like the position of the dome hatch) on your screen, and mark the approximate position of the astronaut's center of mass.

3. Allow the film to run several seconds and still frame again. Whil the frame is still, move the paper screen so that the reference point coincides with the image now formed on the screen. After realignment, again mark the position of the astronaut's center of mass. Repeat this procedure for at least two more trials giving 4 center of mass positions.

4. After you have taken your data, use a ruler to connect the center of mass points. If some care was taken in the location of each center of mass point, the plotted points should lie on the same straight line. (See physical principles 1 and 3, pages 1 and 2 of these film notes.)

5. Repeat this procedure for other scenes showing a translating astronaut. Note that the motion of the center of mass is determined at the beginning of the sequence (a push off a wall for example); the astronaut moves with constant velocity in a straight line until the end of the sequence.

B. Activity Two - DESCRIBING THE ROTATION OF A BODY ABOUT ITS CENTER OF MASS.

Instructions

1. Allow the film to run through again, this time watching closely the rotation of astronaut Owen Garriott in scenes three, four, and five of film section one. Note that each sequence shows a change in rotational velocity due to a change in body moment of inertia somewhat like the change an ice skater makes in order to pirouette on earth. (Note the diagram on page 3 of these film not

2. As the film repeats this sequence, stop frame the film during the beginning of a fast rotation, noting the position of the astronaut's limbs. As the film is allowed to run, start the timing clock.

3. Attempt to count the number of complete rotations made by the astronaut until the projector and clock are stopped at the same instant, before the sequence has ended. While the frame is stopped, attempt to estimate the exact whole number of turns plus any fraction of a complete turn made by the astronaut during the time interval.

   Trial 1: Record the time and number of turns made by the astronaut for the fast rotation as described above.

   Trial 2: Record the time and number of turns made by the astronaut for the slow rotation sequence which follows.

   Trial 3: Allow the film to re-run and repeat Trial 1.

   Trial 4: Repeat Trial 2 for the slow rotation.

The data table shown below will be useful for organization of your data.

Trial	Sequence	Time (sec)	Number of Turns	Angle (Radians)	Rotational Velocity (rad/sec)
1	fast				
2	slow				
3	fast				
4	slow				

4. Now calculate the rotational velocity of the astronaut in radians/sec for each trail. A sample calculation below is given as a guide.

Rotation: 3 3/4 **revolutions**
Time: 3 **seconds**

a. 1 Revolution (360°) $= 2\pi$ **radians**
$= 3\ 3/4\ (2\pi)$ **radians**
$= 7.5\pi$ **radians**

b. Rotational Velocity $= \dfrac{7.5\pi \text{ radians}}{3 \text{ sec}}$

$= 2.5\pi$ **radians/sec**

C. Activity Three - REPEAT THE ABOVE PROCEDURE FOR ANOTHER SECTION OF THE FILM SHOWING ROTATION.

D. Activity Four - ESTIMATING AN ASTRONAUT'S ROTATIONAL INERTIA.

1. The rotational inertia (moment of inertia) of a long rod about its center of mass is

$$I_{c.m.} = 1/12\ Ml^2$$

where M is the mass in kilograms, and l is the astronaut's length in meters. The units of I are therefore kilogram - meter.^{2}

An astronaut's moment of inertia about his center of mass may be approximated by the relation given above when he is in a rigid, full-length, extended position. Using l = 1.8 meters (6 feet) and M = 75 kilograms, calculate the astronaut's moment of inertia in kilogram - meter.^{2}

2. Now calculate the astronaut's angular momentum about his center of mass. Use the result found in part 1 above plus the data taken from Activity 2, Trials 1 and 3, and use the relationship (for a rigid body),

$$L = I x \omega$$

or angular momentum = moment of inertia x angular velocity. (The units for angular momentum will be kilogram - meter^2/sec.)

E. Activity Five - FINDING THE FINAL ROTATIONAL INERTIA FOR AN ASTRONAUT WHO CHANGES HIS MASS ORIENTATION.

1. Again watch closely the rotation of astronaut Owen Garriott for which data was taken in Activity 2. (Scenes three, four, and five, of film section one.)

2. Collect from the previous activities the following data:

   a. Calculated initial angular momentum of the astronaut from Activity 4, part 2.

      L_i = ____________________ kilograms - m^2/sec

   b. The final rotational velocity of the astronaut from Activity 2,

      Trial 2: ω_f = ________________ rad/sec
      Trial 4: ω_f = ________________ rad/sec
      Average = ________________ rad/sec

3. The Conservation of Angular Momentum (Principle 2, page 1 of film notes) requires that the angular momentum not change for an astronaut who is free from all outside torques. This means that for the slow rotation, large moment of inertia (initially) to the fast rotation, small moment of inertia (finally) we may say that

$$L_i = I_i\omega_i = I_f\omega_f$$

Solving for the final rotational inertia gives

$$I_f = \frac{L_i}{\omega_f}$$

The values of L_i and ω_f are found in part 2 above. Calculate I_f and interpret the results.

F. Activity Six - ANALYZING BODY MOVEMENT WHEN THERE IS NO INITIAL MOTION.

1. Watch carefully the last section of the film which initially shows Astronaut Joe Kerwin being carefully positioned at rest near the center of the orbital workshop.

2. Attach the paper screen to the wall and run the film through for a second time. As Kerwin is being positioned, stop frame the action just as he is set free and mark his center of mass.

3. As the sequence continues, stop frame several times noting the position of his center of mass relative to the initial position of the center of mass. Is it possible for him to move his center of mass?

4. Many basic physics texts pose the problem of removing yourself from the surface of a frictionless pond. Now we may rephrase this question more realistically: How would you suggest that Astronaut Kerwin remove himself from the "at rest" position, assuming that no one is available to give assistance?

V. References

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