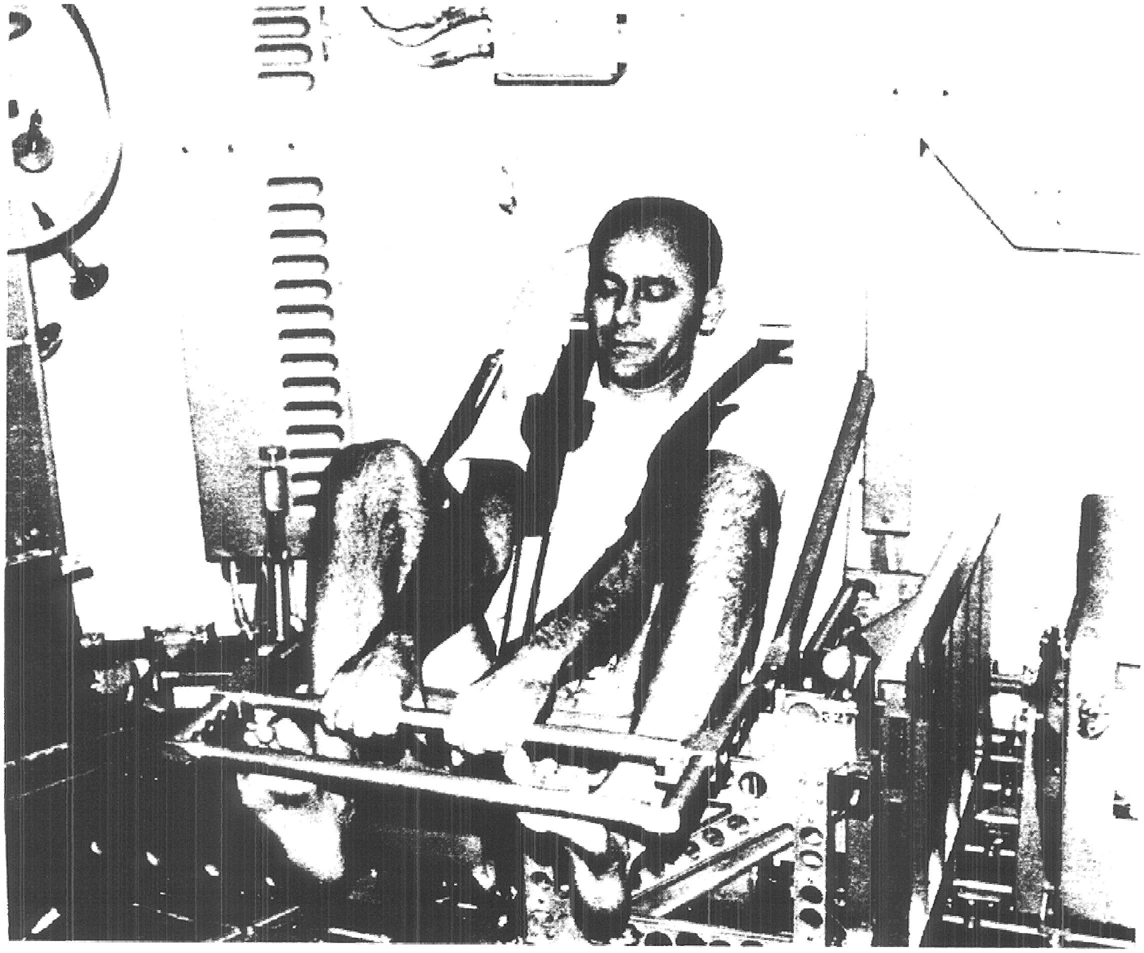
A Teachers Guide for the Videotape Starts at 06:11:
Segment 4 Run Time 01:59:

HUMAN MASS MEASUREMENT



NASA
National
Aeronautics and
Space
Administration

FILM FOOTAGE FROM NASA SKYLAB MISSIONS

Edited and Produced for the AAPT
by Thomas Campbell
and Robert Fuller

I. Introduction

Since the beginning of the manned space program there have been many questions asked concerning man's ability to survive or perform tasks while in space. While orbiting the earth in a nearly circular orbit, 386 kilometers (240 miles) above the surface, the unique Skylab facility provided a laboratory for the most complete study to date of man's physiological, psychological and social adaptative reactions to prolonged space travel.

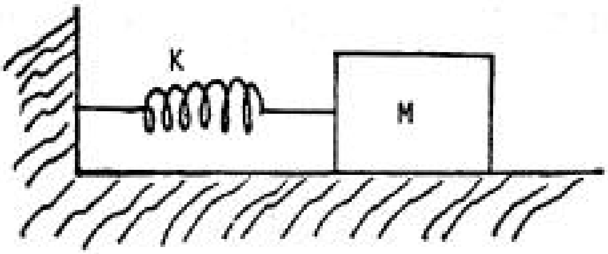
To investigate man's physiological adaption to space flight, 19 major experiments were designed and conducted during the three manned Skylab flights. Several of these experiments required accurate daily body mass measurement of each astronaut. How can mass be measured in the weightless environment of space travel? This film illustrates how basic mass measurements can be accurately determined in space, and shows how the astronauts' masses were measured by the Body Mass Measuring Device (BMMD) aboard Skylab.

II. Background

Most of us measure our body weight without giving much thought to the procedure. Our weight measuring devices rely upon the attraction of our body's mass to the earth; this force of attraction is called weight. The measure of this gravitational force is typically performed for us either by the extension of a calibrated spring (spring balance) or by the comparison of the force of attraction with that on a known or calibrated mass (double arm balance).

In an orbiting space laboratory like Skylab, however, the weight (the force measured by a spring balance) is zero. How, then, is an astronaut in space to measure the daily change of his body mass?

This fundamental question was answered with the development of the Body Mass Measuring Device known as the BMMD. The basic principle of this device involves the measurement of the period of vibration of an oscillating spring-mass system. The diagram below represents a simplified form of this device, showing a Hooke's law spring attached to a rigid support at one end and to a large mass at the other. (A Hooke's law spring is one which, when elongated or compressed from its equilibrium position, exerts a restoring force towards its undeformed position in proportion to the distance it is displaced. In symbols, $F = -kx$, where F is the force, x is the displacement from equilibrium and k is a positive constant of proportionality, or spring constant.)



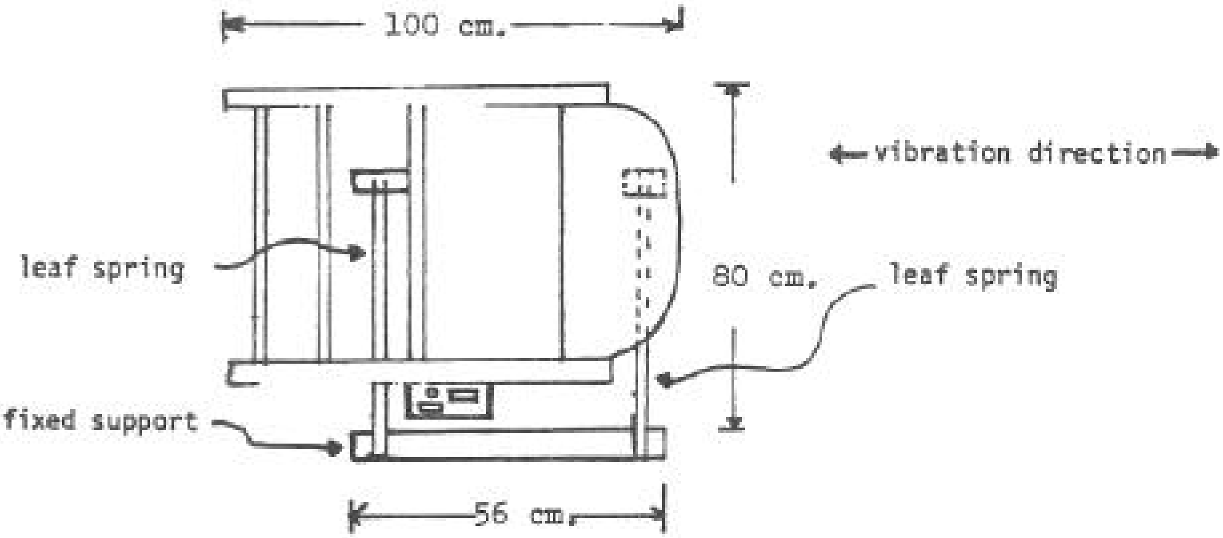
Using Newton's second law (Force = mass x acceleration) and the Hooke's law force, and neglecting friction, one can show that the time required for one complete back and forth oscillation (called the period of oscillation) is proportional to the square root of the mass of the oscillating object.

period---proportional to---square root of mass

$$\tau \quad \propto \quad \sqrt{M}$$

III. The Body Mass Measurement Device (BMMD)

The primary purpose of the BMMD was to support other biomedical experiments conducted aboard Skylab which required an accurate daily measurement of body mass. The BMMD, designed in the form of a chair, is capable of measuring the mass of human bodies up to 100 kilograms. The diagram provided gives dimensions and overall orientation of the BMMD.



TOP VIEW BMMD

The operating principle of this experiment involves the measurement of the period of vibration of the spring-mounted oscillating chair system. The chair in this system is supported by a leaf-type spring. The motion of the chair is simple harmonic motion to a first approximation.

For an astronaut in the BMMD, the total vibrating mass (astronaut and vibrating portion of the chair) would be given by

$$M_{total} = CT^2 \qquad (1)$$

where M is the mass in kilograms, T is the period of oscillation in seconds, and C, the proportionality constant, is related to the spring constant of the system ($C = k/4\pi^2$). To modify expression (1) to find the mass of the astronaut from the measured period of vibration, the equivalent mass of the chair must be subtracted, hence

$$M_{ast} = M_{total} - M_{chair} = CT^2 - M_{chair},$$

or

$$M_{ast} = CT^2 - B \qquad (2)$$

where B is a constant representing the effective mass of the vibrating portion of the chair. Both constants may be calculated from the calibration data given on page 6.

IV. Skylab Experiment M172 - Body Mass Measurement

Experiment M172, Body Mass Measurement, is designed to: 1) demonstrate body mass measurement in a zero-gravity environment; 2) validate theoretica behavior of the body mass measurement device; 3) support biomedical experiments M071 (Mineral Balance), M073 (Bioassay of Body Fluid), and M171 (Metabolic Activity) that require knowledge of the body mass of the crewmen.

The experimental equipment for M172 is the Body Mass Measurement Device (BMMD). This device consists of a seat, a spring loading system, and a timing system with a digital display. A latch is provided to release the seat from a fixed, spring-loaded position to permit oscillation. The time (period) value measured during the third, fourth, and fifth oscillations is read from the digital display. The timing system electronically times oscillations of the seat and provides the period data which can be converted into mass measurements. The digital display is composed of six light emitting diode numerical displays with monitoring range of 0.00000 to 9.99999 seconds. The six-digit readout measures the time period for three oscillations in seconds. After activation, the astronaut records the data from the digital display. These data are later voice transmitted to the ground.

V. Film Synopsis

The list below provides a brief annotated synopsis of the three major sections of the film.

SECTION 1:

Scene 1: "Astronaut Eating" - This sequence shows a typical eating scene in the Skylab wardroom featuring astronaut Gerald Carr as eater.

Title: "How do you measure your change in mass?"

Scene 2: "Astronaut Eating" - This section shows astronaut Carr being joined by astronaut Ed Gibson. The orientation of crew members and equipment illustrate the weightless environment of Skylab.

SECTION 2:

Title: "If you vibrate an object . . ."

Scene 1: "First Push-up" - This short scene shows a mass being vibrated, that is, astronaut Allen Bean doing what would appear to be a push-up. As you watch, remember that he is in a weightless environment. Watch the time required to complete the cycle.

Title: ". . .and its MASS is increased"

Scene 2: "Second Push-up" - This scene shows a mass (astronaut Jack Lousma) being added to the first mass and both being vibrated. The result is a longer period of vibration.

Title: "The period of vibration is increased. . ."

Scene 3: "Third Push-up" - This scene shows a third mass (astronaut Owen Garriott) being added to the first and second masses and the total mass being accelerated. Again the result is an increase in the "period of vibration."

SECTION 3:

Title: "Body MASS Measurement"

Scene 1: "Chair Entry" - The scene shows astronaut Jack Lousma entering the BMMD and straping himself in.

Scene 2: "Vibration" - After sequencing the digital counting equipment, the chair and the astronaut are oscillated and the oscillation time is counted for three periods.

Scene 3: "Digital Output" - A close-up shows the astronaut cycling the counting system and the resulting digital output.

Scene 4: "Data Recording and Leaving Chair" - This sequence shows an astronaut recording the oscillation period which converts easily to a mass measurement. The system is then turned off and the chair is vacated. Recorded data was later voice transmitted to earth.

VI. In-flight BMMD DATA from Skylab

The data provided below are actual, unaltered, in-flight data from Skylab Mission Two (Garriott, Bean and Lousma). Data were obtained in the following manner:

A. Calibration Data - Three rectangular containers with removable drawers (pictured on page 10) were weighed at Houston (weight given in first column) and then placed aboard Skylab for launch. While orbiting the earth, the astronauts attached these containers to the BMMD and the resulting periods were measured (time for three periods is given in the second columns).

B. Astronaut Data - Each day in space, crew members were required to enter the BMMD and to report their resulting three periods of oscillation. Selected times of oscillation and corresponding days of the mission are given for astronauts Garriott and Lousma.

A. Calibration Data (From mission day 211)

	Calibration Container* Houston Weight (lbs.)	3 Periods (Sec)
1	unloaded chair	2.70446
2	30.94	3.74937
3	52.65	4.33138
4	74.35	4.84393
5	99.05	5.36340
6	123.38	5.83326
7	147.50	6.26495

B. Astronaut Data

Astronaut	Day	3 Periods (Sec)
Garriott	210	6.035
Garriott	211	5.994
Garriott	212	5.988
Garriott	230	5.959
Garriott	247	5.952
Garriott	267	5.942
Garriott	268	5.942
Lousma	214	6.954
Lousma	263	6.899

(*Note: Although this procedure for using "Pounds equivalent Houston" is convenient in some respects, teachers and/or students may find it less confusing and therefore helpful to convert the Houston weight measurements to Mass in kilograms. This activity is suggested in Related Activities 1, page 6.)

Questions

1. What major factors would influence an astronaut's daily change in body mass?

2. Why were common bathroom scales (spring scales) not used for weight and mass measurements conducted aboard Skylab?

3. Are there any other ways to measure mass in a weightless environment besides the spring-mass system which was used? (Hint: Read about Newton's 2nd law in any basic physics textbook and formulate a procedure for measuring inertial mass.)

4. Would you expect the BMMD to work properly at the earth's surface? Explain your answer carefully.

Related Exercises and Experiments

1. Make a plot of the calibration data (page 5) on a full sheet of finely ruled graph paper showing (mass in kilograms) as the abcissa and (period in seconds)^2 as the ordinate. (Don't forget that the time intervals given are for three periods of vibration.)

2. Record the time measurement shown in the film and determine the mass of the astronaut from the calibration curve plotted in exercise 1.

3. In-flight astronaut data is given (page 5) for Garriott and Lousma for various days during their 59 day mission.

   a. Use the calibration curve plotted in exercise 1 and determine the mass of each astronaut on the days given.

   b. Plot a graph showing the mass of astronaut Garriott as a function of mission day. Comment on rate of loss of body mass at the beginning of the mission compared to the end.

4. If you were a Skylab astronaut what time measurement would you expect your body to produce if oscillated in the BMMD?

5. Construct a simple inertial balance from two blocks of wood (approximately 10 cm. x 5 cm.) and two hacksaw blades as shown in the sketch below.

Secure one end of the balance to a heavy table so the other end is free to vibrate freely.

Procedure

a. Displace the free end of the balance slightly sideways from its rest position and determine the resulting period of vibration. (For good accuracy, time the oscillations through 20 to 30 vibrations and divide by this number to find the time per vibration.)

b. Put a known mass (50-100 grams) on the free end of the balance and determine the new period of vibration using the technique suggested in part a. (Added masses must be rigidly attached and not allowed to slide. A small piece of putty or tape may be used for this purpose if it is not removed and is considered to be part of the balance.)

c. Repeat exercise b for at least three additional known masses, recording the period of vibration for each mass.

d. Make a plot of the data recorded on a sheet of graph paper showing (MASS in grams) as the abcissa and (period in seconds)^2 as the ordinate.

e. Place an unknown mass on the balance and vibrate to determine the period. Then do the following:

   1. Determine the mass of the unknown body from the graph constructed in exercise d.

   2. Determine the mass of the unknown body using an available laboratory balance and compare the resulting measurement to the value found above.

f. Try the balance in different orientations to the earth's gravitational field. Compare the results to the data found above.

g. Use a thumbtack to secure a styrofoam cup to your balance. Place a large ice cube in the cup and prevent its movement with some crumpled paper. (Be sure to wedge the ice cube tightly enough so that the ice must move with the motion of the cup.) Oscillate the system for 50 oscillations and determine the mass of the cup, paper, and ice. (What do you need to do to find the mass of the ice alone?)

h. Allow the ice cube above to melt in the cup. After the ice has melted, time the system again for 50 oscillations. Compare the time found to that found in part g. Discuss what the oscillation of the liquid does to the period of the balance.

References

Physics Content

1. Halliday and Resnick, Physics Parts I and II, John Wiley & Sons, Inc. (1967), Simple Harmonic Motion, page 348.

2. PSSC, College Physics, Raytheon Education Company, (1968), Simple Harmonic Motion, page 247.