Name:___________________________

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Jumping on the Moon

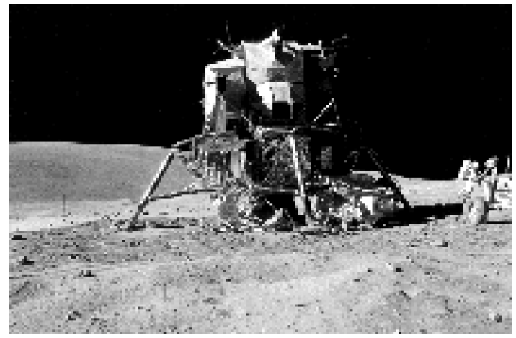


Figure 1: The Apollo 16 Lunar Module parked on the moon's surface

In April 1972 three Apollo 16 Mission Astronauts, John Young, Thomas Mattingly and Charles Duke, spent 71 hours on the Moon conducting scientific experiments. Among the video clips transmitted back to the Earth during the mission is a clip showing one of the astronauts jumping on the moon. Your mission in this activity is to verify the theoretical predictions for the acceleration of an object at the moon's surface. Newton's Universal Law of Gravitation ($F_{grav} = Gm_1m_2/r^2$), along with measurements of the size and mass of the Earth and of the Moon, predicts that the magnitude of free-fall acceleration near the Earth's surface is 9.8 m/s^2. This equation also leads us to predict that free-fall acceleration on the Moon is about 1/6th of that on Earth.

Theory is all well and good, but what really happens when someone jumps on the moon? The video clip you'll be using was adapted from the Official Apollo 16 Mission website at:

http://www.lpi.usra.edu/expmoon/Apollo16/A16_oview.html

Completing this mission will require you to obtain height vs. time data from the video clip and then use *analytic mathematical modeling techniques to*: (1) choose an analytic function that you think ought to describe the data; and (2) then choose coefficients that lead to an equation that models your data. In addition, you can explore what the coefficients of the analytic function tell you about the details of the astronaut's jump. For example, you should be able to use the coefficients to determine the astronaut's initial position and velocity as well as his acceleration.

Begin your investigation by viewing the video clip entitled <Apollo16_MoonJump.mov>. Open the movie in *QuickTime Player*. Play the movie or advance it frame-by-frame using the right arrow key (→) on your keyboard. Yup, the video clip looks pretty crummy. Remember that it was taken well over 30 years ago in a hostile environment and appreciate that it turns out to be analyzable.

1. Preliminary Questions

Note: You will receive **full credit for each prediction** made in this preliminary section whether or not it matches conclusions you reach in the next section. As part of the learning process it is important to compare your predictions with your results. **Do not change your predictions!**

(a) Objects, including astronauts, falling freely near the surface of a spherical planet or moon should have a constant acceleration. Use this assumption to determine which of the kinematic equations might describe the altitude of a jumper as a function of time in terms of his or her vertical acceleration constant (a_y), initial velocity (v_{0y}), initial position (y_0) and initial time t_0 chosen to track the jump. **Important Note:** In the Logger *Pro* software, the initial time t_0 is called the "Time Offset" and denoted by t_0.

(b) Why should the gravitational (free-fall) acceleration on the Moon be less than the gravitational acceleration on the Earth?

(c) On Earth a fit astronaut without a space suit and life support pack can leap straight up and leave the ground with an initial vertical velocity of about v_{1y} = 2.4 m/s and rise to a height of about h = 0.24 m above the point where he first loses contact with the ground. On the other hand, an astronaut on the moon is burdened with a space suit and life support pack to protect him from the rarified atmosphere and extreme temperatures. This gear weighs about 180 lbs on Earth. Under these conditions do you predict the Astronaut's initial vertical velocity is less, the same, or more on the moon than it would be on the Earth without the gear? Explain the reasons for your answer.

(d) Would the overall height of an astronauts jump on the moon with his gear be less than, the same as, or more than the height of his jump on the Earth without the gear? Explain the reasons for your answer.

2. Activity-Based Questions

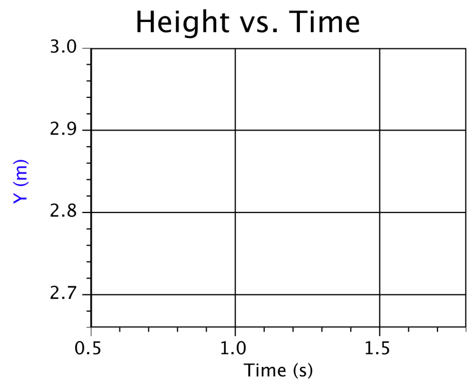
To determine the gravitational acceleration of an astronaut jumping on the moon you'll need to (1) obtain height vs. time data from a video clip of the jump; (2) choose an analytic function; and (3) use the Logger *Pro* ***analytic mathematical modeling*** feature to find an analytic equation that describes the jump.

(a) **Scale the movie and collect vertical data for the jump**: Open the Logger *Pro* Experiment file <MoonJump.cmbl> to obtain a video analysis setup with the Moon Jump movie inserted. Advance the movie to the first frame in which the astronaut's feet no longer touch the ground (frame 5 out of 17 as indicated in the upper left corner of the movie window).

In order to scale the movie and do an accurate video analysis, you should make the movie as large as possible by dragging your mouse outward from a corner of the movie. Assume that the astronaut is 6 ft tall (1.83 m). We added about 18 cm to his height to account for the thickness of his lunar overshoes and the distance between the top of his head and the top of his life support backpack. *This gives the astronaut an apparent length of 2.01 m*.
Set Scale using the length from the top of the astronaut's life support pack to his heels in frame 5. Setting the scale allows you to determine distances in meters, rather than pixels. If needed see ***Video Analysis > Set Scale*** in the help menu for details on how to do this.

To take y vs. t data after scaling, click on the ***Add Point*** tool (⊞) near the top right of the movie window. Next track the astronaut's jump by clicking on the same point on the astronaut in each frame from frame 5 (with t = 0.500 s) through frame 17 (where t = 1.700 s) to record the vertical position y of a known location on the astronaut (say the top of his life support pack.)

After you do complete the tracking of the astronaut's jump, reduce the size of the movie so you can see the y vs. t graph. Next, draw your data points in the graph frame shown on the right.



Note: If you mess up, you can close and re-open the movie or start over by using the ***Clear All Data*** feature in the Data menu. Alternatively, you can find the frame with the bad point, click on the ***Select Point*** tool (⧄) and then drag your bad point to the desired location.

(b) **Model your data**: Select the data (frames 5 through 17) that you want to analyze. Then select the ***Model*** feature in the ***Analyze*** menu. Based on the physical situation (where you expect the moon's gravitational acceleration to be constant) choose the type of equation that you think will best match the data (***Proportional, Linear, Quadratic***, and so on). Next click on the ***Time Offset*** box so the time the astronaut leaves the ground in frame 5, t_0, is automatically set to 0.5 s.

Use your knowledge of the physical situation to change the values of your coefficients intelligently. Write down the equation that you obtain when you think the model curve best matches the graph of your data. List the value of the ***Time Offset*** and the coefficients that you find match the data (t_0, A, B, C, D, etc.).

(c) Does the function you chose seem appropriate? In other words, does the model line match your data well? Yes or no. Explain your basis for deciding whether or not it matches well.

Note: If the model isn't satisfactory for any reasonable set of coefficients perhaps you are trying to use the wrong analytic function and should repeat the analysis in step 2(b) using another function.

(d) Use the kinematics equation you found to determine the vertical component of the acceleration of the astronaut, a_y. Explain how you determined a_y from your equation. **Hint**: The coefficient “A” has the same units but does not have the same value as a_y.

(e) Use similar considerations as you did in part (d) to relate other coefficients (B, C, and so on) to the astronaut’s initial velocity component, v_{1y}, and initial position, y_1, at time $t = 0.500$ s. Then list the values of astronaut’s initial velocity component, v_{1y}, and initial position, y_1 in the space below.

(f) Use the tabulated data to find the height, h, of the astronaut’s jump between frames 5 and 11. Show your calculations and list the height of the jump in the space below and compare it with your prediction in 1(d). In other words is your measured height less than, equal to, or greater than the 0.24 m for a typical jump on Earth.

(g) Suppose the astronaut has a weight on Earth of 190 lbs and is wearing a space suit that weighs an additional 180 lbs on Earth. What is the *y*-component of the force in newtons on the astronaut and his space suit during a jump on the Moon? Show your calculation. Does the force act upward or downward?

3. Reflections on Your Findings

(a) Compare the value of the astronaut’s vertical acceleration component to the theoretical value of $a_y = -1.63\ \text{m/s}^2$. Comment of whether or not the comparison is good enough for your to conclude that your experimental results help to verify Newton’s theory of Universal Gravitation.

(b) Compare the value of the astronaut’s initial vertical velocity component v_{1y} to the value you estimated in part 1(c).