LAB 6

Lab Handout

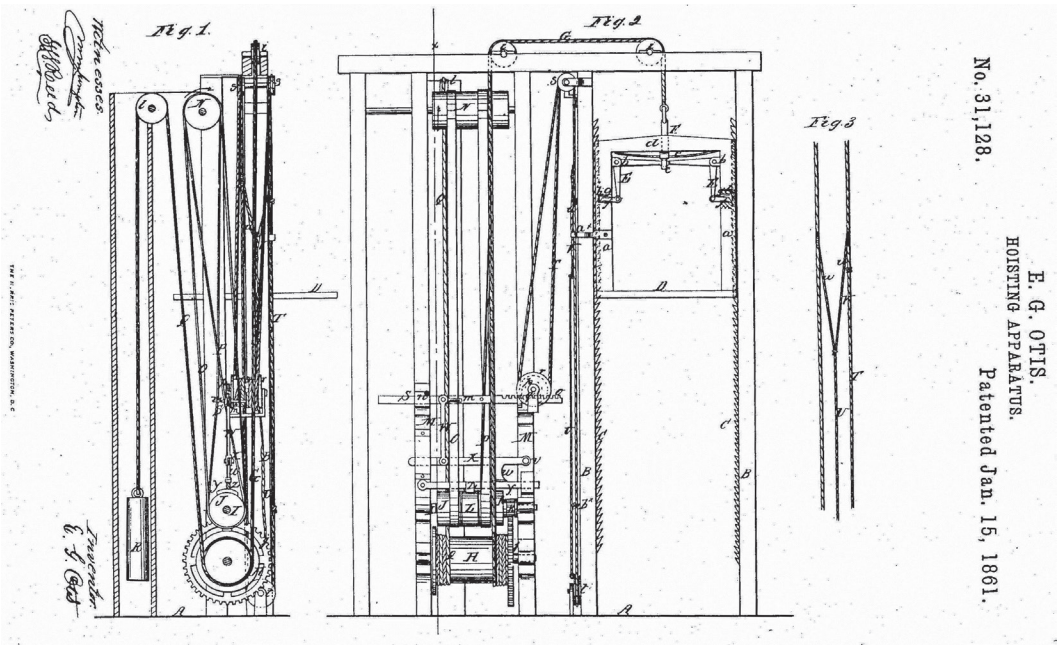
Lab 6. Forces on a Pulley: How Does the Mass of the Counterweight Affect the Acceleration of a Pulley System?

Introduction

There are many products that we now take for granted but were revolutionary when they were first invented. One of these products is the elevator. When elevators were first invented, there were numerous design problems related to moving the car up and down an elevator shaft. One of these problems was controlling the acceleration of the car as the mass of the car changed with the addition of people. In 1861, Elisha G. Otis patented a new design for an elevator; Figure L6.1 shows the patent drawing. To help moderate the acceleration of the car, Otis added a counterweight to the system. The counterweight is attached to the elevator via two pulleys at the top of the elevator shaft. This basic idea is still used in elevators today.

FIGURE L6.1

Drawings from Otis's 1861 patent application for an elevator



The basis for Otis's decision to add the counterweight to the system came from Newton's second law of motion, which states that the acceleration of a system is proportional to the net forces acting on the system. Acceleration is equal to the rate of change of velocity with time, and velocity is equal to the rate of change of position with time. A counterweight

works because the force of gravity pulls both the elevator car down and the counterweight down. Because the counterweight is on a different side of the pulley from the elevator car, the force of gravity on the counterweight acts in a different direction (relative to the pulley) than the force of gravity acting on the elevator car. Thus, the total acceleration of the elevator car and counterweight, in accordance with Newton's second law of motion, is equal to the sum of the forces acting on each part of the system divided by the total mass of the system.

Otis's elevator design is an application of one class of simple machines called pulleys. The first scientist to study simple machines was Archimedes. Although he did some research on the behavior of pulleys, his main focus was on the behavior of a simple machine called the screw. Renaissance scientists took up the mantle from Archimedes and began to explore the behavior of other simple machines, including wheels, levers, and pulleys. However, it was not until the work of Isaac Newton that scientists were able to mathematically model the motion of simple machines. This ability to use equations to describe the forces acting on a simple machine allowed physicists and engineers to apply these equations to the design of new systems that incorporated much more complicated machines. Otis, for example, applied the mathematical insights of Newton's laws to study pulleys that could be used to improve on the design of an elevator.

Your Task

Use what you know about forces and motion, systems and system models, stability and change in systems, and the relationship between structure and function in designed systems to design and carry out an investigation to explore the relationship between the mass of the counterweight and the acceleration of the pulley system. You will then develop a conceptual model that can be used to explain the behavior of this simple machine. Once you have developed your model, you will need to test it to determine if it allows you to make accurate predictions about its behavior.

The guiding question of this investigation is, ***How does the mass of the counterweight affect the acceleration of a pulley system?***

Materials

You may use any of the following materials during your investigation:

- Safety glasses or goggles (required)
- Ring stand
- Pulley
- Hanging mass set
- Electronic or triple beam balance
- String or fishing line
- Stopwatch
- Ruler
- Meterstick

If you have access to the following equipment, you may also consider using a video camera and a computer or tablet with video analysis software.

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Safety Precautions

Follow all normal lab safety rules. In addition, take the following safety precautions:

1. Wear sanitized safety glasses or goggles during lab setup, hands-on activity, and takedown.
2. Keep your fingers and toes out of the way of moving objects.
3. Wash hands with soap and water after completing the lab.

Investigation Proposal Required? ☐ Yes ☐ No

Getting Started

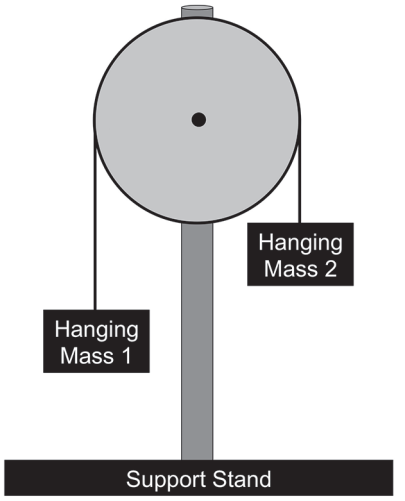
The first step in developing your model is to determine how the mass of a counterweight affects the acceleration of a pulley system. One way to gather the information you need is to create a physical model of the system to see how it behaves. In this investigation, you can use a set of hanging masses and a pulley attached to a support stand to study the movement of the entire system. Figure L6.2 shows how you can set up a pulley system using the available materials. Before you can design your investigation, however, you must determine what type of data you need to collect, how you will collect it, and how you will analyze it.

To determine *what type of data you need to collect,* think about the following questions:

- What are the boundaries and components of the system you are studying?
- How might the structure of the pulley system determine its function?
- Which factor(s) might control the rate of change in this system?
- How could you keep track of changes in this system quantitatively?
- What forces are acting on the system?
- What forces act on each mass?
- How will you determine the acceleration of the system?
- What will be the independent variable and the dependent variable?

FIGURE L6.2

Equipment used to explore the movement of a pulley system



To determine *how you will collect the data,* think about the following questions:

- What other factors do you need to control for as you collect data?
- What measurement scale or scales should you use to collect data?
- What equipment will you need to take the measurements?
- For any vector quantities, which directions will be positive and which directions will be negative?
- How will you make sure that your data are of high quality (i.e., how will you reduce error)?
- How will you keep track of and organize the data you collect?

To determine *how you will analyze the data,* think about the following questions:

- How could you use mathematics to describe a change over time?
- How could you use mathematics to describe a relationship between variables?
- What type of calculations will you need to make?
- What will be the positive convention and what will be the negative convention?

Once you have determined how the mass of the counterweight affects the acceleration of a pulley system, your group will need to develop a conceptual model to explain it. Your model also must include information about all the forces acting on each component or structure found in the entire pulley system.

The last step in this investigation is to test your model. To accomplish this goal, you can use different hanging masses (ones that you did not use earlier) to determine if your model enables you to make accurate predictions about the acceleration of the entire pulley system. If you are able to use your model to make accurate predictions about the function of the system based on the structure of that system, then you will be able to generate the evidence you need to convince others that your model is valid.

Connections to the Nature of Scientific Knowledge and Scientific Inquiry

As you work through your investigation, you may want to consider

- the difference between observations and inferences in science, and
- how the culture of science, societal needs, and current events influence the work of scientists.

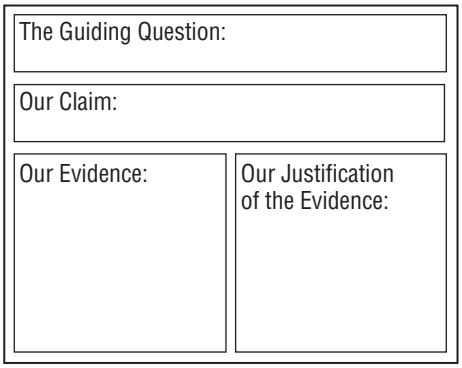
Initial Argument

Once your group has finished collecting and analyzing your data, your group will need to develop an initial argument. Your argument must include a claim, evidence to support your claim, and a justification of the evidence. The *claim* is your group's answer to the guiding question. The *evidence* is an analysis and interpretation of your data. Finally, the

justification of the evidence is why your group thinks the evidence matters. The justification of the evidence is important because scientists can use different kinds of evidence to support their claims. Your group will create your initial argument on a whiteboard. Your whiteboard should include all the information shown in Figure L6.3.

FIGURE L6.3

Argument presentation on a whiteboard



Argumentation Session

The argumentation session allows all of the groups to share their arguments. One or two members of each group will stay at the lab station to share that group's argument, while the other members of the group go to the other lab stations to listen to and critique the other arguments. This is similar to what scientists do when they propose, support, evaluate, and refine new ideas during a poster session at a conference. If you are presenting your group's argument, your goal is to share your ideas and answer questions. You should also keep a record of the critiques and suggestions made by your classmates so you can use this feedback to make your initial argument stronger. You can keep track of specific critiques and suggestions for improvement that your classmates mention in the space below.

Critiques about our initial argument and suggestions for improvement:

If you are critiquing your classmates' arguments, your goal is to look for mistakes in their arguments and offer suggestions for improvement so these mistakes can be fixed. You should look for ways to make your initial argument stronger by looking for things that the other groups did well. You can keep track of interesting ideas that you see and hear during the argumentation in the space below. You can also use this space to keep track of any questions that you will need to discuss with your team.

Interesting ideas from other groups or questions to take back to my group:

Once the argumentation session is complete, you will have a chance to meet with your group and revise your initial argument. Your group might need to gather more data or design a way to test one or more alternative claims as part of this process. Remember, your goal at this stage of the investigation is to develop the best argument possible.

Report

Once you have completed your research, you will need to prepare an investigation report that consists of three sections. Each section should provide an answer to the following questions:

1. What question were you trying to answer and why?
2. What did you do to answer your question and why?
3. What is your argument?

Your report should answer these questions in two pages or less. This report must be typed, and any diagrams, figures, or tables should be embedded into the document. Be sure to write in a persuasive style; you are trying to convince others that your claim is acceptable or valid!