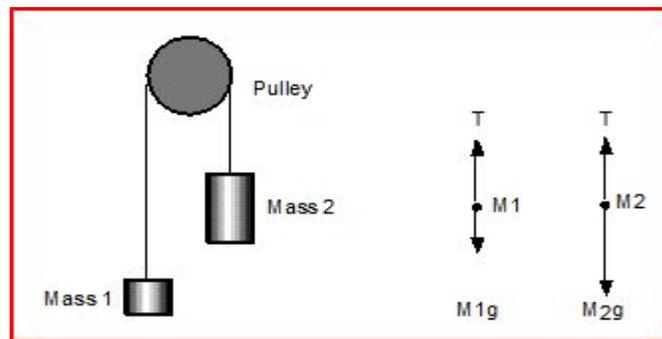

Atwood's Machine

Introduction

Newton's 2nd Law (NSL) states that the acceleration of an object depends on the net applied force and the object's mass ($F = ma$). In an Atwood's Machine, the difference in weight between two hanging masses determines the net force acting on the system of both masses. This net force accelerates both of the hanging masses; the heavier mass is accelerated downward, and the lighter mass is accelerated upward.

Consider the following free body diagram for a typical atwood's machine, where T is the tension in the string, $M_2 > M_1$, and g is the acceleration due to gravity:



Utilizing NSL we can solve for the net force of both masses, using the convention that movement up is positive and movement down is negative:

$$\vec{F}_{net} = M_1(+a) = T_1 - M_1g$$

$$\vec{F}_{net} = M_2(-a) = T_2 - M_2g$$

To find the theoretical acceleration of the system, both equations must be utilized to solve for \vec{a} in which assumptions are made concerning the string and pulley:

1. Pulley: Massless & Frictionless
2. String: Massless & Stretchless

Thus, $T_1 = T_2$ and T can be eliminated:

$$T_1 = M_1(+a) + M_1g = M_2(-a) + M_2g = T_2$$

$$a(M_2 + M_1) = g(M_2 - M_1)$$

$$\vec{a} = \frac{g(M_2 - M_1)}{(M_2 + M_1)} = \frac{\vec{F}_{net}}{M_{total}}$$

and NSL is recovered. A key observation must be noted: acceleration is always less than gravity. Can you see why?

Goal

To analyze the relationship among force, mass and acceleration using an Atwood's Machine.

Equipment

Photogate/Pulley System (Smart Pulley)
Mass & Hanger Set
Table Clamp
String

Setup

Computer

1. Log in, open Capstone, then click 'Hardware Setup':



2. Click the Digital Channel 1 button on the interface picture and add 'Photogate with Pulley'.

3. Click the new tab that appears called 'Timer Setup':



1. Uncheck all except 'Linear Speed'.
2. Ensure '**Spoke Arc Length**' is set to **0.015 m**. This setting is critical to the successful outcome of the lab. If this is not properly set, you will have to redo the entire lab!
3. Click 'Save'.

4. Click the 'Data Summary' tab:



1. Click 'Linear Speed' to highlight, then click the Gear icon to the right of it.
2. Click 'Numerical Format' and change the 'Number of Decimal Places' to 3, then click 'Ok'.

5. Click 'Graph' on the right hand pane and drag it into the center of the workspace.



6. Click 'Select Measurement' on the y-axis and choose 'Linear Speed'. You should now have a Velocity vs. Time graph.

Atwood's Machine

1. The Photogate/Pulley system should already be setup on the mounting rod. It is adjustable with thumbscrews for height clearance.
2. The string connecting the masses must ride in the groove of the pulley.
3. The mass hangers at each end are 5 g each. Do not forget to consider this when adding mass.
4. A foam landing pad is to be placed under the masses so they do not crash into the table.
5. Always stop Mass 2 from swinging before release and don't allow masses to collide during run.

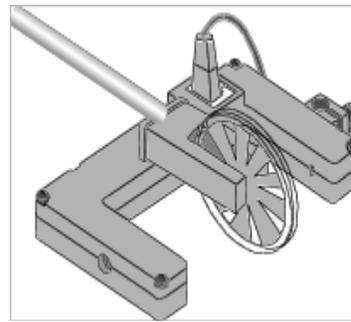


Illustration 2: Photogate with pulley.

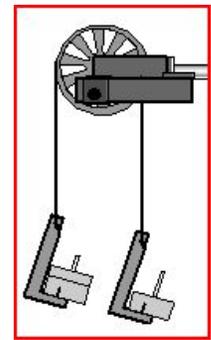


Illustration 1: Atwood's Machine with Mass Hangers

Helpful Hints:

1. Make sure you properly set the 'Spoke Arc Length'
 2. When you pull M_1 downward until M_2 is close to the pulley, be sure that M_1 is touching the pad and M_2 is not touching the pulley or photogate. This will protect the photogate, and ensure a soft landing for M_2 so that the masses won't bounce off the mass hanger.
 3. The direction in which the pulley rotates will determine the sign of linear acceleration. You may use its absolute value.
 4. Sometimes the string will pop off the pulley after M_2 lands. Be sure to reset it.
 5. Ensure the masses do not swing during the course of their travel. This can cause error in your data, and can also cause the masses to collide. If the masses collide, you must redo the run.
 6. If you start recording prior to release of M_1 , and/or before M_2 lands, your graph will have non-linear ends. If this happens, highlight just the linear portion to make the linear fit.
-

Procedure

Objective 1: Constant Total Mass

1. Add 10g to one mass hanger and 80g to the other, for a total of 15g and 85g, respectively.
2. Record the total masses for each in Table 1 for Run 1, where M_2 is the heavier mass at 85g.
3. Ensure that the height of the pulley allows M_2 to rest on the landing pad while M_1 is not touching the pulley.
4. Pull M_1 down until M_2 is close to the pulley.
5. Start recording immediately after release of M_1 and stop recording just before M_2 hits the pad.
6. You should now have a linear plot.
7. Click the "Scale to fit" button () to rescale the Graph axes to fit the data.
8. If your graph includes ends that are non-linear, highlight () only the linear portion.
9. Next, click the 'Fit' menu button (). Select 'Linear'.
10. The slope of Velocity vs Time is experimental acceleration (a_{exp}). Record this value in Table 1, Run 1.
11. Calculate F_{net} (from M_1 & M_2), Total Mass (M_{tot}), Theoretical Acceleration (a_{theory}) and Percent Error between a_{exp} and a_{theory} .
12. For Run 2: move 5g from M_2 to M_1 , and repeat # 2-11.
13. Repeat for Runs 3-5.

Objective 2: Constant Net Force

14. Copy the data from Run 5 to Run 6.
 15. For Run 7: add 5g to both sides. Perform run, data collection and calculations.
 16. Repeat #15 for runs 8-10.
-

Data

* If a_{exp} is negative (due to rotation direction of pulley), use its absolute value *

Table 1: Constant Total Mass

Run	M_1 (kg)	M_2 (kg)	a_{exp} (m/s^2)	F_{net} (N)	$M_1 + M_2$ (kg)	a_{theory} (m/s^2)	Percent Error
Run #1							
Run #2							
Run #3							
Run #4							
Run #5							

Show Work:

Table 2: Constant Net Force

Run	M_1 (kg)	M_2 (kg)	a_{exp} (m/s^2)	F_{net} (N)	$M_1 + M_2$ (kg)	a_{theory} (m/s^2)	Percent Error
Run #6							
Run #7							
Run #8							
Run #9							
Run #10							

Show Work:

Analysis

1. What is a real world application of an Atwood's Machine?
2. What are some reasons that would account for the percent error calculated above?
3. For the Constant Total Mass data (Table 1), plot (by hand) a graph of F_{net} vs. a_{exp} , and draw a linear fit.
4.
 - (a) What physical quantity does the slope of the best-fit line represent?
 - (b) Calculate the % Error between this quantity and your slope.
5. For the Constant Net Force data (Table 2), plot (by hand) a graph of a_{exp} vs $1/M_{\text{tot}}$, and draw a linear fit.
6.
 - (a) What physical quantity does the slope of the best-fit line represent?
 - (b) Calculate the % Error between this quantity and your slope.
7. Explain how the Force vs. Acceleration plot relates to Newton's Second Law.