

# Determining the relationship between masses in equilibrium and the angle of a frictionless plane

Noah Alexiou

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# 1 Introduction

## 1.1 Research Question

When the mass of an on a frictionless plane is altered, and the mass of a hanging object adjusted so equilibrium is achieved, can this be used to measure the angle of the plane? What is the accuracy and uncertainty of this method in comparison to conventional measuring techniques.

## 1.2 Rationale

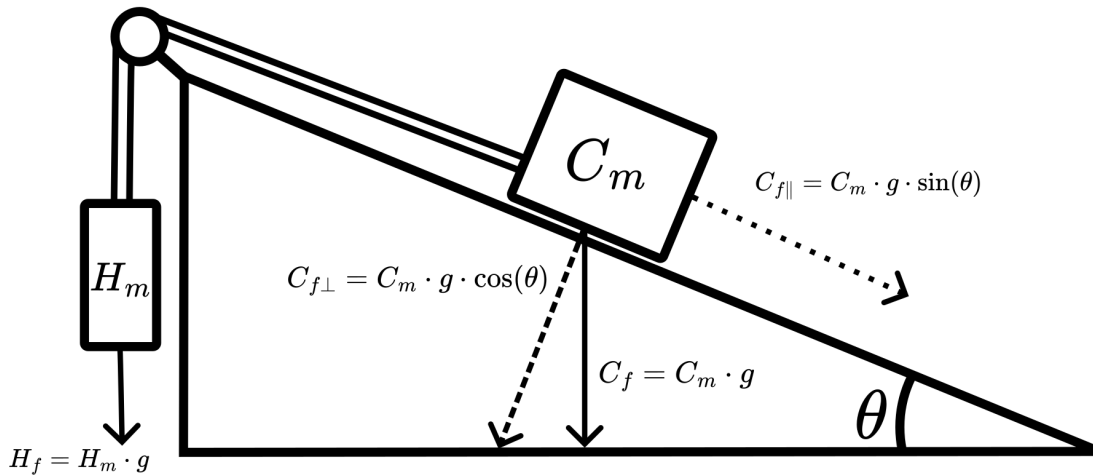
The original experiment was conducted to confirm the relationship between the mass of a carriage ( $C_m$ ) and a hanging mass ( $H_m$ ) when a frictionless plane was inclined at different angles. In theory  $C_m$  should have been

It was found during the experiment that the angle measurement device, an ‘angle gun’, had a large uncertainty ( $\pm 1$  deg) compared to the scale used to measure masses ( $\pm 0.01$ ). Considering the established relationship between the masses, it was questioned whether the relationship between the masses in equilibrium could be used to determine the angle of the plane with improved accuracy and reduced uncertainty.

Considering Newtons first law, under equilibrium the net force is 0 (Britannica, 2023). If we consider how the data will be plotted once recorded then we can find  $\theta$  in terms of  $H_m$ , and  $C_m$ .

$$\begin{aligned} H_m &= C_m \cdot \sin(\theta) \\ \frac{H_m}{C_m} &= \frac{1}{\text{gradient}} = \sin(\theta) \\ \therefore \sin^{-1} \left( \frac{H_m}{C_m} \right) &= \sin^{-1} \left( \frac{1}{\text{gradient}} \right) = \theta \end{aligned}$$

Since we now have the angle in terms of the gradient, we can use it to find the uncertainty in the angle. This implies the uncertainty in the gradient is equivalent to uncertainty in the angle.



## 1.3 Methodology

### 1.3.1 Modifications

The following modifications to the method were implemented

- The plane was kept at a constant angle throughout the entire duration of the experiment. This was done to isolate it from the independent and dependent variables and ensure that the results of all trials would point to the same relationship between them and the angle.
- The independent variable became the hanging mass ( $H_m$ ) to reduce uncertainty in its force via removing factors such as unaccounted for friction and unnecessary trigonometric calculations. This places as much of the uncertainty as possible on the dependent variable, therefore allowing it to be measured more easily.
- The dependent variable became the carriage mass ( $C_m$ ) as the large area inside each carriage allowed for fine adjustment of its mass via the addition of brass weights. Multiple carriages could be connected to allow for a greater range of weight's to be added which enhanced this.

### 1.3.2 Materials

- Angle gun
- Frictionless plane
- Brass weights
- Blue tack
- Scale
- Carriage

### 1.3.3 Method

1. Set up slope at a constant angle. It will remain at this angle for the entire duration of the experiment.
2. Set the hanging mass ( $H_m$ ) to its minimum value initially.
3. Alter the mass of the carriage ( $C_m$ ) until equilibrium with the  $H_m$  is achieved.
4. Measure and record masses.
5. Repeat for 3 trials with current  $H_m$  value.
6. Increase  $H_m$  by 50 grams.
7. Repeat for each  $H_m$  value.

### 1.3.4 Risk Assessment

#### Frictionless plane

- Mishandling of heavy masses on the frictionless plane could result in them sliding down the slope at high speed. This could damage equipment or cause injury. The slope will be turned off not required, and one person will always be supporting the carriage whenever possible to prevent this.
- Using too low fan speed on the frictionless plane may not create enough of an air pocket to support heavy weights. This could cause rubbing between the surfaces which could damage both the plane and carriage. The plane will be set to the highest possible speed throughout the experiment to negate the possibility of this occurring.

#### Masses

- Heavy masses or items containing many brass weights may cause injury if dropped or mishandled. participants will wear enclosed footwear to negate injury if this occurs.

## 2 Results and Evaluation

### 2.1 Results

#### 2.1.1 Raw Data

Carriage mass					Hanging mass			
1	2	3	Uncertainty	Average	1	2	3	Average
138.550	139.200	138.540	0.330	138.763	50.180	50.160	50.140	50.160
277.270	278.870	278.010	0.800	278.050	100.240	101.230	100.220	100.563
418.050	418.480	418.500	0.225	418.343	150.160	150.390	150.270	150.273
554.870	555.460	554.890	0.295	555.073	200.180	200.180	200.170	200.177
696.860	696.990	697.860	0.500	697.237	250.180	250.210	250.200	250.197
848.190	849.060	849.060	0.435	848.770	300.300	300.200	300.240	300.247

Figure 1: Raw results with additional calculations

#### 2.1.2 Sample Calculations

Absolute uncertainty for  $C_m$  when  $H_m = 50.160$

$$\begin{aligned}
 \sigma(C_m) &= \pm \frac{\max - \min}{2} \\
 &= \pm \frac{139.20 - 138.55}{2} \\
 &= \pm 0.33
 \end{aligned}$$

Average mass of  $C_m$  when  $H_m = 50.16$

$$\begin{aligned}
 \bar{C}_m &= \frac{\sum_{i=1}^n C_m}{n} \\
 &= \frac{138.55 + 139.20 + 138.54}{3} \\
 &= 137.76
 \end{aligned}$$

### 2.1.3 Plotting

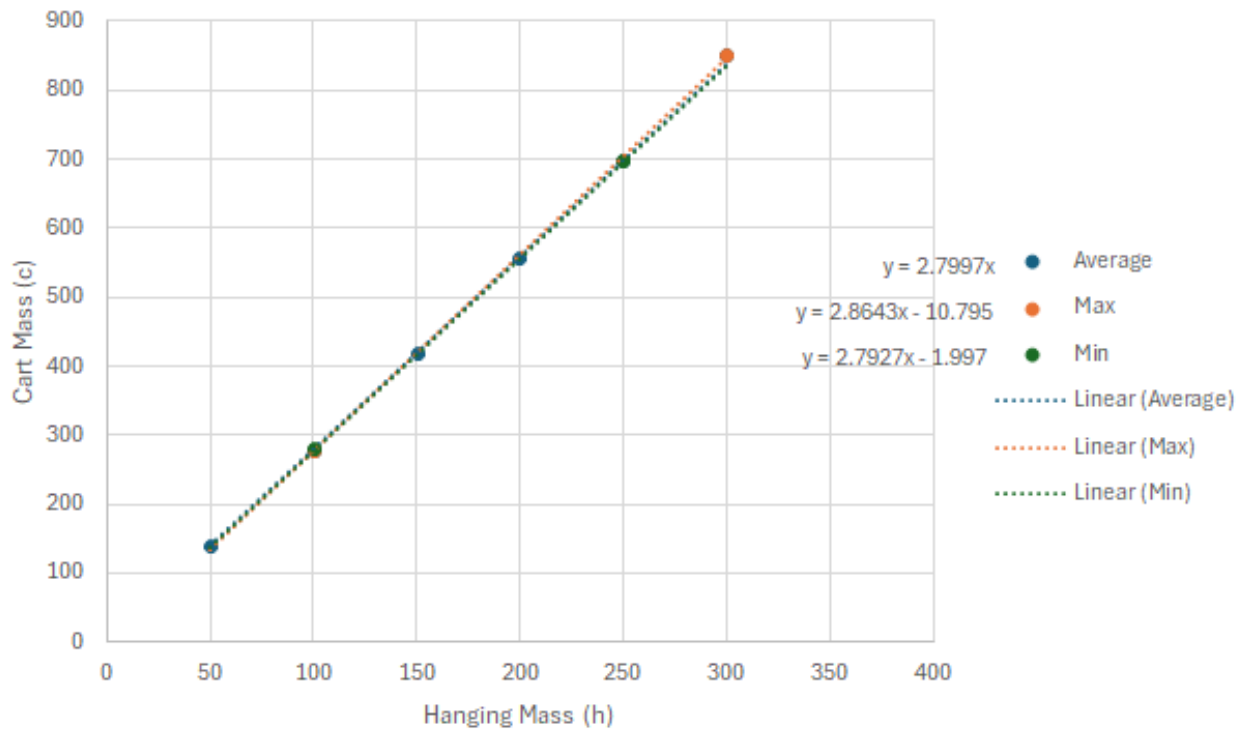


Figure 2: Average  $H_m$  and  $C_m$  values

## 3 Discussion

### 3.1 Analysis of evidence

Figure 2 shows a clear linear trend that continues throughout the entire plot with almost no deviance. For the average trendline, in the form of  $y = mx + c$ ,  $c = 0$ , which shows

### 3.2 Evaluation

## 4 Conclusion

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