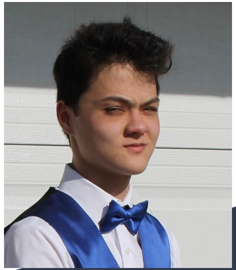
Observing the Effect of Friction on Household Objects and on Objects in Freefall



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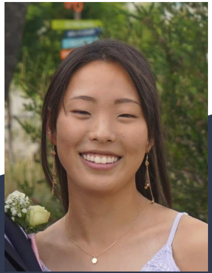

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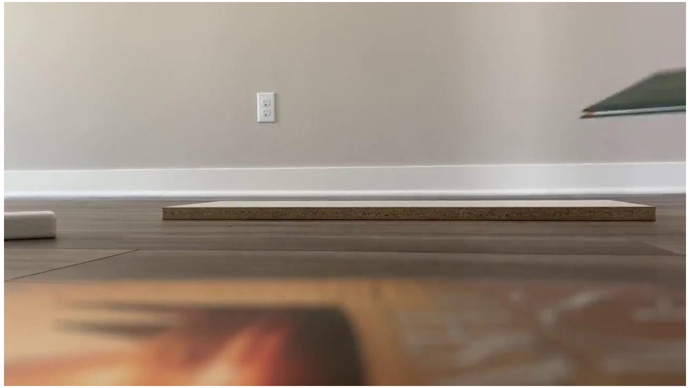
Introduction

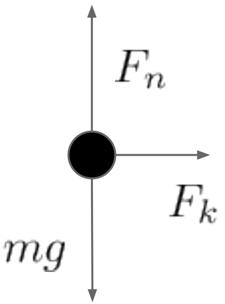
Focus:
- Friction between object and various surfaces; coefficients of friction
- Air friction in dropped objects
- Magnus Effect, due to air friction on rotating objects

Hypotheses:
- Find true descriptions of motion that are different from motion that is calculated from idealized analysis
- Magnus effect (force perpendicular to motion in direction of rotation, causing eventual lift); find linear relationship between horizontal velocity and upward acceleration; observe that rotating objects stay in air for a longer time.

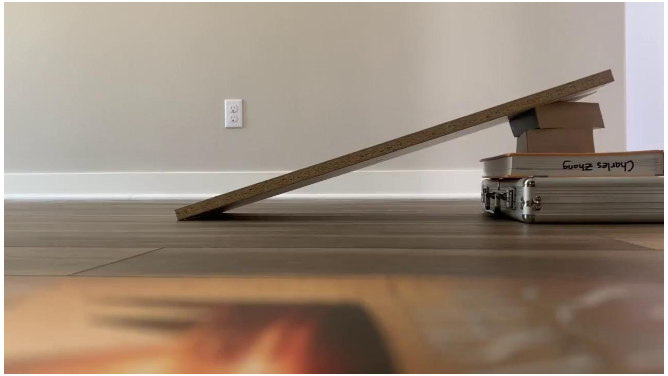
Methods - Translational Motion

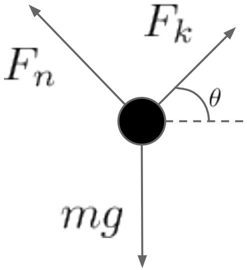
Flat-Ground Setup





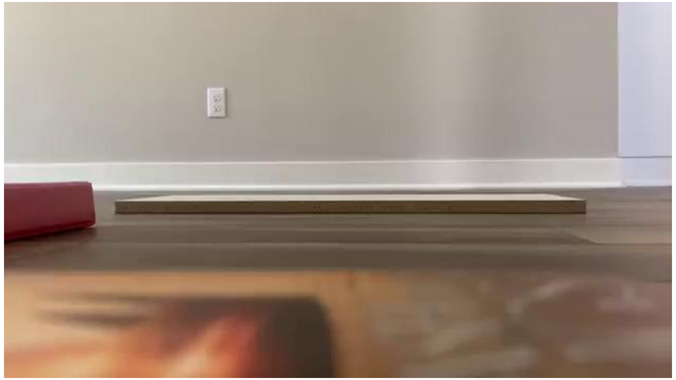
Angled Setup

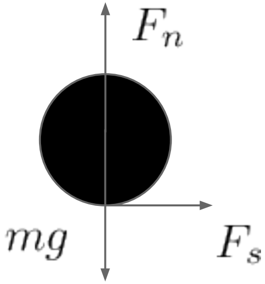




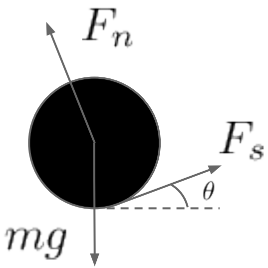
Methods – Rotational Motion

Flat-Ground Setup





Angled Setup



Methods – Vertical Motion

Methods - Data Taking Protocols

- All frictional trials were performed on the same surface to ensure consistency
- All data was collected using the Tracker software
- All tracking began from the frame the object left the hand and ended on the frame the object left the surface/hit the ground
- All objects in the frictional trials were subjected to 3 flat-ground trials and 3 angled trials

Data Extraction

```python
from os import listdir
from os.path import isfile, join
import json

def createJSONFile(slidingPath, rollingPath):
    filenameDict = {}
    slidingDict = {}
    rollingDict = {}
    slidingfiles = [join(slidingPath, f) for f in listdir(slidingPath) if isfile(join(slidingPath, f))]
    rollingfiles = [join(rollingPath, f) for f in listdir(rollingPath) if isfile(join(rollingPath, f))]
    labellist = []
    for file in slidingfiles:
        print(file)
        filename = file.split('/')[-1]
        information = filename.split(' ')
        label = information[0]
        angle = information[2]
        if not angle[-1].isdigit():
            angle = angle[:-1]
        if not angle.isdigit():
            angle = "0"
        trialNum = information[-1][0]
        print("Inferred Information: " + label + ", " + trialNum + ", " + angle)
        correct = input("Is this correct? (y/n)")
        if correct == "n":
            print("Existing Labels: ")
            for label in labellist:
                print(label)
            label = input("Enter Label: ")
            trialNum = input("Enter Trial Number: ")
            angle = input("Enter Angle: ")
        if label in labellist:
            slidingDict[label].append((file,trialNum,angle))
        else:
            labellist.append(label)
            slidingDict[label] = [(file,trialNum,angle)]
        print("\n")
```

Data Analysis

```python
def analyzeData(trial,mass,key):
    filename = trial[0]
    trialNum = trial[1]
    angle = int(trial[2])*2*np.pi/360
    data = np.loadtxt(filename,delimiter=',')
    time = data[:,0]
    x = data[:,1]
    polyfit = np.polyfit(time,x,2)
    accel = 2*polyfit[0]
    time_model = np.linspace(time[0],time[-1],1000)
    y_model = polyfit[0]*(time_model**2) + polyfit[1] * time_model + polyfit[0]

    pred_acc = 9.81 * np.sin(angle)*np.cos(angle)
    pred_polyfit = [pred_acc, polyfit[1],polyfit[2]]
    y_pred_model = 0.5*pred_polyfit[0]*(time_model**2) + pred_polyfit[1] * time_model + pred_polyfit[2]

    plot_data = (time,x,time_model,y_model,time_model,y_pred_model)
    title = "Horizontal Position vs Time for " + key + " at angle " + str(angle)[:4] + ", Trial " + trialNum
    axesLabel = ("Time (s)","Position (m)")
    legendLabel = ("Data","Best Fit Model","Ideal Model")
    label = key
    save_plot(plot_data,title,axesLabel,legendLabel,label,trialNum,angle)
    print("Plot Saved")
    return (key,angle,trialNum,accel,polyfit)
```

Data Analysis – Friction

Sliding Trials

Object	Coefficient (0^o)	Coefficient (19^o)
Binder	0.248 ± 0.023	0.394 ± 0.003
Book	0.266 ± 0.019	0.364 ± 0.002
Box	0.283 ± 0.012	0.347 ± 0.001
Charger	0.191 ± 0.025	0.463 ± 0.003
Diploma	0.220 ± 0.079	0.469 ± 0.003

Rolling Trials

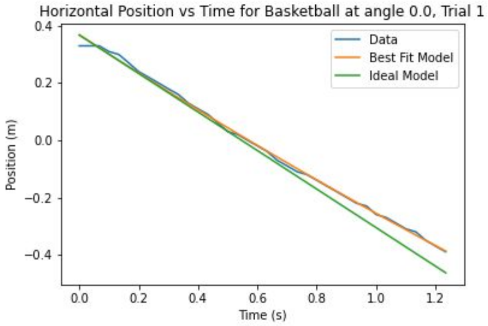
Object	Coefficient (0^o)	Coefficient (10^o)
Basketball	0.022 ± 0.008	0.245 ± 0.009
Lysol Container	0.044 ± 0.006	0.227 ± 0.005
Tennis Ball	0.031 ± 0.008	0.238 ± 0.006

Known Values

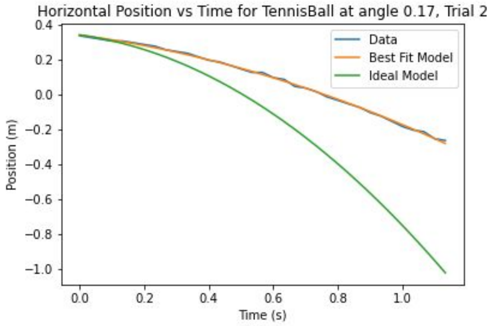
Object	Coefficient
Wood	0.4 (McKenzie, 1968)
Cardboard	0.3 (*Container Handbook*, 2020)
Tennis Ball	0.25 (Brody, 1995)

Data Analysis – Friction

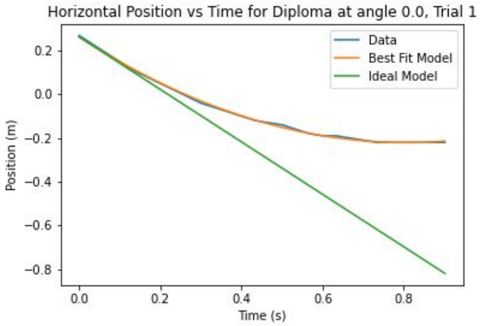
Rolling/Flat Trial



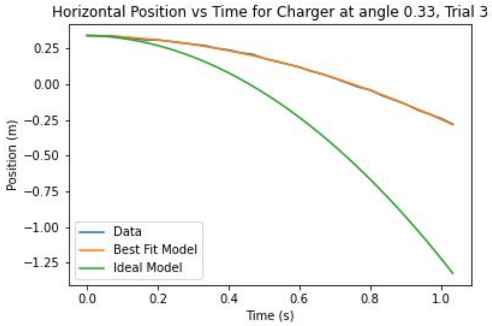
Rolling/Angled Trial



Sliding/Flat Trial



Sliding/Angled Trial



Sources of Error - Objects and Surfaces

- The objects may have been moving in multiple directions, but were tracked as if the motion was 1-dimensional
- The surfaces at play weren't necessarily uniform, perhaps causing varying amounts of friction per trial
- The amount of initial velocity on the flat trials varied greatly, sometimes causing the objects to stop far earlier than other trials
- The area to which the initial force was applied to the flat trials wasn't consistent, occasionally causing the objects to turn as they moved

Observations and Replication

Observations:

- Frictional measurements using a slope, and therefore a consistent initial velocity, were much more consistent and accurate than flat trials with inconsistent initial velocities

- Rolling trials tended to produce more linear results compared to sliding trials, and were much more similar to our theoretical frictionless model

- Apart from the diploma and box, the coefficients are more or less what we expected based on our reference objects

Future Prospects:

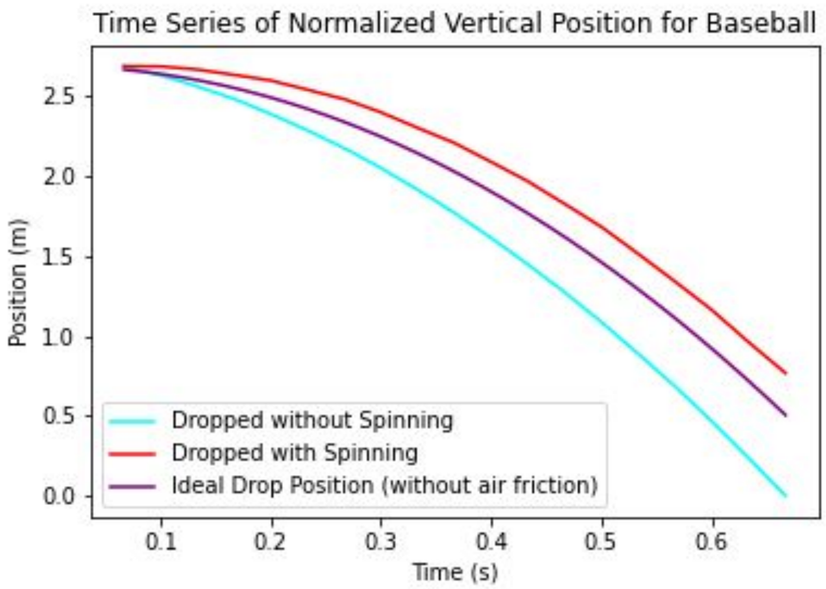
- Repeating this experiment while varying the slope of the ramp would likely produce better results with less error

- A wider variety of surfaces and objects may provide insight into the accuracy of this method when it comes to low friction vs. high friction

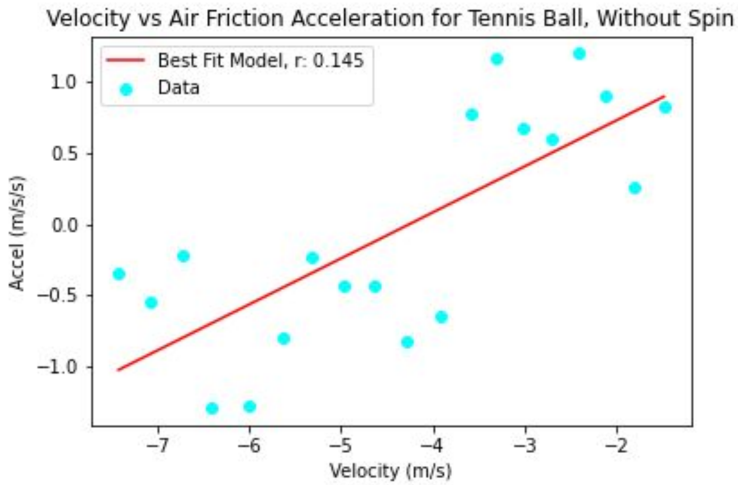
Conclusions: Surfaces

+ In all of these experiments, we do observe deviations from the idealized calculations of physical phenomena which deem friction negligible.
+ For the objects that do not rotate, like the charger, an even larger discrepancy between experimental and theoretical data arose.
+ Frictional forces should not always be ignored in physical analysis.

Data Analysis - Air Friction

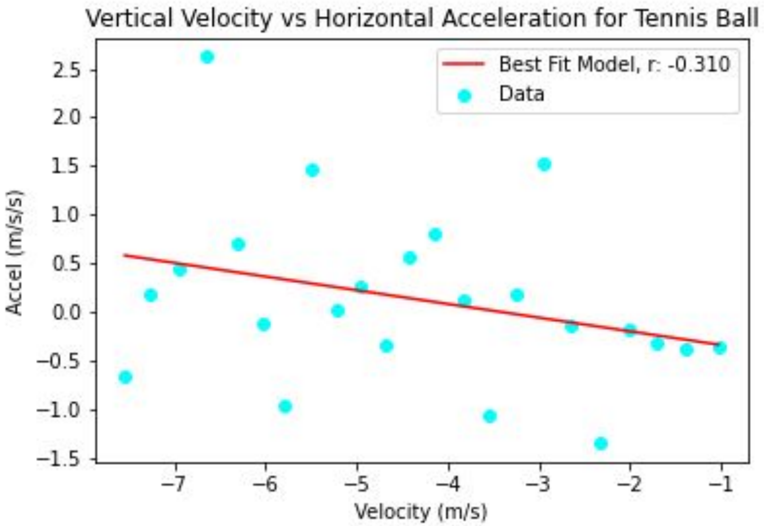


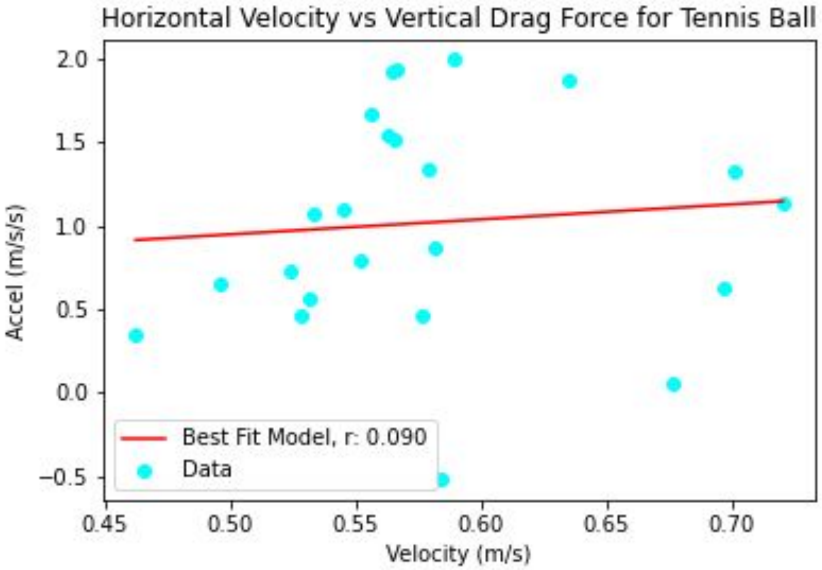
Drag force = −bv, where b is a constant



Shows the proportionality of upwards acceleration due to air friction to the velocity of the tennis ball

Data Analysis – Air Friction

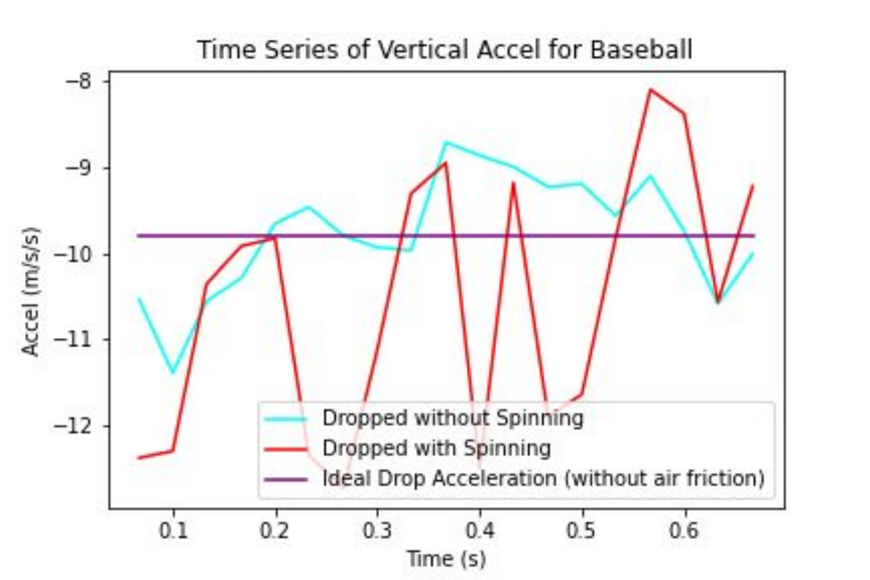


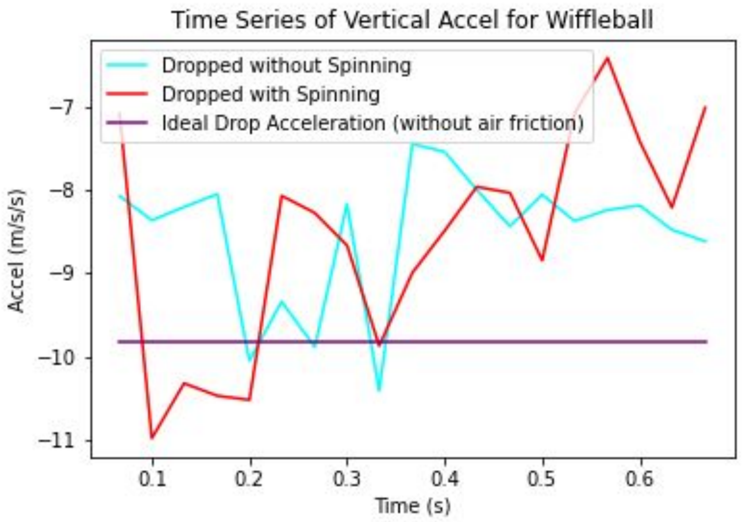


Ideally, a proportional relation between upwards acceleration due to air friction and the Magnus force to the velocity of the ball

Sources of Error: Drag Force

This disparity may be attributed to errors in measurement of acceleration - as seen in the acceleration time series, the measured acceleration was not consistent decreasing/increasing.





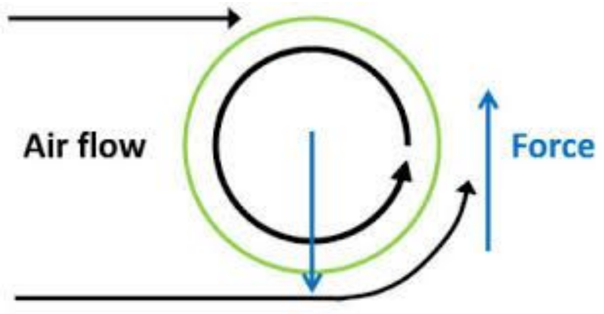
Conclusions: Freefall

+ Significant differences between the theoretical motion and experimental results; but not in the desired direction
+ Theoretical computations estimated that the ball would take longer to reach the ground

+ Similar findings were observed across the trials

Conclusions: Magnus Effect

+ When spun, the ball hangs in the air for a longer time, higher than both the theoretical estimation and the experimental path when simply dropped



+ When an object rotates, pressure increases below the spinning ball, causing lift

+ Drag force that comes from air flowing along the direction of rotation accelerates the ball upwards

+ Ideally, should have seen evidence of horizontal velocity leading to increased vertical acceleration

References

Brody, Howard. Tennis Science for Tennis Players. University of Pennsylvania Press, 1995.

“Securing the Product in the Container.” *Container Handbook*, 2020. www.containerhandbuch.de/chb_e/stra/index.html?%2Fchb_e%2Fstra%2Fstra_04_04_05.html.

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