INVESTIGATION OF ROLLING CANS BASED ON BEHAVIOUR OF INTERNAL FLUIDS

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ABSTRACT

In this investigation, the behavior of the internal fluids of cans rolling down an incline was analyzed. The displacement and velocity were measured by rolling both cream and consommé cans down inclines of 8 different heights. Through analysis, it was determined that on steeper inclines, the sliding of the consommé along the can causes friction and greater energy loss. On shallower inclines, the speed is insufficient for the cream to adhere to the can, causing it to slide against itself, causing even greater energy loss than the consommé.

I INTRODUCTION

In this experiment, two cans of soup, one containing cream and the other containing consommé, were rolled down an incline and then across a flat surface. On a slight slope, the consommé rolls further. On a steep slope, the cream rolls further. The goal of this experiment is to determine the effect of the incline angle on the internal contents of the cans that cause these variations to occur in the results. An analysis was made to explain the behavioural changes of both fluids over time.

II THEORY

To compute required quantities from the data, four equations were used.

The first equation yields the angular velocity of an object:

$$\omega = \frac{v}{r} \qquad [1]$$

(HRW)

Where:
- ω = Angular velocity (rad s^{-1})
- v = Velocity (ms^{-1})
- r = Radius (m)

The second equation yields the standard deviation of a set of data with Bessel's correction:

$$\sigma = \sqrt{\frac{\sum(x-\bar{x})^2}{n-1}} \qquad [2]$$

(HRW)

Where:
- σ = Standard deviation
- $\bar{x}$ = Arithmetic mean
- n = Number of terms
- x = Value of term

The third equation is the conservation of mechanical energy in a system:

$$T_1 + U_1 = T_2 + U_2 \qquad [3]$$

(HRW)

Where:
- T = Kinetic energy (J)
- U = Potential energy (J)

The fourth equation describes the centripetal acceleration required for uniform circular motion:

$$a = \frac{v^2}{r} \quad [4]$$

(HRW)

Where:

a = Centripetal acceleration (ms^{-2})
v = Speed (ms^{-1})

III Method

The lab equipment was thoroughly tested. Measurements of the dimensions of the can, incline, and mats were effected as well as the weights of the cans. In addition, the accuracy of the motion detector was evaluated by measuring the distance from the detector to the can using a ruler and comparing it to the measurement given by the detector. Through this procedure, the minimum effective range was determined to be 18 cm. The motion detector was used to measure the distance of the can on the incline over time and was configured to take 50 samples per second. The incline and mats were chosen to have as much friction as possible in order to prevent slippage and to ensure the cans wouldn't roll too far away. Textbooks were used to raise up the incline to heights at an increment of 2.5 cm. Ten runs were effected for each incline height and a total of 8 heights ranging from 5 – 22.5 cm inclusive were analyzed.

A phone was used to record each run to check for slippage. Through video analysis, the cans were verified to roll down the incline without slippage by comparing the predicted rotations with that of rolling without slippage.

IV Data

Data of the distance rolled by each can, the consommé and cream, were collected when the incline was placed at different heights, thus changing the angle or slope of the incline. The following data displays the average distance rolled by both cans over 10 different runs for 8 different incline heights as well as their uncertainties, found using [2]:

			Distance (cm)	
Index	Incline Height (cm)	Incline Angle (º)	Consommé	Cream
1	5.0±.1	5.6±.1	101±6	12.0±.5
2	7.5±.1	8.3±.1	155±3	142±7
3	10.0±.1	11.2±.1	191±6	192±3
4	12.5±.1	14.1±.1	227±8	237±4
5	15.0±.1	17.0±.1	264±4	281±4
6	17.5±.1	19.9±.1	298±2	310±3
7	20.0±.1	22.9±.1	313±4	339±3
8	22.5±.1	25.9±.2	328±5	353±3

Figure 1: Average Distance Travelled. The table displays the average distance travelled by the consommé and cream cans over 10 runs on each of the eight incline heights. Additionally, it also contains the angles of the inclines with their uncertainties.

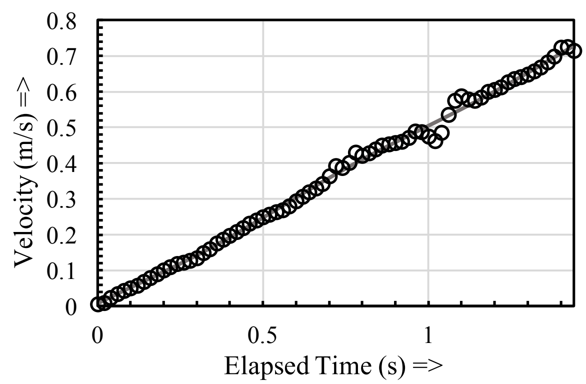

Figure 2: Velocity vs. Time Graph. This figure shows the velocity over time for run 3 of the consommé can on an incline angle of 5.6º, with the regression curve overlaid.

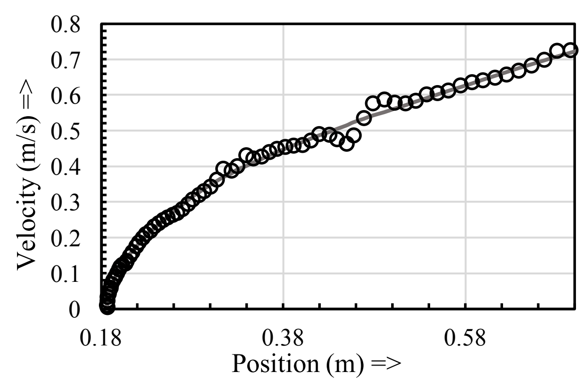

Figure 3: Velocity vs. Position Graph. This figure shows the velocity over position for run 3 of the consommé can on an incline angle of 5.6º, with the regression curve overlaid.

V Analysis

The data collected agrees with the expected result: the distance travelled by the consommé is farther than that of the cream on shallower inclines while the cream gradually surpasses the consommé on steeper inclines. From the data, it can be estimated that the cream surpasses the consommé when the initial height is around 10 cm where the angle of the incline is 11.2˚.

First, the data collected from the Vernier motion detector was regressed to observe any general trends. The data was regressed as a sum of a linear function and a decaying sinusoidal function. This was chosen since it was speculated that the velocity would have some sort of sinusoidal behaviour. Since the data points suggest that such behaviour loses relevance over time, it was believed that the sinusoidal component would exponentially decay. Thus, it has the form:

$$v = a_1 t + a_2 + a_3 exp(a_4 t) sin(a_5 t + a_6) \quad [5]$$

It was noted that the cream can exhibited a periodic pattern in its velocity which became negligible during runs where the angle of the incline was 14.1˚ and higher. At incline angles 14.1˚ and higher, the cream also overtook the consommé in distance. The periodic pattern of velocity was especially extreme during the runs of angle 5.6˚, so a loose correlation between energy loss from frictional forces and the periodic "jitter" of the velocity of the can was discerned. This was also evident in the runs with consommé as well, but the deviation also became negligible after the can reached a certain velocity.

It could also be discerned that the "jitter" smooths out to resemble a linear trend after a certain velocity is reached. This is particularly noticeable in the cream can runs when the incline angle was 11.2˚, as well as the consommé runs when the incline angle was 8.3˚. The velocity at which the periodic motion halts is around 0.6 ms^{-1}. This can be correlated to the minimum velocity to engage in circular motion which, using the equations [1] and [4], yields a value bounded by 0.51 ms^{-1} and 0.57 ms^{-1}, depending on the slope of the incline. The data agrees to such an observation.

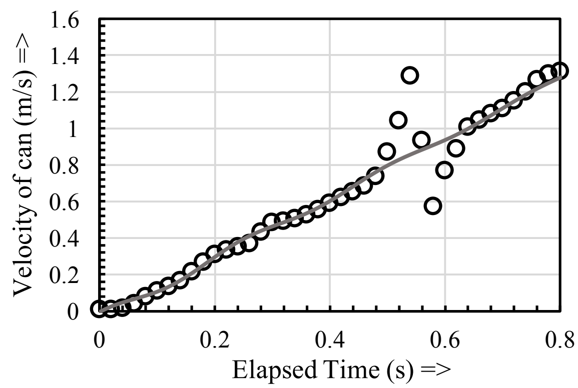

Figure 4: Velocity vs. Time Graph. This figure shows velocity over time for run 8 of the cream can on an incline angle of 14.1°, with the regression curve overlaid as modelled by [5] is v = (1.04±.02)t+(-0.03±.01) + (0.01±.01)exp((2±1)t)sin((17.4±.9)t+(-15.2±.8)). Periodic "jitters" and "bumps" can both be seen on this graph.

Additionally, a consistent "bump" in the velocity-time graphs was observed after approximately one rotation of the can. This characteristic is likely due to the fluid having insufficient angular velocity to perform circular motion and instead, chaotically falling and interfering with parts of the fluid in contact with the walls of the can.

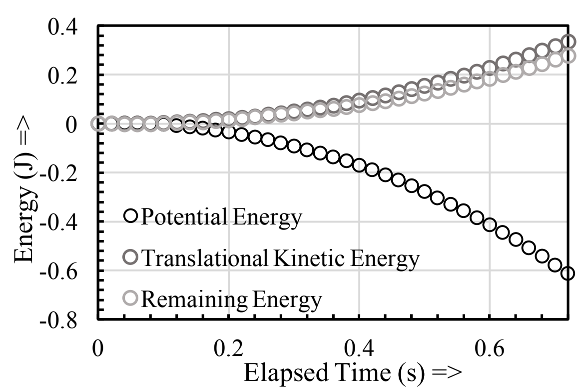

Figure 5: Distribution of Energy Over Time This figure graphs the potential energy, linear kinetic energy, and the remaining energy in the system for run 7 of the cream can on an incline angle of 22.9°. The initial height is set to be 0 as a standard for the purposes of determining potential energy.

As shown in Figure 5, plotting the potential and kinetic energies as functions of time yields the rate at which the potential energy was converted into kinetic energy. The remaining energy includes both the rotational energy and energy lost due to both rolling friction as well as between the fluid and the can.

It can be observed that at higher sloped incline runs, where the cream can travel further than the consommé can, the rotational energy and energy loss sum to around the same value as the kinetic energy. In a non-slip system, this indicates that the moment of inertia may be approaching that of a hollow cylinder and that energy loss becomes reduced. As a result, most of the fluid within the can undergoes circular motion. This assumption is supported by the fact that the difference in distance travelled by the two cans seem to remain constant as the slope of the incline is increased after the 14.1^{o} angle threshold. This constant difference implies that the energy loss differences are also near constant; the low difference implies a low energy loss in the cans. This fits the expectation that the cream is viscous enough for most of the fluid to undergo circular motion along the edge of the can at a sufficient velocity. It was also observed that the consommé can experiences a constant amount of energy loss throughout each run, indicating that the consommé does not undergo circular motion and the moment of inertia approaches that of a solid cylinder at high velocities.

VI Sources of Error

An aspect of the experiment process that could be improved is reducing the impact of external forces on the rolling can system. While it was confirmed that the can rolled without sliding through kinematic analysis, further precision could be met if steps were taken to mitigate the sliding of the can on the incline. The incline itself could have more structural support to reduce the effect of deformation affecting the run values. Furthermore, if the cans used for the experiment were perfectly symmetrical, the precision of rolling would improve.

It was noticed that the motion detector exhibited some consistent measurement errors at specific distances from the detector. Effort was made to mitigate some of the effects, such as testing its accuracy compared to a ruler and restricting the bounds of the run to be within the range of the effective range of the motion detector, but it could be further improved by using a more accurate detector.

VII Conclusion

It can be concluded from the analysis that the cream can will travel further than the consommé can when the angle of the incline is higher than $(11.2 \pm .1)^{\circ}$. The factors that cause the change in distance is the reduced energy loss due to a higher acceleration which leads to the quicker increase to the threshold velocity of circular motion for the cream can, while the energy loss of the consommé can remain relatively constant. Once the threshold velocity is attained, the cream exhibits circular motion and the moment of inertia of the can is maximized as the cream will have the tendency to spread along the edges of the wall, whereas the consommé, lacking circular motion, continues sliding along the bottom of the can. In shallower inclines, the velocity for circular motion is not attained, thus the cream dissipates energy from sliding along the bottom of the can and travels a shorter distance than the consommé can.

VIII Sources

van Bemmel, H., "AP Physics C Laboratory Manual," DRMO Press, 2019

[2]*, "Handling of Experimental Data", DRMO Press, 2019*

Walker, J. et al (2014). Fundamentals of Physics (9th ed.). John Wiley & Sons, Inc.