IB PHYSICS (HL) EXTENDED ESSAY
ON TIMING CHARACTERISTICS OF SAXON BOWL

THE EFFECT OF BOWL MASS AND BOTTOM HOLE DIAMETER ON BOWL SINKING TIME IN WATER

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1. Introduction

This research was inspired by a nostalgic moment with my mother. Last year, after many years, we rewatched 'Titanic'. As we watched the dramatic scenes of the sinking of the ship, we discussed, "'How could such a large structure sink so quickly?" This idea led me to explore the physics behind sinking objects, namely fluid dynamics. As I delved deeper, I discovered the Saxon Bowl, an ancient timing method based on the same physical principles. This fusion of history and physics intrigued me, motivating my experimental research.

Before mechanical and electrical clocks, people used simple timing methods like the Saxon Bowl, a historical device based on fluid dynamics. When it is placed on the surface of water, a hole at its base allowed water to enter. People timed it by observing the sinking of the bowl in water.

The time for sinking is governed by several factors. The size, shape, height, mass, the base area of the bowl, and the size and even the shape of the hole at the bottom of the bowl have an effect on the water injection rate through the hole. [1]

Figure 1. A Celtic bowl with embossed gold leaf decoration from the princely burial at Schwarzenbach, Rhineland, Germany. 5th century BCE. (Staatliche Museum, Berlin) [6]

This extended essay aims to analyze the physics underlying the Saxon Bowl's sinking process, focusing specifically on how its mass and bottom hole diameter affect sinking time. The experiment will provide quantitative data on the relationship between these variables. While historical findings primarily depict hemispherical bowls, this research investigates cylindrical bowls to explore their potential for continuous timing rather than fixed intervals.

Through this research, I hope to gain a deeper understanding of the physics of sinking objects and how theoretical physics translates to real-world phenomena.

2. Background Information

2.1. Fluids in Motion

There are many factors that determine the flow of a fluid in a pipe. If the fluid maintains a smooth flow by sliding over the neighboring layers and the layers of the pipe, it is called *streamline* or *laminar flow*. If the fluid is fast and the internal friction called viscosity is much greater, the flow becomes *turbulent flow*. [7]

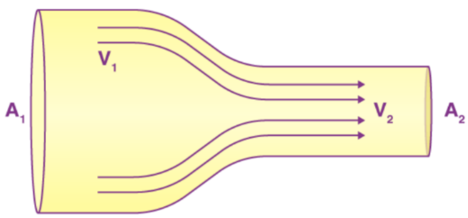


Figure 2. Fluid flow through a pipe of varying diameter

The volume of fluid passing a given point per second is called *volumetric rate of flow*;

$\frac{\Delta V}{\Delta t} = \frac{A\Delta l}{\Delta t} = A\vartheta$, *where A is the cross sectional area of pipe, l is the length covered in time t and ϑ is the velocity of fluid in the pipe.* [7]

In laminar flow of incompressible liquids, volumetric flow rate is constant as they flow through successive pipes of different diameters.

$$Av = constant\ (Continuity\ Equation)\quad [7]$$

Bernoulli derived the following equation which sets out his principles on flows;

$$P + \rho_{liquid}gh + \frac{1}{2}\rho_{liquid}v^2 = constant \quad [5]$$

In equation, P is the liquid pressure, h height in respect to ground, ρ density, ϑ the velocity of fluid and g gravitational acceleration of the Earth.

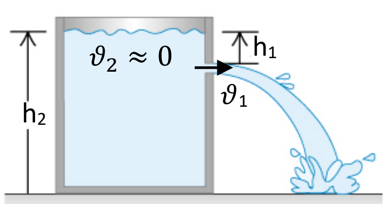


Figure 3. Torricelli's theorem

Bernoulli's equation can be applied to many situations. As seen in *Figure* 3, when water flows from a very wide reservoir into a narrow pipe, we neglect the third term in the Bernoulli equation since the water flow velocity in the reservoir will be relatively small compared to the smaller pipe. The equation obtained below will also be used to calculate the speed of water entering the narrow hole at the bottom of the bowl in this experiment.

$$P_0 + \rho g h_1 + \frac{1}{2}\rho_{liquid}{v_1}^2 = P_0 + \rho g h_2 \qquad \vartheta_1 = \sqrt{2g(h_2 - h_1)} \qquad \text{(Torricelli's Equation) [7]}$$

2.2. Buoyancy

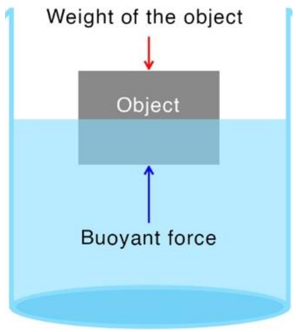


Figure 4. Floating object

The buoyant force exerted by a liquid occurs because of the pressure in a fluid increases with depth. And the buoyant force is equal to

$$F_b = V_{immersed}\rho_{fluid}g \quad [7]$$

The object in liquid would reach static equilibrium when its weight equals the buoyancy force that the liquid exerts on it. If the weight of the object exceeds the maximum buoyancy force, it would sink. Now let's consider the object dropped into the liquid as an empty container with a small hole at the bottom. As the container floats down, liquid will fill it. On the one hand, the weight of the container will increase as the amount of liquid inside increases, and on the other hand, the buoyant force will increase as the volume of the immersed part increases. If the forces applied to the container manage to remain in balance throughout the fall, the container will sink at a constant speed.

2.3. Modeling of the Saxon Bowl

To analyze the sinking time of the Saxon bowl as a function of various factors, the bowl is modeled as follows. The model is a lightweight, open, cylindrical container made of thin, transparent plastic with a hole in the bottom. The hole is modeled as a pipe from which the flow properties can be calculated using the Bernoulli equation. The bowl is submerged in a larger container.

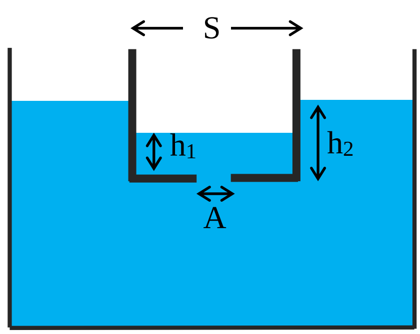


Figure 5. Modeling of the bowl

S is the area and **m** is the mass of the bowl. $\mathbf{h_1}$ is the height of water inside the bowl and $\mathbf{h_2}$ is the sunk height of the bowl. **r** is the radius and **A** is the area of the hole. $\boldsymbol{\rho}$ is the density of water.

The sinking time of the bowl can be affected by the viscosity, which is related to how one layer of the fluid affects the motion of the neighboring layers. [5] Since the bowl is very thin, the viscosity in the bowl is relatively small compared to the other parameters. Therefore, the thickness of the bowl and the viscosity of the water in the hole are neglected. In addition, during the calculations, it was assumed that there was no turbulence in the water flow and that the container moved downwards at a constant speed, since the linear relationship between the depth of the water in the container and time can be clearly seen in the videos taken.

When the speed of water flowing into the bowl is constant, gravitational force exerted downward is compensated by buoyancy;

$$Gravitational\ force = (m_{bowl} + m_{water})g = (m + Sh_1\rho)g$$

$$Buoyant\ Force = Sh_2\rho g$$

$$(m + Sh_1\rho)g = Sh_2\rho g$$

$$h_2 - h_1 = \Delta h = \frac{m}{S\rho}$$

The volume of water at time t is equal to the product of constant volumetric flow ($A\vartheta$) and time;

$$Sh_1 = A\vartheta t \text{ where } \vartheta = \sqrt{2g\Delta h} = \sqrt{2g\frac{m}{S\rho}}$$

The time it takes for water to fill the bowl completely ($h_1 = h_{bowl}$);

$$t = \frac{Sh_{bowl}}{A\vartheta} = \frac{Sh_{bowl}}{\pi r^2\sqrt{2g\frac{m}{S\rho}}}$$

At the end of the experiment, it is expected that the sinking time (t) of the bowl in water will be inversely proportional to the $r^2\sqrt{m}$ product.

$$t \sim \frac{1}{r^2\sqrt{m}}$$

3. Experiment

3.1. Research Question

How do the mass of a cylindrical plastic container and the diameter of the circular hole drilled in the bottom of the container affect the time it takes for the container to completely sink into the water?

3.2. Hypothesis

When the mass of Saxon bowl that is slowly dropped onto the surface of the water is increased by adding modeling clay without changing its size, the time it takes to completely sink into the water is shortened. The density of the overall bowl increases with this process and denser objects sink faster.

As the diameter of the hole opened at the bottom of the bowl increases, the time for the bowl to completely sink into the water decreases. The larger the aperture, the faster the decline.

Theoretical justifications for both predictions are presented in the Background Information section.

3.3. Key Variables

	Variable	***How it will be measured / manipulated***
Dependent Variable	Time required for the bowl to completely submerge in water	The bowl's sinking was recorded by camera and analyzed to determine its time.
Independent Variables	Total mass of the bowl and contents	When the bowl is released on water, it initially floats even with a hole in its bottom due to its lower average density than water. To sink it, weight was added incrementally using clay. The minimum required mass was 32.2 g, and 10 clay samples were prepared, ranging up to 176.03 g.
	The diameter of the circular hole drilled into the base of the bowl	Despite sufficient weight and a bottom hole, if the hole was too small, the bowl did not sink due to surface tension. The minimum hole diameter that would allow it to sink was determined as 0.80 cm. Taking into account the width of the bowl bottom, the maximum hole diameter was determined as 4.60 cm.

Table 1. Dependent and independent variables, how they will be manipulated or measured

Controlled Variables	***How would this variable affect the data if NOT controlled***	***How it will be controlled***
The material bowl is made of and its surface texture	Objects with a smooth surface encounter less resistance when moving through a fluid than those with a rough or porous surface.	Light cylindrical containers of the same dimensions and made of the same material were used in the experiment.
Size and shape of the bowl	The buoyant force exerted on a container is directly proportional to the volume of the container submerged in the liquid. This affects both the sinking speed of the container and the time required for the entire container to sink.	
Initial velocity of the bowl	While sinking, both the total mass of the container increases as water fills through the hole in the bottom of the container and the buoyant force applied increases as immersed volume increases with time. The time it takes to travel the entire distance to sink varies depending on its initial speed.	The container was placed gently on the water surface so that it did not have initial speed.
Initial position of the bowl	The angle and cross-sectional area of the surface that the water encounters affect the drag force applied to the container. As the cross-sectional area increases, the drag force also increases.	The bowl is left in its initial position with its base parallel to the water.
Density of liquid	The buoyant force exerted on an object in a liquid is directly proportional to the density of the liquid. If the buoyant force exerted on the bowl by the liquid changes, its terminal velocity will change. This affects the time of the motion.	Water taken from the same source was used in all stages of the experiment.
Purity of liquid	Molecular structure of liquid and presence of dissolved substances increases the viscosity of liquids by disrupting molecular motion. Higher viscosity increases drag, slowing the container's descent.	Modeling clay was added to change the weight of the bowl during the experiment. If small pieces of clay were observed in the water in the larger container, it was replaced with fresh water from the same source.
Temperature of water	Increase in temperature decreases the density and viscosity of liquids.	The temperature of water is kept at room temperature and checked throughout the experiment.

Table 2. Controlled variables, how they will be controlled and their possible effects on the result if they are not controlled

3.4. Experimental Setup

The equipment of the experiment is shown below.

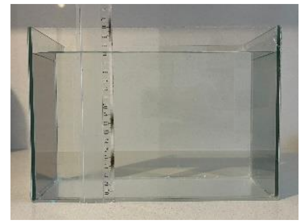
 *Transparent plastic bowl (30 cm x 40 cm x 50 cm)*	 *Drill bits of different diameters*	 *Transparent container filled with water to be used bathtub (30 cm x 40 cm x 50 cm) and 30 cm long ruler (± 0.05 m)*
 Modeling clay (100 g)	 *Weighing scale (± 0.01 g)*	 *Graduated cylinder (± 0.1 ml)*

Figure 6. Materials used in the experiment

3.5. Safety Issues

When preparing plastic containers used as Saxon bowls, a drill and a utility knife are used to make holes in the bottom of containers. Using a drill requires manual dexterity and great care. Similarly, the utility knife is very sharp. It may be useful to get help from an adult for all these operations. It is also important that none of the materials used are consumed and that these materials do not pollute the environment.

3.6. Methodology

Preliminary work and subtleties to consider

The experimental setup seems simple at first glance, but a few subtleties that I discovered in the preliminary experiments need to be noted to obtain more accurate and reliable results.

The experiment began by drilling a hole in the bottom of a transparent plastic container, chosen for its ease of modification and visibility of water flow.

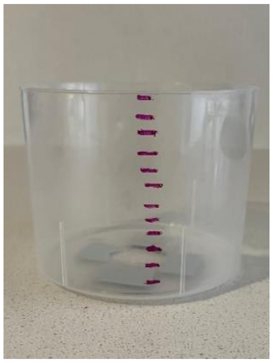


Figure 7. The graduated bowl with a hole in its base

A wood drill bit ensured a clean cut, with burrs removed using a knife. To track water flow, the container was scaled by dividing its 200 ml capacity into 10 equal parts, marking water levels in 20 ml increments. Since the container's edges were not perfectly perpendicular, volume, rather than height, was used for accurate scaling.

In the preliminary experiments, it was also realized that mass distribution required precision when adding weight to the bowl. If the mass distribution is not taken into account, it was observed that the bowl easily topples over as it sinks. This was due to the net torque created by the relative location of the bowl's center of mass and the point of application of the buoyant force, which is the center of mass of the displaced water. Therefore, the clay was added to the outermost part of the bowl base in a ring shape.

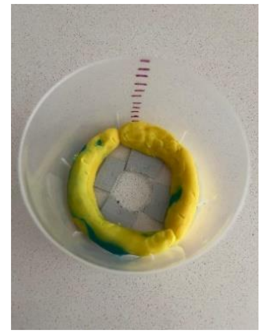


Figure 8. The clay on the bowl base

Experiment to investigate the effect of bowl mass

The large transparent container to be used as a bathtub is filled with water. The phone is placed 20 cm from the edge of the glass container so that its camera is facing the container and is level with the surface of the water. A small hole is opened in the bottom of the transparent plastic bowl. In order for the water flow to occur efficiently, the smallest hole in this experiment was opened with a diameter of 0.80 cm. 32 grams of play dough is placed on the bottom of the bowl in the shape of a ring.

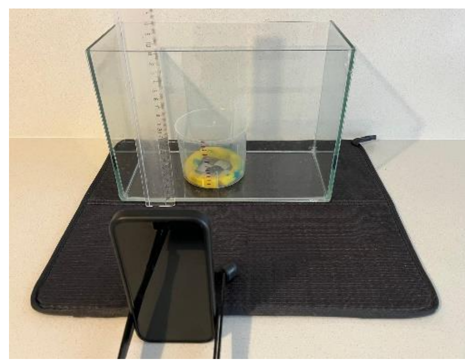


Figure 9. Experimental setup

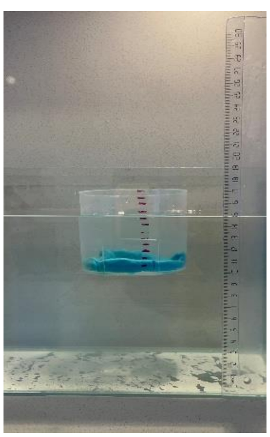


Figure 10. Sinking bowl

It is important to place the dough as far out as possible and in a way that it is distributed uniformly (see *Figure 8*). When placing the bowl, the bottom of the bowl should be slightly in contact with the water surface evenly. The camera is turned on and the bowl is released. The camera is stopped when the bowl is completely submerged in the water. The same setup is tried two more times and each is recorded. In subsequent trials, the same measurements are repeated, increasing the mass of the dough by almost 16 g in each trial. A total of 10 measurements are made, with a final trial of 176 grams. To increase the reliability of the data, 3 trials are conducted for each measurement.

Experiment to investigate the effect of hole diameter

With each trial, the hole opened in the bowl base will need to be enlarged a little more. Totally 10 trials will be conducted. It is important that this enlargement is made by considering the diameter of the largest hole (4.60 cm in diameter in this experiment) in the last trial. The smallest hole diameter is 0.80 cm in the experiment. Since the hole is not a perfect circle, it would be correct to take its average diameter. Therefore, its circumference was measured with the help of a rope and the diameter was calculated with the equation; Circumference of a circle = $\pi \times$ diameter.

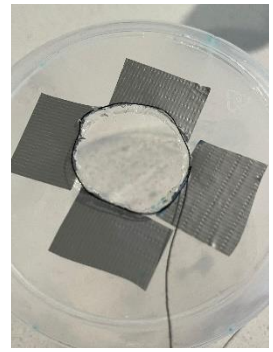


Figure 11. A string placed around a circle to measure its circumference.

3.02 g of clay is placed in the bowl again and the measurement is completed in 3 trials. In subsequent measurements, the diameter of the hole is increased each trial without changing the bowl used and the mass of clay placed in it. It is important that each measurement is made in 3 trials.

4. Data Analysis

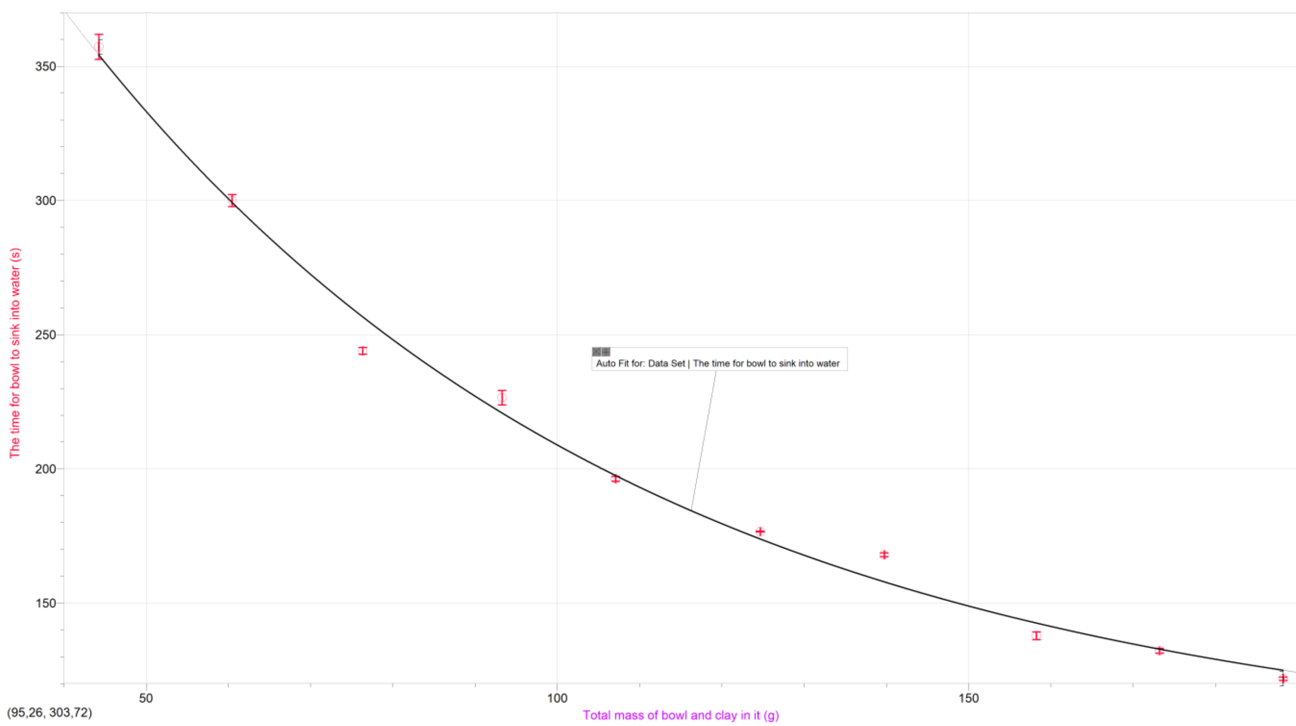
4.1. Investigating the Relation Between Mass of Bowl and Sinking Time

Data No	Mass of modeling clay put in the bowl / g (±0.01)	Total mass of bowl and clay in it **(m)** / g (±0.01)	The time for bowl to sink into water / s (±0.02)			Average time for bowl to sink into water **(t)** / s (±0.02)	Uncertainty in readings of time for bowl to sink **(Δt)** / s
			Trial 1 (t_1)	**Trial 2 (t_2)**	**Trial 3 (t_3)**		
1	32.02	44.25	361.41	358.27	352.12	357.26	4.65
2	48.23	60.46	297.26	297.53	293.05	299.99	2.24
3	64.11	76.34	242.51	244.31	245.01	243.94	1.25
4	81.06	93.29	229.43	226.17	224.01	226.54	2.71
5	94.86	107.09	197.22	196.15	195.49	196.29	0.86
6	112.44	124.67	176.53	176.84	176.56	176.64	0.16
7	127.52	139.75	168.45	167.05	168.47	167.99	0.71
8	146.02	158.25	136.24	139.13	138.17	137.85	1.44
9	160.99	173.22	133.18	131.39	132.15	132.24	0.90
10	176.03	188.26	121.15	122.36	122.01	121.84	0.18

Table 3. The time observed for identical bowls (12.23 g) containing different masses of clay to sink into water.

Calculation	Formula	Example calculation for the first trial
Mean of sinking time	$t = \frac{\sum t}{n}$	$t = \frac{361.41 + 358.27 + 352.12}{3} = 357.26\ s$
Uncertainty calculation for time between different trials	$\Delta t = \frac{t_{max} - t_{min}}{2}$	$\Delta t = \frac{361.41 - 352.12}{2} = 4.65\ s$
Uncertainty in mass readings	The smallest reading of the electronic balance; ± 0.01 g.	
Uncertainty in time readings	When calculating the sinking time, the time at which the sinking action ended was subtracted from the time at which it started. Taking into account the error propagation, the uncertainty in time was calculated by taking twice the precision in the video recordings; ± 0.02 s.	

Table 4: Formulas and sample calculations.



Graph 1. Variation of the time bowl takes to sink in water depending on the total mass with its components.

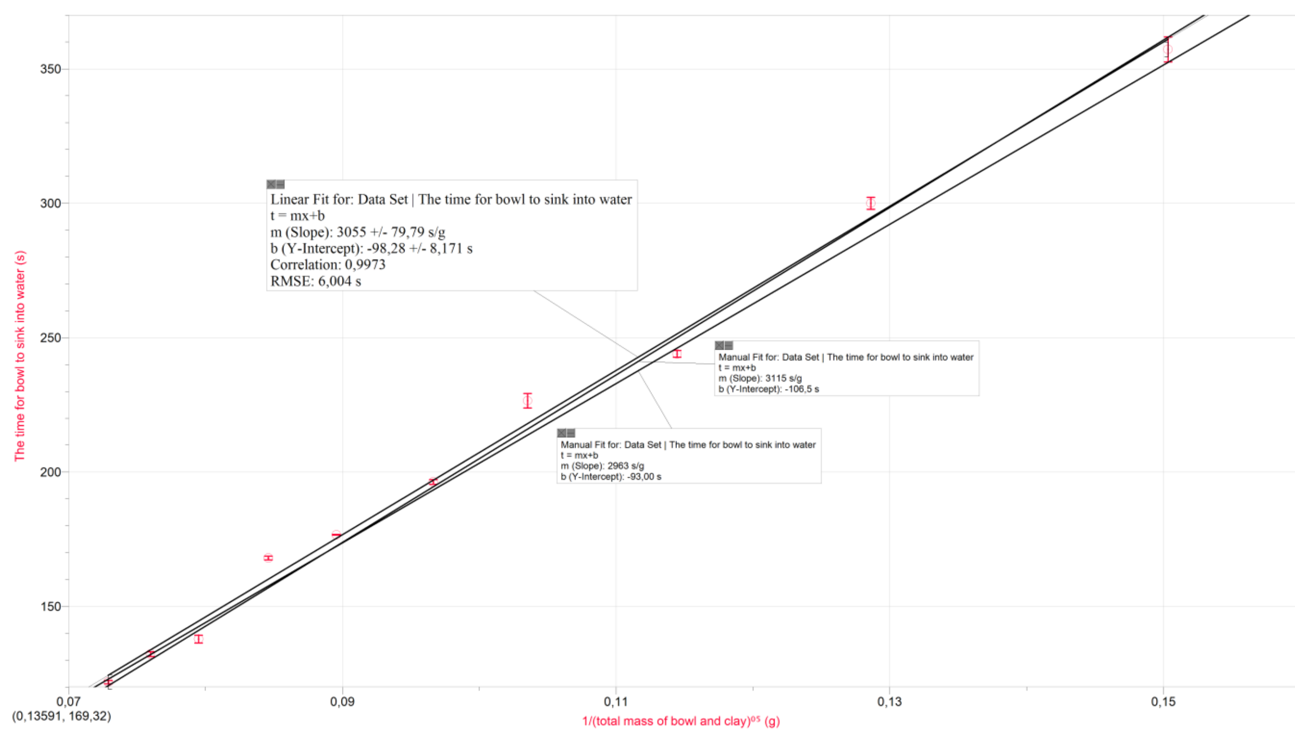
The inverse proportion between the variables in the graph is noticeable. As stated in the Background Information section, since the sinking time is estimated to be inverse to the root of the mass, it was decided to draw a graph between these variables.

Data No	Total mass of bowl and clay **(m)** / g (± 0.01)	$\frac{1}{\sqrt{\boldsymbol{m}}}$ / $s^{-\frac{1}{2}}$	Uncertainty of $\frac{1}{\sqrt{\boldsymbol{m}}}$ / $\times 10^{-5} s^{-\frac{1}{2}}$	Average time for bowl to sink into water **(t)** / s
1	44.25	0.150	1.70	357.26 ± 4.65
2	60.46	0.129	1.06	299.99 ± 2.24
3	76.34	0.114	0.75	243.94 ± 1.25
4	93.29	0.104	0.54	226.54 ± 2.71
5	107.09	0.097	0.45	196.29 ± 0.86
6	124.67	0.090	0.36	176.64 ± 0.16
7	139.75	0.084	0.30	167.99 ± 0.71
8	158.25	0.079	0.25	137.85 ± 1.44
9	173.22	0.076	0.22	132.24 ± 0.90
10	188.26	0.073	0.19	121.84 ± 0.18

Table 5: Processed data and uncertainty.

Calculation	***Formula***	***Example calculation for the first trial***
Uncertainty propagation in $\sqrt{\boldsymbol{m}}$ ***calculation***	$\Delta(\sqrt{\boldsymbol{m}}) = \left(\frac{1}{2} \times \frac{0.01}{m}\right) \frac{1}{\sqrt{\boldsymbol{m}}}$	$\Delta(\sqrt{\boldsymbol{m}}) = \left(\frac{1}{2} \times \frac{0.01}{44.25}\right) 0.150 = 1.6986 \times 10^{-5} s^{-\frac{1}{2}}$

Table 6: Error propagation and sample calculation.



Graph 2. Variation of the time bowl takes to sink in water depending on $\frac{1}{\sqrt{total\ mass\ of\ the\ bowl}}$*. Note that the horizontal error bars too small to be clearly seen.*

Two sensible ways can be used to determine the uncertainty in gradient for this experimental conditions. The first is to use the uncertainty of the gradient by the software automatically. The second is to use the maximum and minimum slopes possible given the instruments uncertainty and deviation during the trials and define that $\Delta\ gradient = \frac{\max gradient - \min gradient}{2}$. Since both are logical approaches, both are calculated and largest of them is accepted.

- The gradient of the best fit line and its uncertainty are given by the software automatically.

Gradient: 3055 ± 79.79 s$\sqrt{g}$

$Percentage\ uncertainty\ in\ the\ gradient = \frac{79.79}{3055} \times 100 = 2.6\ \%$

- The uncertainty estimated using maximum and minimum gradient lines:

$\text{Absolute uncertainty in gradient} = \frac{\max \text{gradient} - \min \text{gradient}}{2} = \frac{3115 - 2963}{2} = 76$

$\text{Percentage uncertainty in gradient} = \frac{76}{3055} \times 100 = 2.49\ \%$

4.2. Investigating the Relation Between Diameter of Hole and Sinking Time

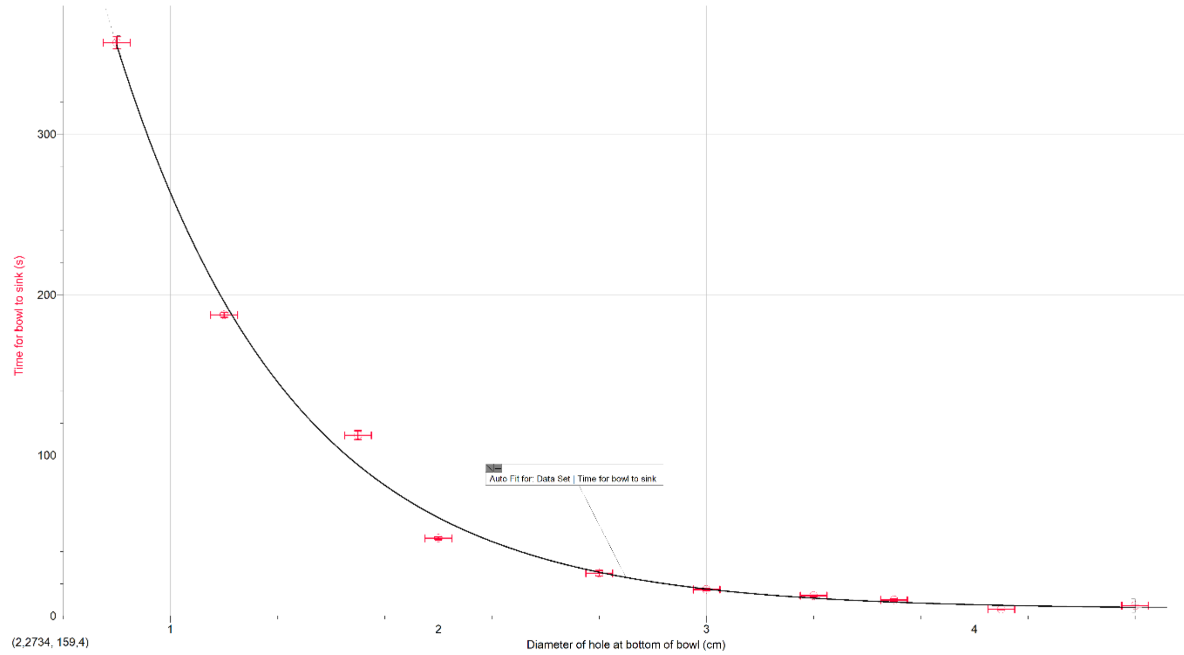
The diameter of the hole at the bottom of the bowl, which reached a total weight of 44.25 grams with the clay added, was enlarged in each trial and the time it took to sink into the water was observed. 3 trials were made for each hole. The data is shown below.

Data No	The diameter of hole at the base **(d)** / cm ($\pm$0.05)	The time for bowl to sink into water / s ($\pm$0.02)			Average time for bowl to sink into water **(t)** / s ($\pm$0.02)	Uncertainty in readings of time for bowl to sink **(Δt)** / s
		Trial 1 (t_1)	**Trial 2 (t_2)**	**Trial 3 (t_3)**		
1	0.80	357.27	361.21	353.54	357.01	3.84
2	1.20	188.52	188.56	185.34	187.54	1.61
3	1.70	109.54	115.11	113.02	112.56	2.78
4	2.00	47.56	49.32	48.21	48.36	0.88
5	2.60	28.35	25.04	26.47	26.62	1.66
6	3.00	17.26	15.62	16.49	16.46	0.82
7	3.40	13.08	12.15	12.41	12.55	0.46
8	3.70	10.53	9.23	10.02	9.93	0.64
9	4.10	6.41	6.37	6.55	4.10	0.09
10	4.60	4.41	4.37	4.55	6.44	0.09

Table 7. The time taken for a 44.25 g bowl containing clay to sink into water, depending on the diameter of the hole at the bottom.

Calculation	*Formula*	*Example calculation for the first trial*
Mean of sinking time	$t = \frac{\sum t}{n}$	$t = \frac{357.27 + 361.21 + 353.54}{3} = 357.01\ s$
Uncertainty calculation for time between different trials	$\Delta t = \frac{t_{max} - t_{min}}{2}$	$\Delta t = \frac{361.21 - 353.54}{2} = 3.84$ s
Uncertainty in diameter readings	The uncertainty of the length measurements was taken as the half of the smallest reading of the ruler; ± 0.05 cm as it is analogue device.	

Table 8. Formulas and sample calculations.



Graph 3. Variation of the time bowl takes to sink in water depending on the diameter of the hole at the bottom.

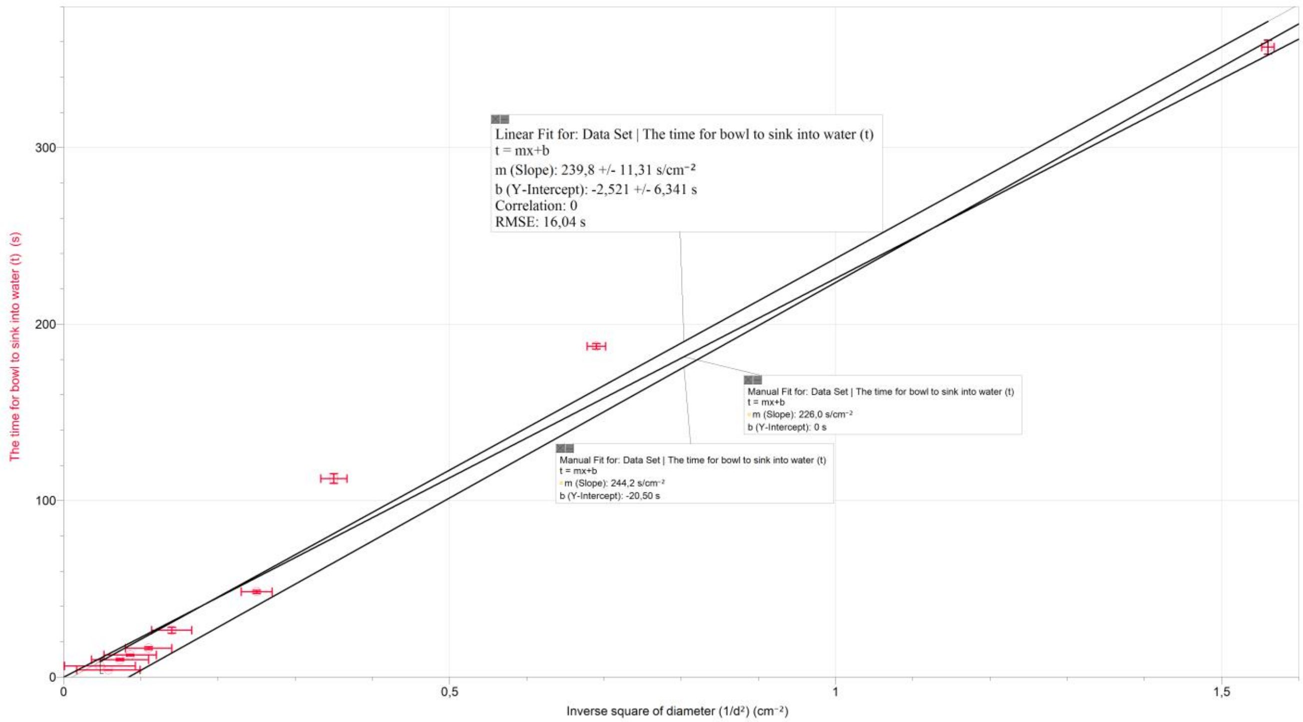
Data No	$\frac{1}{d^2}$ / cm^{-2}	Uncertainty of $\frac{1}{d^2}$ / $10^{-2} cm^{-2}$	Average time for bowl to sink into water **(t ± Δt)** / s
1	1.56	19.50	357.01 ± 3.84
2	0.69	5.75	187.54 ± 1.61
3	0.35	2.05	112.56 ± 2.78
4	0.25	1.25	48.36 ± 0.88
5	0.14	0.52	26.62 ± 1.66
6	0.11	0.37	16.46 ± 0.82
7	0.09	0.25	12.55 ± 0.46
8	0.07	0.20	9.93 ± 0.64
9	0.06	0.14	6.44 ± 0.09
10	0.05	0.10	4.44 ± 0.09

Table 9: Processed data and its uncertainty

Calculation	*Formula*	*Example calculation for the first trial*
Uncertainty propagation in $\frac{1}{\boldsymbol{d}^2}$ ***calculation***	$\Delta(\frac{1}{\boldsymbol{d}^2}) = \left(2 \times \frac{0.05}{d}\right)\frac{1}{\boldsymbol{d}^2}$	$\Delta\left(\frac{1}{\boldsymbol{d}^2}\right) = \left(2 \times \frac{0.05}{0.80}\right)1.56 = 0.195\ cm^{-2}$

Table 10: Error propagation and sample calculation.

As seen in the *Graph 3*, there is an exponential relationship between the diameter of the hole and the sink ing time of the bowl. Since the sinking time is estimated to be inversely proportional to the square of diameter, it was decided to draw a graph between these variables.



Graph 4. Variation of the time bowl takes to sink in water depending on inverse square of diameter.

- The gradient of the best fit line and its uncertainty given by the software;

  Gradient: 239.8 ± 11.3 scm^2

  $Percentage\ uncertainty\ in\ the\ gradient = \frac{11.31}{239.8} \times 100 = 4.7\ \%$

- The uncertainty estimated using maximum and minimum gradient lines:

  $\text{Absolute uncertainty in gradient} = \frac{\text{max gradient} - \text{min gradient}}{2} = \frac{244.2 - 226}{2} = 9.1\ sm^2$

  $\text{Percentage uncertainty in gradient} = \frac{9.1}{239.8} \times 100 = 3.8\ \%$

4.3 Combined Equation of Relationship

$$t = c\frac{1}{d^2\sqrt{m}}$$

$$c = gradient \times \sqrt{m} = 2.4 \times 0.04425 = 0.1062\ sm^2\sqrt{kg}$$

$$t = 0.1062\frac{1}{d^2\sqrt{m}}$$

5. Conclusion

This research was designed to examine the sinking time of the Saxon Bowl timing device experimentally, specifically to find out how the mass of the bowl and the diameter of the hole at the bottom of the bowl affect the sinking time and to derive a function of sinking time that depends on these two variables. As a result, the time function of the Saxon bowl examined in the experiment is presented as follows; $t = 0.1062\frac{1}{d^2\sqrt{m}}$.

As stated in the Hypothesis section, an inverse relationship is expected between the mass of the container and the sinking time in water. After analyzing the collected data, it can be concluded that the results support the Hypothesis. This relationship can be clearly seen in both *Tabl*e 3 and the exponential curve of *Graph 1*. In order to reveal this relationship more specifically, t - $\sqrt{m}$ graph is plotted. The linear graph line proves that the sinking time of the container changes inversely proportional to the square root of the mass. This result is consistent with the equations stated in the Background Information section. The linear trend in *Graph 2* is confirmed by the R^2 of 0.9973. When we examine the literature, we see that similar results are obtained in many scientific studies. The graphs of the experiment conducted by Daniel Norouzi (2020) is seen in *Figure 12* and 13. [2]

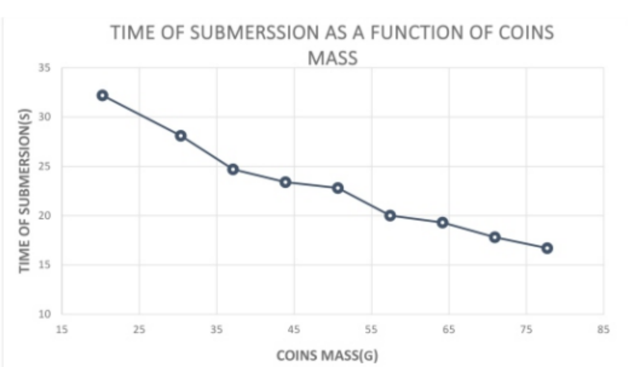


Figure 12. Time of submersion as a function of coin's mass (Norouzi, 2020) (2)

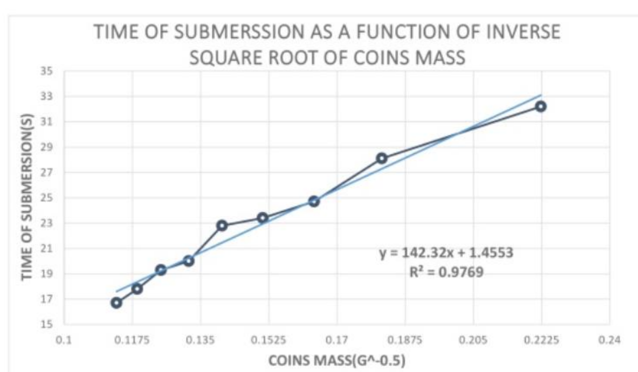


Figure 13. Time of submersion as a function of inverse square root of coin's mass. (Norouzi, 2020) (2)

A second variable that was observed in the experiment was the diameter of the hole drilled in the bottom of the bowl. Research results show that the sinking time of the bowl is inversely proportional to the square of diameter. The exponential curve of sinking time versus diameter of hole graph (*Graph 3*) and the linear relation with the correlation coefficient of 0.9912 in sinking time versus inverse square of diameter graph (*Graph 4*) confirm this result.

Greer and Kincanon also concluded in their experiment that the negative second power of the aperture is directly proportional to the sinking time (*Figure 14 and 15*). (4)

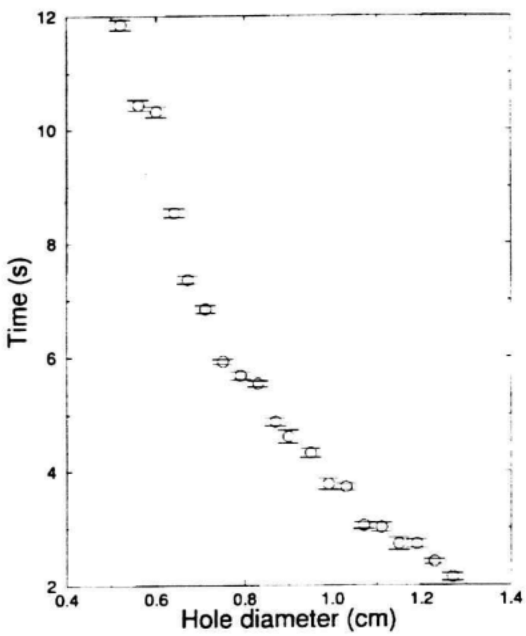


Figure 14. Time of submersion as a function of hole diameter. (4)

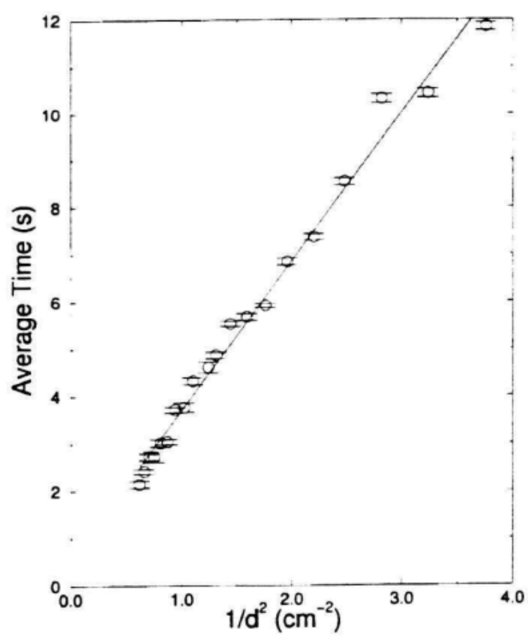


Figure 15. Time of submersion as a function of inverse square of hole diameter. (4)

Similarly, Jiameng Hong also revealed the reciprocal square relationship between time and aperture in his study, as seen in *Figure 16*. The findings of Norouzi's experiment are also seen in *Figure 17*. (2)

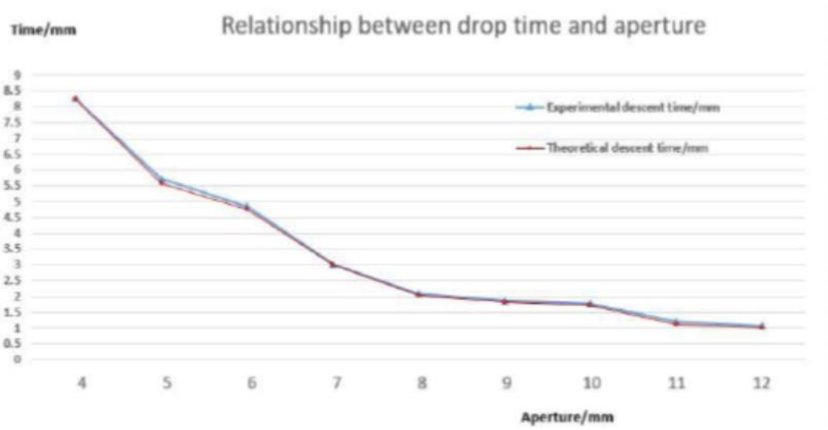


*Figure 16. Relationship between drop time and aperture. (*Hong, 2021) *(3)*

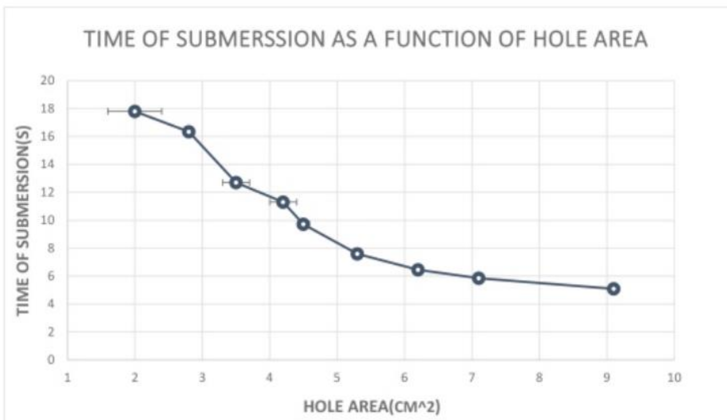


Figure 17. Time of submersion as a function of hole area. (Norouzi, 2020) (2)

This investigation was initially motivated by my curiosity about the rapid sinking of the Titanic. The findings of the study confirmed that both the diameter of the hole and the mass of the body are critical factors in determining how quickly an object fills with water and submerges. Historical analyses of the Titanic disaster indicate that the iceberg caused a series of punctures along approximately 91 meters of the ship's starboard hull. If these openings are considered collectively as a single equivalent circular hole, the diameter would be approximately 1.2 meters. Another significant factor contributing to the Titanic's rapid sinking was its immense mass. With over 52,000 tons of steel, wood, and cargo, the ship had an enormous gravitational force pulling it downward. As water filled the compartments, the additional weight further accelerated the descent, reducing the overall sinking time. The Titanic sank about 2 hours and 40 minutes after the collision, a timeframe that corresponds with the experimental findings of this study to complex real-life phenomena.

6. Evaluation

6.1. Strengths

The data obtained from the experiment showed a strong correlation with the theoretical predictions. The main reason behind this agreement between my experimental data and the theoretical predictions can be mainly attributed to the successful data collection process of this study. As it is known, a large data set collected in the experiment and the number of repeated trials for each measurement will increase the reliability of an experiment. The data collection process in this study included ten separate data points for each independent variable and there were three repeated trials per measurement. So, it was possible to see the trend clearly in the plotted graphs. In addition, the control of variables such as temperature, purity and initial container placement provided a high level of accuracy for the experiment.

Apart from this, the range of the data for both variables was also adjusted precisely. It was observed that the bowls with low mass and small diameter openings at the bottom remained on the water surface after being dropped and did not start to sink afterwards. Therefore, the lowest mass was determined for which the average density of the bowls was just above the density of water. Again, while determining the maximum mass, it was thought that the sinking time of the bowls should not fall below a certain value considering the uncertainty in the time measurement.

A similar situation occurred with very small holes. Surface tension would prevent the bowl from sinking when gently placed on the surface, even though it was heavy enough and had a hole in its bottom. The size of the holes drilled in the bottom of the bowls was also carefully determined with the same problems in mind.

The relative location of the bowl center of mass and the center of buoyancy will cause the bowl to tip over very easily due to the net torque on the bowl. Therefore, the bowl shape and mass distribution are important. To manipulate the mass of the bowl, a ring of uniform clay was added to the outermost part of the bowl base. When the bowl was observed to sink in the water and an imbalance was noticed, the clay was repositioned and the measurement was repeated.

6.2. Limitations and Suggestions

Despite the strengths of this study, there were some limitations that needed to be acknowledged. One of the primary limitations is the simplified theoretical assumptions used in the experiment.

Although the percentage uncertainties in the slopes of the linear graphs (*Graph 2* and *Graph 4*) are very low (2.6% and 4.7%), some outliers are observed in both graphs, indicating that there are errors in both experiments. The flow through the hole is expected to increase in direct proportion to the area of the hole, i.e. r^2, but the effect of the hole diameter on the flow rate is different due to the viscosity effects that will be felt differently in small and large holes. Therefore, deviations from the line were observed at larger diameters.

The model did not take into account factors such as water viscosity, turbulence and surface tension. All of these factors can significantly affect the sinking process. Also, since the depth of the hole is not long enough, using the Bernoulli equation assuming a pipe flow may have caused some systematic differences. Therefore, it is natural that the experimental and modeling results are different but have a close trend as can be seen in the graphs. Therefore, they do not sacrifice any of the experimental findings and real-life correlation. However, they may affect the Saxon Bowl and the sinking time, so the experiment can be improved by taking such factors into account in the calculation of the sinking time.

Another limitation was the imprecise hole geometry due to the manual drilling process. Despite efforts to ensure consistency, the holes were not perfectly circular as we assumed when making the calculations. Due to the shape differences of the holes, the entry velocity was affected altering the uniformity of the sinking time measurements. Like the previous limitation, this one also doesn't change the applicability of the finding in real life because usually the hole in the bottom of a body will not be perfectly circular. However, the calibration of a Saxon Bowl must be precise. Therefore, if you want to increase the accuracy of your findings, a precise circular opening of the hole should be obtained by 3D modeling.

The use of clay for adjusting the mass introduced a secondary variable that was difficult to fully control. When clay is submerged in the water, it absorbs some of the liquid and can gradually dissolve. This factor affects the density, hence the viscosity of the water, which is an important factor while measuring time. Although the water was changed frequently, small changes in the density and viscosity due to dissolved particles may have affected the buoyant and drag forces acting on the bowl. If one wants to improve the accuracy of the findings, he or she might use another substance to model the weight of the body, which does not absorb or dissolve in water.

Although efforts were made to place the clay in the container so that it would be evenly distributed over the outermost part of the base and the center of gravity would be in the middle of the base, perfect uniformity may not have been achieved. Therefore, its changing level as it sinks may alter the water flow rate through the hole. Again, failure to initially place the container level on the water surface may have caused inconsistencies in the initial water entry.

Measurement precision was another limitation, as the sinking process was recorded using a cell phone camera. This introduced uncertainty in defining the exact moment of complete submersion, as video frame rates limited the ability to track motion with high precision. A high-speed camera with motion-tracking software would allow for much more accurate measurements, reducing uncertainties and improving the reliability of recorded data. Similarly, using more precise measuring devices such as a Vernier caliper to measure length, and a more precise weighing scale will minimize error. Again, repeating the experiments more will increase the accuracy of the experiment.

6.3. Future Researches

In this study, two variables affecting the sinking time of the Saxon bowl were investigated. However, in order to establish and calibrate the time characteristic of a Saxon bowl, the effects of other variables, such as the dimensions, shape, and mass distribution of the bowl, should also be investigated. In addition, the motion tracking of bowls with different geometries and instantaneous change of the sinking speed can be monitored to verify the predictive power of the generated models.

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