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Testing Free Fall Vs Non-Free Fall using Kinematic Equations

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ABSTRACT:
Kinematic Equations are one of the most common concepts in Physics I courses that students learn in their college. This concept can be applied in the real world and several applications can be seen in everyday life. The most exciting thing in this research is to apply concepts of free fall on types of materials with various conditions to see whether they follow free fall or not. For this research, 28 different types of objects were dropped and data was collected as hands-on experiments and then compared with the theories and concepts of free fall. It is found that some objects follow free fall but some may not. The details can be seen in the paper below. This research work is good insight to show an honor project that is done with the connection of Physics I concepts that helps learning and applying Physics to the real world by undergraduate students within the classroom.
KEYWORDS*: Free fall, Non free-fall, Gravity, Air resistance, Weight, Physics, Hands-on Experiments, Applications, Kinematics. Algebra based Physics courses.*

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I. INTRODUCTION:

Everything that's happened in life has a reason and a name. An apple falling from a tree, a person who dropped a pencil from a desk by accident. Both of these are examples of a free falling action. But What is a free fall? Free fall is any falling body or object from a height where only gravitational force acts on it. Newton's second law said, "The force that acts on an object is equal to the mass of the object times its acceleration; F= ma." [1] How is free fall different from a non-free fall? A free fall has only force gravity acting on it while a non-free fall has a gravity force and air resistance or any additional force in any direction. For example, if one day a person decides to do skydiving, while you are in the air release the parachute you will feel you are going up. So, you are having a wind resistance, eventually you will go down due to your force of gravity. Vertical movements that are not free fall are: a kite in the air, a flying balloon whereas throwing a ball with a force is also not a free fall. Air resistance is when there is an upward force due to air that stops objects from falling down due to gravity only. So, a net force occurs on the object.[2] In these hands-on experiments, our goal is to test how experiments can be performed at home within materials that can be found at home easily and how Physics can be related to it using some easy experiments. COVID limited chances to go out in various laboratories to perform experiments, so this research work also shows how experiments can be performed and how theory can be used to understand Physics in terms of real world applications in daily life events. The purpose of this research work is to provide an application based learning and teaching environment to an undergraduate student who can perform hands-on experiments at home within reachable materials and see how kinematics of free fall works or whether objects show forced fall or non-free falls. A few studies can be seen on this type of research and were used as a reference for this research work as well. [3]

II. MATERIALS AND METHODS:

Here are the names of the 28 objects that were found at home and used to do the experiments. Jumbo paper clips; Hair bun donut; Pillow; Malt beverage cap; Youth T-pass; Tissues; Paper towels; Filler Paper ball; Plain paper; Paper towels ball; Filler Paper ball; Plain paper ball; Newspaper; Thickness paper; paper board; Cereal books paper ; Tissue Paper 1 fold; Tissue Paper 2 fold; Tissue Paper 3 fold; Tissue Paper 4 fold; Paper towels 1 fold; Paper towels 2 fold ; Paper towels 3 fold; Paper towels 4 fold; News paper 1 fold; Newspaper 2 fold; News paper 3 fold; News paper 4 fold.

These objects were used to drop from the height of the undergraduate student which was 1.68 m and a smartphone was used to record time of fall as T_{exp}. Five trials were taken for each object and the average value of the time of fall was calculated as T_{avg}. Reaction time of the experimentalist was counted as T_r and then it was subtracted to get a calculated value of time of fall for every object as T_{cal} to get more accurate data. Then

Kinematic equations and theories as shown in the theory section were used to calculate acceleration of fall as a_cal from T_cal. Then this a_cal is compared with gravity of Earth "g" to find out a_air and then percent errors were calculated. All these details can be seen in the result section.

III. THEORY USED:

I use kinematic equations for Y direction to test free fall vs non-free fall. Some part of theory has taken from the reference used on free fall as shown here. [3]

Kinematic Equation in Y direction:

Vy=Voy+ay*t (1)
Y=Voy*t+½*ay*t^2 (2)
Vy^2=Voy^2+2ay*Y (3)
Y=(Voy+Vy)*t/2 (4)

Facts

Y=H
ay=-g
Voy=0

Facts applied to equations:

H=½*g*t^2 (5)
T_th= √2H/g ⇒ g = 9.80m/s^2 (6)
% error 1 = (T_th - T_exp)*100/T_th (7)
a_exp = 2*H/(T_exp)^2 (8)
a_exp = g - a_air (9)
a_air = g - a_exp (10)
T_cal = T_exp - T_r ⇒ (T_r = 0.17s for student) (11)
% error 2 = (T_th - T_cal)*100/T_th (12)
a_cal= 2*H/(T_cal)^2 (13)
a_cal = g- a_air_cal (14)
a_air_cal = g - a_cal (15)

IV. RESULTS:

Here are the results of all experiments done with 28 objects. Some objects are very light in weight and have higher volume as thin paper whereas some objects may have pockets or space to hold air in it with folds of paper or as a shape of object as hat or cap, some objects are wide enough like a pillow and some are compact and can be fallen with more force as jumbo clip. All of them are dropped from the height (H) = 1.68 m which is the height of the student. The details of all these data and experiments with their time of the fall for five trials for each object can be seen in the series of **Table 1.**

Table 1: Show five trials of each object dropped and then calculate average experimental time.

Object #1 (Jumbo paper clip)

Trials	1	2	3	4	5	Avg
T_exp (s)	.46	.63	.46	.52	.65	.544

Object #2 (Hair bun donut)

Trials	1	2	3	4	5	Avg
T_exp (s)	.70	.60	.80	.69	.63	.684

Object #3 (Pillow)

Trials	1	2	3	4	5	Avg
T_exp (s)	.72	.72	.86	.83	.58	.742

Object #4 (Malt beverage cap)

Trials	1	2	3	4	5	Avg

T_exp (s)	.76	.46	.48	.59	.60	.578

Object #5 (Youth T-pass)

Trials	1	2	3	4	5	Avg
T_exp (s)	.71	.63	.59	.55	.70	0.636

Object #6 (Tissue)

Trials	1	2	3	4	5	Avg
T_exp (s)	02.36	02.50	02.19	02.89	02.55	2.498

Object #7(Paper towels)

Trials	1	2	3	4	5	Avg
T_exp (s)	03.26	02.52	02.88	01.95	02.96	2.714

Object #8(Filler Paper)

Trials	1	2	3	4	5	Avg
T_exp (s)	02.45	02.93	02.72	02.86	02.89	2.77

Object #9(Plain paper)

Trials	1	2	3	4	5	Avg
T_exp (s)	02.33	02.36	02.83	02.90	02.52	2.588

Object #10(Paper towels ball)

Trials	1	2	3	4	5	Avg
T_exp (s)	.68	.80	.89	.79	.69	.77

Object #11(Filler Paper ball)

Trials	1	2	3	4	5	Avg
T_exp (s)	.70	.78	.50	.79	.63	.68

Object #12(Plain paper ball)

Trials	1	2	3	4	5	Avg
T_exp (s)	.65	.76	.65	.72	.73	.702

Object #13(News paper)

Trials	1	2	3	4	5	Avg
T_exp (s)	02.55	02.69	02.16	02.15	02.25	2.36

Object #14(Thickness paper)

Trials	1	2	3	4	5	Avg
T_exp (s)	01.22	01.05	01.13	01.33	01.33	1.212

Object #15(paper board)

Trials	1	2	3	4	5	Avg
T_exp (s)	0.90	0.88	0.96	0.85	0.96	0.91

Object #16(Cereal Books Paper)

Trials	1	2	3	4	5	Avg
T_exp (s)	01.29	01.29	01.19	01.29	01.30	1.272

Object #17(Tissue Paper with 1 fold)

Trials	1		2	3	4	5	Avg
T_exp (s)	01.61		01.58	01.56	01.93	01.83	1.702

Object #18(Tissue Paper 2 fold)

Trials	1	2	3	4	5	Avg
T_exp (s)	02.02	02.19	02.06	02.36	02.42	2.21

Object #19(Tissue Paper 3 fold)

Trials	1	2	3	4	5	Avg
T_exp (s)	01.72	01.70	01.90	01.65	01.55	1.704

Object #20(Tissue Paper 4 fold)

Trials	1	2	3	4	5	Avg
T_exp (s)	01.20	01.09	01.20	01.15	01.20	1.168

Object #21(Paper towels 1 fold)

Trials	1	2	3	4	5	Avg
T_exp (s)	01.63	01.92	01.89	01.22	01.03	1.538

Object #22(Paper towels 2 fold)

Trials	1	2	3	4	5	Avg
T_exp (s)	01.59	01.60	01.27	01.53	01.53	1.504

Object #23(Paper towels 3 fold)

Trials	1	2	3	4	5	Avg
T_exp (s)	01.20	01.36	01.43	01.25	01.33	1.314

Object #24(Paper towels 4 fold)

Trials	1	2	3	4	5	Avg
T_exp (s)	01.07	01.00	0.99	0.99	01.03	1.016

Object #25(News paper 1 fold)

Trials	1	2	3	4	5	Avg
T_exp (s)	00.95	00.83	00.93	00.85	00.86	0.884

Object #26(News paper2 fold

Trials	1	2	3	4	5	Avg
T_exp (s)	00.73	01.10	01.62	01.33	01.65	1.286

Object #27(News paper3 fold)

Trials	1	2	3	4	5	Avg

T_exp (s)	00.85	00.95	00.99	01.10	01.00	0.978

Object #28(News paper4 fold)

Trials	1	2	3	4	5	Avg
T_exp (s)	00.98	00.78	00.95	00.83	00.83	0.874

Based on these data collected by dropping each object from the same height, the average value of the time of fall is calculated. The kinematics equations can be seen that are applied to these research work in the theory section. The theoretical value of time of fall T_th is calculated using equation # 6. The percent error between T_th and T_avg is calculated using equation # 7 and then percent error is also calculated between T_th and T_cal to see how reaction time affects in the time of fall using equation # 12. These data details can be seen in the **Table # 2.** The Table 2 also has color coding for some rows and they are explained after this table why rows have color coding.

Table 2- Shows each objects with their name and a order number as they are used to drop, the average experimental time (T_avg) and theoretical time (t_th) of fall, percent error between T_exp, T_th [% error (1)], reaction time of the student (T_r) , calculated time (T_cal) and percent error between T_r and T_cal [% error (2)].

Objects #	Objects	T_ avg (s)	T_th	% error (1)	T_ r (s)	T_cal	% error (2)
1	Jumbo paper clips	0.544	.58	6.207	0.17	0.374	35.52
2	Hair bun donut	0.684	.58	17.93	0.17	0.514	11.38
3	Pillow	0.742	.58	27.93	0.17	0.572	1.380
4	Malt beverage cap	0.578	.58	0.3448	0.17	0.408	29.66
5	Youth T-pass	0.636	.58	9.655	0.17	0.466	19.66
6	**Tissues**	**2.498**	**.58**	**330.7**	**0.17**	**2.328**	**301.4**
7	**Paper towels**	**2.714**	**.58**	**367.9**	**0.17**	**2.544**	**338.6**
8	**Filler Paper**	**2.77**	**.58**	**377.6**	**0.17**	**2.6**	**348.3**
9	**Plain paper**	**2.588**	**.58**	**346.2**	**0.17**	**2.418**	**316.9**
10	Paper towels ball	0.77	.58	32.76	0.17	0.6	3.448
11	FillerPaper ball	0.68	.58	17.24	0.17	0.51	12.07
12	Plain paper ball	0.702	.58	21.03	0.17	0.532	8.276
13	**News paper**	**2.36**	**.58**	**306.9**	**0.17**	**2.19**	**277.6**
14	Thiksnessy paper	1.212	.58	109.0	0.17	1.042	79.67
15	paper board	0.91	.58	56.90	0.17	0.74	27.59
16	Cereal box paper	1.272	.58	119.3	0.17	1.102	90.00
17	**Tissue Paper 1**	**1.702**	**.58**	**193.4**	**0.17**	**1.532**	**164.1**

Objects #	Objects	T_ avg (s)	T_th	% error (1)	T_ r (s)	T_cal	% error (2)
	fold						
18	**Tissue Paper 2 fold**	**2.21**	**.58**	**281.0**	**0.17**	**2.04**	**251.7**
19	**Tissue Paper 3 fold**	**1.704**	**.58**	**193.8**	**0.17**	**1.534**	**164.5**
20	Tissue Paper 4 fold	1.168	.58	101.4	0.17	0.998	72.07
21	**Paper towels 1 fold**	**1.538**	**.58**	**165.2**	**0.17**	**1.368**	**135.9**
22	**Paper towels 2 fold**	**1.504**	**.58**	**159.3**	**0.17**	**1.334**	**130.0**
23	Paper towels 3 fold	1.314	.58	126.6	0.17	1.144	97.24
24	Paper towels 4 fold	1.016	.58	75.17	0.17	0.846	45.86
25	News paper1 fold	0.884	.58	52.41	0.17	0.714	23.10
26	News paper2 fold	1.286	.58	121.7	0.17	1.116	92.41
27	News paper3 fold	0.978	.58	68.62	0.17	0.808	39.31
28	News paper4 fold	0.874	.58	50.69	0.17	0.704	21.38

Free Body Diagram (FBD) is made to show a model of free fall versus non free fall and can be seen in **Figure 1**. This FBD shows four cases of fall as a) free fall, b) forced fall, c) weak air resistance, d) strong air resistance. All 28 objects that were dropped from the same height fall into these four categories of model shown in Figure 1. Some objects show free fall with almost similar times of fall as T_th with T_cal and show a_cal close to gravity of Earth as g. This is considered model (a) as Free Fall. Whereas a couple of objects show model (b) as Forced fall. In this case the acceleration of fall is not g but it is greater than g and they take less time of fall than T_th. It shows the presence of the downward force as additional or applied force that made these falls as Forced Fall. Some of the objects show model (c) as the presence of Fall with Weak Air Resistance and show time of fall is somewhat higher than T_th. They are considered Weak Non-Free Fall. Some of the objects show strong air resistance with over 100% error in time of fall between theoretical time and calculated time of fall. Their time of fall is much longer than the theoretical time, T_th. These objects follow the fourth model (d) as Strong Air Resistance Model with very high air resistance.

The color coding shown in Table 2 follows the FBD Models shown in Figure 1. The Purple color represents Model (a), The Yellow color represents Model (b). The Blue color represents Model (c) and the Gray color represents the Model (d).

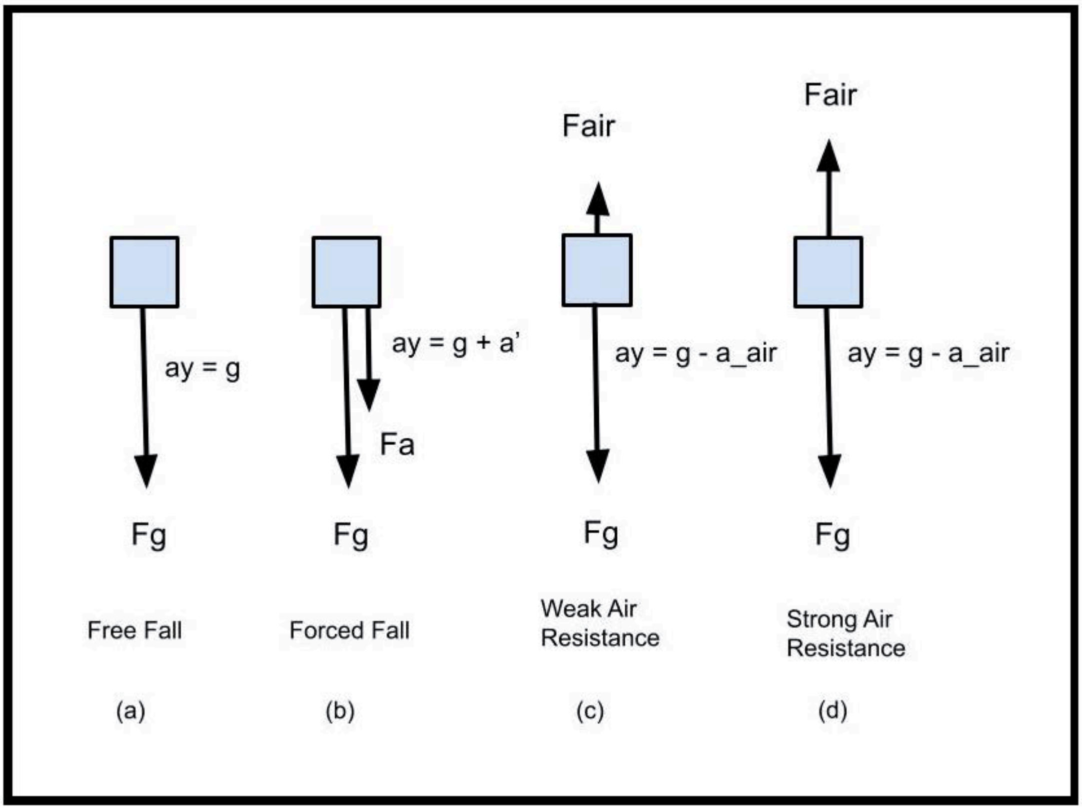

Figure 1: Free Body Diagram (FBD) is showing four Models of free fall versus non-free fall cases.

For each object, the experimental acceleration a_exp, the experimental air resistance, a_air, the calculated acceleration a_cal, and the calculated air resistance a_cal_airwere calculated using the theory mentioned in the theory section. Then these values were compared with the value of gravity, g. If the value of a_cal is almost equal to g, then it follows model (a), if a_cal is higher than g, then it follows model (b). If a_cal is smaller than g, then it follows model ©, and if a_cal is much smaller than g, then it follows model (d). All these data details can be seen in **Table 3**.

Table 3 - Shows the values of experimental and calculated acceleration in Y direction (a_exp, a_cal), experimental and calculated air resistance (a_air, a_cal_air) and g.

Objects #	g	a_exp	a_air	a_cal	a_air_cal
1	9.8	11.35	-1.55	24.02	-14.22
2	9.8	7.18	2.62	12.72	-2.92
3	9.8	6.10	3.70	10.27	-0.47
4	9.8	10.06	-0.26	20.18	-10.38
5	9.8	8.31	1.49	15.47	-5.67
6	9.8	0.54	9.26	0.62	9.18
7	9.8	0.46	9.34	0.52	9.28
8	9.8	0.44	9.36	0.50	9.30
9	9.8	0.50	9.30	0.57	9.23
10	9.8	5.67	4.13	9.33	0.47

11	9.8	7.27	2.53	12.92	-3.12
12	9.8	6.82	2.98	11.87	-2.07
13	9.8	0.60	9.20	0.70	9.10
14	9.8	2.29	7.51	3.09	6.71
15	9.8	4.06	5.74	6.14	3.66
16	9.8	2.08	7.72	2.77	7.03
17	9.8	1.16	8.64	1.43	8.37
18	9.8	0.69	9.11	0.81	8.99
19	9.8	1.16	8.64	1.43	8.37
20	9.8	2.46	7.34	3.37	6.43
21	9.8	1.42	8.38	1.80	8.00
22	9.8	1.49	8.31	1.89	7.91
23	9.8	1.95	7.85	2.57	7.23
24	9.8	3.26	6.54	4.69	5.11
25	9.8	4.30	5.50	6.59	3.21
26	9.8	2.03	7.77	2.70	7.10
27	9.8	3.51	6.29	5.15	4.65
28	9.8	4.40	5.40	6.78	3.02

V. DISCUSSION:

Following Table 1 data details, a graph is plotted for all 28 objects for their T_avg and T_th and it can be seen that T_avg is widely spread around to T_Th. The values of T_avg that are near to T_th are in free fall. This can be seen in **Figure 2**. Based on the Model discussed in Figure 1, all 28 objects follow these four models described in Figure 1.

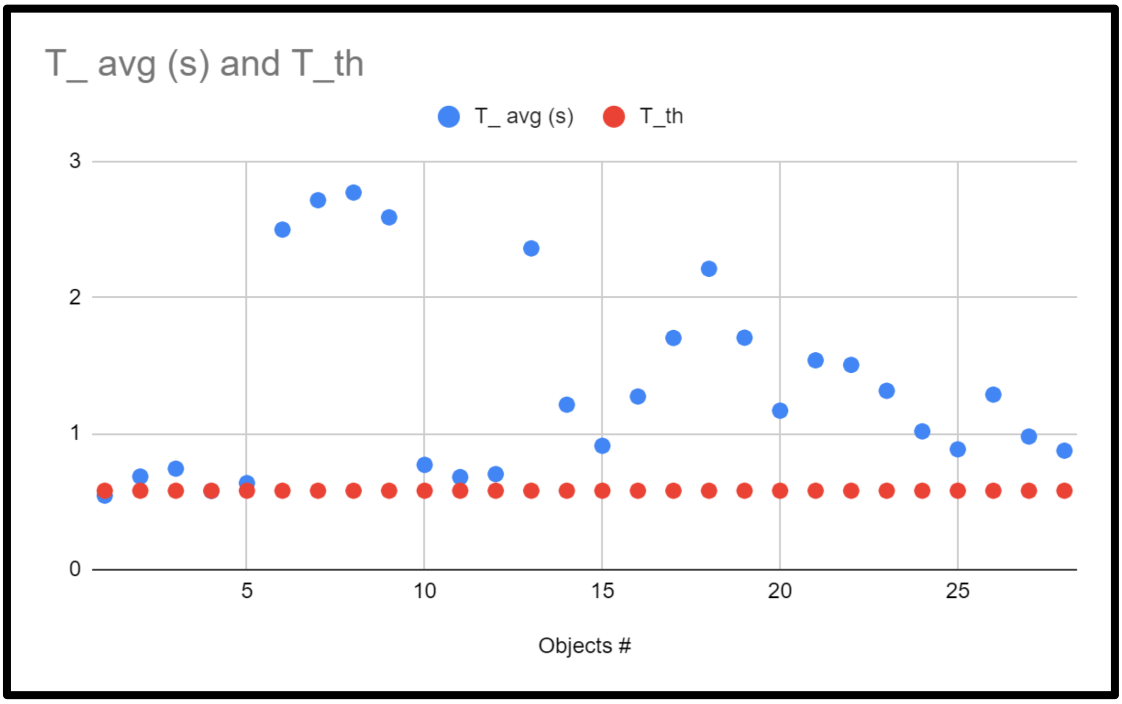

Figure 2: This graph shows experimental time and theoretical time of fall for 28 objects.

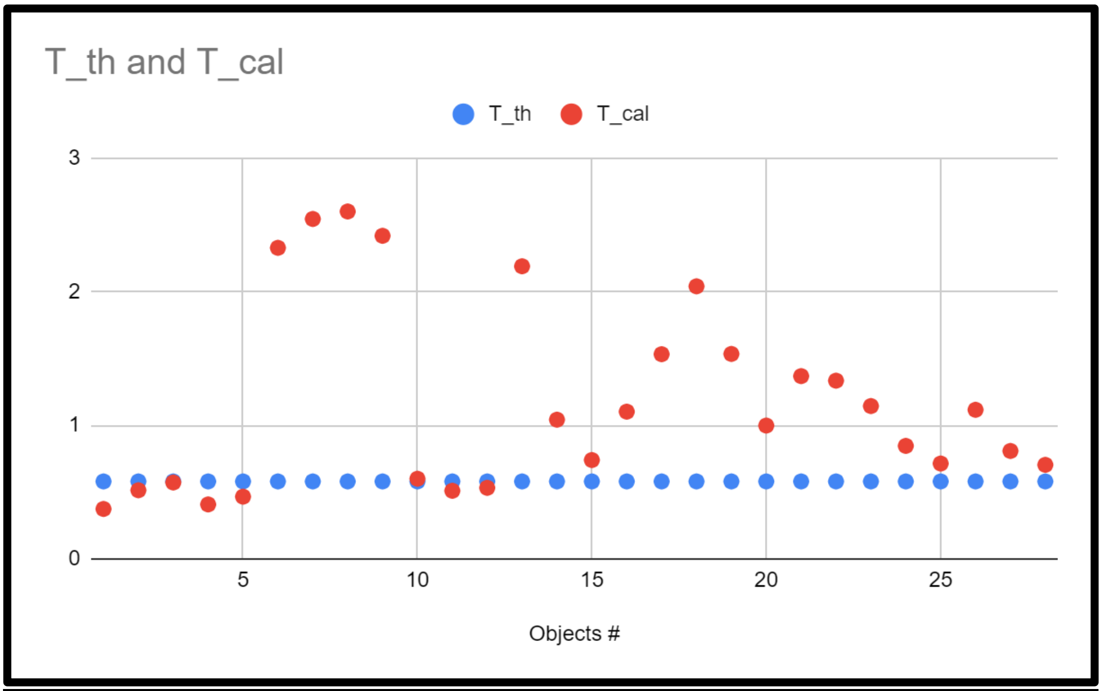

Figure 3: This graph shows the theoretical and calculated time of fall of 28 objects.

Counting reaction time of the person who performed experiments, the calculated time is calculated and then compared with theoretical time and then plotted here in **Figure 3.** More data points move towards T_th when T_cal is considered compared to Figure 2. That indicates that the chances of having error in getting time fall is less and more objects follow free fall concepts especially those that are around to T_th in Figure 3.

The percentage error calculated for T_avg and T_th as error 1, and percentage error calculated between T_cal and T_th as error 2 are compared here in **Figure 4.**

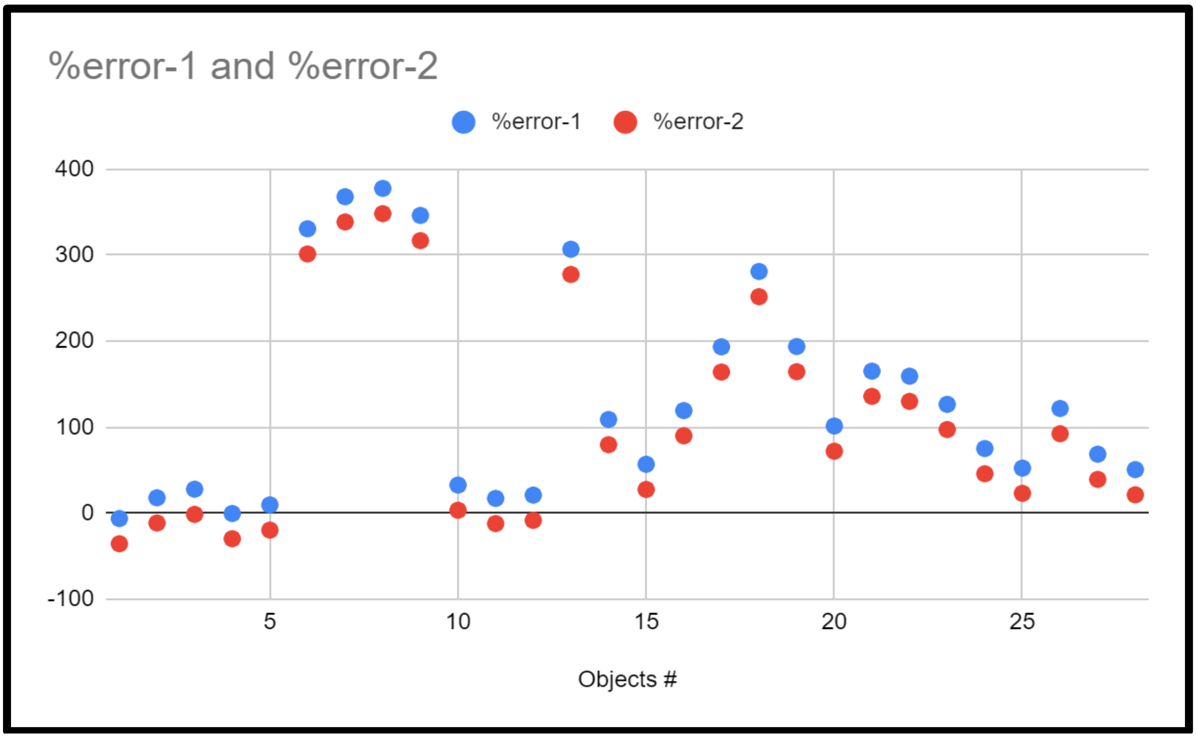

Figure 4: This graph shows a comparison between percent errors of (1) and (2) type and it is clear that percentage error (2) has more objects near zero percentage following free fall.

Figure 5 is plotted for gravity, calculated acceleration and experimental acceleration for fall. It is seen that a_cal has more objects around gravity and it satisfies more accuracy of data. On average, it can be seen that object #1 and #4 has a higher value of a_cal than g which indicates a Force Fall. Whereas objects # 2, 3, 5, 10, 11, 12, 15, 25, 27 and 28 are more around g and shows Free Fall. The object # 14, 16, 20 23, 24 and 26 show lower value of a_cal than g and indicate Weak Air resistance. Now the left objects those are # 6, 7, 8, 9, 13, 17, 18, 19, 21, and 23 are the ones those have much lower a_cal than g which means very strong Air Resistance.

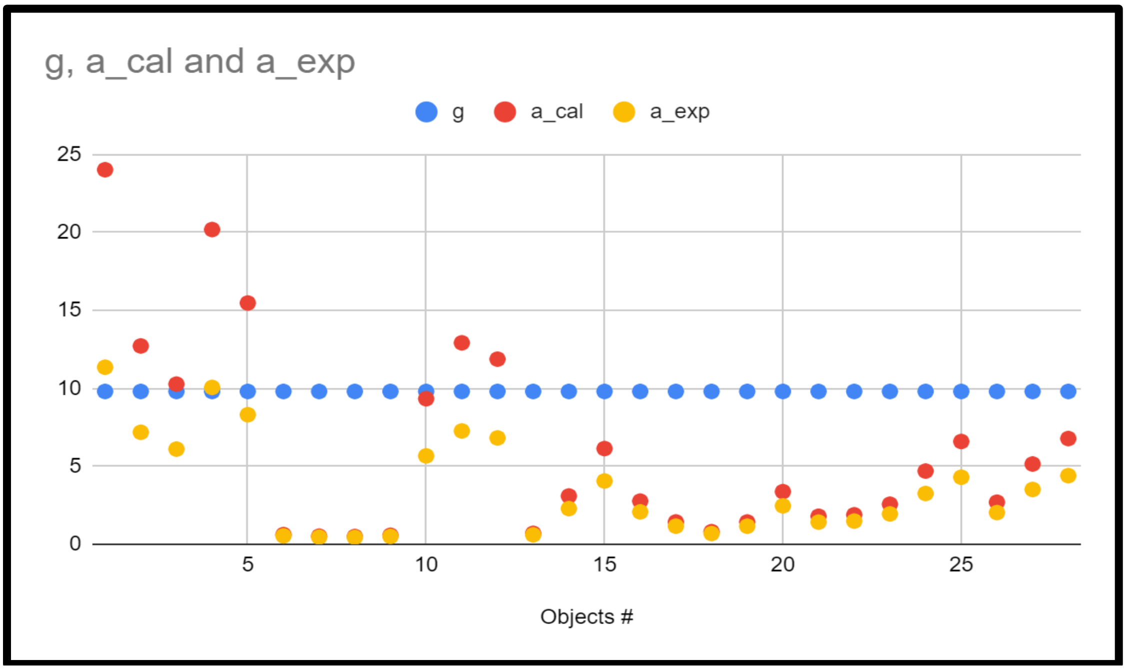

Figure 5: This graph shows a comparison between g, a_cal and a_exp. The Red balls that are around Blue balls follow Free Fall. The Red ball that is values 25 and 20 follow Forced Fall. The Red balls that are a little farther away from blue balls on the lower side, follow Weak Air Resistance, whereas the left Red balls that are nearest to zero follow Strong Air Resistance.

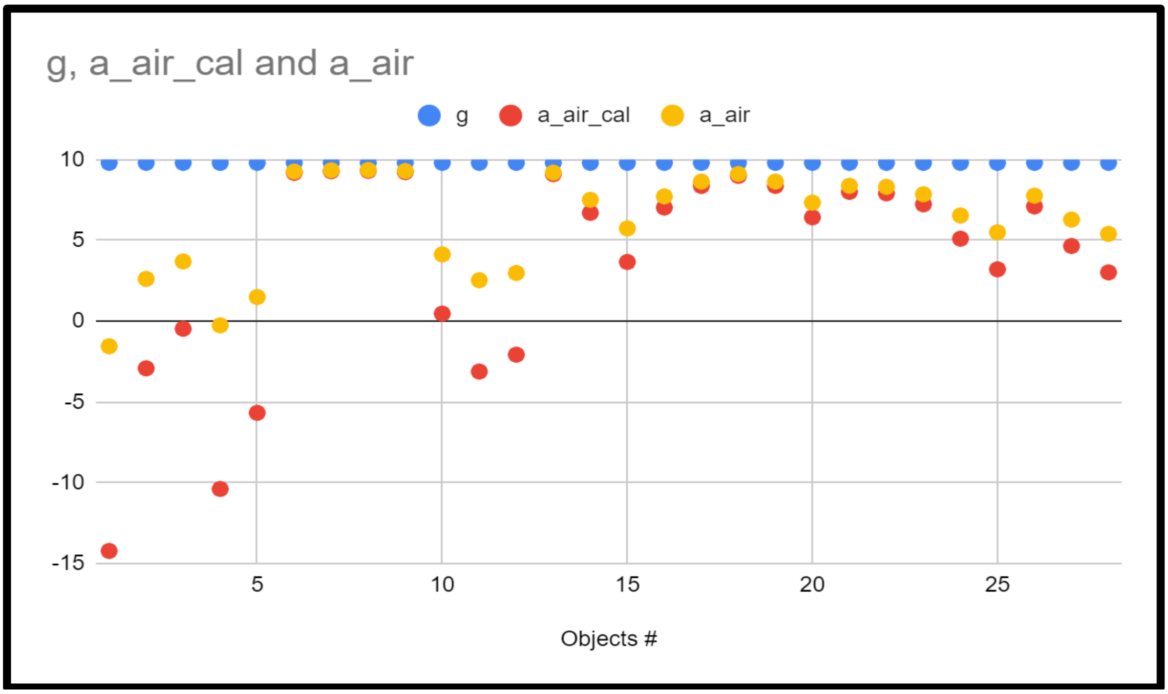

Figure 6: This graph shows a comparison between g, a_air_cal and a_air.

Air resistance is calculated from a_cal and a_exp and shown in **Figure 6** with gravity. It is seen that a_air_cal is more accurate as it has more data points around itself. The a_air_cal has red balls and g has Blue balls. The more Red balls that are near to zero (anywhere from zero to value of +/- 5 show Free Falls as they have almost No Air resistance whereas, the Red balls that are below than -5 show Forced Falls. The Red balls that are above +5 show Weak air resistance and the Red balls that are near to Blue balls or next g have maximum or Strong air resistance force.

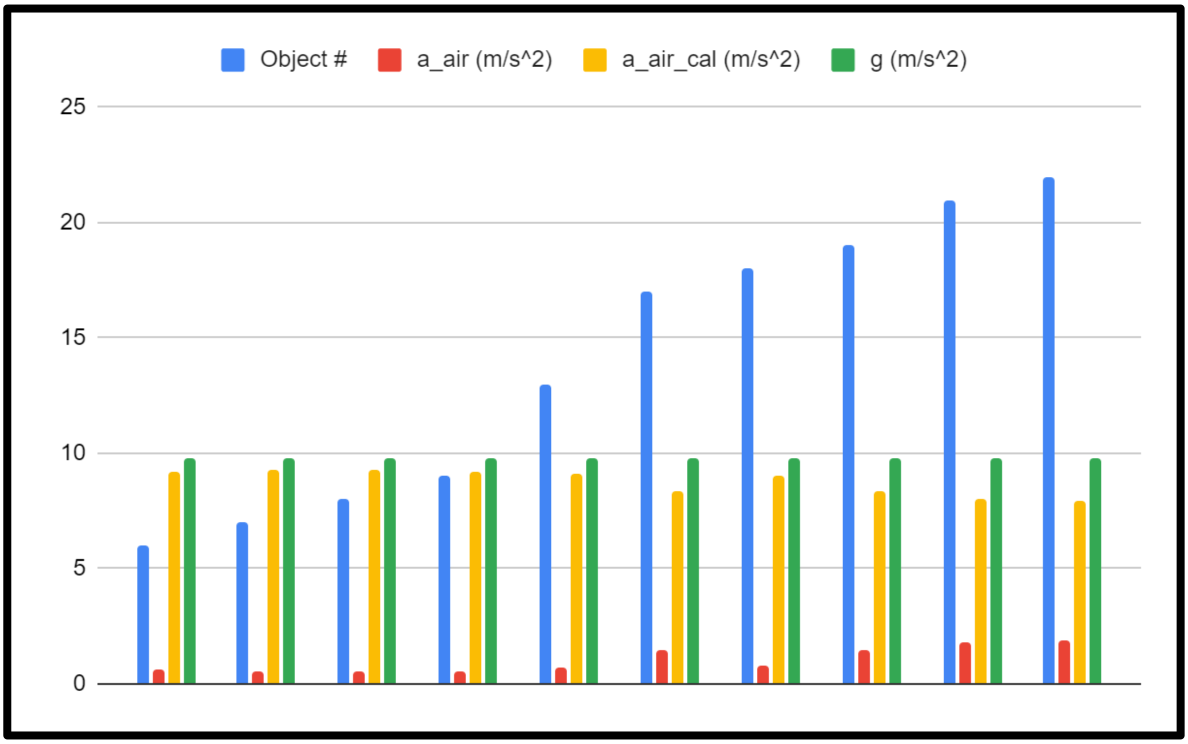

Figure 7: This is a summary graph for 10 objects that show highest air resistance.

There are a total 10 objects that have highest air resistance and lowest acceleration of fall showing slowest fall and highest percent error in the time of fall indicating Model (d) as Strong Air Resistance. These objects are shown in the summary **Table 4.** The graphs of these 10 objects can be seen in **Figure 7**.

Table 4 - Summary table that shows the objects that have the highest air resistance a_air_cal, lowest acceleration of fall a_cal, highest percent error in time of fall.

Object #	**Object**	**% error in T_cal**	a_air (m/s^2)	a_air_cal (m/s^2)	g (m/s^2)
6	Tissues	301.4	0.62	9.18	9.8
7	Paper towels	338.6	0.52	9.28	9.8
8	Filler Paper	348.3	0.5	9.3	9.8
9	Plain paper	316.9	0.57	9.23	9.8
13	News paper	277.6	0.7	9.1	9.8
17	Tissue Paper 1 fold	164.1	1.43	8.37	9.8
18	Tissue Paper 2 fold	251.7	0.81	8.99	9.8
19	Tissue Paper 3 fold	164.5	1.43	8.37	9.8
21	Paper towels 1 fold	135.9	1.8	8	9.8
22	Paper towels 2 fold	130	1.89	7.91	9.8

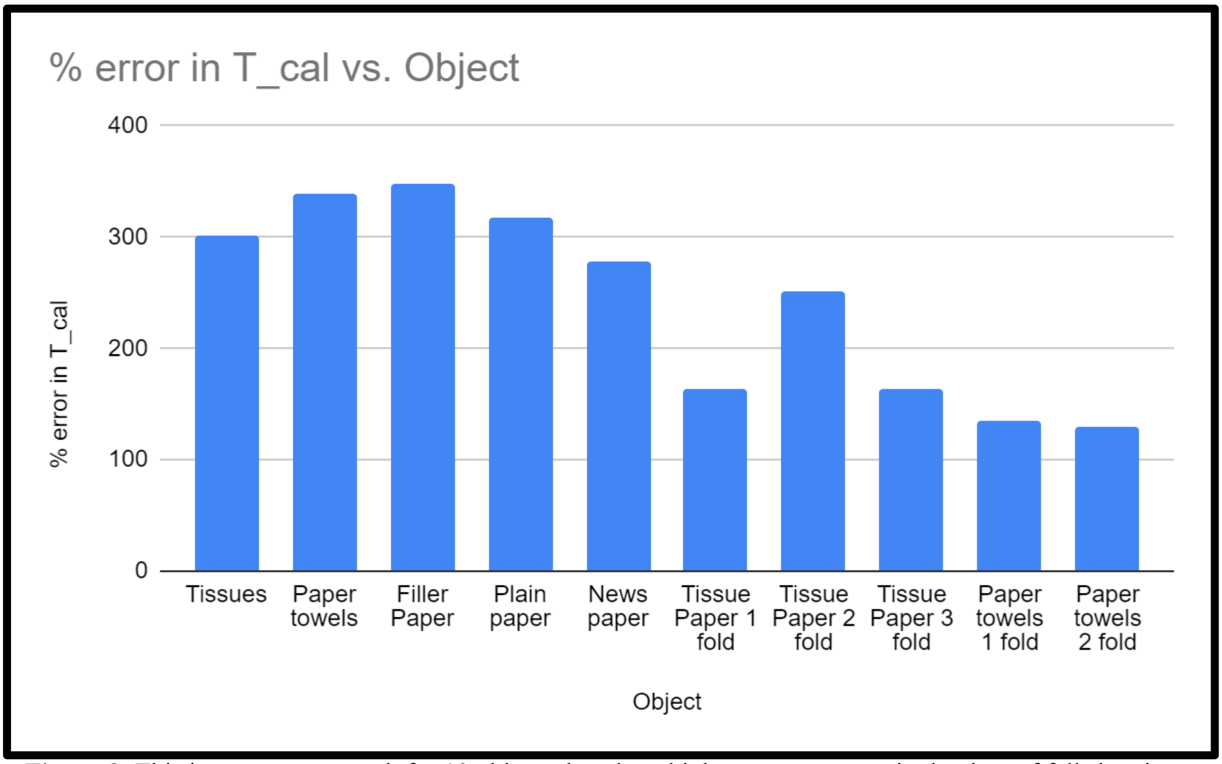

Figure 8: This is a summary graph for 10 objects that show highest percent error in the time of fall showing Non-free fall with strongest air resistance.

Figure 8 shows that 10 objects have the highest percent error in T_cal compared to T_th indicating Non-Free Fall with highest air resistance and lowest acceleration of fall as a_cal with highest time taken to fall. It is clear from

Figure 8 that all of these 10 objects are paper based. The Filler paper is the lightest paper among all types of papers and had the highest percent error. When papers are given folds, their percent error starts decreasing as their area is decreasing and the effect of air resistance is decreasing as well. But tissue paper with 2 folds shows oppor=site effect that the one fold and it seems that when tissue paper had no folds, it had highest percent error as its area was more but it was given one fold, its area decreased and it showed lower percent error compared to no folded tissue paper but when it was given two folds, it started creating air pockets to fill air and showed higher percent error again which went down with three folds.

VI. CONCLUSION:

This research work shows hands-on experiments for free fall versus non- free fall with household objects that are easily available at one's home. It also shows how some conceptual based experiments can be performed at home during COVID time to apply concepts of Physics I as real world applications. In this experiment, 28 objects were dropped from a constant height of 1.68m. And the time of fall was recorded. The time of fall is compared with the theoretical time of fall using Kinematic equations. It is found that some objects show Free Fall but some shows Forced Fall and some Non-Free fall with weak to strong air resistances. This work is done as an honor project with relation to Physics 201 course to see how concepts of Physics I be applied to daily life in terms of real world applications.

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REFERENCES:

[1]. The Three Laws of Human Behavior - BehavioralEconomics.com | The BE Hub
[2]. gravity | Definition, Physics, & Facts | Britannica
[3]. Sharma, O., & Sharma, D. (2021). How Free is a Fall That Occurs in Real World? *European Journal of Applied Sciences*, *9*(4), 39–53. https://doi.org/10.14738/aivp.94.10446