In What Ways Does Shape Material and Surface Area Affect the Terminal Velocity of a Parachute?

Physics Extended Essay

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Aim

The aim of this experiment is to analyze how the air resistance and gravitational pull are related in a parachute. I will do this by investigating which type of parachute has a lower terminal velocity by changing shapes, surface area, and material of the parachute and by keeping as first constant the gravitational pull on the parachute and its mass and as second constant the height at which the parachute will start its descent.

Hypothesis

I expect that the best material will be plastic since it doesn't allow any air to pass through it. The best shape in my opinion will be the circle since being uniform without any angles it should curve in such a way that the air will come out from underneath the parachute so the one that will glide down more slowly will be the largest since it has more air facing it so more resistance and less speed. Lastly the best string length will be the longest since it allows the parachute to be more stable.

Background Information

Mainly there are two forces acting on a parachute; Gravity and Air resistance.

Gravity is the downwards force, it's the force that pulls the parachute towards the ground. It is the force of attraction between matters. Although its one of the weakest forces in nature it still manages to keep galaxies together and us attached to the earth.

This force was put in formulae by Sir Isaac Newton, an English mathematician, in his general law that governs gravitational forces:

"Every particle of matter in the universe attracts every other particle with a force which is directly proportional to the product of their masses and inversely proportional to the square of their distances apart."[1]

Put into formulae its:

$$F_g \propto \frac{m_1 m_2}{r^2}$$

OR

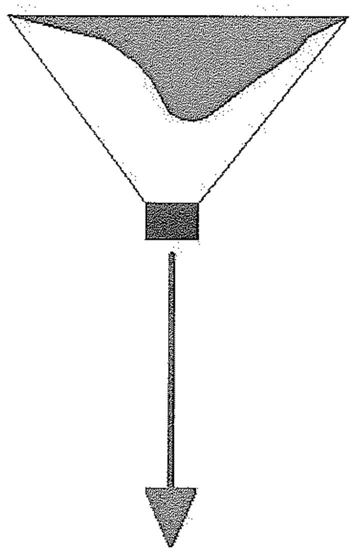
[1] Advanced Physics Fifth Edition Tom Duncan

$$F_g = G\frac{m_1 m_2}{r^2}$$

Where:
F = Force in Newton's
$G = 6.67x10^{-11}$ = Gravitational Constant
M_1 = First Mass in Kilograms
M_2 = Second Mass in Kilograms
r = Distance in metres between m_1 and m_2

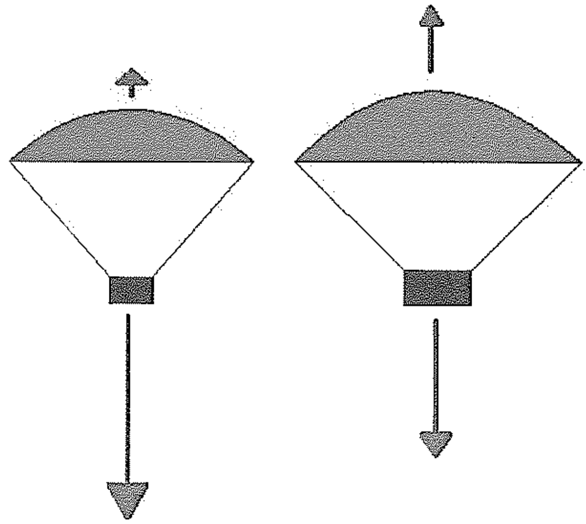
In a Vacuum the parachute independently from the mass, surface area, material or shape, it would fall with an acceleration of 9.8 m s $^{-2}$. For the parachute to glide down there has to be another force acting on it working as an opposite force to gravity and pulling the parachute upwards. This force is air resistance; it increases as the speed of the parachute increases. The more surface area there is of the parachute the higher the air resistance since there is more air facing the parachute and applying resistance to it.

Initially the parachute gliding down at the very moment it has been released it has acceleration due to gravity of 9.8 m s^{-2} downwards.



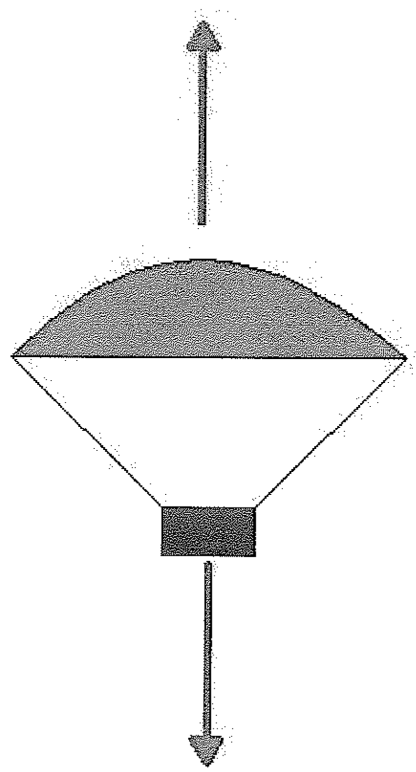
Parachute not yet been released
Maximum downwards pull Zero air resistance

After it has been released the parachute gradually decelerates since there is air resistance acting upwards on it…



Parachutes during the descent.
Downward velocity decreases
Upward pull increases.

…until it reaches its terminal velocity. Terminal velocity occurs when there is no acceleration and the resultant force on the parachute equals to 0 since both forces balances each other out (F_g=F_{ar}). This means that it happens when air resistance equals the gravitational pull on the object. In this period of the glide the velocity of the object remains constant. Terminal velocity is not always the same; a larger surface area of the parachute means a lower and earlier terminal velocity whilst a higher mass specially if small and dense means a higher and later terminal velocity. So terminal velocity depends from the size of the parachute, how much mass put on it and also from the shape of the parachute.



Procedure

The tools that are needed for this experiment are the following:

- Paper is the first material of the parachute to be tested
- Thin cotton sheet is the second material that will be tested
- Thick cotton sheet for example a towel is the third material to be tested
- Pieces of strings of different lengths
- Different weights to be used as the mass dragging the parachute towards the earth
- More than 1Kg of pongo to keep the gravitational pull always constant
- A balance to weigh each component of the parachute and be sure that each parachute has the same gravitational pull

In this investigation there will be four experiments:

Experiment 1: Best shape of parachute

The constants in this experiment will be the length of the string that attaches the mass to the parachute, the mass that drags the parachute down, the material of the parachute and the shape.

Circles will have to be cut out of paper of radii 10 cm, 15 cm, 20 cm, 25 cm and 30 cm. Strings of length 40 cm will have to be attached to paper shapes on one end and to the mass on the other end that will be of more or less 1 kg since it will vary depending on how much the parachute weights. The total mass of the whole system will have to be constant at 1 Kg. The parachute will then be dropped from a height of 20 m so to allow the parachute to reach its terminal velocity. For this experiment to be correct there has to be no external force acting on the parachute for example wind.

Experiment 2: Best shape of parachute

For this experiment the constants will be the length of the string that attaches the mass to the parachute, the mass that drags the parachute down, the material of the parachute and its surface area.

After having cut the paper into circles of radius 10 cm, 15 cm, 20 cm, 25 cm and 30 cm there will have to be cut squares of the same area so of side length 17.7 cm, 26.6cm, 25.4cm, 44.3cm and 53.17cm. Strings of length 40 cm will have to be attached to the paper shapes on one end and to the mass on the other end. The mass as before will be of more or less 1Kg since it will vary depending on how much the parachute weighs. The total mass of the whole system will have to be 1 Kg always constant. The parachute will then be dropped again from a height of 20 m so to allow the parachute to reach its terminal velocity. For this experiment to be correct there has to be no external force acting on the parachute for example wind.

Experiment 3: Best material for the parachute

In this experiment the constants will be the length of the string that attach the mass to the parachute, the mass that drags the parachute down, its surface area and the shape of the parachute for all four different materials.
The four materials tested are paper, thin cotton sheet, thick cotton towel and plastic. Circles of 30cm in radius will have to be cut out from all four materials. Strings of length 40 cm will have to be attached to the paper shapes on one end and to the mass on the other end. The mass as before will be of more or less 1Kg since it will vary depending on how much the parachute weighs. The total mass of the whole system will have to be constant at 1 Kg. The parachute will then be dropped again from a height of 20 m so to allow the parachute to reach its terminal velocity. For this experiment to be correct there has to be no external force acting on the parachute for example wind.

Experiment 4: Best String Length

This experiment will have as constants the material of the parachute, the mass dragging the parachute down, its surface area and the shape of the parachute. Always with the same thick cotton parachute of radius 30 cm, strings of different lengths 10cm, 15cm, 20cm, 25cm, 30cm, 35cm, 40cm, 45cm, 50cm, 55cm, 60cm will have to be attached to it on one side. On the other side of the parachute there will be a mass of more or less 1Kg since it will vary depending on how much the parachute weighs. The total mass of the whole system will have to be constant at 1 Kg. The parachute will then be dropped again from a height of 20 m so to allow the parachute to reach its terminal velocity. For this experiment to be correct there has to be no external force acting on the parachute for example wind.

Results

Radii of the circle parachute cm	Time for the parachute to touch the ground / Seconds
10	0.609
15	0.821
20	1.097
25	1.273
30	1.458

Area of the parachute cm2	Time for the circle parachute to reach the ground / Seconds	Time for the Squared parachute to reach the ground / Seconds
314	0.592	0.589
707	0.657	0.614
1257	0.707	0.643
1963	0.763	0.641
2827	0.952	0.792

Material of the parachute	Time for the parachute to touch the ground / seconds
Paper	1.458
Thin cotton sheet	0.826
Thick cotton towel	0.986
Plastic	1.512

Length of the string / cm	Time for the parachute to reach the ground / Seconds
10	0.589
15	0.742
20	0.892
25	1.011
30	1.102
35	1.182
40	1.233
45	1.299
50	1.362
55	1.431
60	1.458

Calculations

V=S/T

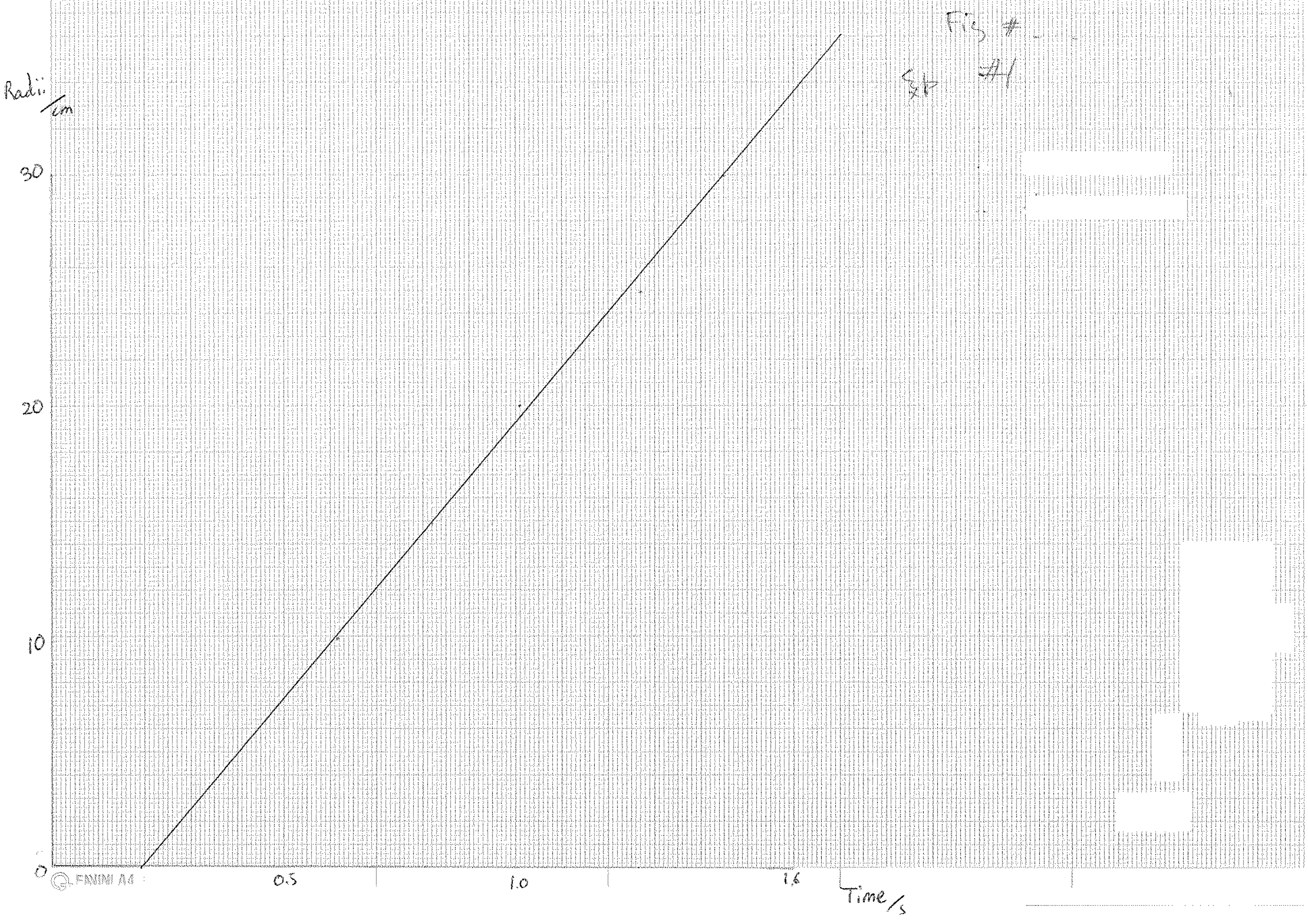
Radii of the circle parachute / cm	Average Velocity of the parachute / m/s
10	3,218
15	2,387
20	1,786
25	1,539
30	1,344

Area of the parachute / cm2	Average Velocity of the circle parachute / m/s	Average Velocity of the Squared parachute / m/s
314	3,311	3,327
707	2,983	3,192
1257	2,772	3,048
1963	2,569	3,057
2827	2,206	2,474

Material of the parachute	Average Velocity of the parachute / m/s
Paper	1.344
Thin cotton sheet	2.372
Thick cotton towel	1.988
Plastic	1.296

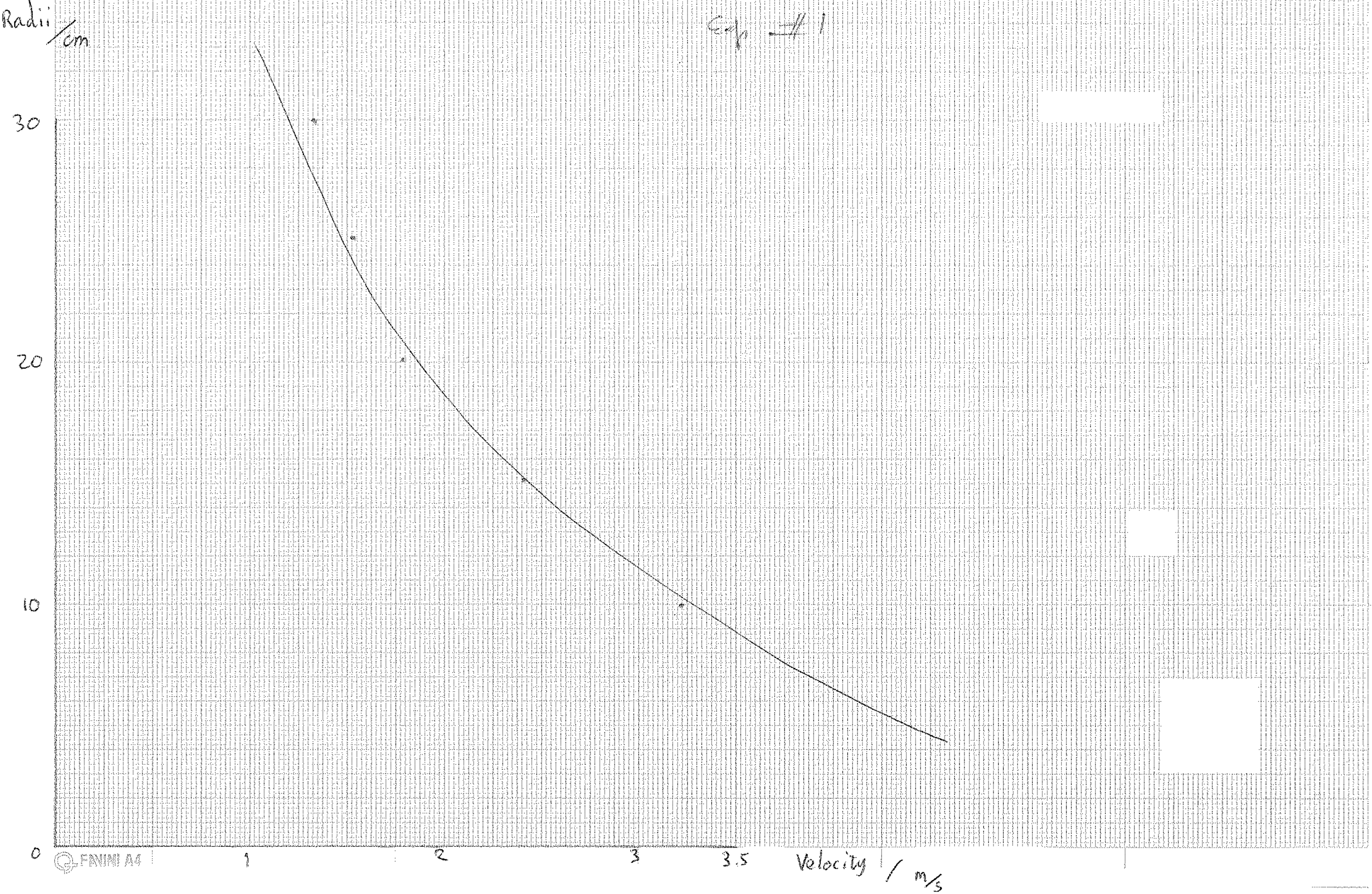
Length of the string / cm	Average Velocity of the parachute / m/s
10	3,327
15	2.641
20	2.197
25	1.939
30	1.779
35	1.658
40	1.590
45	1.509
50	1.439
55	1.370
60	1.344

Graph Showing Radius of a Parachute against time for Descent

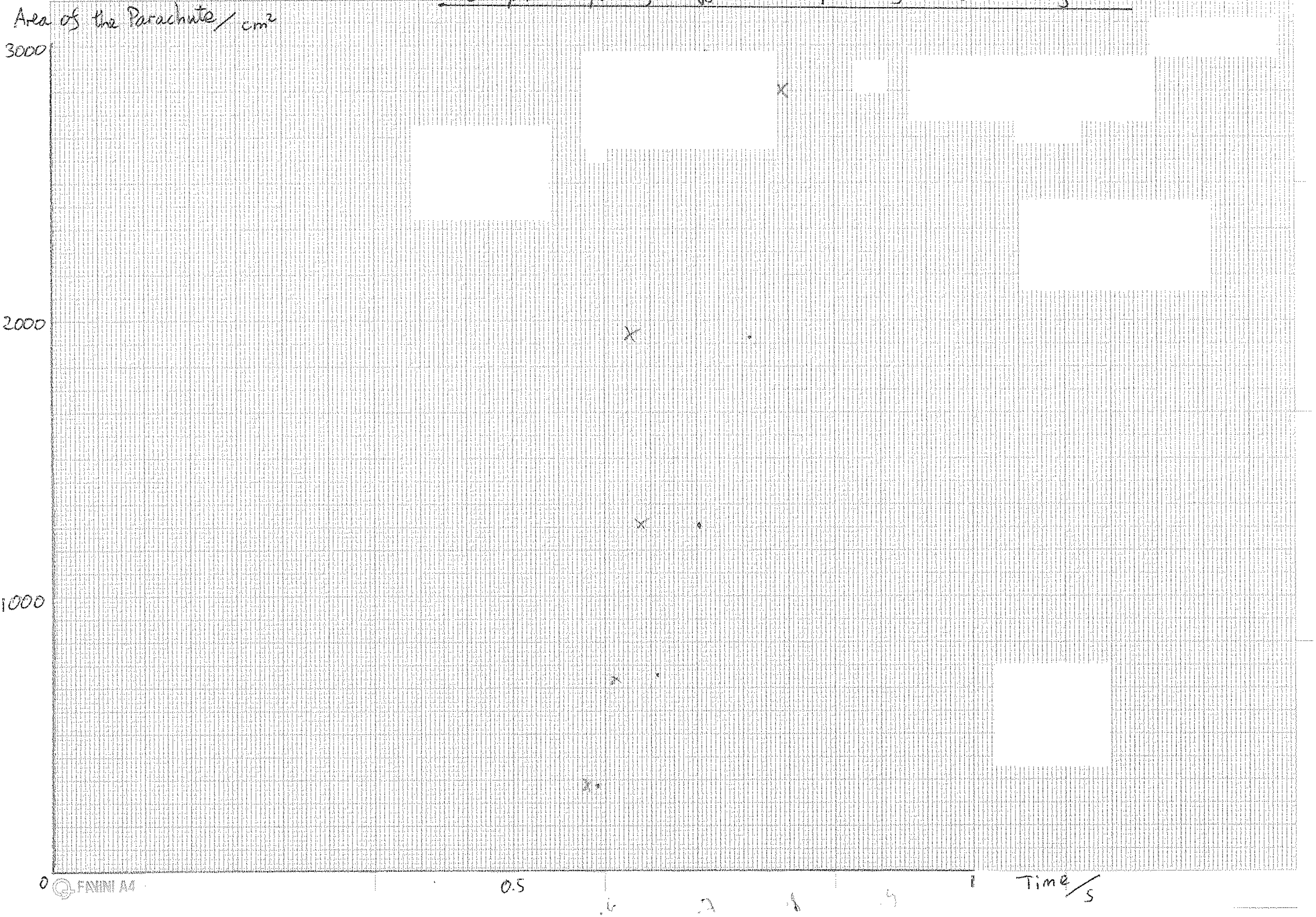


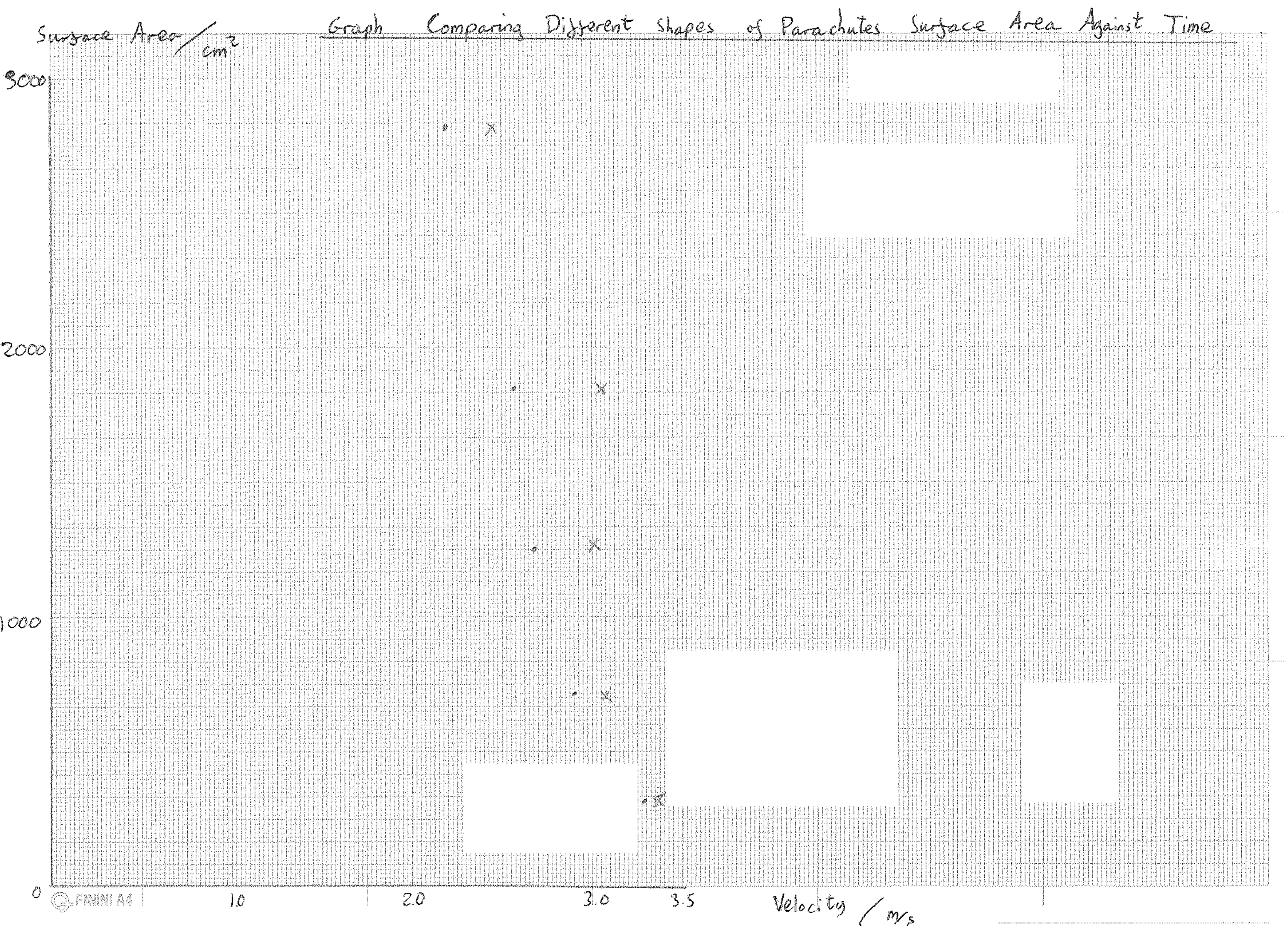
Graph Comparing the Radii of the Parachute to its Average Velocity

Exp #1



Graph Comparing Different shapes of Parachutes Against Time




Graph Comparing Different Shapes of Parachutes Surface Area Against Time
Surface Area / cm²
3000
2000
1000
0
1.0
2.0
3.0
3.5
Velocity / m/s
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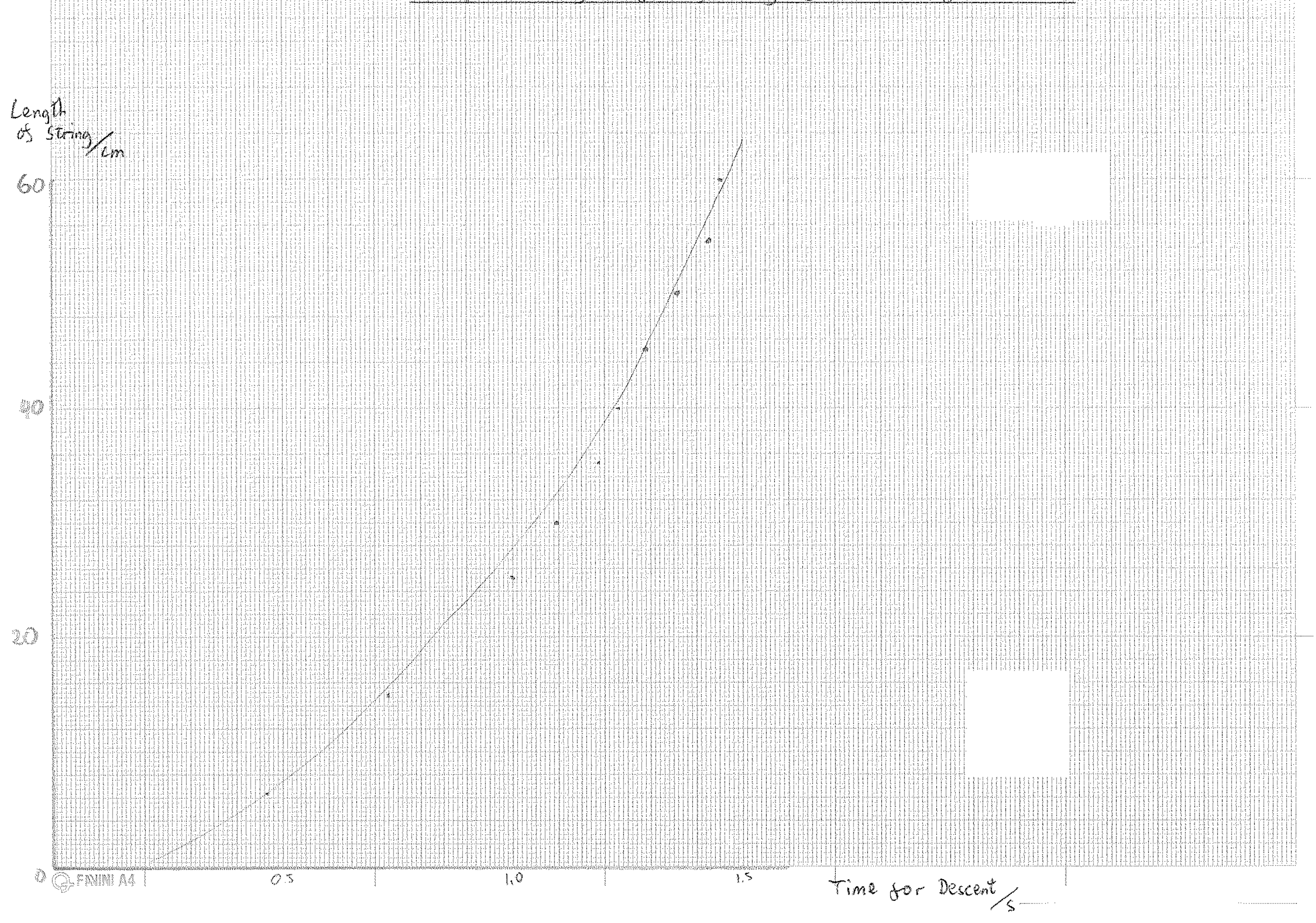
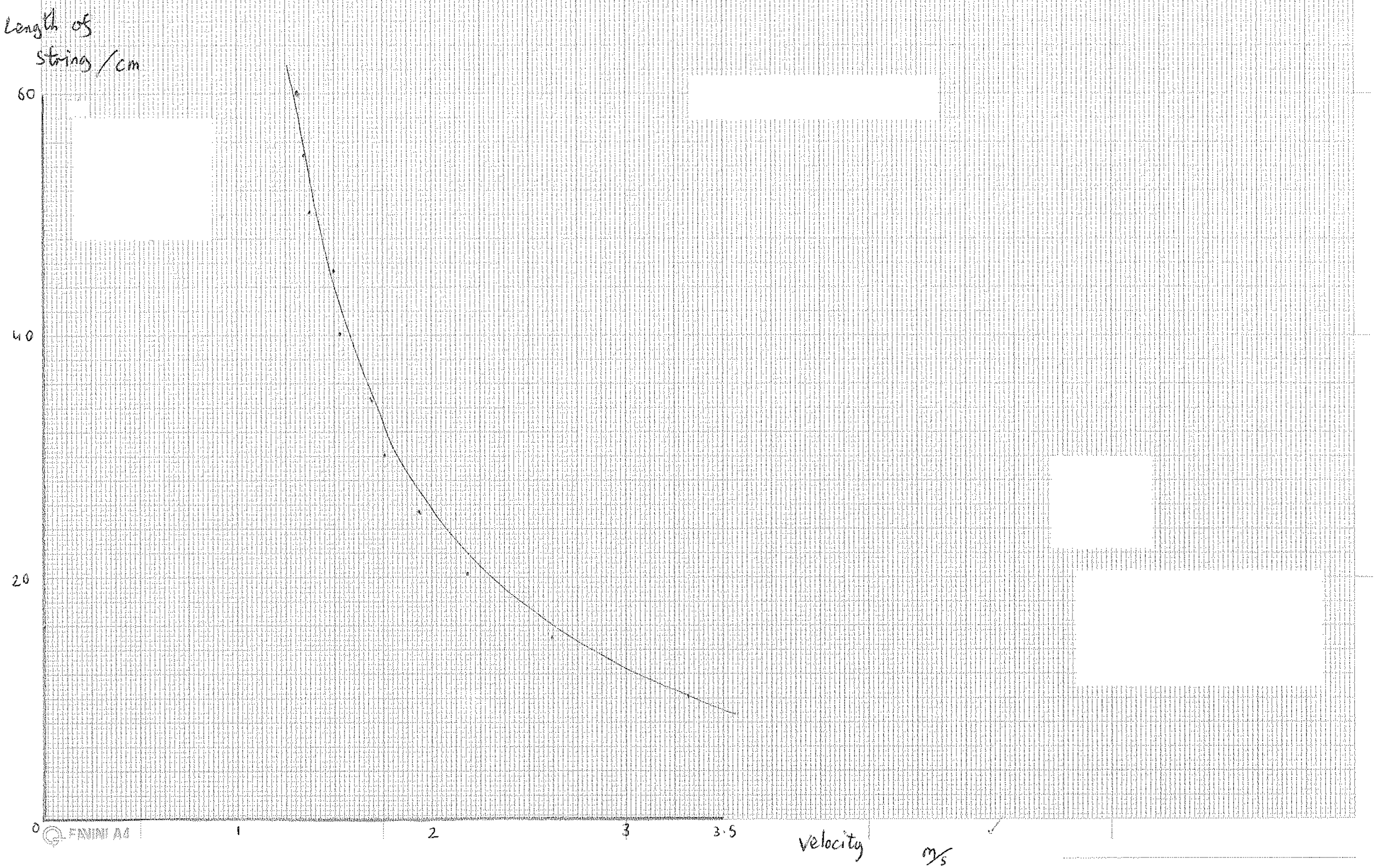
Graph Showing Length of String Against Time for Descent



Graph Comparing Length of String Against Velocity



Conclusion

As it can be seen from the results calculations and graphs my hypothesis was correct.

Experiment number one made a straight-line graph that suggests that the parachutes radius is directly proportional to the time. From the table of results it can be said that the parachute with the lower velocity so the best one was the 30 cm radius, the one with the biggest surface area. Experiment number two showed from the graphs that the perfect shape a large parachute should have is circular. In small dimensions instead the parachute should be squared, this occurs since the 2 graphs intersect which means that a longer time is taken for the descent at low surface areas. The best material should be plastic as shown in the results of experiment three since plastic has the lowest Average Velocity while the last experiment made clear that the best string was the longest one so the 60cm one.

Evaluation

Several difficulties had been encountered while doing this experiment. The major and most damaging to the errors is that the 20 M height where the experiment should have been done was always windy so the parachute would have been blown away making a significant error in the results if it was tested there. It was decided that the experiments would have been done in a closed environment so with no wind but on the other hand doing it in this place made it impossible to have a height constant of 20m. The experiment was done from a height of 1.96 m. This change didn't allow an accurate calculation of the average velocity since it didn't allow the tested parachute (specially the smaller ones) to reach their terminal velocity. The small parachutes initially had a downwards acceleration due to gravity and before the parachute opened up and started to do resist to air making an upwards force, the parachute had already touched the ground. The results that were taken I still took them in consideration since they still gave an approximate idea of what the velocity would be.

The second difficulty I encountered was the mass I used. In the planning it was decided that the mass dragging the parachute down would have been of 1Kg so the downward force was 10 Newtons. Doing the experiment I discovered that this mass was extremely high and that it dragged the parachute down too rapidly and it didn't allow it to open well enough so to create an upwards force and reach the terminal velocity. To avoid this to happen I drastically reduced the mass to 0.1 Kg and this change provided a much more accurate reading for the big parachutes. On the other hand for the smaller parachutes I realized that 0.1 kg wasn't enough since they behaved in the same way as described above; the results so couldn't be extremely reliable though since they still followed a general trend or pattern I still considered them while analyzing the results.

All the results were approximately how I expected apart from in the experiment of the best material. First of all I expected paper to be the best material though it was plastic, furthermore I didn't expect the cotton parachutes to be so faster than the plastic and paper. This is probably caused by the fact that air in paper and even more in plastic is trapped completely inside the parachute and released on the sides while in the cotton parachutes some air passes trough them making the air resistance less so a lower upwards force. On the other hand it can also be said that plastic is lets less air pass trough the material than paper does, this is why its average velocity was lower than the one of paper.

The results of the different shapes and different dimensions of the parachute as variables followed a similar pattern that was: between the largest variable and the second largest there was the biggest gap, then the more the dimension became smaller, the more the difference between results was smaller.

The experiment of the different lengths of string instead didn't have this pattern, what happened is that it decreased slightly the more the strings were short but only at about 20 cm it had a significant decrease. This is probably because parachutes having 20 cm and less of string length could not reach their terminal velocity before the parachute reached the ground so the air resistance was not significant in the tests.

This experiment as I described at the beginning of the evaluation had many difficulties so first of all to improve the experiment these difficulties should be dealt with, a height of 20 m with no wind and a smaller mass of approximately 0.05 Kg should be used. In addition other tests should be done using other materials for example nets to see if the theory of air blocked in the material is the cause of difference in results for the tests on plastic and cotton, and other shapes should be used for example rectangles and triangles. A last way of improving the results of the experiment is, since it will be done from a height of 20 m, a timer could be started when the parachute has traveled for three meters and stopped when the parachute reaches the ground. This allows the results to be more precise since only the section where the parachute has reached its terminal velocity is measured; the acceleration part where the upward and downward forces are balancing out is not counted. To extend the experiment a ticker tape timer could be used so it could be seen exactly how much time the parachute takes to reach its terminal velocity and the exact velocity at each stage of the acceleration.

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