TERMINAL VELOCITY

Felix Baumgartner is an Austrian skydiver and a BASE jumper. He is renowned for the particularly dangerous nature of the stunts he has performed during his career. With a team of scientists and sponsor Red Bull he plans a free-fall from 120000 feet, the highest sky-dive on record attempting to break the sound barrier. On 25 July 2012, Baumgartner completed the second of two planned test jumps from 96640 feet. His free fall was estimated to have lasted three minutes and 48 seconds before his parachutes were deployed. His top speed was 536 mph.

From physics we know that the acceleration g is roughly $10 m/s^2$. Therefore, the velocity of a body in free fall increases by 10m/s each second. The fact that Baumgartner's top speed was much less than 2280m/s is due to air resistance. Although air resistance is often ignored in the physics classroom, Baumgartner did not fall indefinitely with constant acceleration.

A. Preparation

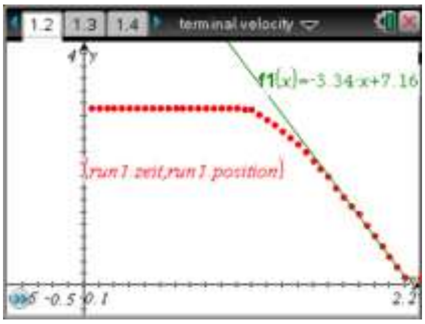
1) Hold a cuboid made of glued plastic foil (or another very light object) in your hand. Release it and watch it fall to the ground. Make a sketch of a height vs. time graph.

2) Then glue two pieces used in 1) together and release them. Do you expect the two objects fall faster, slower or at the same rate as one object?

3) What kind of mathematical relationship do you predict will exist between the velocity of fall and the number of objects?

B. Observation of an experiment

Preliminary experiments:



1) Study the picture on the right where a distance vs. time graph is shown.
2) The dots represent the corresponding data points of time and height during the fall of a body described in A1). Describe the motion in detail.
3) The line represents a linear function f1(x) = -3.34 x + 7.16. What does the coefficient of x specify?

C. Modeling the situation in the laboratory

1) Place light objects under a motion sensor, release them and view the collected data.

2) Determine the velocity of the falling object from the slope of the distance vs. time graph. Observe the two different parts of the graph: (a) a region of increasing slope at the beginning, and (b) afterwards a linear portion.

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3) Vary the mass of the following object in a controlled way and repeat step 2) to explore the relationship between the mass of the objects dropped and the terminal velocity.

4) Draw a free body diagram of the object described in A1). Explain, why there are only two forces acting on the object. Mathematically the drag force can be described using F_{drag}= - bv or F_{drag} = $-cv^2$. The constants b and c are called the drag coefficients that depend on the size and the shape of the object.

5) *Extension*: Make a small parachute and use the motion detector to analyze the air resistance and terminal velocity as the weight suspended from the chute increases.

D. Evaluating the data obtained

1) What you can discover from the fitted line to only to the linear region of the distance vs. time graph?
2) Generate plots for the terminal velocity v_T (y-axis) as a function of object weight (x-axis) for each run.
3) Determine which relationship is more appropriate: $v_T \sim m$ or $v_T^2 \sim m$ and choose between the two models of the drag force. Explicate how you can make a decision by evaluating the graphs.
4) Explain why during terminal velocity the drag force is equal to the weight of the falling object.
5) How does the time of fall relate to the weight (mg) of the falling body (drag force)? If an object with mass m fall in time t, how long would it take for an object with mass 4m to fall, assuming that the objects are always moving at terminal velocity?

E. Show your results

Thinking about your observations, discuss the correctness of the following statements:

a) Without air resistance, a football and a sheet of paper would fall at the same rate.

b) At terminal velocity there is a net force pointing upwards.

c) For falling objects terminal velocity squared is proportional to mass. Therefore the terminal velocity of an object with mass 30g is about three times as large as the terminal velocity of object weighing 10g. +

d) The fall of an object with mass 40g would take half as long as the fall of an object with 10g.

e) At terminal velocity, air resistance matches the downward force, so there is no net force.

f) At terminal velocity, the net force is constant.