Name: ________________________________

Partner(s): _____________________________

Section: _______

Desk # _______________

Date: ________________

Surviving a High-Rise Fall

You may use pencil, as there will be no data taking.

Figure 1: http://www.physlink.com/education/askexperts/Images/ae411a.jpg

Highlight of the theory

The equation describing the motion of an object falling in the air is

$$mg - bv^2 = ma \text{, or } a = g - \frac{b}{m}v^2$$

where bv^2 is the drag force. In the optimum positions, b/m is roughly 0.003 m^{-1} for a human skydiver, and 0.02 m^{-1} for a cat. We will use these numbers in this lab.

Start Microsoft Excel. Create a worksheet like the one below:

	A	B	C	D	E	F
1	Skydiver					
2	Parameters					
3	g	9.81	m/s^2			
4	b/m	0.003	m^(-1)			
5	delta t	0.5	s			
6	Initial data					
7	t initial	0	s			
8	v initial	0	m/s			
9	y initial	0	m			
10						
11	start time	end time	velocity	acceleration		
12	s	s	m/s	m/s^2		
13	0	0.5	0	9.81		
14	0.5	1	4.905	9.7378229		

Formulae are used when the content of a cell is calculated from other cells. A formula is composed of cell addresses, numbers, and operators and starts with an "=" sign. For example:

In cell A13 type =B7

This sets the "start time" in row 13 equal to "t initial" or cell B7.

In cell B13 type =A13+$B$5

This sets the "end time" of the first time interval to be the "start time" (cell A13) plus Δt (cell B5). A13 is called a relative address and $B$5 with the dollar signs is called an absolute address. If you copy this cell to other cells, the relative address changes accordingly and the absolute address remains the same. So, if you copy cell B13 to B14, the formula will become A14+$B$5.

In cell C13 type =B8

This sets the "velocity" in row 13 equal to "v initial" or cell B8.

In cell D13 type =$B$3-$B$4*C13^2

This calculates the "acceleration" in row 13 based on $a_1 = g - \frac{b}{m} v_1^2$

Now, work out what you should enter on row 14, fill in the blanks below, and type them in Excel. This is the most important row in this spreadsheet, and every cell must start with an "=" sign.

In cell A14 type ___________

Set the "start time" of the second interval to the "end time" of the first interval. Should this formula contain "$" sign?

For cell B14 copy B13 to B14.

Similar to B13, B14 sets the "end time" to the "start time" plus Δt. That is why you can copy from B13. Two ways to copy are: 1. "Copy" then "Paste". 2. Click the little black square and drag down.

In cell C14 type ___________

Type in the formula based on $v_2 = v_1 + a_1 \Delta t$*, paying attention to relative or absolute addresses.*
Tip: the "$" sign can be turned on/off with the "F4" key on your keyboard.

For cell D14 copy D13 to D14.

$$This\ is\ the\ quickest\ way\ to\ get\ the\ right\ formular\ a_2 = g - \left(\frac{b}{m}\right) v_2^2$$

You have spent some time to work out the motion for the first second of the motion. The rest is easy: copy Row 14 to rows below to calculate the velocity and acceleration to 20 seconds.

Graphing the motion of the skydiver

To plot a *v* vs. *t* graph, select the relevant data in columns A and C, (hold the "Ctrl" key to select column C), then click menu item "Insert – Chart", choose "XY (Scatter)" option, and click "Finish". Create an *a* vs. *t* graph similarly.

We also want to know how the position changes with time. You need to add a new column "distance" after the "acceleration" column:

$y_1 = 0$
$y_2 = y_1 + v_1 \Delta t$
$y_3 = y_2 + v_2 \Delta t$
………

and graph *y* vs. *t*. The three curves, *y* vs. *t*, *v* vs. *t* and *a* vs. *t* give us a good understanding of the motion of the skydiver with air resistance.

Graphing the motion of the cat

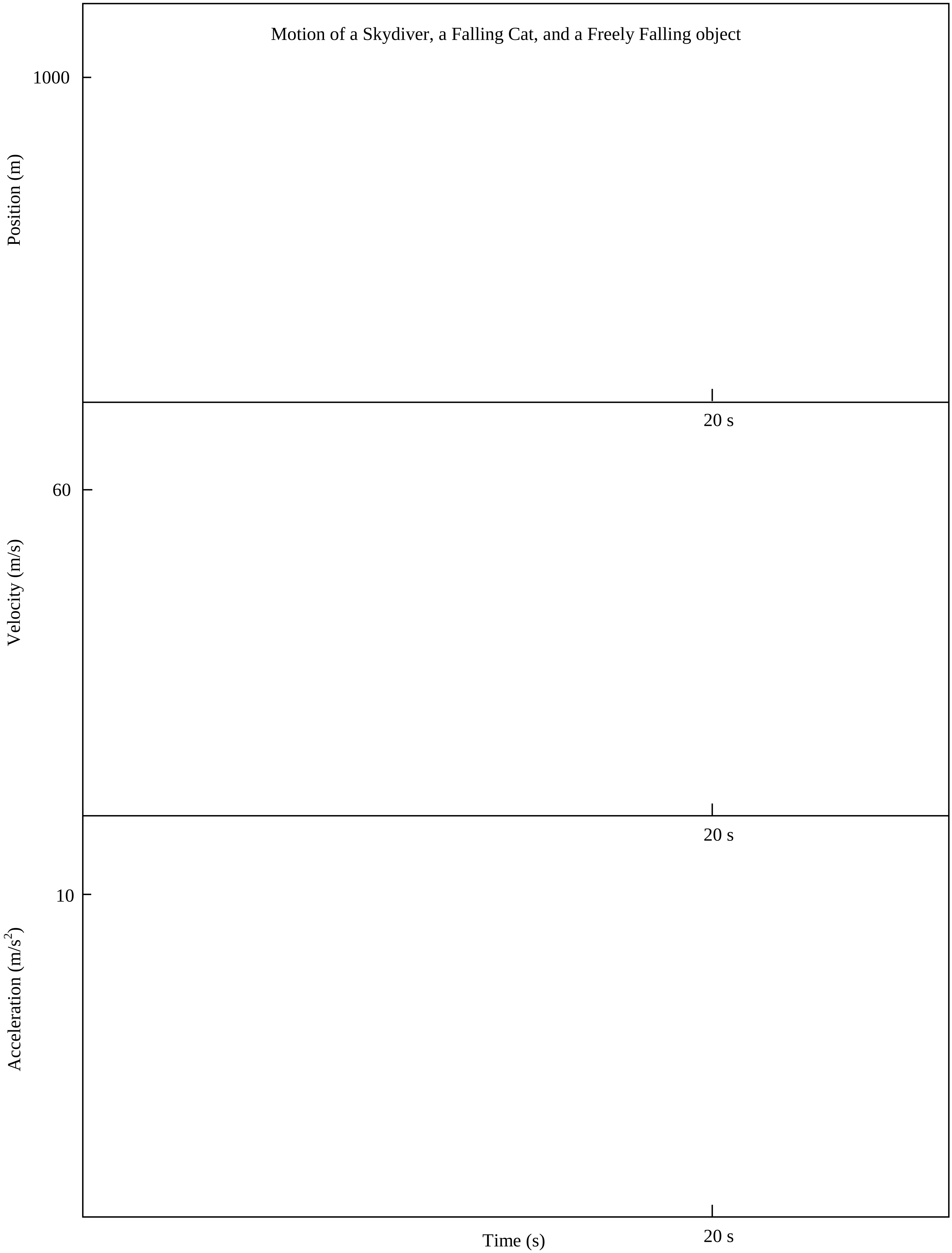
Copy your worksheet to a new sheet and find the motion of a cat falling with air resistance by changing the *b/m* value.

Graphing free fall

Copy your worksheet to another sheet and modify it to model a free falling object (no air resistance).

Now you should have 3 worksheets with names like "skydiver", "cat" and "free fall". On the next page, sketch the curves for the position, the velocity and the acceleration of each. There will be nine lines. *Do not spend more than 10 minutes on the sketches*.

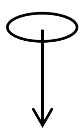
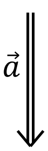
- Label each axis with the proper name and unit. (This is done for you.)
- Use different types or colours of lines for each object and state them in a legend.
- What is important is the relationship between the curves, not the exact values.


Motion of a Skydiver, a Falling Cat, and a Freely Falling object
1000
Position (m)
20 s
60
Velocity (m/s)
20 s
10
Acceleration (m/s2)
20 s
Time (s)

Understanding the motion

1. Describe the motion (acceleration and velocity) of an object in free fall.

2. Draw a FBD for each of the following instants: (1) the skydiver just starts falling (zero speed), (2) the skydiver has been falling for a short while, and (3) the skydiver has been falling for a long time. Next, draw the velocity and the acceleration vectors. Then use words to explain the motion of the skydiver. Instant (1) is done as an example. (We'll use a single arrow for $\vec{v}$ and a double arrow for $\vec{a}$.)

FBD	Velocity and acceleration	Explain the acceleration (using the drag force and the net force).	Explain the velocity and how is it changing (using acceleration).
Just start falling 	$\vec{v} = 0$ $\vec{a}$ 	The drag force is 0 because the velocity is 0. The net force (equivalent to the gravitational force) is big, therefore the acceleration is big.	The velocity is 0 because it has just started falling. However, it is increasing at a fast rate because the acceleration is big.
After falling for a short while 			
After falling for a long time 			

3. Given enough height, an object falling in air will eventually reach a constant velocity, called the "terminal velocity". Redraw the last FBD in the previous question below, and derive an equation between the terminal velocity v_T and *b/m*.

4. Calculate the terminal velocity for the skydiver using the relation you just derived and the numbers on the bottom of Page 1.

5. Calculate the terminal velocity of the cat similarly.

6. Do the terminal velocities on your spreadsheets agree with your results of Question 4 and 5?

7. Who reaches the terminal velocity earlier, the cat or the skydiver?

8. Fill in blanks based on your sketches or worksheets, to 2 or 3 significant digits. You may want to change to a smaller time interval (Δt) for this question and later questions.

8a. If there were no air, a skydiver jumping from 25 stories high (about 100 m) will land on the ground with a speed of ________ m/s. A cat jumping from 25 stories will land with a speed of ________ m/s. The two speeds are _____________ (same / different) because _________________________________

____.

8b. With the presence of air, a skydiver jumping from 25 stories high will land on the ground with a speed of ___________ m/s. A cat jumped from 25 stories will land with ___________ m/s. The two speeds are _____________ (same / different). This shows the _________________ (skydiver / cat) will have a much better chance of survival.

8c. In Question 8b, the landing speed of the skydiver is equivalent to free falling from ______ stories. The landing speed of the cat is equivalent to free falling from ______ stories.

9.   Landing of the skydiver: Obviously, the skydiver cannot land with the terminal velocity as given in your sketch or worksheet. He has to open his parachute before landing. Let's examine the effects of opening the parachute:

9a. Effects on the acceleration: Before opening the parachute (after falling a long time), the skydiver's acceleration is ___________. Right after opening the parachute, the direction of the skydiver's acceleration is pointing ____________. This is because the magnitude of the upward drag force on the skydiver is _________________ (bigger than / smaller than / equal to) the force of gravity.

9b. Effects on the velocity: Before opening the parachute (after falling a long time), the skydiver's velocity is pointing _____________ and its magnitude is ____________ (increasing / decreasing / constant). Right after opening the parachute, the skydiver's velocity is pointing _____________ and its magnitude is _______________ (increasing / decreasing / constant).

9c. Effects on the *b/m* value of the skydiver and on his terminal velocity: Opening the parachute will make the *b/m* value of the skydiver _______________ (bigger / smaller) and his terminal velocity _______________ (bigger / smaller).

10. Landing of the cat: During the fall, the best gesture of the cat to keep is facing down with legs stretched out (picture 3 in Figure 1). However, the cat has to pull in her legs right before landing (picture 4 in Figure 1). It is painful to imagine what would happen if she did that too late. But, what would happen if she did it too early? (This illustrates how tough it is to survive the high-rise fall, even for the cat.)

11. (Optional) Quantitative analysis of the landing of the skydiver:

11a. Figure out a safe landing speed for the skydiver: imagine yourself jumping from a ladder. How high do you think you can comfortably jump from? Use this height and one of your worksheets to get the safe landing speed. (Does it matter which worksheet you use?)

11b. In order to achieve a terminal speed that equals the landing speed above, what value must b/m be for the skydiver? (You may use the equation you got in Question 3.)

11c. Copy your skydiver worksheet to a new worksheet and play with the initial velocity, b/m, and Δt to simulate the motion after the skydiver opens the parachute and verify your answer.

Parameters for the spreadsheet: initial velocity = ______ m/s, Δt = ______ s, b/m = ______ m^{-1}.

The new terminal velocity with the parachute open is __________ m/s. Just after opening the parachute, the drag force is ____________________ than the gravity so that the magnitude of the skydiver's acceleration is ____________________ than the gravitational acceleration.