**Terminal Velocity Answer Key:**

Note: The answers on this key also include descriptions of useful spreadsheet language and formulas as well as instructions of how to perform any spreadsheet manipulations necessary to solve a given problem.

Table 1.1: Terminal Velocities should be accurate to 3 significant figures

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Item | Mass (kg) | CSA (m^2) | Drag Coefficient | Time Increment (sec) | Predicted Terminal Velocity (m/sec) | Actual Terminal Velocity (m/sec) |
| skydiver | 95 | 0.6 | 0.55 | 0.5 |  | 53.1 |
| skydiver (head first dive) | 95 | 0.06 | 0.55 | 1 |  | 118. |
| skydiver (open parachute) | 95 | 25 | 0.5 | 0.1 |  | 8.63 |
| feather | 0.001 | 0.002 | 0.55 | 0.02 |  | 2.98 |
| javelin | 0.8 | 0.0004 | 0.45 | 1.5 |  | 209. |
| penny (sideways) | 0.003 | 0.0000019 | 0.5 | 1 |  | 176 |
| penny (facing down) | 0.003 | 0.0002834 | 0.55 | 0.1 |  | 13.7 |
| piece of paper | 0.005 | 0.0616 | 0.6 | 0.01 |  | 1.15 |
| bullet | 0.013 | 0.0000785 | 0.45 | 0.5 |  | 60.1 |

**Development Questions:**

There are sometimes more than one correct answer(s) for development questions. Their main purpose is to assess student understanding of formulas and spreadsheet applications such as functions.

1. This spreadsheet assumes uniform acceleration over the specified time interval. For this to hold true, what has to be true about the time interval being used?

*In order for this assumption to hold true the acceleration has to be changing slowly compared to the time increment. In other words the time increments have to be small in order to assume non-uniform acceleration to be uniform over a time increment.*

1. Why is it useful to be able to change the time increment at the top of the spreadsheet?

*Changing the time increment in only one place and having it recount in column A allows for the spreadsheet to be easily used for objects with extremely different terminal velocities such as a feather or a sky diver in a head-first dive.*

1. What do the dollar signs in each formula mean?

*Dollar signs in a formula refer to cells that are at a fixed location. When the formula is dragged and dropped to perform calculations the cell referred to as $Letter$Number will remain the cell that is calculated. If no dollar signs are present and the formula is dragged down one place, the reference cell is moved down as well.*

1. How is the net force on the object determined and how does it relate to acceleration?

*The net force on the object is equal to the weight of the object minus the drag force. This is related to acceleration using Newton’s 2nd Law (Eq. 1.3) by dividing the net force on the object by its mass.*

*A typical velocity vs. time graph for a falling object encountering air resistance:*

**Questions:**

1. Why does a skydiver travel different speeds in the different conditions?

*The sky diver’s mass remains the same regardless of his orientation. However, the cross sectional area of the skydiver does vary from one position to the next. Since the drag force is directly proportional to the cross sectional area, an increase in drag force results in a decrease in terminal velocity. As expected, the terminal velocity is the greatest in the head first dive, and the least with the open parachute.*

1. Describe the effect of increasing or decreasing each of the following on an objects terminal velocity holding other factors constant. a) mass b) cross sectional area (CSA) c) drag coefficient

*a). An increase in mass will cause an objects terminal velocity to increase holding other variables constant. Decrease in mass will cause terminal velocity to decrease. b/c) An increase in cross sectional area or drag coefficient will decrease terminal velocity and decrease in CSA will cause terminal velocity to increase holding mass constant.*

1. The Returning Bullet: If a bullet was fired straight up, it would slow down to a velocity of zero and fall back toward earth. Would it be as deadly on its way down if it left the gun at 350 meters per second?

*The bullet would begin to accelerate down toward the earth. In an ideal case the velocity of the bullet would be equal upon returning to the ground, however, with air resistance the velocity of the bullet cannot exceed its terminal velocity of 60.05 m/sec. Therefore, it would not be as deadly when it returned to earth at that speed compared to the 350 m/sec muzzle velocity of the gun.*

1. The actual terminal velocity of a rotating penny varies. Why?

*As the penny rotates (not about the center axis of the circle but end over end) its cross sectional area varies from a maximum value when the face is horizontal to a minimum value when the face is vertical. As a result, the terminal velocity will fall somewhere between the two extreme possibilities: 14.4 m/s<VT<176 m/s, but closer to 14.4 m/s.*

1. At the beginning of each graph, there is a region that appears to be linear. What is the slope of that region? Explain your answer.

*The slope of any velocity vs. time graph is equal to the acceleration of the object. At the beginning of the graph the acceleration closely resembles the acceleration due to gravity, which is 9.8 m/sec2. As the velocity increases and the net force approaches zero for each object as its velocity gets close to the terminal velocity, the acceleration becomes zero.*

1. If an object was traveling straight up in air, how would its acceleration compare to 9.8 m/sec2? If it was falling straight down, how would its acceleration compare to 9.8 m/sec2? Assume gravity and air resistance are the only forces acting on it.

*As an object travels straight up with air resistance, its acceleration will be greater than 9.8 m/sec2. This is because the net force acting on it is equal to the weight of the object (downward) plus the downward air resistance force. This drag force causes a net force magnitude to be greater than the weight of the object and a downward acceleration greater than 1 g. On the way down the acceleration is less than 9.8 m/sec2 because air resistance is causing the net force to be less than the weight of the object and the acceleration is between 9.8 m/sec2 when the object is at rest and 0 m/sec2 when the object is moving at its terminal velocity.*

1. Choose 3 sports implements (like baseballs, golf balls etc.) and look up or measure their standard masses and diameters to calculate their cross sectional areas, assume a drag coefficient of 0.45 and determine their terminal velocities.

*Golf ball: 30.79 m/sec*

*Baseball: 27.3 m/sec Other choices will vary test an object of known mass and CSA on the spreadsheet.*

1. Determine the diameter of a rain drop in cm if it has a mass of 2.9\*10-8 kg if its terminal velocity is 1.03 meters per second. Use a drag coefficient of 0.6 and a time increment of .005. *Hint: start with a very small CSA, use goal seek, then solve for diameter.*

*Using a small starting value for the area such as 0.0000001, goal seek calculates the cross sectional area to be* ***4.5 \* 10-7m2****. Multiply by 4 and divide by pi and then take the square root and you will get the diameter that is equal to* ***0.000756 meters*** *or* ***0.756 mm****.* In order to do this **set cell: B95…to value: 1.03…by changing cell: B2. The dollar signs in the formula are not necessary (they appear when you click the cells rather than type the address).**

