Name: ______________________________________ Date: ________________________

Extension: Air Resistance

Learning goals
After completing this activity, you will be able to …

- Explain the qualitative and quantitative effects of air resistance on moving bodies.
- Create and interpret acceleration curves for real-life mechanical systems.

Vocabulary: air resistance

Air particles constantly hit most objects near Earth's surface. For typical objects at rest, the force of particles striking one side is approximately the same as the force of particles hitting the other, so these air particles have no net effect. However, if an object is moving these particles tend to slow down the object. For example, the bottom of a falling ball will tend to hit more air particles than the top because it is moving downward. This net force acting to oppose motion is called **air resistance**. In this exercise you will use what you have learned so far to estimate the velocity curves of a skydiver and a runner moving against air resistance.

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Dan and Jake are twins. Each has a mass of 100 kg. Dan is a sprinter; Jake, a skydiver. One day Dan begins a race at time = 0 seconds, the same instant that Jake drops from a plane.

For ease of calculation, assume the acceleration due to gravity is 10 m/s^2. Further assume that Dan's body produces 1600 watts of useful power.

1. The force of air resistance is very small during the first split-second of Dan's and Jake's motion. Assume there is zero air resistance between t = 0 seconds and t = 0.125 seconds.

   A. What is Dan's kinetic energy at t = 0.125 s? ____________ joules

   Explain your reasoning: ____

   B. What is Dan's speed at t = 0.125 s __________________ m/s

   Show your work:

   C. Who is traveling faster, Dan or Jake? _____________________

   Show how you determined Jake's speed below:

2. Assume that air resists both men with a force whose magnitude (in newtons) equals 0.75*v^2, where v is speed in meters per second. Calculate the force of air resistance on each twin:

   Dan: ___________ newtons   Jake: ___________ newtons

3. Some of the power Dan's body generates must be spent fighting air resistance. The rest can be used to accelerate him. In this problem you will estimate his speed at T = 0.5 seconds. As Dan goes faster and faster, the air resistance against him will increase, but for purposes of estimation, assume the air resistance stays the same from t = 0.125 s until t = 0.5 s.

   A. What was Dan's average acceleration between t = 0 seconds and t = 0.125

      seconds? (Refer to your answers from question 1.) ______________ m/s^2

   B. Assume Dan keeps accelerating at the same rate as during the first 0.5 seconds.

      Estimate the distance he runs between T = 0.125 and T = 0.5. __________ meters

      Show your work:

   C. Use $W = Fd$ to estimate the work Dan does against air during that time. (Recall that the force Dan exerts against air equals the force air exerts against Dan.)

   D. Assuming the rest of the energy Dan's body produces is converted to kinetic energy, estimate his kinetic energy at T = 0.5 seconds.

   E. Approximately how fast is Dan running at T = 0.5 seconds? _____________ m/s

      Show your work below:

4. It is easier to approximate Jake's velocity after 0.5 seconds.

   A. You found the force of air resistance for Jake in question 1C. What is the net force on him at *T*=0.125 s? (Hint use $F = ma$ to find the force of gravity.) __________ N

   Show your work below:

   B. Estimate Jake's speed at 0.5 seconds. (As in the last question, assume that air resistance stays the same between t = 0.125 s and t = 0.5 s.) ___________ m/s

5. On a separate piece of paper, perform the calculations necessary to complete the table below. (When estimating the distance Dan travels in each interval, use the acceleration from the previous interval. So to find the distance Dan travels between 1 and 2 seconds, you'll use the acceleration between 0.5 and 1 second.)

	Dan			Jake	
Time (s)	K.E. (J)	Speed (m/s)	Air Res. (N)	Speed (m/s)	Air Res. (N)
0	0	0	0	0	0
0.125	*200*	*2*	*3*	*1.25*	*1.17*
0.5					
1					
2					
4					

6. On a separate piece of graph paper, plot the data in your table on a single graph.

   A. At what time ($t>0$) are the twins moving at about the same speed? ______ s

   B. In part 2 of the Guided Learning activity for power, you found that the acceleration curves for a skydiver and a sprinter match $v = t$ and $v = \sqrt{t}$ when there is no air resistance. Find good values for k_1 and k_2 such that Dan's speed is approximated by $v = k_1\sqrt{t}$ and Jake's is approximated by $v = k_2 t$.

      k_1 = ________________________ k_2= ______________________

   C. How much of a difference does air resistance make up during the first 4 seconds? How can you tell?

      ____

      ____

7. **Challenge:** How would you determine the terminal velocities for each of the twins? Describe your method and answer below.

8. **Challenge:** You assumed in this exercise that air resistance is proportional to the square of velocity, which is approximately true when objects are bulky enough that air cannot easily stream around them. Why do you think the force of air resistance is proportional to the square of velocity in this case? (Hint: Consider the kinetic energy gained by an air particle initially at rest when it is struck by an object moving with a velocity v. This energy was lost by the object. Show that the power required to overcome air resistance is proportional to the cube of velocity, and then show this means the force of air resistance is proportional to the square of velocity.)