

Chapter 3 Application Project: The Ultimate Hail Mary

In April 2021, legendary NFL tight end Rob “Gronk” Gronkowski set a world record by catching a football that was dropped from a helicopter hovering 600 ft overhead. In the words of ESPN’s Adam Scheffer, this was the “highest altitude catch” ever! In this project, we will examine the behavior of objects dropped from high altitudes. Throughout Questions 1–5, we will ignore air resistance; then in Questions 6–8, we will develop the tools to include it in our calculations, allowing us to make our predictions much more accurate.

1. An object is dropped from the window of a hovering helicopter at an altitude of 250 ft. How long is it in the air and what is its speed of impact?
2. Answer Question 1 under the assumption that the object is dropped from the same altitude from a helicopter that is ascending vertically with a constant speed of 16 ft/s.
3. What happens if the helicopter is accelerating vertically upward at 0.5 ft/s^2 but its altitude and instantaneous upward velocity are the same as in Question 2 at the moment the object is dropped? Explain.
4. Based on your answers given above, do you think the situation for Gronk would have been different if the football had been dropped from a vertically ascending or descending (rather than hovering) helicopter? Explain.
5. Answer Question 1 if an object is dropped from a helicopter hovering at an altitude of 600 ft. Is your answer realistic? Could this have been true of the football Gronk caught? Explain.

In order to develop a model to more accurately reflect (and predict) what happens in real-life free falls, we must consider air resistance. From your answers to the next questions, you will be able to better approximate the actual speed of the football when Gronk caught it. It was indeed a highly impressive feat!

6. When air resistance is taken into account, does a free-falling object constantly accelerate throughout its motion? If not, what can you say about its acceleration and velocity? Explain. (**Hint:** Think of falling rain drops or snowflakes.)
7. The resistance of the medium surrounding a moving object exerts a force directly opposing the motion. That force, commonly called the *drag force*, is obtained from the formula

$$F_d = \frac{1}{2} \rho v^2 C_d A$$

where v is the velocity and A is the cross-sectional area of the moving object, ρ stands for the density of the surrounding medium, and C_d is called the *drag coefficient*, which depends on the general shape of the object. (Note that A is actually the area of the cross-section perpendicular to the direction of motion. Can you see why?)

Use Newton’s Second Law of Motion (see Topic 2 in Section 3.7) to find a formula for the maximum velocity that a free-falling object attains when falling in air. This is called the object’s *terminal velocity*. (Assume that the altitude is not high enough to affect air density.)

8. a. Use your answer to the previous question to estimate the speed of the falling football at the moment Gronk caught it, setting a world record. (**Hint:** We will assume that the ball was falling with its major axis oriented horizontally and approximate its cross-section as an ellipse. The formula for the area of an ellipse can be found in Example 3 of Section 7.4.) A football's major and minor axes are 11 and 7 in., respectively, and its mass is approximately 0.9 lb. Use 0.77 for the drag coefficient of a football falling with its major axis perpendicular to the direction of the fall. Use 0.075 lb/ft^3 for air density.
- b. Compare the above result to your answer given in Question 5. How significant is the effect of air resistance on a falling football? Do you think the same would be true of a falling rock? Why?
- c. Considering your answers above, how do you think you need to modify your answers to Questions 1–4 when air resistance is taken into consideration? Explain.