I. Characterizing Air resistance

Previously, we noted that air resistance had several forms. It could be...

(i) proportional to the speed of the object (with magnitude $c_1 |v|$),

(ii) proportional to the square of the speed (with magnitude $c_2 v^2$), or

(iii) a combination of the above two terms (linear and quadratic).

where c_1 and c_2 are positive constants. Both of these velocity terms are in the *opposite* direction as the velocity. Practically speaking, we operate under a few rules of thumb to determine which terms are most important.

- Small, slow objects tend to have $c_1 \neq 0$ and $c_2 \approx 0$
- Large, fast objects tend to have $c_1 \approx 0$ and $c_2 \neq 0$

Which terms do you think will apply to the motion of a cannonball fired from a cannon?

II. Calculating Air resistance in 2D

Suppose you have an object moving with a velocity $\vec{v} = (30\,\frac{\text{m}}{\text{s}}, 40\,\frac{\text{m}}{\text{s}})$ and the drag coefficients $c_1 = 0.0001\,\frac{\text{kg}}{\text{s}}$ and $c_2 = 0.01\,\frac{\text{kg}}{\text{m}}$. These coefficients are consistent with large objects moving through air.

(a) Calculate the magnitude of the air resistance force on the object noted above. Consider the linear and quadratic terms separately. Is it appropriate to ignore either term?

(b) Calculate the vector $\hat{v}$ for the velocity vector $\vec{v}$ given above. Does this vector have units? What is the length of this vector? What direction is this vector pointing in compared to the velocity? What direction is this vector pointing in compared to the air resistance?

$$\hat{v} = \frac{\vec{v}}{|\vec{v}|}$$

(c) Calculate the air resistance force in component form (F_x, F_y). You can ignore any contributions to this force that are small.

Contact: wolfs15@ecu.edu

(d) If you know the velocity components (v_x, v_y), write an algebraic expression allowing you to find the air resistance force assuming $c_1 = 0$. Double check your expression by ensuring that you get the same numerical answer as you did for part (c). [Question: Why did I make you calculate $\hat{v}$ in part (b)?]

⇒ **PAUSE and check with an instructor or another group.**

III. Projectile motion with drag

Let's go back to the Kenyan Coast and use the data from Wednesday. To this data, we'll include the following:

- The mass of a cannonball is 1.0 kg.
- The drag coefficients are $c_1 = 3.3 \times 10^{-5}\,\frac{\text{kg}}{\text{s}}$ and $c_2 = 2.9 \times 10^{-3}\,\frac{\text{kg}}{\text{m}}$

I have created an app which allows you to generate the motion for the cannonball with the ability to tune parameters to fit the motion that we are studying. It is linked to the Canvas page for today's assignment.

In my code, I defined the following function to calculate the turbulent (quadratic) drag force. In the space to the right, describe what is being done on each line (beginning with line 7). Convince yourself that this is correctly calculating the drag force.

```
1  def turbDrag(c,v):
2      ''' Calculates the turbulent drag force.
3      Inputs:
4          c = Drag coefficient (positive number)
5          v = Velocity vector (two components in x,y directions)
6      '''
7      [vx, vy] = v
8      spd = np.sqrt(vx**2+vy**2)
9      vhat = v/spd
10     FdragMag = c*spd**2
11     Fdrag = - FdragMag * vhat
12     return Fdrag
```

III.A Final task

(a) Find the launch angle θ which gives the largest range for the cannon.

(b) Play with the parameters in the app and figure out something interesting, then write out what that is and give the parameters that you used to generate that knowledge. (This should be a paragraph or so. It would be great if you got screenshots and put them in a document that you uploaded to Canvas with this assignment).

Contact: wolfs15@ecu.edu