BMME 201 Summer 2021
PA2: Penguin Poo
Due: Friday, 5/28, at 8 pm

Background

The junction of basic kinematics, fluid dynamics, physiology, and aquarium science is the study of penguin excrement, or spheniscid scatology. Penguins, like most birds, prefer to projectile poop outside their nests (Fig. 1), and the required rectal pressure can be impressive. Understanding the turd trajectory is important in habitat design to reduce feces films on barriers, manure mats along pedestrian walkways, and dung decoration atop handlers and observers.

Fig. 1. Real-life images of Adelie penguins. Explusion away from nest in a bird's (turd's?) eye view (left). High-framerate image of fecal expulsion (right) [1].

Problem

As Kowalski the penguin, you were asked by your boss Skipper to calculate how Rico can hit a target d = 0.6 m away given two methods: fixed fecal launch angle (θ) or a fixed fecal launch velocity (v_0). Rico is sitting on a cliff awaiting orders so that his sphincter is at a height h = 1 m (Fig. 2). For simplicity, assume that the excrement is contained in a single sphere instead of the toothpaste-like squirt in Fig. 1.

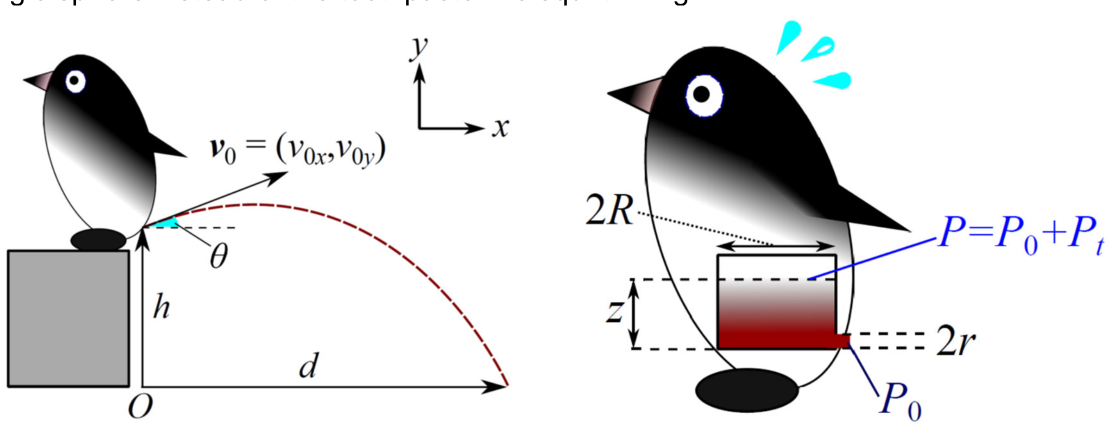

Fig. 2. Schematic of penguin defecation, showing initial physical and launch kinematic parameters (left). Model of abdomen and anus (right) [2].

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Fix the launch angle at 45°

- Calculate the x distance traveled as a function of the launch velocity magnitude ranging from 0 to 3 m/s.
- Plot the x distance traveled as a function of launch velocity magnitude. On the same plot, draw a horizontal line at the target distance.
- Zoom in at the intersection of the two lines. Hardcode (i.e., define a variable) this value in your declarations section.

Fix the launch velocity magnitude at 2 m/s

- Calculate the x distance traveled as a function of launch angle ranging from -90° to 90°.
- Plot the x distance traveled as a function of launch angle. On the same plot, draw a horizontal line at the target distance.
- Zoom in at the intersection of the two lines. Hardcode these values in your declarations section.

Finally, using your results from parts 1 and 2, make a single plot of y vs. x showing the trajectories of the rock. They should all start at the height of the penguin and end at the target located at (0.6 m, 0 m).

Output

When run, your code should print the answers to the two different situations using `fprintf` with some explanatory text and sufficient significant figures. It should also make three separate plots:

i. Plot of x distance vs. launch velocity magnitude (fixed angle of 45°)
ii. Plot of x distance vs. launch angle (fixed launch velocity magnitude of 2 m/s)
iii. Plot of y distance vs. x distance for all three solutions

Strategy

While you can do this problem in several ways, here is a suggestion:

- Define a custom function that calculates the x distance traveled given initial kinematic parameters. This function takes as its input the launch velocity magnitude (scalar or vector), launch angle (scalar or vector), and initial y position. It returns a vector of total x distance traveled.
- Define another custom function that calculates the x and y positions for the trajectory. It is like the previous function except that it also takes an input of the number of subdivisions between t = 0 and t = time of flight. It returns two vectors with the x and y positions at each time.
- Now organize your code. Start with a declarations section where you define ALL numerical variables. Next, solve the fixed launch angle problem. Then, solve the fixed launch velocity problem. Lastly, have one section where you print your results to the command window, and then another section with the three plots.

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Note that custom functions are NOT required but a good suggestion. You will not be penalized if you don't use them; however, they will help keep your code clean and organized.

Scoring

Doing all the steps above perfectly will receive a maximum of 80/100. For a higher score, implement any of the three changes below:

- (10 pts) Instead of identifying the best velocity/angle by looking at the graph yourself and hardcoding the values into your output code, write code to solve for it automatically to the nearest HUNDREDTHS place. Remove the hardcoded solution. See the hint later. We will test it by changing variables like distance to the target and initial height of penguin, and EVERY plot and output should be correct (e.g., ranges on plots should auto-scale, the horizontal line in graphs 1 and 2 should adjust, etc.). Each variable should be changed ONCE in the Declarations section, so make sure you don't have numbers after your Declarations section that are not defined as variables.
- (5 pts) Read Section V in the paper by Tajima and Fujisawa. It discusses how to use the kinematics to find the abdominal pressure of a penguin. Specifically, check Eqs. 5.5 and 5.7 (neglect viscosity in the next section). In your output, include the required output abdominal pressure for the three solutions in kPa (kilopascals). You can assume that *C*, *ρ*, *r*, and *R*, whose values are found earlier in the paper, do not change, in case you want to code them into a custom function without making them function inputs.
- (5 pts) Add a picture of a penguin to the trajectory figure. It should be to the left of the plot in the gray area, and it will likely cover one or more tick marks. Scale the picture appropriately. BE SURE TO INCLUDE THE PICTURE FILE IN YOUR ONLINE SUBMISSION, or you won't receive credit for this part (since your code will not run).

Theory

See the journal article included online that discusses some of the basic kinematics. You've seen this in physics, though. Recall the motion of an object discussed in mechanics. Acceleration (*a*), velocity (*v*), and displacement (*s*) are related by derivatives/integrals. For the y component:

$$a_y(t) = g$$
$$v_y(t) = \int a_Y(t)\,dt = gt + v_{y0}$$
$$s_y(t) = y(t) = \int v_y(t)\,dt = \frac{1}{2}gt^2 + v_{y0}t + y_0$$

where t is time, g is gravity (-9.81 m/s^2), v_0 is the initial velocity, and y_0 is the initial displacement. Some specialized versions of these equations exist, but you can derive everything necessary in this problem from these three or use whatever you want from the paper. The analogous equations in the x direction are simpler, since there is no a_x component.

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Hints

- **START THIS ASSIGNMENT EARLY**. This will take a while since you're still new to MATLAB. Struggling through parts of it on your own and asking questions will really solidify many concepts.
- **CODE INCREMENTALLY**. Don't try to write the entire program before running it. Get part 1 to work, and get a plot of the distance traveled vs. launch velocity. Make sure it looks reasonable. Then, do part 2 and check its plot. Finally, do the trajectory. If you want to do the extra parts, then make a backup copy of your program so that you don't ruin the code that worked well before.
- Time of flight is determined solely by the y component. To find the total horizontal distance traveled, find the time t_0 when y_0 equals 0 and evaluate $x(t_0)$.
- If you refer to the paper, remember that they use g = +9.81 m/s^2, whereas I defined my equations with g = -9.81 m/s^2. Careful with the equations.
- When displaying angles using `fprintf`, you can make a degree symbol using `%c` and its Unicode, 176; e.g., 45°C is `fprintf('%2.1f%cC\n',45,176).`
- For the extra part of finding launch velocity and angle automatically, you can use the functions `min` and `max` with two outputs. The first output is the min/max value (which is irrelevant), and the second is the vector index at which this occurs. Look at a plot of (x distance traveled – target distance) for the possible velocities or angles, and think of how you can modify it so that the minimum value of the plot is near 0. If you have multiple possible answers, then figure out an automated way to exclude the first answer that you find to get the second using `max`. Don't assume that you always pick the lower (or upper) angle first!
- Also, for the first extra part, the step size of your velocity/angle variable will determine the number of significant figures in your launch angle/velocity. Get an answer at least to the nearest hundredths place.
- If you want to check your answers, you can use the input parameters in the paper and check your graph or pressures. It's always smart to test your code with a known set of inputs before changing them to something else.

Sources:

1. http://www.meyer-rochow.com/penguinpoo.htm (first pair of figures)
2. H. Tajima, F. Fujisawa. "Projectile Trajectory of Penguin's Faeces and Rectal Pressure Revisited" arXiv:2007.00926 (2020). (second pair of figures)
3. V.B. Meyer-Rochow, J. Gal. "Pressures produced when penguins pooh – calculations on avian defaecation." *Polar Biol* (2003). (amusing article)
   Winner of the 2005 Ig Nobel Prize in Fluid Dynamics