Final

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1 Forces

This problem includes multiple forces that act to accelerate the bicyclist. These are the bicyclist peddling (in truth, this would be friction, but this is a simplified explanation), aerodynamic and viscous drag, gravity, rolling resistance and internal friction. Due to issues acquiring information without paying for it, internal friction was not accounted for.

1.1 Peddling

The bicyclist applies a force by peddling. In cycling, this is often expressed as a power output. For this problem, I used a mass of 70 kg, and a power-to-weight ratio of 16.6 W/kg, which is the value I found for a moderately-skilled rider [Min]. This gives a power of 1162 watts

1.2 Drag

The bicyclist will experience both aerodynamic and viscous drag. The formula for aerodynamic drag is

$$F_d = \frac{1}{2}\rho u^2 c_d A \tag{1}$$

I used the values of this equation we were given in class, which is that $c_d = 0.9$, $\rho = 1.29kg/m^3$, and $A = 0.33m^2$. In this equation, u is the relative fluid velocity.

1.3 Gravity

The force of gravity in this situation is not the one we are accustomed to, rather, it is actually the horizontal component of the normal force, which will be

$$F_g = mgh\sin(\theta) \tag{2}$$

where θ is determined by the grade of the ground. This leads into the biggest (ongoing) headache this problem has caused, which is covered later.

1.4 Rolling Resistance

Bicycles experience rolling resistance between the tires and the ground. This is often expressed as a wattage per tire. It was difficult to find a good value for this, but I used a value of 25 watts combined, or 12.5 watts per tire. My value was based on a database I found compiling a large number of different road bike tires [unk]

2 The Model

The model for this scenario is quite simple, as we are accounting for a single differential equation, which takes the form

$$\frac{dV}{dT} = \frac{P}{mv} + \frac{\frac{1}{2}\rho u^2 c_d A}{m} + \frac{mgh\sin(\theta)}{m} - \frac{R}{m} \tag{3}$$

Where R is the total rolling resistance. I applied the Euler method to solve this equation, which uses the following system

$$y_1 = y_0 + hf(x_0, y_0) \tag{4}$$

where h, in this case, is the time step of the model. I used a time step of 0.1 seconds, as anything more started taking an increasing amount of time to calculate.

3 The Program

Now that a velocity equation has been found, one can begin to model the equation. My program does this in the following way: It solves for the velocity given time and then uses that velocity to solve for position. This is done using the Euler method to solve for velocity, and then uses $x_1 = V * h + x_0$, again using h as the time step. It then appends x_1 to a list, and then uses that as the next value of x_0.

3.1 Grade

To find the grade of the ground, I used a real route, and imported the data from it as a gpx file. I created a list of coordinates, each one being a data point from the file, containing a latitude, longitude, and elevation.

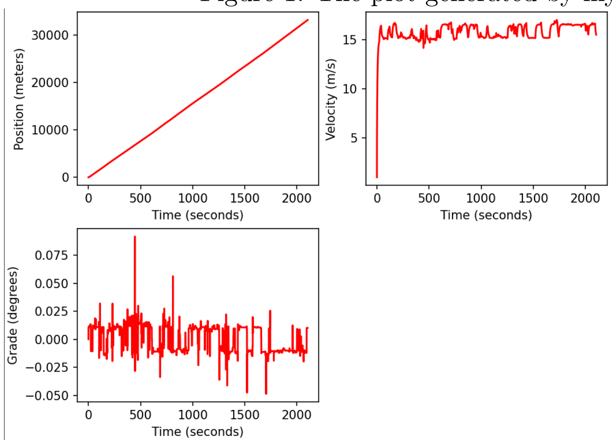
Next, I convert those coordinates into a list of points in 3D space using a method articled by Don Cross [Cro].

Then, with a list of points, I convert them into a list of markers, which is a class I devised that contains information more useful to the program. Each marker contains its index, distance between it and the previous marker, distance along the route, and grade between it and the previous marker. Finally, with this list, it is trivial to then take in a position along the route and output the associated grade.

3.2 Putting it together

Now that the program has solved for the velocity and position of the cyclist, it needs to format the data in a way people can read. This is done using the pyplot module, which I use to generate 3 plots: the position as a function of time, the velocity as a function of time, and the grade as a function of time. This is then output to the user, resulting in a figure such as what follows.

Figure 1: The plot generated by my program



4 The Headache

As I mentioned in 1.3, there is a major issue with my program, which is that it is nonfunctional. Due to an unknown issue, the velocity plot produced is extremely jagged, when it should be smooth. I know the issue lies in the code that solves for velocity, as the curve should be smooth. I tried to solve using a better approximation than the Euler method, but had to abandon that approach due to time constraints and not seeing any appreciable results.

5 Conclusion

This problem seemed very simple to me at the beginning, but as described in the previous section, became a massive issue. It involved some enjoyable problem solving, especially when it came to the process of solving for the grade, however, it quickly became frustrating once I could not identify the point of error. My final thoughts on this problem, and class as a whole, was that it was an enjoyable use of computers to solve problems in physics, and assuredly something I will continue to do in my free time whenever I can find a use for it.

References

[Cro] Don Cross. *Calculating Azimuth, Distance, and Altitude from a Pair of GPS Locations in JavaScript.* URL: https://javascript.plainenglish.io/calculating-azimuth-distance-and-altitude-from-a-pair-of-gps-locations-36b4325d8ab0. (accessed; 12.10.2024).

[Min] Petr Minarik. *What Is a Good Average Cycling Power? How Do You Stack Up?* URL: https://www.cyclistshub.com/average-cycling-power. (accessed; 12.10.2024).

[unk] unknown. *Road Bike Tires Overview.* URL: https://www.bicyclerollingresistance.com/road-bike-reviews. (accessed; 12.10.2024).