**Frisbees**

Frisbees are flying objects used to entertain people. As it does not require a lot of abilities to throw them, the concept behind them seemed very simple. In contrary to this assumption, they are complex since they operate under two physical concepts, aerodynamic lift and gyroscopic stability[[1]](#footnote-1). Looking at Bernoulli’s principle and the lift force which causes an object to stay in the air, the Frisbee could be compared to a wing. Gyroscopic stability is responsible to keep the Frisbee straight. Other forces implied with the stability such as the angular momentum are exerted, and they all play a role in preventing it from flipping over during its flight period. In this project, our focus was on what is the angle of attack to throw a Frisbee in order to reach a maximum flight distance. Using some different methods and equations, all the variables will be optimized to get the best possible answer. Our hypothesis was that the optimal angle of throw should be between 10 and 15 degrees since it would maximize the lift force which allows the frisbee to fly and minimize the drag force which slows it down.

**Model**

Since there is a lot of variables to consider, we will use many different equations. First, to be able to find the angle of attack which allows us to reach the greatest distance, we need to separate the problem into four phases.

First, we need to calculate the drag coefficient and force generated at a certain angle as well as the same variables for the lift. To find the drag force—a force parallel to the velocity, but that acts in opposite direction—we used the following formula:

(1)

where represents the density of the fluid, *A* represents the Frisbee’s area and *v* its average velocity, but we will first need to calculate a drag coefficient given by the equation

. (2)

Same thing with the lift force which is perpendicular to the drag force. The lift coefficient *Cl* will need to be calculated with:

(3)

And the force generated by the lift corresponds to this equation:

(4)

The Frisbee’s area, the air pressure, the density of the fluid which in this case will be air, the acceleration and the height of the fluid will have to be considered in these formulas too. The velocities and pressures are linked together, and they act inversely to each other. The initial velocity of a Frisbee throw we will use is approximatively 14 m/s. The standard air density we will use in this case will be 1.23 kg/m3, the Frisbee’s area will be 0.0531m2 and as we might need it, the viscosity of air used will be 1.73x10-5N s/m2. The values of the constants we use were found in the article we based our project on and is referred in the work cited. It is also important that the variables calculated in this step will be updated as the angle of the frisbee changes over time.

Then, we will calculate the acceleration of the object as it travels. To do so, we will decompose it into two components (x and y) because it is a two-dimensional problem which are calculated with

(5)

(6)

Where is the angle between the velocity vector and the x-axis, m is the mass of the frisbee, which we found to be 0.175 kg, and g being the gravity. We assumed the initial angle of the velocity vector to be the same as the angle of attack. However, as time goes on, it will be updated with by using the its x and y components. Since the acceleration varies depending on the point at which frisbee is in its trajectory, these formulas will only hold true for small period of time and will be updated with the new conditions to establish the acceleration throughout the displacement.

The third part of the problem was to make sure we get the most accurate angle of throw. We used the Golden Search method to optimize the results to find the best angle of attack by taking in the distance reached with the angles it provided.

Lastly, to measure the distance reached by the frisbee at the angle found with the Golden Search method, we used Euler’s method to update the angle of the frisbee, its acceleration, velocity, as well as distance over time. By incrementing the conditions based on the previous ones, we were able to maximize the distance reached.

**Computational Methods**

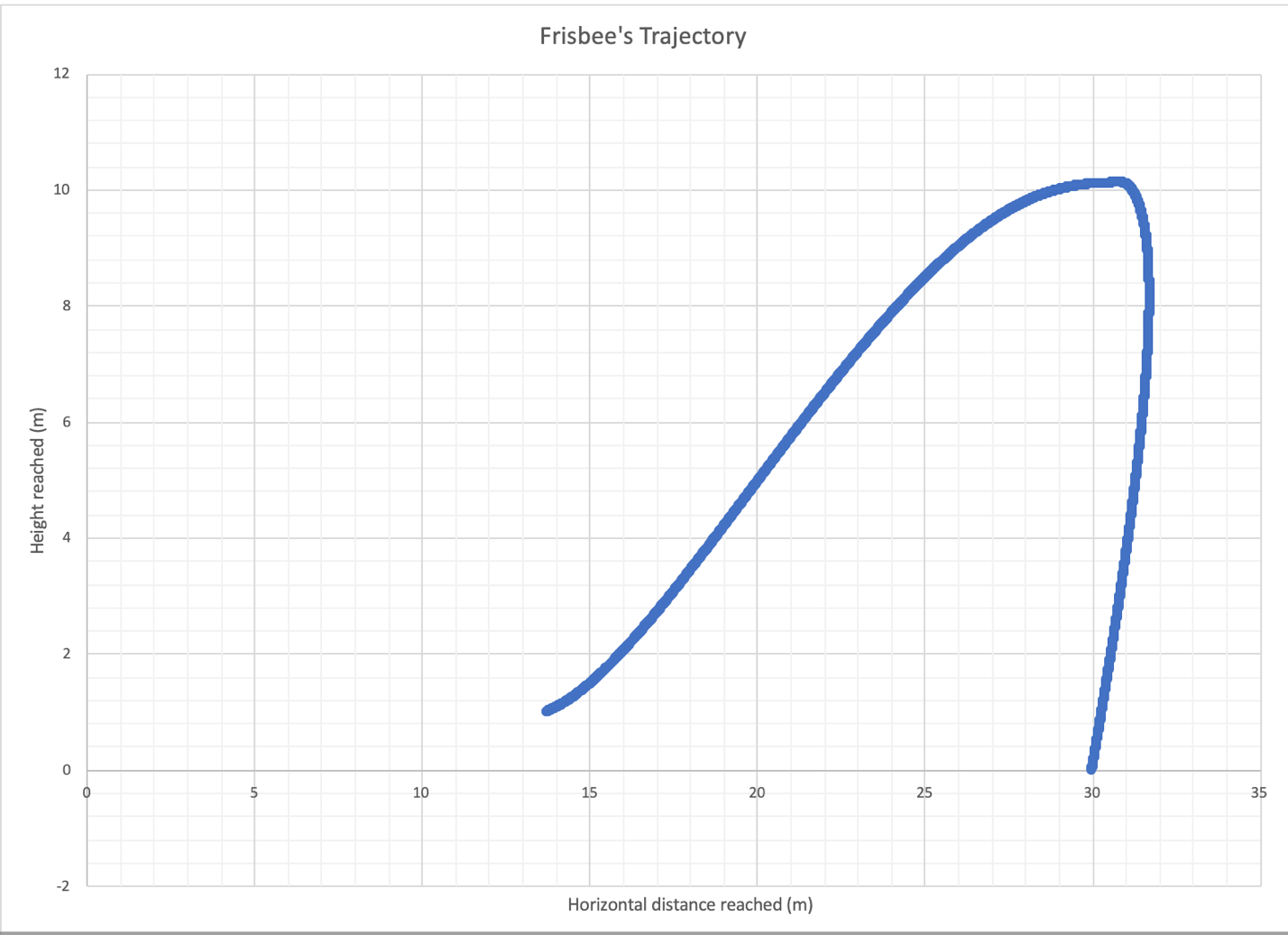
The Frisbee’s components in our main method were used in some numerical methods described in the previous section. We either used some conventional constants such as the air density at sea level and the gravitational acceleration or we used constants like the frisbee’s area and mass, the minimum drag due to friction and pressure, the induced drag, the slope of the graph of a linear function of angle of attack, the angle of attack that produces the less lift, and the initial velocity of average of a throw from the data we have looked at.

The boundaries we used to calculate the optimal angle with the Golden Search method where based on the fact that we know the maximum (90o) and minimum (0o) angles at which we can throw a Frisbee, but we narrowed down the range of angle to between 0 and 30. We made this assumption based on the fact that from an angle greater that 30, the frisbee will just go higher up while reaching a smaller distance. Moreover, our program did not support angles greater than 30 so we simplified it. Since this method is usually used to find a minimum value, we will have to use the inverse of our distance function because in this case, we want to find a maximum value. The Golden Search will also be useful because it is a unimodal function, meaning there is a single optimal value.

In one of our method, we have also calculated the distance travelled by the frisbee and we used data such as the velocity, the x and y initial positions, the angle and we have created arrays. In the same method, we have also used Euler’s method to find the x and y positions, the acceleration, the velocity and the distance. Since all of these values are always changing, this method is also used to update them each time the program is run. To validate our program, we will compare our answers with graphs that have already been made. X and Y values will be printed after running our code and we will then plot a height (m) vs distance (m) graph with our optimal angle of attack.

**Results**

After running our program, we printed the x and y positions for the optimal angle and we transformed into an excel graph to illustrate the trajectory of the frisbee. Since the optimization part of our program was not working very well and simply went to infinity when the angle of attack was greater than 30, we used the angle found in the article which is 12 degrees. The initial vertical position was approximatively 1m and the initial horizontal position was 0m. After looking at the data and the graph, a final horizontal distance of 29.985609 m was observed.



The results we obtained were somewhat close to the ones found by the (name of the author of the article) whose frisbee reached the mark of 40 meter and a maximum height of 7.7 meters when the angle of attack was of 12 degrees(reference the article). This means that the percent error for the distance is of about 25% and of about 30% for the maximum height reached by the frisbee.

**Discussion**

Therefore, the discrepancies between our results and theirs suggests an issue in our program which we were not able to fix. However, our initial hypothesis which was that the optimal angle of attack would be between 10 and 15 degrees was confirm as it was found to be 12 degrees.

**Reference**

1. Morrison, V.R. “The Physics of Frisbees”. *Electronic Journal of Classical Mechanics and Relativity.*Http://scripts.mit.edu/~womens-ult/frisbee\_physics.pdf. [↑](#footnote-ref-1)