"How does the drag coefficient affect the distance travelled by a golf ball?"

The research question asks, "How does drag coefficient affect the distance travelled by a golf ball?" As an object travels from one place to the other (in earth's atmosphere), it displaces air as it moves. When the object does this, it experiences force acting against it, and that is called "drag." The object experiences more drag as its velocity is increased. Therefore, as an object accelerates, its drag and velocity increases. My experiment deals with a golf ball, but the drag coefficient is always taken into account in real world applications when designing cars, for example. Car designers try to reduce drag coefficient in order to travel faster and improve efficiency. My research question is worthy of investigation because of drag coefficient being factored in, as this topic requires further, more in-depth investigation into projectile motions. Also, as an avid golfer myself, I hope to better understand the physics of teeing off and maybe improve my golf game.

In this experiment I am using the simulation found at http://phet.colorado.edu/sims/projectile-motion/projectile-motion_en.html to model the effects of firing a golf ball out of a cannon. This simulation is a simple projectile motion simulation but it allows us to factor in the drag coefficient of the desired object being fired. I will be modifying the level of air resistance and examining how this affects the distance the ball travels. The simulation allows for the launch angle, launch velocity, mass and diameter of the object to be changed as well. My data collection should be fairly accurate, probably with a few constant uncertainties and inaccuracies, as this is just a simulation and a few trials would yield the same values. The simulation is based on theories of projectile motion and drag coefficient, so a limitation would be that there are no real world factors being taken into account. However, a big advantage with using a simulation is the level of detail that I can get in my results. Also, it is just a simulation so I wouldn't need to be aware of safety precautions or environmental concerns for this experiment.

My hypothesis is that the greater the drag coefficient is made, the shorter the distance the golf ball will travel. This is because of Newton's second law of motion states that the acceleration of a body is in the same direction and proportional to the force acting on it. This is shown in the formula $a = F / m$. The drag coefficient affects the resistive force F acting on the ball. Since the mass of the ball is always the same, the greater the F value, the greater the acceleration a. In this case, since F is a resistive force, a is a negative acceleration and will slow the ball down. If the magnitude of this negative acceleration is greater, the ball will slow down quicker and therefore travel a shorter distance.

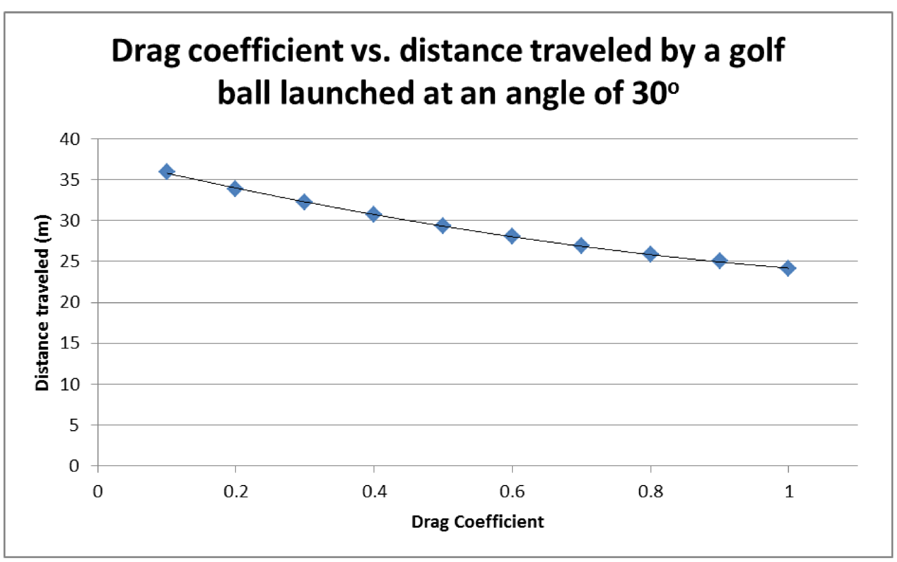
So here is my method. I will be using the simulation to fire the golf ball at an angle of 30^{o} to the horizontal and with an initial velocity of 20 m s^{-1}. The mass of the golf ball is 0.046 kg and its diameter is 0.043 m. I will start with a drag coefficient of 0.1 and increase it by increments of 0.1 until it reaches 1. I will then repeat this for launch angles of 45^{o}, 60^{o} and 75^{o}. I will record my results and then visually display the relationship between the drag coefficient and distance travelled in graphs.

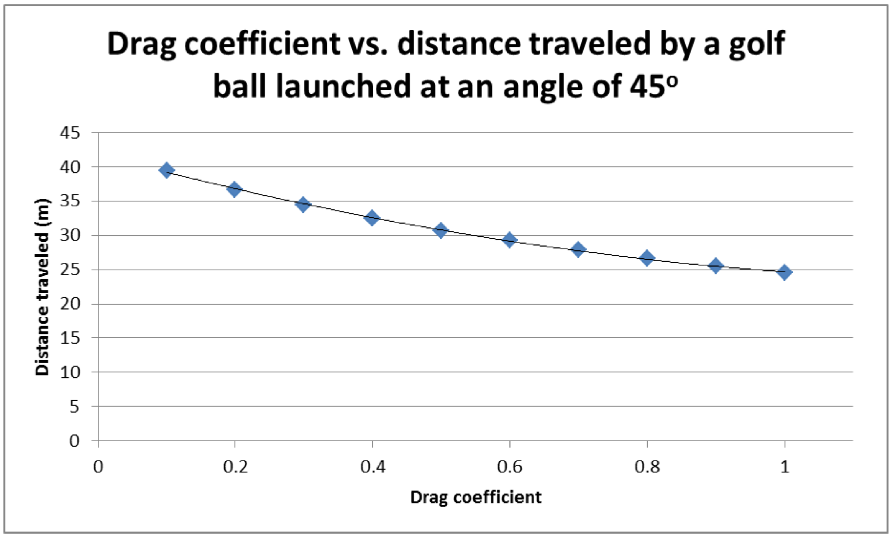
For this experiment my independent variable is the drag coefficient at each launch angle, and my dependent variable is the distance travelled. The controlled variables are mass and diameter of the golf ball, launch speed and launch angle. Since this is a simulation, I am not too worried about other controlled variables like I would have been if this were a hands-on experiment, as the simulation will not factor those in anyway.

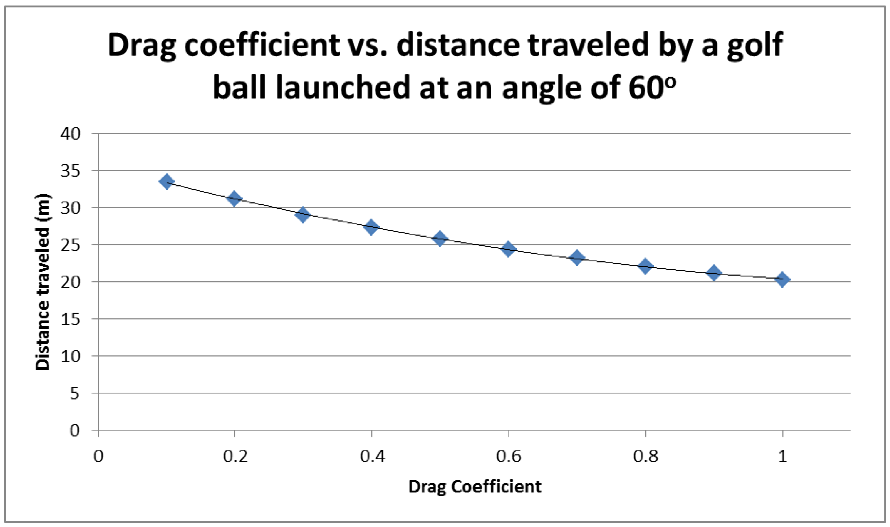
Launch Angle (degrees) Raw Data	Drag Coefficient Raw Data	Distance Travelled ±0.05m Raw Data
30	0.1	35.9
	0.2	33.9
	0.3	32.2
	0.4	30.7
	0.5	29.3
	0.6	28.1
	0.7	26.9
	0.8	25.8
	0.9	25.0
	1.0	24.1
45	0.1	39.4
	0.2	36.7
	0.3	34.4
	0.4	32.5
	0.5	30.7
	0.6	29.2
	0.7	27.9
	0.8	26.6
	0.9	25.5
	1.0	24.5

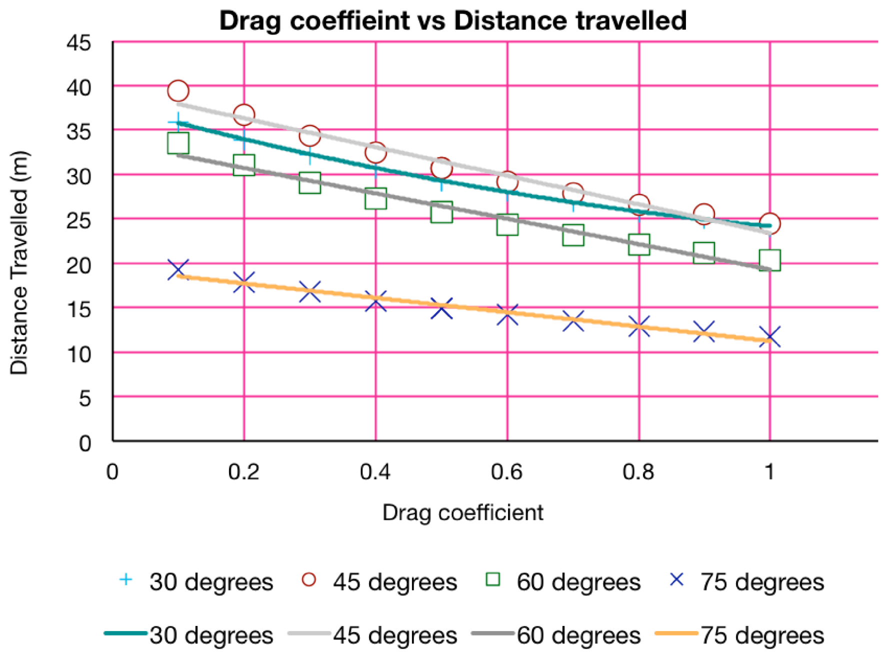
60	0.1	33.5
	0.2	31.1
	0.3	29.0
	0.4	27.3
	0.5	25.8
	0.6	24.4
	0.7	23.2
	0.8	22.1
	0.9	21.2
	1.0	20.3
75	0.1	19.3
	0.2	17.9
	0.3	16.8
	0.4	15.8
	0.5	14.9
	0.6	14.2
	0.7	13.5
	0.8	12.9
	0.9	12.3
	1.0	11.8

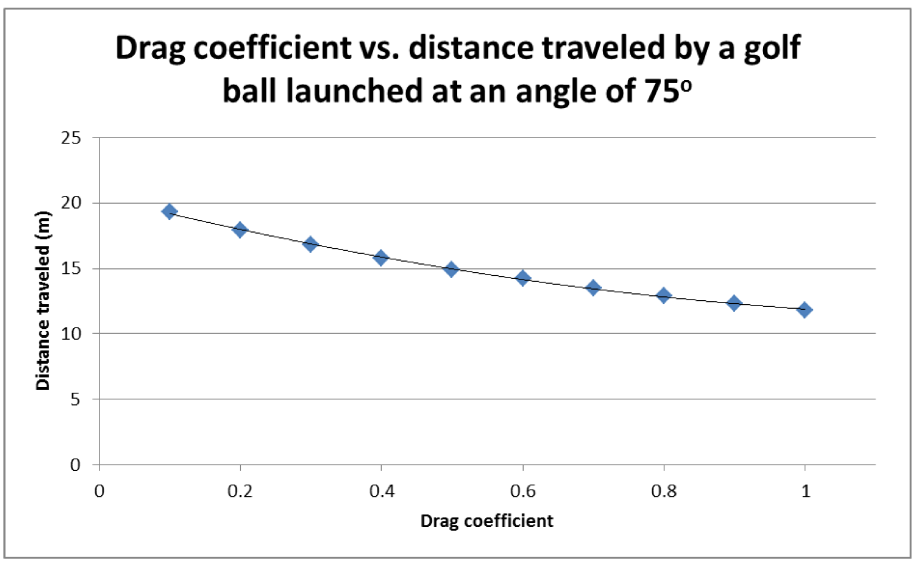
And now I process my raw data. To analyse the trends in the data, I had to represent it visually through graphs. I made a graph for each launch angle, showing the effect of the drag coefficient on the distance. The error bars on the graphs are too small to see.




Drag coefficient vs. distance traveled by a golf ball launched at an angle of 45°
Distance traveled (m)
Drag coefficient
0
5
10
15
20
25
30
35
40
45
0
0.2
0.4
0.6
0.8
1


Drag coefficient vs. distance traveled by a golf ball launched at an angle of 60°
Distance traveled (m)
Drag Coefficient
0
5
10
15
20
25
30
35
40
0
0.2
0.4
0.6
0.8
1

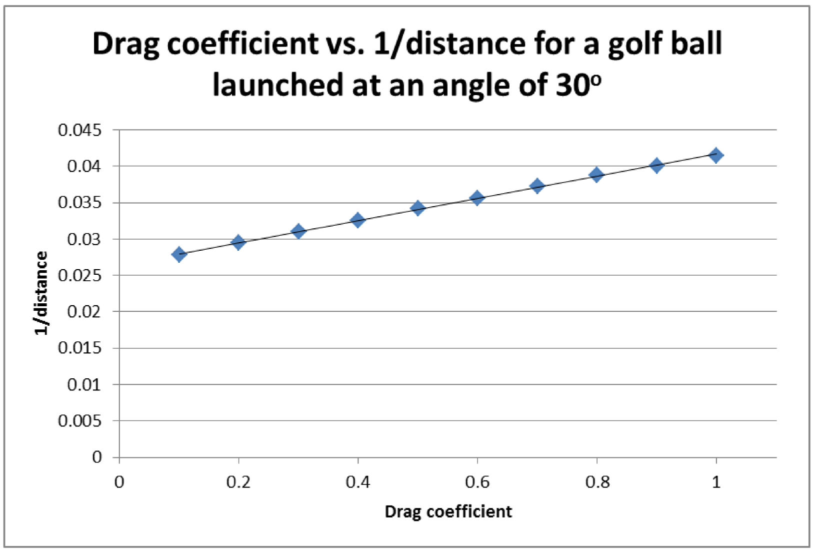


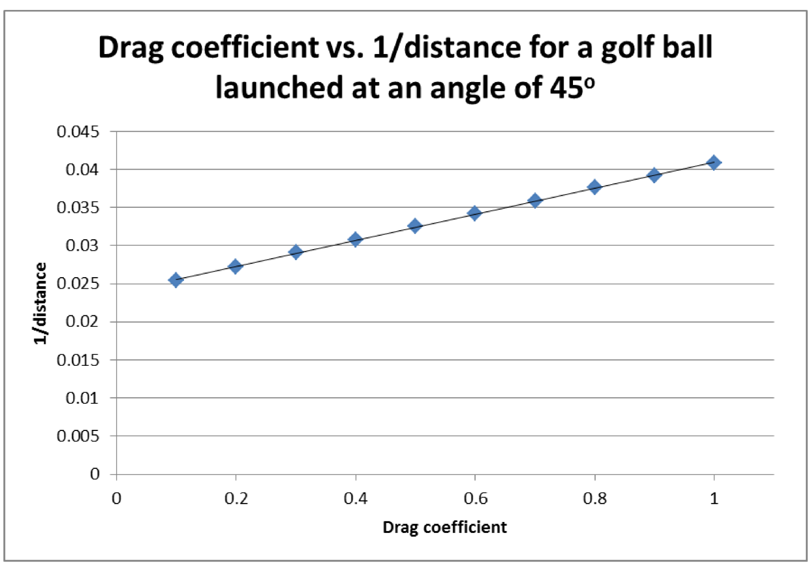


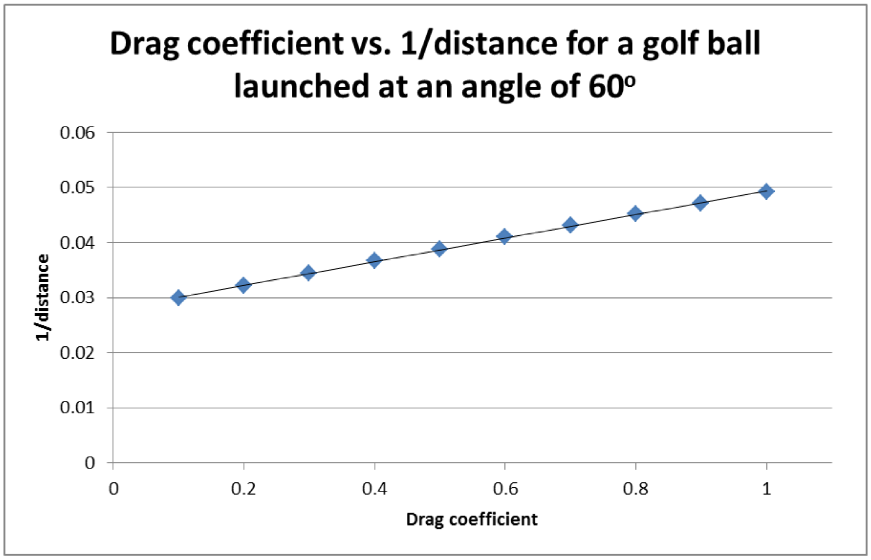
Now, for my scientific analysis of the results. The graphs that I made confirmed that the drag coefficient has a negative effect on the distance that the ball travelled. The launch angle changed the overall range of distances, but the negative effect from the drag coefficient is present in all four-launch angles. The “Drag coefficient vs. Distance travelled” graph is all 4 graphs put together, in order to see the relationship between the different angles of launch. This graph clearly shows that the ball travels the furthest when it is launched at 45 degrees, followed by the other launch angles. Also, there is a curve in the trend lines, which show that the distances travelled decreases when drag coefficient is increased. This is because as the drag coefficient is increased, the force acting on the ball against the direction of travel is increased causing the ball to travel a smaller distance.

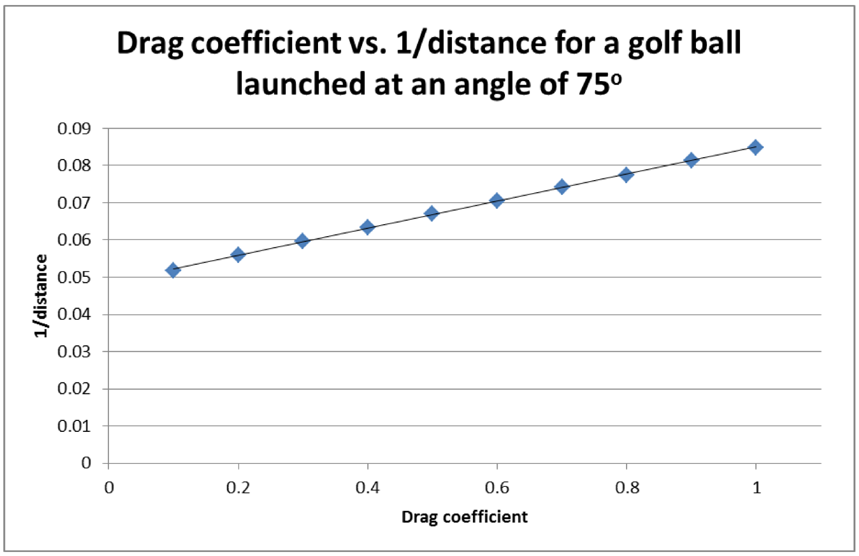
The first thing that I noticed about these graphs is that the relationship between the drag coefficient and the distance travelled by the golf ball seems to be logarithmic and not linear as I expected it to be. I was able to manipulate the graphs by taking the reciprocal value of the distance travelled by the ball and plotting that against the drag coefficient to turn it into a linear proportionality.

Here are the updated graphs that I made:









The updated graphs that I made show that the relationship between the drag coefficient and the reciprocal of the distance travelled is linear. I decided to test the accuracy of the proportionality.

I did this by taking two points from the graph. If the relationship is proportional, y_1/x_1 will equal y_2/x_2. To make my conclusion more accurate, I did this twice with different points for all four graphs.

Launch angle of 30^o	Launch angle of 45^o	Launch angle of 60^o	Launch angle of 75^o
0.0279/0.1 = 0.279 0.0295/0.2 = 0.148 0.0311/0.3 = 0.104 0.0326/0.4 = 0.0815	0.0254/0.1 = 0.254 0.0272/0.2 = 0.136 0.0291/0.3 = 0.0970 0.0307/0.4 = 0.0768	0.0299/0.1 = 0.299 0.0322/0.2 = 0.161 0.0345/0.3 = 0.115 0.0366/0.4 = 0.0915	0.0518/0.1 = 0.518 0.0559/0.2 = 0.280 0.0595/0.3 = 0.198 0.0633/0.4 = 0.158

For all four-launch angles, the ratio of y_1/x_1 to y_2/x_2 is not constant. It decreases as the drag coefficient is increased. This shows that no proportionality constant exists in this relationship so the two values are not directly proportional. However, a linear relationship does exist between the drag coefficient and the reciprocal value of the distance that the ball travelled.

The following is my conclusion. At the beginning of this experiment, I hypothesized that with an increase in the drag coefficient the distance that the golf ball travelled would decrease. Just as predicted, the higher I made the drag coefficient in the simulation, the shorter the distance the golf ball travelled. This is because the drag coefficient increases the force of air resistance acting on the ball, meaning there are more molecules of air, which collide against the surface of the golf ball as it travels through the air. These collisions make the ball lose kinetic energy, which means that it decelerates a lot quicker than the higher the drag coefficient. This resistive external force and its effect on the acceleration of the ball is described and modelled by Newton's second law of motion. Due to its quicker deceleration in both the vertical and horizontal directions the ball can no longer fly as high or as long as it would otherwise be able to. This lowers the distance travelled by the ball. I expected the relationship between the drag coefficient and the distance travelled to be an inverse one which was linear. This was not the case. The relationship was an inverse one but seemed to be logarithmic. I took the reciprocal value of the distance and then plotted the drag coefficient against it. This new relationship did turn out linear. I tested its proportionality and demonstrated that the two values were not proportional. Despite this, I was able to confirm my main hypothesis that the drag coefficient does negatively affect the distance that the golf ball travelled.

To evaluate my data I collected is quite accurate with limited uncertainties, therefore the data is reliable. However, the limitations of the data lie within the simulation. Since the simulation is based on theories, real world factors are not taken into account and therefore some of my data could have been different if I were to do hands on experiment with the same topic of investigation. If I were to expand on this investigation, I would look at how the velocity of the golf ball affects the distance travelled, while having drag coefficient factored into the equation Even though my current data gives me some knowledge that when velocity is increased, the drag coefficient would increase as well, it is worthy of investigation as it would give me details as to how much the velocity actually impacts the distance travelled.

Simulation link: http://phet.colorado.edu/sims/projectile-motion/projectile-motion_en.html