ISSN: 2710-0588

A Study on Factors Affecting Baseball Pitch Trajectories

Haoyu Yang[1, a], Ziyue Guo[1]

[1]Beijing Haidian Foreign Language Shiyan School, Beijing, 100195, China

[a]yanghaoyu2609@163.com

Abstract

Baseball has always been a fascinating sport. Players not only need to possess excellent skills in batting, base running, pitching, and catching, but also must be able to make quick judgments based on the situation on the field. My research focuses on the factors that affect the flight trajectory of the baseball. By understanding these factors, players can predict the flight trajectory of the baseball and make appropriate decisions. I first collect some data from the official website of MLB (Major League Baseball) including ball speed, spin rate, and date. Then, I obtained the humidity and wind speed information for the corresponding date from the US Weather Information Bureau. By organize and compare these datas, I initially analyzed the impact of meteorological factors on the pitching effect. Subsequently, I designed and conducted an experiment with controlled variables. I adjusted the humidity conditions and recorded the changes in pitching speed to verify the effect of climate on the deceleration of the ball speed. The research results show that in the case of increased humidity, the air resistance coefficient significantly increases, the proportion of ball speed deceleration rises, and the pitching becomes slower. This finding provides data support for a deeper understanding of the impact of humidity on the movement of baseball.

Keywords

Baseball, Humidity, Rotation, Magnus effect.

1. Introduction

This study mainly focuses on the influence of environmental factors on the flight trajectory of baseball during the game. Although there are already numerous studies on predicting the trajectory of baseball, these models are often overly idealized and fail to take into account the complex and variable weather conditions in actual games. For instance, when throwing a ball on a wet and humid field after a recent rain compared to a dry and hot environment, the flight speed and trajectory of the ball are likely to differ significantly. Currently, there is very little research on how environmental factors specifically affect the speed and flight path of the ball. Therefore, my study aims to fill this gap. I will systematically explore the effects of variables such as humidities and wind speeds on the flight state of the baseball, providing theoretical support and data basis for decision-making and strategies in real games.

In the existing study, the reason why a baseball change its direction and trajectory in the air after being thrown is primarily according to the air resistance and the Magnus effect. As the ball spin while moving through the air, the rotation interact with the surrounding airflow to create a pressure difference on either side of the ball, producing a force perpendicular to the directions of motion. This force is known as the Magnus force and it change the trajectory which cause the ball to curve. In addition, the friction between the baseball and the air create a boundary layer on the ball's surface, which further influence the airflow pattern. Because of that, different throwing techniques such as fastballs, curveballs, or sliders can produce difference spin shape, leading to distinct flight paths and behaviors (Terry Bahill, 2005)[1]. In the research of table

ISSN: 2710-0588

tennis (which is similar to baseball), factors that influence the trajectory of the ball include gravity, air resistance, and the Magnus force that generate by the ball's rotation. When the ball is flying, gravity cause it to fall, air resistance slowing its speed, and rotation causing a result in a curve trajectory. The magnitude of the Magnus force is not only relate to the speed of the ball's rotation but also affected by the flight speed and the state of air flow, allowing it to have a complex nonlinear characteristics (Lvchengxu et.al, 2023)[2]. Furthermore, in the research of golf, the trajectory of the ball is influenced by multiple physical forces. When the ball is hit, it first experiences the continuous downward force that is pull by gravity, causing it to move in a parabolic path. At the same time, air resistance increases as the ball speed increases, exerting a decelerating effect on the ball. Rotation is one of the important factors affecting the trajectory to be a curve shape, it involved topspin, backspin, and sidespin which cause the ball to rise during flight, delay its descent, or change its direction. This process of motion is caused by a force called Magnus effect. The initial velocity, launch angle, surface structure, and environmental wind speed and direction also have a significant impact on the final trajectory (liyizhou, 2018)[3].

2. Methodology

The methods of this study are divided into two parts: data collection and analysis, and field experiments. In the first part of my experiment, I collected the data from MLB (The Major League Baseball). I collected the pitching information of specific players by consulting the data on the official website MLB. I selected only one pitcher from a certain team as the research subject. This approach could maximize the control over factors such as the pitcher's physical condition and technical proficiency that could affect the data. I recorded the initial speed, rotation speed, and the specific date of each pitch. Subsequently, base on these dates, I obtained the environmental information from the National Weather Database of the United States, focusing on wind speed and humidity. All the data were sorted and entered into a table, establishing a one-to-one correspondence. I analyzed the relationship between environmental factors and data such as ball speed and rotation through charts, thereby observing the potential impact trends and forming quantitative conclusions.

In the second part, I designed and conducted a field experiment to further verify the actual impact of environmental variables on the ball-throwing effect. The experiment was first carried out on a field where the wind speed was close to zero. I designated the same experimental pitcher to repeatedly throw the ball each time to control individual physiological differences. During the experiment, the temperature is stay same. During the experiment, I recorded the initial and final speeds of each throw and thereby calculated the attenuation ratio of the ball speed and the air resistance coefficient. The core of the experiment was to gradually adjust and increase the humidity in the experimental environment. Thus, I could observe the specific impact of humidity changes on the attenuation of the ball speed and the air resistance coefficient while keeping other variables constants.

3. Practice

First, I accessed the database of the MLB (Major League Baseball) website and selected the Red Sox team as the research subject. II collected a total of four sets of data under different conditions, where the first and second sets explored the influence of humidity on the flight trajectory of the baseball (with changes in ball speed as the core, determine the place where pitch the ball is the initial velocity and the place where catch the ball is the final velocity), and the third and fourth sets studied the impact of wind speed. In the first set of data, I controlled variables such as the pitcher (Brennan Bernardino), the type of ball (Curveball), and the wind speed (approximately 18 mph). These factors could all affect the ball speed, so controlling them

ISSN: 2710-0588

helped us observe the effect of humidity more clearly. It is worth noting that the wind speed information could not be directly obtained from the MLB website. I first found the time and date of each ball's release in the MLB data, and then used the National Oceanic and Atmospheric Administration (NOAA) to search for the wind speed and humidity at the corresponding time and location, thereby indirectly obtaining the meteorological conditions. Through this method, I successfully matched the speed of each ball with the humidity at that time. I organized these data into tables and drew line graphs, with the X-axis representing humidity (%) and the Y-axis representing ball speed (mph), to visually represent the impact of humidity change on the ball speed:

red sox(18mph, curve ball)

Humidity	Ball speed
40	85.3
51	90.8
53	89.4
55	83.7
67	79.4
79	79
90	76.1
100	78.7

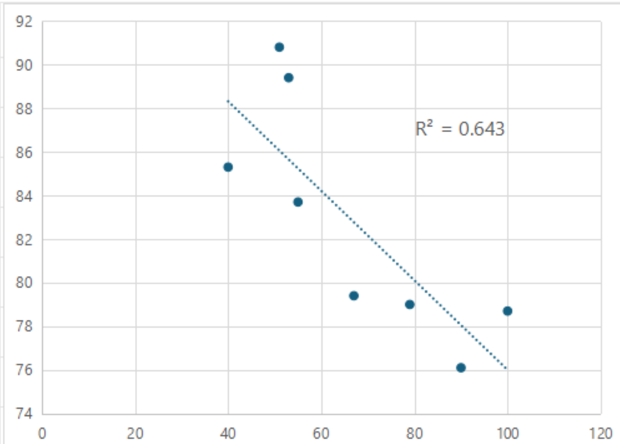

Figure 1. Relationship Between Humidity and Pitch Speed for Curveballs Thrown by Brennan Bernardino

In the second set of data, I controlled for variable such as the pitcher (Houck Tanner), the type of ball (Fastball), and the wind speed (approximately 10 mph):

red sox(10mph, Fastball)

Humidity	Ball speed
22	102.3
35	92.8
49	94.9
64	93.2
71	91.2
73	92.8
88	92.2
95	91.5
100	90.2

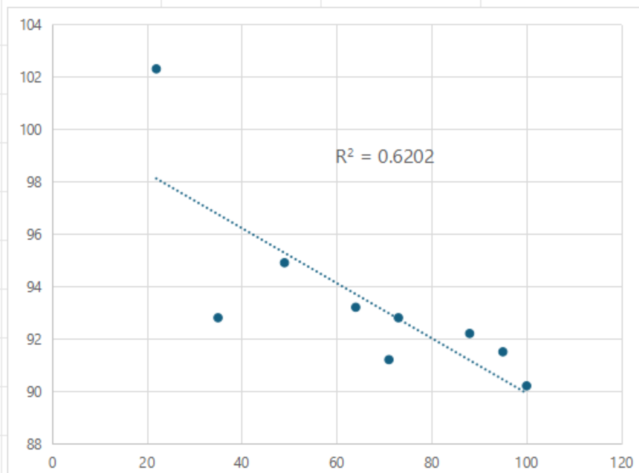

Figure 2. Relationship Between Humidity and Pitch Speed for Fastballs Thrown by Tanner Houck

In the third set of data, I controlled for variables such as the pitcher (Buehler Walker), the type of ball (Fastball), and the humidity (approximately 30%), in order to study the effect of wind speed on the ball speed:

ISSN: 2710-0588

red sox(30 humidity, Fastball)

Wind speed (downwind)	Ball speed
0	90.2
4	93
5	91.3
8	92.6
13	93.8
14	96.2
17	95.4
21	98.2
23	97.3

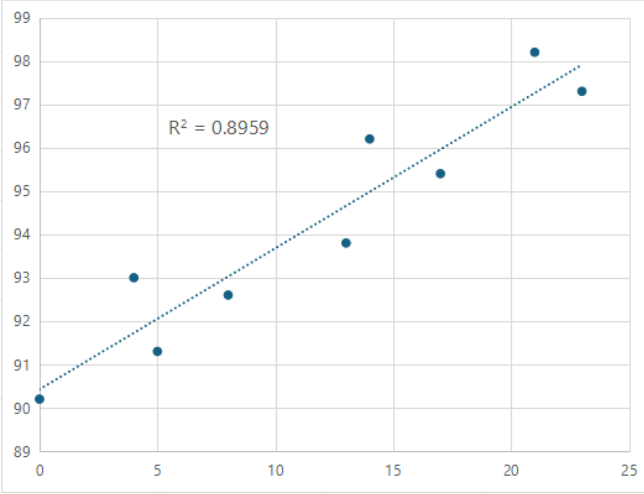

Figure 3. Effect of Wind Speed on Fastball Velocity (Pitcher: Walker Buehler)

In the last set of data, I controlled for variables such as the pitcher (Newcomb Sean), the type of ball (curveball), and the humidity (approximately 40%):

red sox(40 humidity, curveball)

Wind speed (headwind)	Ball speed
1	79.2
5	76.1
8	75.9
10	73
12	72.1
15	73.2
19	71.9
22	71.2

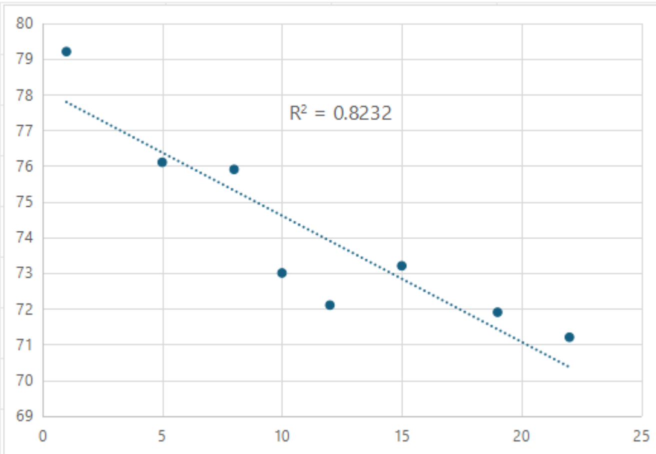

Figure 4. Effect of Wind Speed on Curveball Velocity (Pitcher: Sean Newcomb)

The second part of my field experiment mainly focused on the effect of humidity on the flight speed of baseballs. To minimize the interference from wind speed, I conducted the experiment in an indoor gymnasium without wind, ensuring that this variable remained constant.

The experimental equipment included a speed measuring gun, baseballs, a tape measure, a humidity meter, a humidifier, and a net. The speed measuring gun was used to measure the initial and final speeds of the baseballs. The humidifier was used to adjust the humidity variable to explore the effect of humidity on the flight speed of the baseballs. The tape measure was used to measure the pitching distance of 18.5 meters (this distance is the actual distance from the pitcher to the batting box). The humidity meter was used to measure the humidity of the environment. The net was used to block the baseballs at the end to prevent them from flying elsewhere and damaging the venue. To ensure the reliability of the data, I invited two students with strong pitching abilities - Zhao Xingzhe and Zhu Dongqing - to act as the pitchers for this experiment. Here, I also express my gratitude to their cooperation and efforts.

ISSN: 2710-0588

The experimental steps are as follows: The pitcher needs to stand 18.5 meters away from the net, ready to pitch. At this time, a speed measurer should stand on the side of the pitcher, holding the speed measuring gun (placed at chest height) and aiming it at the direction of the ball's flight. When the pitcher pitches, the speed measurer presses the switch of the speed measuring gun to turn it on. At this point, the value on the speed measuring gun is the initial speed of the pitcher's pitch. The speed measurer then records this initial speed. Next, the speed measurer moves to the rear of the net, maintaining the same posture, ensuring that all factors (including humidity, wind speed, and temperature) are the same, and the pitcher performs the same pitch with the same force. At this time, the speed measurer measures and records the final speed. Through this method, I was able to collect multiple sets of complete pitching data containing "initial speed, final speed, and humidity" in a controllable humidity environment, providing a sample basis for subsequent calculations of the attenuation ratio and resistance coefficients.

After each set of pitching test was completed, I used the humidifier to humidify the area where the pitcher was located, artificially increasing the environmental humidity, and monitored the current humidity changes using the humidity meter. After each humidity level was raised to a stable value, I repeated the same experimental steps, allowing the pitcher to complete the pitch again and measure and record the initial and final speed data.

This process was repeated multiple times, enabling me to collect multiple sets of corresponding pitching data under different humidity conditions. Finally, I integrated all the data into a complete table, which included the humidity, initial speed, final speed, and the calculated speed attenuation ratio (the difference between the final speed and the initial speed) and the air resistance coefficient (Cd) for each set of experiments.

By analyzing these data, I can observe and compare the trend of ball speed changes under different humidity conditions, thereby exploring the effect of humidity on the resistance of the ball's flight in the air. This experiment provides data support for the quantitative study of the relationship between humidity and air resistance and lays a solid foundation for subsequent chart analysis and physical modeling.

The final table made is as follows:

Table 1. Experimental Measurements of Baseball Pitch Velocity, Attenuation Ratio, and Coefficient of Resistance at Different Humidity Levels

Humidity (%)	Zhao Xingzhe				Zhu Dongqing			
	Initial velocity(mph)	Terminal velocity(mph)	Attenuation ratio	Coefficient of resistance(Cd)	Initial velocity(mph)	Terminal velocity(mph)	Attenuation ratio	Coefficient of resistance(Cd)
32	48.5	47.2	0.026804124	0.082534966	65.6	64.1	0.022865854	0.070268041
33	49.3	47	0.046653144	0.145113599	64.8	63.2	0.024691358	0.075948041
34	46.4	44.3	0.045258621	0.140675534	64.5	63.1	0.021705426	0.066662857
39	48	45.7	0.047916667	0.14914023	62	59.3	0.043548387	0.135241359
42	47.5	44.6	0.061052632	0.191313198	63.6	59.7	0.061320755	0.192179958
47	46	42.2	0.082608696	0.261771026	61.5	58.4	0.050406504	0.157090193
48	46.5	41.9	0.098924731	0.316163791	62.3	58.6	0.059390048	0.185943922
51	45	40.3	0.104444444	0.334776828	60	56.3	0.061666667	0.19329854
54	44.3	38.2	0.137697517	0.44924417	57	52.5	0.078947368	0.24969219
57	47.3	41.2	0.128964059	0.418786938	59.2	53.4	0.097972973	0.312965285
60	43	37.2	0.134883721	0.439400138	55.8	50.6	0.093189964	0.296939709
63	46.3	38.7	0.164146868	0.54325187	54.9	49.8	0.092896175	0.295957982
66	42.2	35.4	0.161137441	0.532419257	57.4	51.5	0.102787456	0.329177919
69	48	39.2	0.183333333	0.613158497	51.5	45.6	0.114563107	0.369181003
72	47.5	37.1	0.218947368	0.746912177	50	43.3	0.134	0.436314577
75	43.2	33.6	0.222222222	0.759480411	56.3	48.1	0.145648313	0.477221407
78	40.8	32.3	0.208333333	0.706493405	53.7	47.2	0.121042831	0.391407149
81	43.9	34.5	0.214123007	0.72848121	49.5	40.2	0.187878788	0.629936929
84	42.1	31.8	0.244655582	0.846836074	53.5	44.5	0.168224299	0.557985608

As shown in the figure, in the table, in addition to recording the humidity, initial velocity and final velocity that I actually measured, the attenuation ratio and air resistance coefficient (Cd) corresponding to each set of data were also calculated through formulas. Among them, the attenuation ratio is calculated by the formula: $r=\frac{v_0-v}{v_0}$. Because each time the pitcher throws the ball, it is difficult to ensure the same initial speeds. So even if the initial speeds of the two throws are different, this formula can help me measure the degree of speed attenuation using "proportion", reducing the interference of speed and being more suitable for comparison.

In this part of calculate the air resistance coefficient. Through searching, I found that the basic formula for air resistance is: $F_d=\frac{1}{2}\rho C_d A v^2$ (WangXuance et.al, 2017)[4]. However, I don't have the quantity of air resistance (F_d) so I need to modify the formula to convert it into the initial and final velocity I already have. I know that when the baseball changes from its initial velocity to its final velocity, due to the work done by air resistance, its kinetic energy is lost: $\Delta E=\frac{1}{2}mv_0{}^2-\frac{1}{2}mv^2=F_d\cdot d$. $\frac{1}{2}m(v_0{}^2-v^2)=(\frac{1}{2}\rho C_d A\overline{v}^2)\cdot d$, $m(v_0{}^2-v^2)=(\rho C_d A\overline{v}^2)\cdot d$. And then I get: $C_d=\frac{m(v_0{}^2-v^2)}{\rho A\overline{v}^2 d.}$. Since the average speed was not directly measured in the experiment, I adopted the common approximations method and replaced it with the average of the initial and final velocities, that is: $\frac{v_0+v}{2}$, Finally, I can get: $C_d=\frac{m(v_0{}^2-v^2)}{\rho A(\frac{v_0+v}{2})^2 d.}$. After simplification, I get: $C_d=\frac{4m(v_0{}^2-v^2)}{\rho A(v_0-v)^2 d.}$. Among them, apart from the initial velocity and the final velocity, the other several quantities are as follows:

m: Baseball mass (approximately 0.145 kg)

d: Flight distance (18.5 meters)

ρ: Air density (1.2 kg/m^3)

A: Windward area (approximately 0.0043 m^2)

In Excel, my initial velocity and final velocity are in mph units in cells B3 and C3 respectively. They need to be convert to m/s (multiplied by 0.44704), and the corresponding Excel calculation formula is: = (0.145 * ((B3*0.44704)^2 - (C3*0.44704)^2)) / (1.2 * 0.0043 * (((B3*0.44704 + C3*0.44704)/2)^2) * 18.5). The other set of data is in the F3 and G3 columns, then the corresponding formula is: = (0.145 * ((F3*0.44704)^2 - (G3*0.44704)^2)) / (1.2 * 0.0043 * (((F3*0.44704 + G3*0.44704)/2)^2) * 18.5). This formula is the same as the one mentioned above, except that it is presented in the form of a Excel table. With this formula, I can use the Excel table to automatically calculate the air resistance coefficient for all the data.

Based on the datas, I have drawn several graphs:

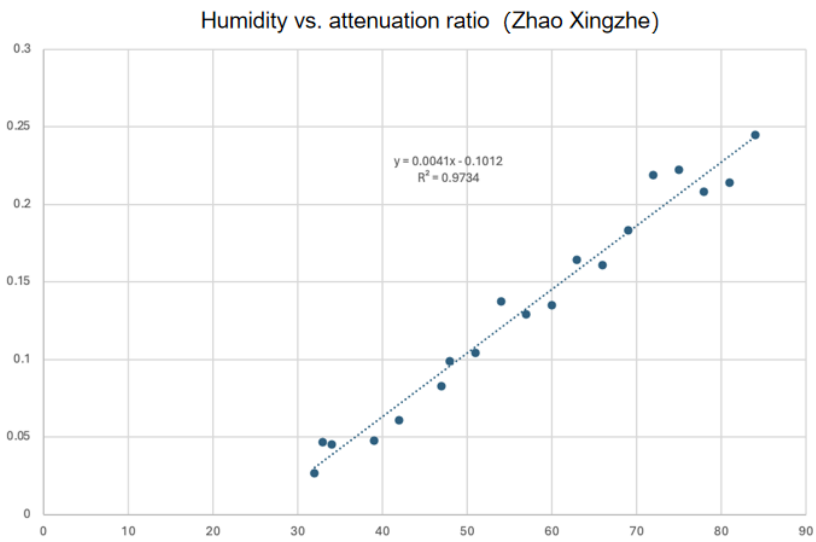

Figure 5. Relationship Between Humidity and Ball Speed Attenuation Ratio for Pitcher Zhao Xingzhe

ISSN: 2710-0588

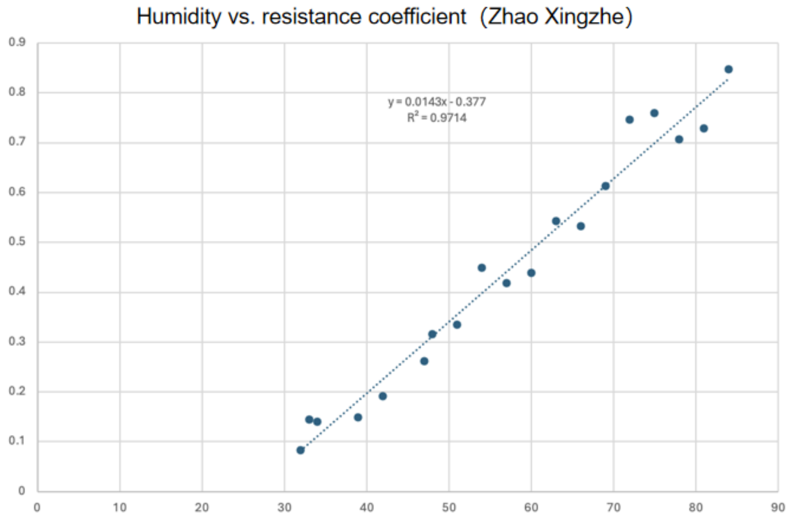

Figure 6. Relationship Between Humidity and Resistance Coefficient for Pitcher Zhao Xingzhe

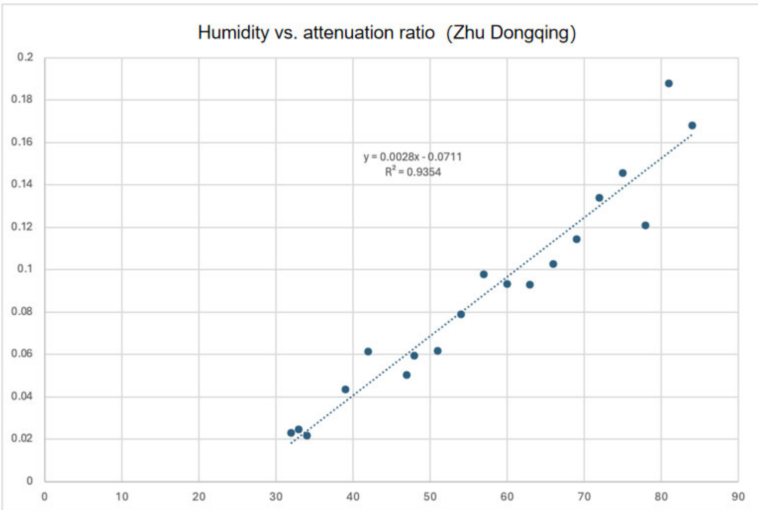

Figure 7. Relationship Between Humidity and Ball Speed Attenuation Ratio for Pitcher Zhu Dongqing

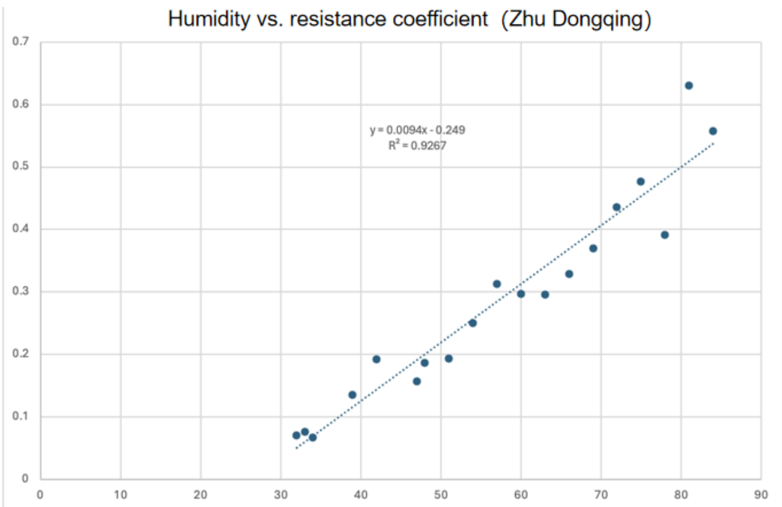

Figure 8. Relationship Between Humidity and Resistance Coefficient for Pitcher Zhu Dongqing

ISSN: 2710-0588

4. Data Analysis

Next, I will conduct a detailed analysis of the experimental data mentioned in the previous text. First, I will analyze the data chart constructed by the MLB (Major League Baseball) official website data and the meteorological information of the National Weather Service of the United States:

red sox(18mph, curve ball)

Humidity	Ball speed
40	85.3
51	90.8
53	89.4
55	83.7
67	79.4
79	79
90	76.1
100	78.7

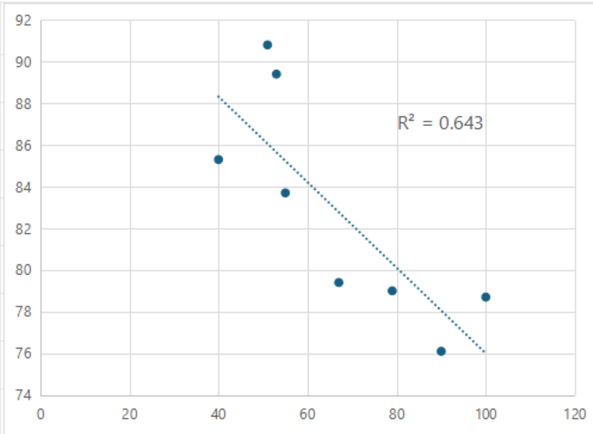

Figure 9. Relationship Between Humidity and Ball Speed Based on MLB Data (Dataset 1)

By observing this group of line graphs, I found that the overall ball speed showed a downward trend as the humidity increased, and the trend line was relatively smooth. However, at the data point where the humidity was 40% and the ball speed was only 85.3 mph, there was a significant outlier, which was significantly lower than the expected ball speed for this humidity range. I believe that the reasons for this deviation may include the following aspects: Firstly, this data point may be affected by the pitcher's physical condition. In a drier environment, the pitcher's hands are prone to drying and slipping, making the grip unstable, which affects the explosive force and speed of the pitchs. Additionally, it is possible that the pitcher had been pitching continuously for an entire inning before this point, resulting in fatigue and the inability to maintain the original speed even in a low humidity environment. Secondly, lower humidity is often accompanied by higher temperatures, and higher temperatures may change the air density or the surface state of the ball, thereby indirectly affecting the flight trajectory and speed performance of the ball. Finally, it is not excluded that the tense situation or critical situation at the game site may affect the pitcher's mental state, causing them to choose stability over full-speed throwing, which may also inhibit the pitching speed psychologically. In conclusion, this outlier point is likely to be interfered by external variables that I did not consider in data processing and experimental control, suggesting that in subsequent analyses, I should pay more attention to these possible human or environmental factors that may affect the results.

ISSN: 2710-0588

red sox(10mph, Fastball)

Humidity	Ball speed
22	102.3
35	92.8
49	94.9
64	93.2
71	91.2
73	92.8
88	92.2
95	91.5
100	90.2

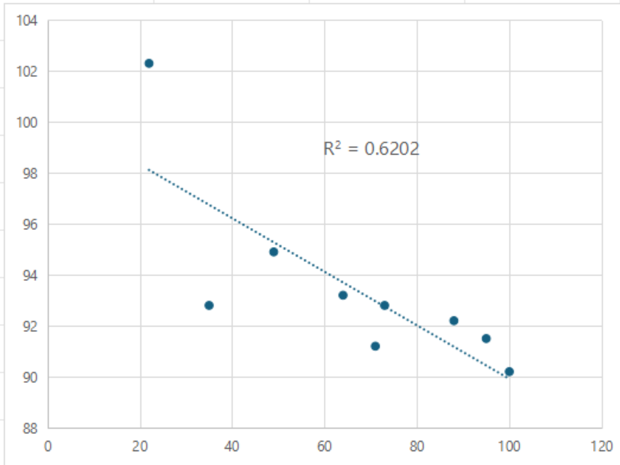

Figure 10. Relationship Between Humidity and Ball Speed Based on MLB Data (Dataset 2)

By observing the charts, at a humidity level of 22%, the ball speed was 102.3, which was a clear peak. As the humidity increased, the ball speed generally showed a downward trend, with some fluctuations in the middle. For instance, at a humidity of 49%, the ball speed was 94.9, and at 71% humidity, the ball speed was 91.2. However, these fluctuations did not affect the overall trend.

From these two images, it can be seen that humidity does have a significant impact on the flight speed of the baseball. Overall, the higher the humidity, the more pronounced the deceleration of the ball speed. This indicates that as the moisture content in the air increases, the air resistant the ball experiences during flight may increase, or the throwing effect of the pitcher may be affected in a certain way in a humid environment. Additionally, the local fluctuations in the data also suggest that, apart from humidity itself, there are other uncontrolled variables (such as temperature, wind speed, pitcher's condition, game rhythm, etc.) that may also be influencing the performance of the ball speed.

red sox(30 humidity, Fastball)

Wind speed (downwind)	Ball speed
0	90.2
4	93
5	91.3
8	92.6
13	93.8
14	96.2
17	95.4
21	98.2
23	97.3

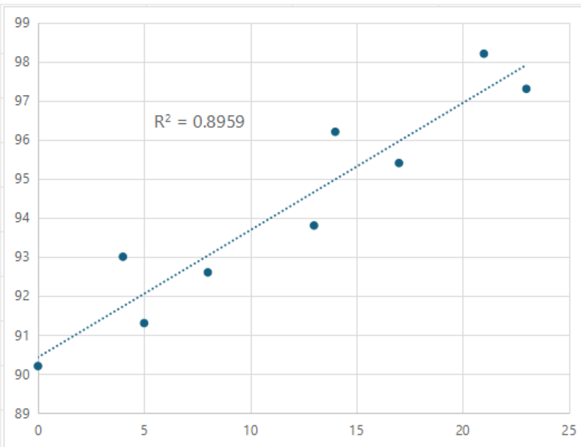

Figure 11. Relationship Between Wind Speed and Pitch Speed Under Downwind Conditions

By observing the charts, I found that: under favorable wind conditions, the greater the wind speed, the faster the ball speed, and the overall trend shows a relatively stable and clear upward trend. In the analyze data, the relationship between ball speed and wind speed is relatively close,

ISSN: 2710-0588

and there are no obvious fluctuations or outliers among the data points, indicate that wind speed, as an external environmental variable, has a higher predictability and stability compared to humidity in influencing ball speed.

red sox(40 humidity, curveball)

Wind speed (headwind)	Ball speed
1	79.2
5	76.1
8	75.9
10	73
12	72.1
15	73.2
19	71.9
22	71.2

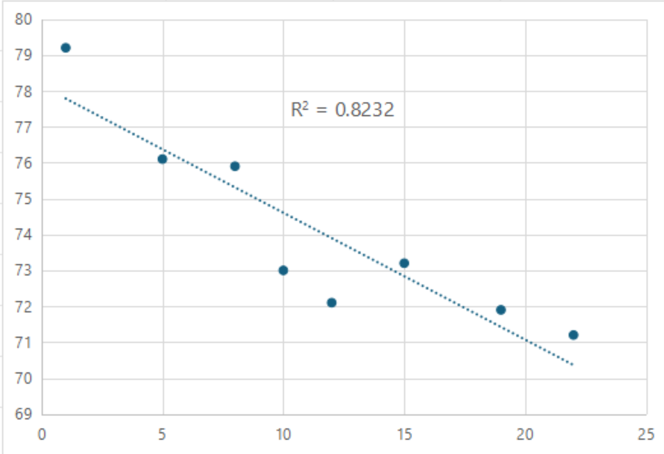

Figure 12. Relationship Between Wind Speed and Pitch Speed Under Headwind Conditions

By observing the charts, it can be seen that under adverse wind conditions, the greater the wind speed, the slower the ball speed, presenting a relatively stable and clear downward trend. As the wind speed increases, the frontal air resistance that the ball encounters during flight significantly increases, resulting in a faster speed decay and a significant decrease in the actual speed at the end point. This trend is consistent in most data and shows a clear regularity, indicating that the inhibitory effect of adverse wind on the ball speed exists. In all the analyzed data, only one data point with a wind speed of 12 mph and a ball speed of 72.1 mph shows a deviation from the expected trend, constituting a minor outlier. I speculate that this deviation may be related to the pitcher's own state changes, interference from the game rhythm, technical movement errors, or other uncontrolled variables. However, this deviation does not change the overall trend of "the greater the wind speed, the slower the ball speed".

Through the systematic analysis of the above experimental data and charts, I can clearly draw two main conclusions: humidity and wind speed both have a significant impact on the flights speed of baseball. Firstly, in terms of humidity, the overall trend shows that the higher the humidity, the more obvious the ball speed decay. This phenomenon may be related to multiple factors such as the denser moist air, increased air resistance, and the pitcher's limited force when gripping the ball in Fa humid environment. Although there are individual deviation values in the graph (such as humidity 40% and ball speed 85.3 mph), these abnormal values may be caused by uncontrollable variables such as pitcher fatigue, hand slipping, or game pressure, and do not affect the overall trend judgment.

Secondly, wind speed has a clear direction of influence on ball speed under both favorable and adverse wind conditions. In favorable wind conditions, the greater the wind speed, the faster the ball speed; in adverse wind conditions, the greater the wind speed, the slower the ball speed. This indicates that the wind direction directly changes the air resistance that the ball experiences during flight, thereby affecting the terminal speed of the ball. Although there are slight abnormal points in the adverse wind image, the overall data shows high stability and predictability.

In conclusion, humidity and wind speed, as key environmental variables, both significantly affect the flight trajectory and speed performance of baseball. The data analysis of this study verifies the clear correlation between them and provides an important basis for further understanding the interference and guidance of environmental factors on game performance in practice.

Next, I will analyze the data table from my field experiment on the second part:

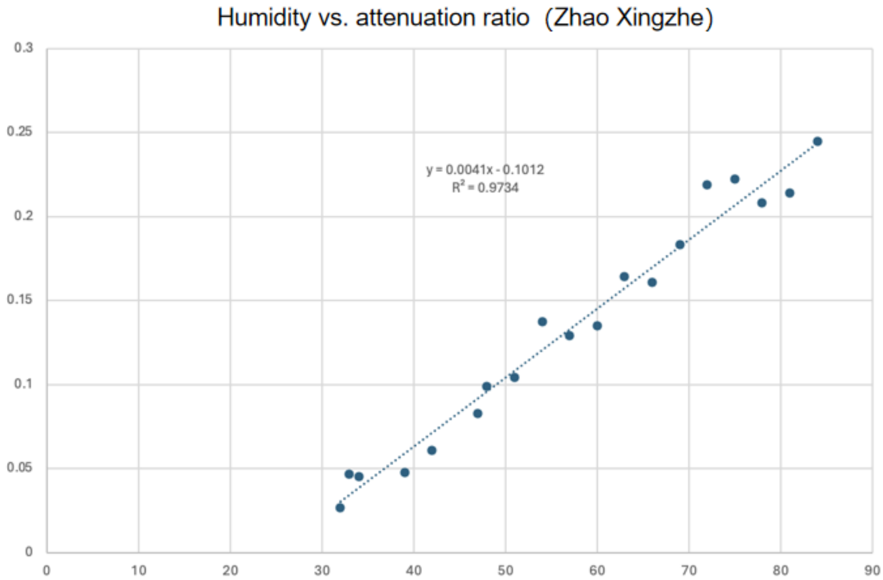

Figure 13. Relationship Between Humidity and Ball Speed Attenuation Ratio for Zhao Xingzhe

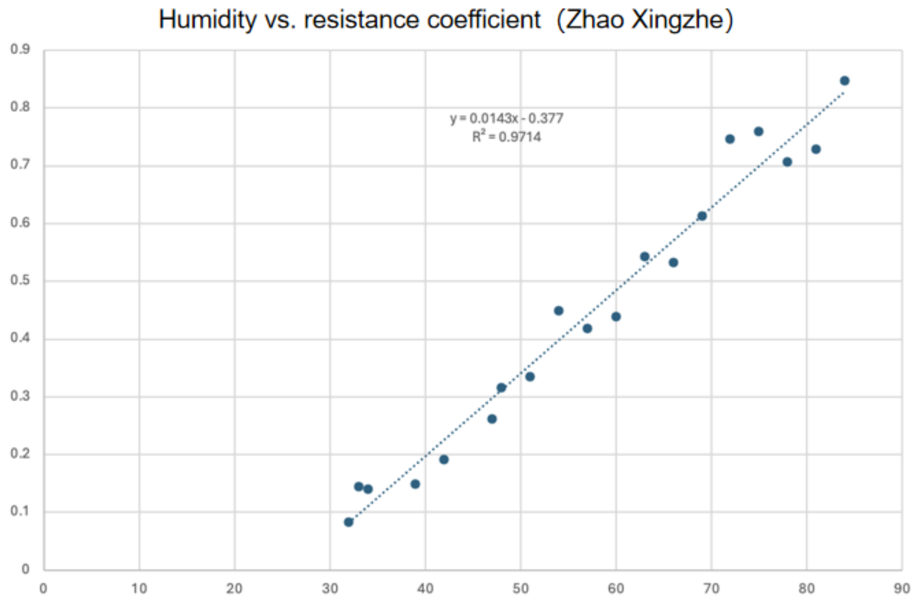

Figure 14. Relationship Between Humidity and Resistance Coefficient for Zhao Xingzhe

ISSN: 2710-0588

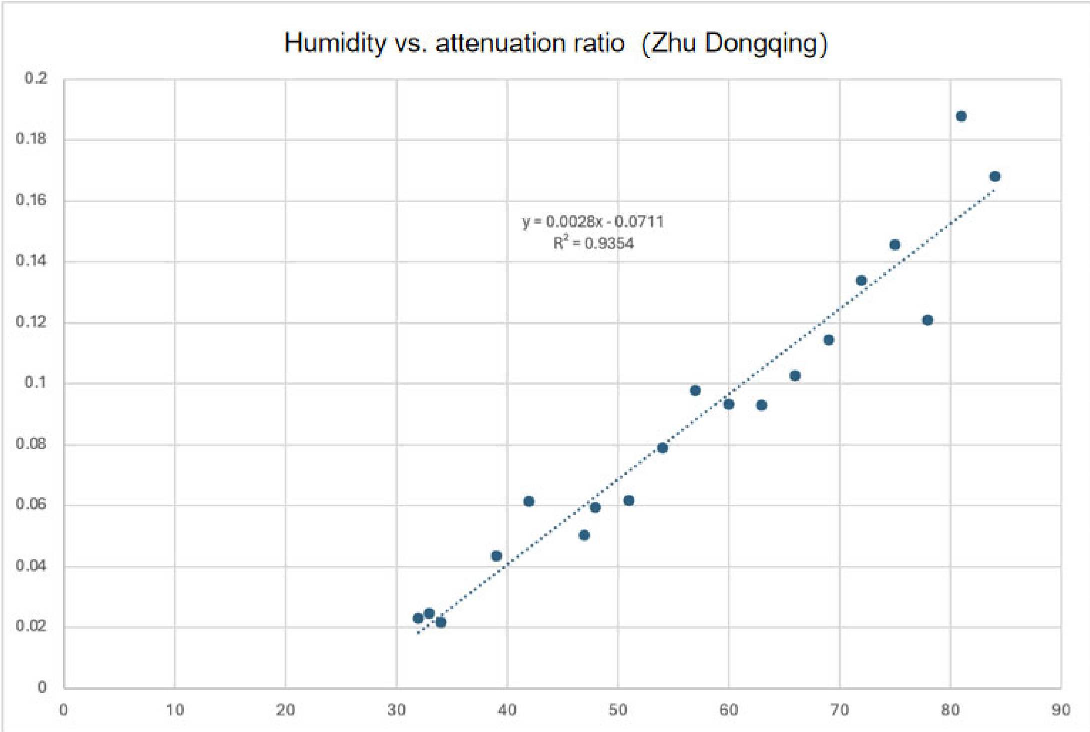

Figure 15. Relationship Between Humidity and Ball Speed Attenuation Ratio for Zhu Dongqing

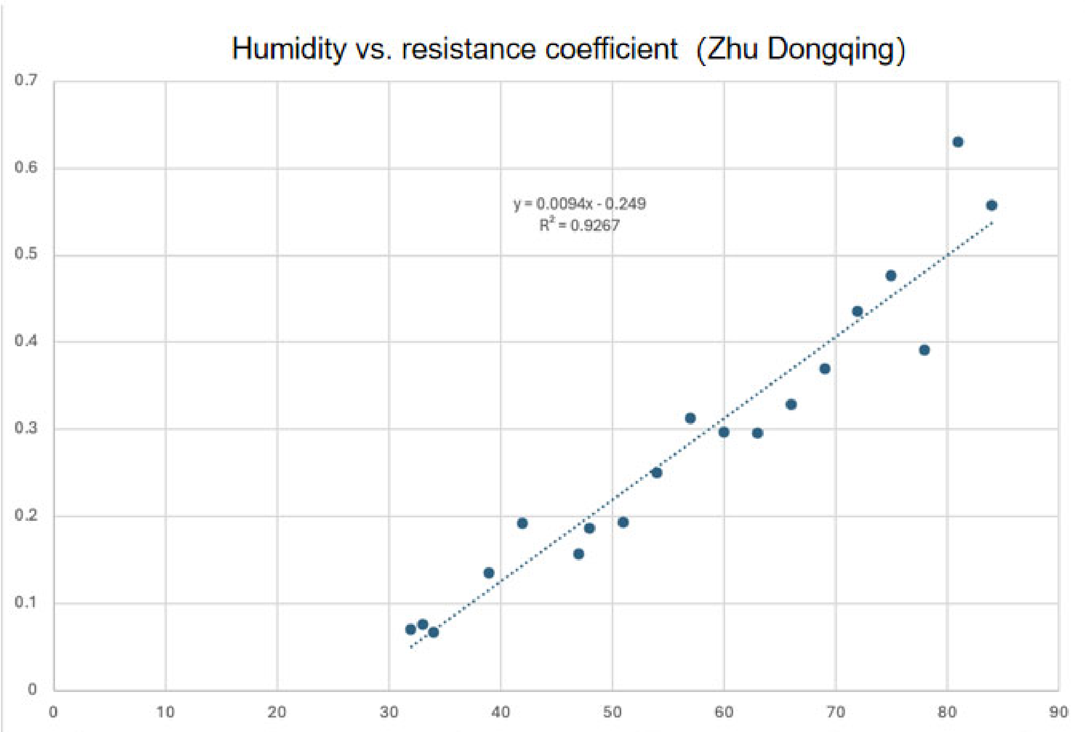

Figure 16. Relationship Between Humidity and Resistance Coefficient for Zhu Dongqing

Through these four graphs, no matter which player's data is examined, a clear upward trend can be clearly observed: the attenuation ratio of the ball and the air resistance coefficient increase continuously as the humidity increases. This fully explains the reason why the ball speed slows down as the humidity rises. Specifically, as the air humidity increases, the air

ISSN: 2710-0588

resistance coefficient that the baseball encounters during its flight increases, meaning the resistance becomes stronger. The increase in resistance will cause the baseball to consume more energy while moving, resulting in a gradual decreases in speed and a slower flight. Therefore, the change in humidity directly affects the flight performance of the baseball, explaining the phenomenon of the decrease in ball speed.

There is also a very interesting phenomenon occurring here - I clearly see that the graph of the attenuation ratio and humidity and the graph of the air resistance coefficient and humidity actually have exactly the same shape, even there are some little differences between their R square and equation. This discovery leads me to conjecture that there is some close connection between the air resistance coefficient and the attenuation ratio. To further verify this, I will plot these two variable on the same chart for comparative analysis:

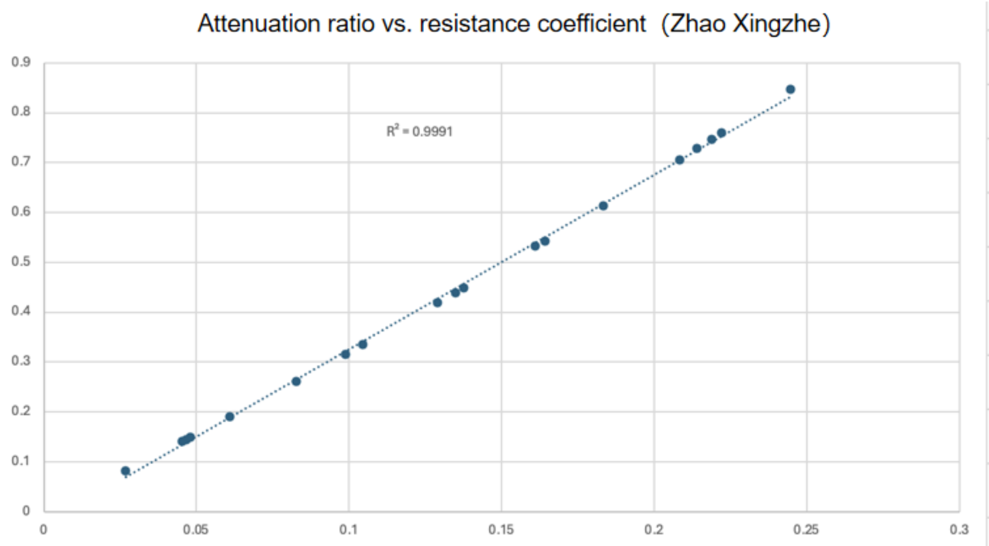

Figure 17. Relationship Between Ball Speed Attenuation Ratio and Resistance Coefficient for Zhao Xingzhe

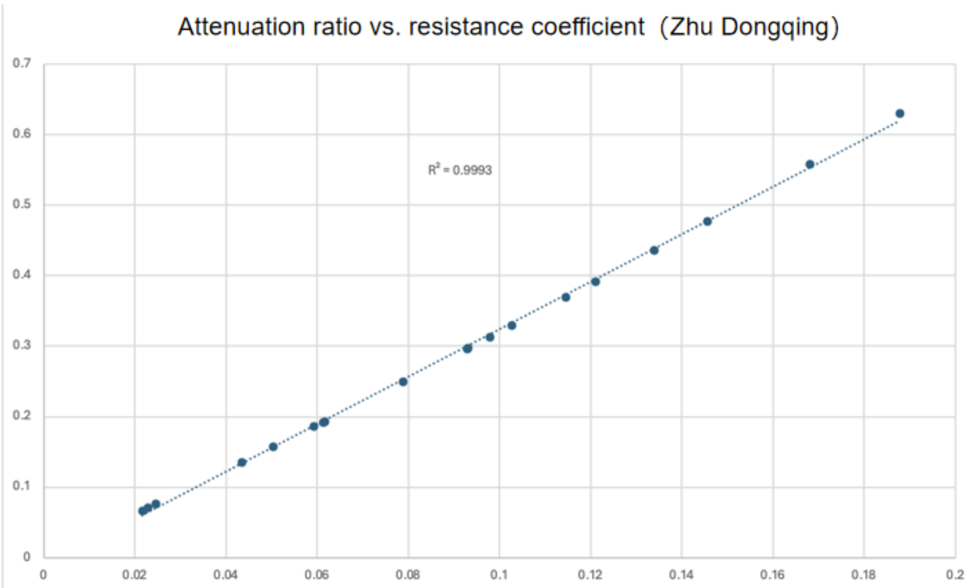

Figure 18. Relationship Between Ball Speed Attenuation Ratio and Resistance Coefficient for Zhu Dongqing

ISSN: 2710-0588

From this, there is no linear relationship between them. Because if there were such a relationship, the R-square value between them would be 1. For example:

1	2
2	4
3	6
4	8
5	10
6	12
7	14
8	16

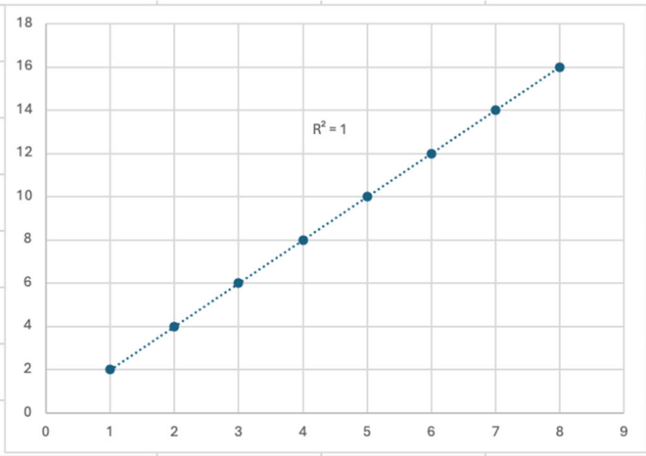

Figure 19. Example of a Perfect Linear Relationship Between Two Variables

However, I are still curious as to why these two variables seem to have such a linear relationship between them, I attempted to derive it using a formula: If they have a linear relationship, then the ratio between these two variables must be a constant value. The formula for the attenuation ratio is as follows: $r=\frac{v_0-v}{v_0}$. Then the formula for the drag coefficient is: $C_d=\frac{4m(v_0{}^2-v^2)}{\rho A(v_0-v)^2 d}$. And then divided them together, I get: $\frac{C_d}{r}=\frac{\frac{4m(v_0{}^2-v^2)}{\rho A(v_0-v)^2 d}}{\frac{v_0-v}{v_0}}=\frac{4mv_0}{\rho A(v_0+v)d}$. Obviously, this value is not a fixed one. However, I have discover that in $\frac{4mv_0}{\rho A(v_0+v)d}$, $\frac{4m}{\rho Ad}$ part is a fixed value, and the remaining part is $\frac{v_0}{v_0+v}$. A part is a constant value, and the remain part is just what I have. Therefore, I guess that this might be because the initial velocity and the final velocity are too similar, so $\frac{v_0}{v_0+v}$ approach to 1/2 and cause $\frac{4mv_0}{\rho A(v_0+v)d}$ like a fix value. To verify this conjecture, I fabricated several data with significant differences in initial velocity and final velocity and presented them with graphs:

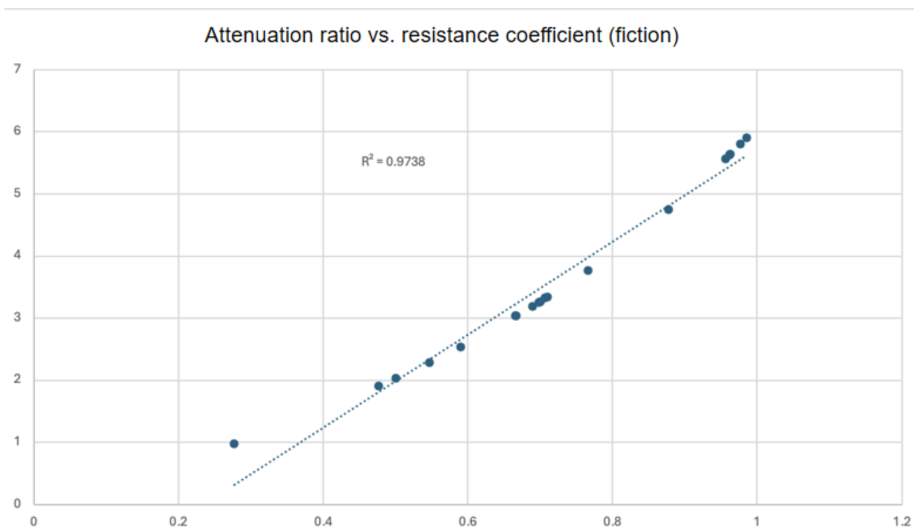

Figure 20. Relationship Between Attenuation Ratio and Resistance Coefficient Using Expanded Velocity Data

ISSN: 2710-0588

It can be seen that after expanding the data range, the image no longer shows a strict linear trend but instead exhibits obvious curve changes and its R-square value became further away from 1. so the reason for observing an approximate linear relationship in the early data is that the initial and final velocities of the pitch were relatively closed， making $\frac{v_0}{v_0+v}$close to 1/2. This resulted in a "linear illusion".

In conclusion, this study through data collection and field experiments, explored the influence of humidity and wind speed on the flight speed of baseball. The results show：

The higher the humidity, the more obvious the attenuation of the ball speed, indicating that air resistance increases with humidity；

When there is a tailwind, the wind speed is greater, and the ball speed is faster； when there is an headwind, the wind speed is greater, and the ball speed is slower

When the initial velocity is close, the attenuation ratio and the resistance coefficient show a linear relationship, but from the formula analysis, this linear relationship is only an appearance and is not a true physical constant

There are occasional abnormal values in the data, which may be related to the pitcher's state, temperature, or other external factors.

5. Discussion and Conclusion

The overall results of this study largely conform to expectations. I found that the higher the humidity, the more significant the decline in ball speed, and the resistance coefficient also increased accordingly. This is consistent with the conclusion of Meyer & Bohn (2007)[5]. In their experiments, they discovered that compared to a dry state, the air resistance of the wet ball significantly increased, thereby affecting its flight distance. Although their research was a static experiment conducted under controlled conditions for storing the baseballs, my study further verified that their conclusion also holds true in dynamic pitching, indicating that humidity does indeed have a significant impact on the flight of the baseball. My experiments also align with the findings in the article "The effect of temperature and humidity on the performance of baseballs and softballs": Under high humidity, the structural characteristics of the ball change, absorbing more energy and increasing the contact area with the air, thereby indirectly increasing air resistance and slowing down the ball speed. My field experiments further confirm the existence of these phenomena from a dynamic perspective. In Barhill's "Effects of Altitude and Atmospheric Conditions on the Flight of a Baseball", it is pointed out that even minor changes in air density in the environment can cause significant changes in the ball's speed and trajectory. In my field experiments, as the humidity increases, the phenomenon of a decrease in ball speed may be precisely due to the increase in water content in the air, which leads to an increase in air density and thus enhances air resistance.

The overall results of this study largely met expectations, but there are still some shortcomings. Firstly, the data collection scope is relatively small, covering only a few teams and players, and the sample size is limited, which affects the generalizability of the conclusions. Secondly, there are many uncontrolled variables in the data, such as player condition, stadium atmosphere, temperature, etc., which may affect the ball speed and accuracy.

In the experimental part, there are also certain errors. For example, consecutive pitching by the pitcher may lead to fatigue, affecting subsequent performance. The biggest problem lies in the measurement of initial and final speeds. I used multiple pitches, which is susceptible to interference from uncertain factors, reducing the reliability of the data. In the future, using dual speed meters or video frame-by-frame analysis to simultaneously obtain more accurate speed data can enhance the scientific nature and accuracy of the experiment.

ISSN: 2710-0588

In the future study, I can use multiple speed measurement guns to ensure that the errors caused by not being the same ball thrown each time during the initial speed and final speed tests are reduced. Additionally, since my humidifier is placed next to the pitcher and cannot cover the entire pitching path, it may cause errors. I can increase the number of humidifiers to ensure the same humidity, or calculate the average humidity along the pitching path.

References

[1] Terry Bahill, David G. Baldwin, Jayendran Venkateswaran (2005). Predicting a Baseball's Path: A batter watches the pitcher's motion plus the spin on the ball to calculate when and where it will cross the plate.
https://www.jstor.org/stable/27858576

[2] Lvchengxu (2023). A Review of Table Tennis Trajectory Prediction and Rotation Measurement Research.
https://kns.cnki.net/kcms2/article/abstract?v=tQ02qvqxHS8FADoRgd4m7LLNsLlUk1fjOzx4xH_7ZzuJXvcmOS3KAx-IaCeV3OIEnoBAACbVrHRNy0QCTFSR8e_wzeRC40Kle4S4wq2BjjcXTjobeQzWJHuxAJkGBYWvHiY9SYFtR9KVzq_GP0QFCkOUe433Z_SEouYMsj4pT5dEkdaJVTSNnA

[3] Liyizhou (2018). Research on the Application of Mechanical Principles in the Flight Trajectory of Golf Balls https://kns.cnki.net/kcms2/article/abstract?v=tQ02qvqxHS-LjFk_XDHMJABU2DQgVHFVzbAWBipFV7ZxH6F3E8A8f2UJsZJIZpHNW09vWjxEho5s39cxgIg7a4W5BuUSbFAjqF7YGHM2L9JZ_X5jglhkULvRMFO1wpnf_pFfWSo24PRnmtm8p5IoiWBH-KP4_kSKoyq8-YgW75LKdlNXT99oUQ==&uniplatform=NZKPT&language=CHS

[4] Wang Xuance, Li Yuhang, Hou Junming, Zhang Lin, Nie Jing. (2017). The optimal physical parameters in mid-range and long-range shooting https://xueshu.baidu.com/usercenter/paper/show?paperid=205f706187ffd8c59c4c4934a67f26ed&site=xueshu_se

[5] Edmund Meyer & John Bohn (2007). Influence of a humidor on the aerodynamics of baseballs
https://arxiv.org/abs/0712.0380?