The Influence of Magnus Effect on The Flying Distance of Baseball and Golf

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Abstract. The Magnus effect is also very common in ball sports, so the study of the causes and applications of the Magnus effect in ball sports is of great significance and practical importance to the teaching level, training effect, and competition performance of ball sports. The effect of the Magnus effect on baseball and golf will therefore be discussed. In the case of baseball, we will consider the effects of drag and the Magnus effect on its motion and establish a three-plane system consisting of gravity, drag, and the Magnus force, thus demonstrating the interaction of the three forces in the trajectory of the baseball. The concept of projectile motion is introduced in mathematics, physics, and engineering disciplines in a vacuum environment, and when applied to real-life situations, the theory differs significantly from the ideal state. This is why baseball's trajectory in a non-ideal situation is studied. In the case of golf balls, the results are subject to large errors because only the air resistance is taken into account in the discussion of the golf ball range problem, and the effect of the Magnus force on its range is ignored. According to fluid dynamics, a golf ball moving through the air is subjected to bypassing (air) resistance and Magnus force. The article will therefore also look at the effect of the bending (air) resistance and the Magnus force on its movement.

Keywords: Magnus effect; Ball sports; Baseball; Golf.

1. Introduction

The Magnus effect is a phenomenon in fluid mechanics, which is the force on a rotating object (e.g., a cylinder) in a fluid. The Magnus effect is a non-linear and complex mechanical phenomenon. An in-depth study of its mechanisms and laws will guide the analysis of the aerodynamic performance of rotating projectiles, missile design, and guidance control [1]. The Magnus effect is also very common in ball sports, so the study of the causes and applications of the Magnus effect in ball sports is of great significance and practical importance to the teaching level, training effect, and competition performance of ball sports [2-3].

The effect of the Magnus effect on baseball and golf will therefore be discussed [4]. In the case of baseball, we will consider the effects of drag and the Magnus effect on its motion and establish a three-plane system consisting of gravity, drag, and the Magnus force, thus demonstrating the interaction of the three forces in the trajectory of the baseball. The concept of projectile motion is introduced in mathematics, physics, and engineering disciplines in a vacuum environment, and when applied to real-life situations, the theory differs significantly from the ideal state. This is why baseball's trajectory in a non-ideal situation is studied [5]. In the case of golf balls, the results are subject to large errors because only the air resistance is taken into account in the discussion of the golf ball range problem, and the effect of the Magnus force on its range is ignored. According to fluid dynamics, a golf ball moving through the air is subjected to bypassing (air) resistance and Magnus force. The article will therefore also look at the effect of the bending (air) resistance and the Magnus force on its movement [6].

2. A comprehensive discussion of the Magnus effect

2.1. Principle of the Magnus effect

The phenomenon that a high-speed rotating ball rubs against the air while flying in the air, causing its orbit to bend, is called the Magnus effect. It is obtained according to the theoretical projection [7].

$$F = \rho A \omega v (R \wedge 3)(\pi \wedge 2) \div 2 \quad (1)$$

The Magnus force is a popular name for the transverse force F obtained in this case. The results of the equations show that the magnitude of the Magnus force depends on the instantaneous velocity (v) of a ball moving in a fluid, the angular velocity of that ball's rotation, the radius of the ball, the density of the fluid (p), and the viscosity of the fluid and the ball.

In the conclusion, the Magnus effect occurs on a rapidly rotating sphere that experiences a force perpendicular to the direction of the flow rest, causing a lateral displacement that changes the original trajectory [8].

2.2. Unavoidable errors due to theoretical calculation

The projectile problem, which is often discussed in the ideal state, is a classical topic in mechanical computer simulation studies (ignoring all external forces except gravity). In contrast, certain practical situations, such as the problem of projectiles involving different spheres, are subject to factors such as air resistance (e.g., the size and roughness of the sphere itself), and their flight diverges significantly from the ideal state. A large amount of hydrodynamic information is required, and this knowledge is not computable [2].

3. For the effect of Magnus effect in baseball

3.1. Analysis on the net force exerted on the baseball

Their findings are supported by the force analysis of Sarafian, H. in the publication Drag force and Magnus effect on baseball trajectories when they consider that the ball is thrown into the air at a random angle above the horizontal. The ball is first launched into the air at a higher inclination than horizontal. In addition to gravity, the ball encounters air resistance. Regardless of the speed at which something moves, drag (resistance to air) acts in the opposite direction, slowing it down. The instantaneous speed and drag of a flying balloon are indicated in Figure 1 in the form of v and FD, respectively [9].

In practice, the ball also spins forward or backward (backspin) at impact (topspin). Its angular velocity determines the degree of rotation. Let us consider a spinning ball whose angular velocity vector is perpendicular to the vertical plane. Now the baseball is parallel to the ground and extends beyond the vertical plane in this way. A topspin ball, on the other hand, is parallel to the ground and extends inward. Figure 1 depicts a backspin ball (counterclockwise). xz plane shows the point at the center of the bullet, corresponding to the head of the arrow. In the chosen scenario, the spinning ball is subjected to an additional force, called the Magnus force, which is caused by the rotation of the object. This force is proportional to $FM \sim \omega \times v$. Therefore, this force is also in the vertical plane, making the three main forces, namely W, FD and FM, three coplanar. In this case, the ball is still in the vertical plane, so the analysis of the problem becomes two-dimensional [10].

3.2. Formulation of the motion of baseball

According to Sarafian, H, the airflow around a baseball is considered as laminar [3]; therefore, the drag force is formatted according to:

$$\boldsymbol{FD} = 12\ CD\ \rho\ Av\ (\ -\boldsymbol{v}\ ) \quad (2)$$

This equation specifies the resistance of the baseball as it moves in the air in the opposite direction. The parameters of this equation are CD, ρ, A, the drag coefficient, the density of the medium (air), and the transverse surface of the bullet. Computer simulations of this problem are performed with the Computational Algebraic System (CAS). However, the drag effect is oversimplified due to velocity-independent coefficients, which leads to false inferences. This can be achieved in several ways (as shown in 2.2, for example, differences in viscosity and air density can be hidden variables). However, a statistical relative approximation is generated due to the parameterization of the rather complex drag coefficient effects based on actual velocity data.

3.3. The result of computer simulation

The parameters of the initial velocity constitute the initial conditions; in the vertical xz plane, this includes the choice of v_0={v_0Cos[θ],0, v_0Sin[θ]}. The authors searched for the starting angle with the largest range in each of the four switch settings, with the original angle settings of "10, 20, 30, 40, 50, 60, 70, 80, 90". Using the interpolated continuous function at their disposal. Table 1 lists the results of the search.

Tab. 1 Values of related parameters

	{αD,βM}= 00	{αD,βM}= 01	{αD,βM}=10	{αD,βM}=11
"max range, m--	139.694	162.57	78.2832	84.095
θ° "-->"	θ → 45	θ → 38.3973	θ → 39.4280	θ → 35.1726

Plots of time of flights vs. the initial angles for four cases of interest is shown in Figure1:

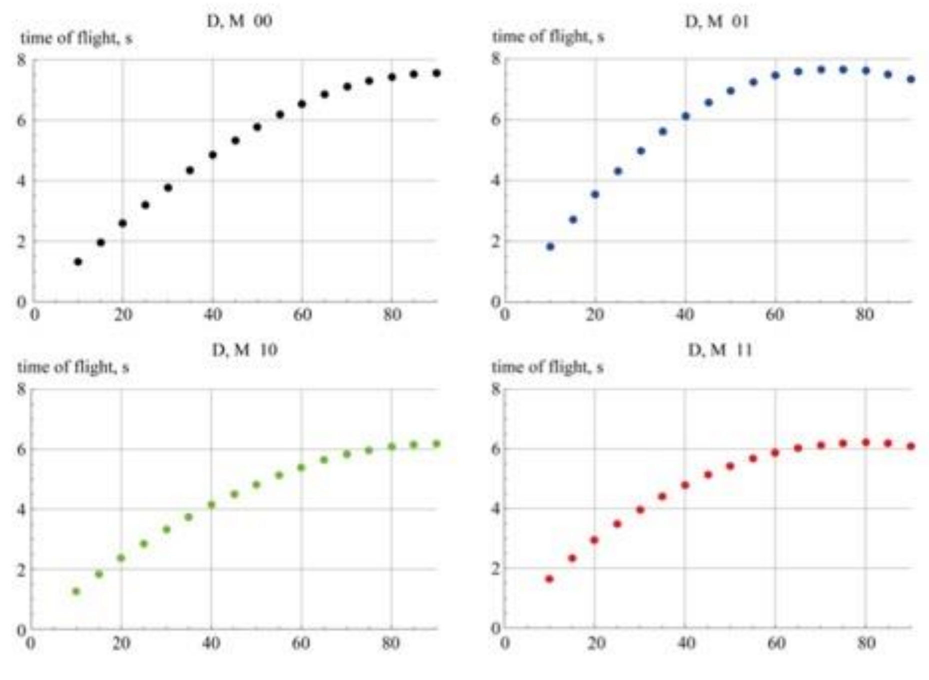

Fig. 1 The initial angles for four cases of interest [3]

Figure 2 displays the plots of time of height vs. range for four examples of interest by plotting the ball's trajectories. As a point of comparison, the black curve represents the journey in a vacuum:

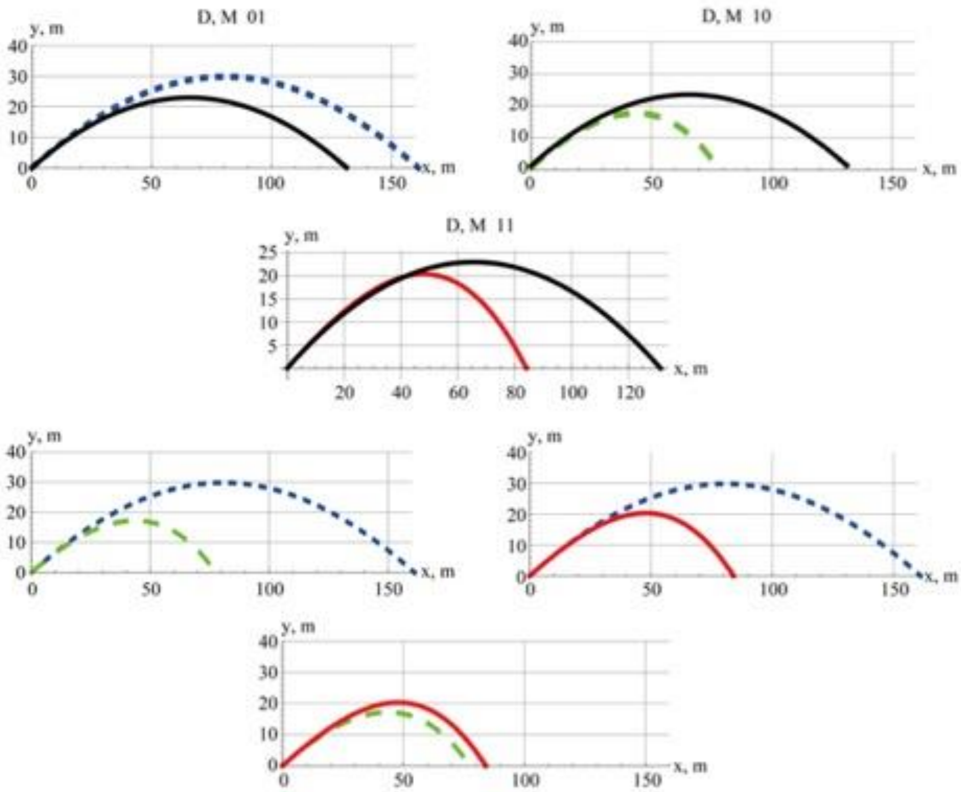

Fig. 2 Height and distance time of four interested examples [3].

4. For the effect of Magnus effect on the golf

4.1. Analyze the forces on a golf ball

4.1.1 Air resistance

When the golf ball flies to the left when the ball flies at a small speed, the fluid molecules near the ball are flowing against the spherical surface, then the resistance of the ball is composed of the viscous resistance of the fluid. When the ball flies fast, a symmetrical vortex forms behind the ball, and the fluid molecules near the ball stick to the ball for a while and then detach from the sphere. This phenomenon is also known as boundary layer separation. Behind the ball is a vortex with little central pressure, and the ball is subjected to a large resistance (see Differential Pressure Resistance). Generally speaking, the greater the flight speed of the ball, the earlier the separation of the boundary layer, and the larger the vortex zone formed behind the ball. The greater this resistance caused by the pressure difference, the more viscous resistance in the air resistance is negligible.

4.1.2 Magnus force

If the ball flying forward does not rotate, the effect of the viscosity of the surrounding air only slows down the speed of the ball. If the ball is rotated, the combined effect of rotation and air viscosity produces circulation in the appendage layer around the ball, and the result of the synthesis of the incoming flow and the circulation of the incoming flow accelerates on the side of the incoming and circulating currents. The flow slows down on the opposite side. According to Bernoulli's principle, the pressure on the side of the accelerated flow decreases, and the pressure rises on the other side where the flow slows down. Thus, creating a pressure difference perpendicular to the translation direction of the object, the force perpendicular to the translation direction of the object that rotates in a viscous medium is called the Magnus force. The Magnus force is also essentially a force generated by differential pressure. Its direction is related to the direction in which the ball rotates. Change the direction of rotation of the ball, the ball can be deflected left or right. When hitting a golf ball, the ball should be rotated clockwise to receive upward lift.

4.1.3 Net force

Golf balls are subjected to the action of gravity FG, air resistance FD and Magnus force FL during flight. The vertical and horizontal axes of coordinates indicate the range and height of the golf ball, respectively. The sizes of FG, FD, FL are respectively:

$$F_G = mg \tag{3}$$

$$F_D = \frac{1}{2}\rho C_D \pi r^2 v^2 \tag{4}$$

$$F_L = \frac{2}{3}\rho \pi r^3 \omega v \tag{5}$$

Where m=0.046 kg is the mass of the ball; ρ = 1.29 kg/m^3 for air density; r = 0.0213 m is the radius of the ball; v is spherical instant speed; ω is the angular velocity of the sphere.

4.2. Range

4.2.1 The effect of initial velocity on range

The kinetic equation of a golf ball is a second-order implicit system of differential equations that is difficult to solve by hand. For this purpose, MATLAB can be used to solve its numerical value and plot the flight trajectory of the ball. The two cases of v 0 =31.09 m/s and v 0=61 m/s are selected for calculation, and the rotational speed ω of the ball is taken as 60π, 120π, 180π and 240π units as rad/s, respectively. The results are shown in Figure 3, Figure 4, and Table 2 (where θ_0 is the ejection angle S m is the maximum range). The solid line in the figure is the flight trajectory of the rough ball imaginary to the flight trajectory of the smooth ball. s is the range, and h is the shooting height.

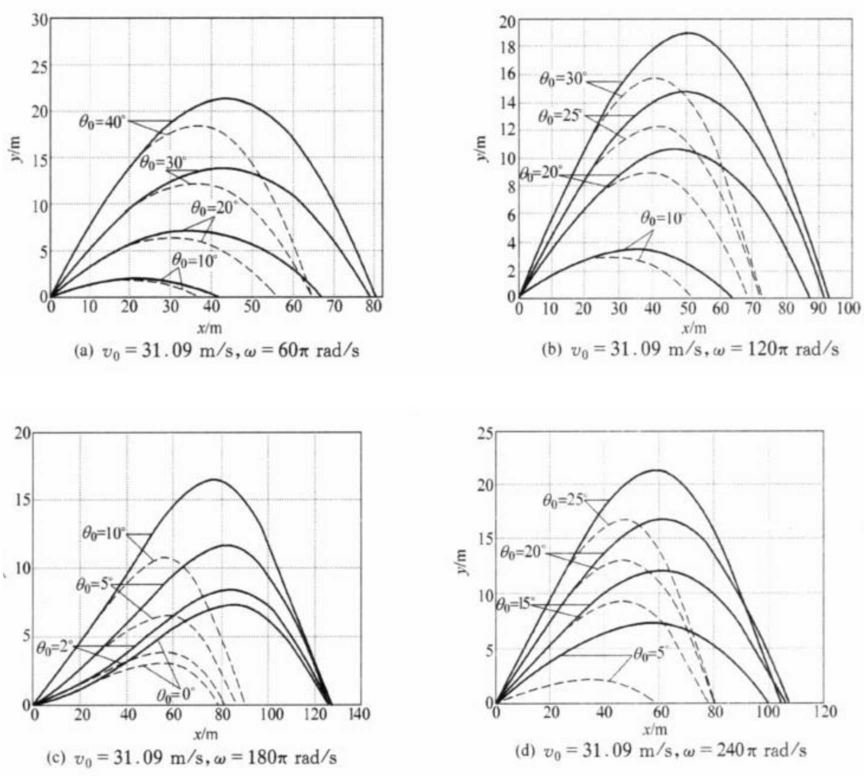

Fig. 3 Flight trajectory of the ball at initial velocity v_0=31.09 m/s.

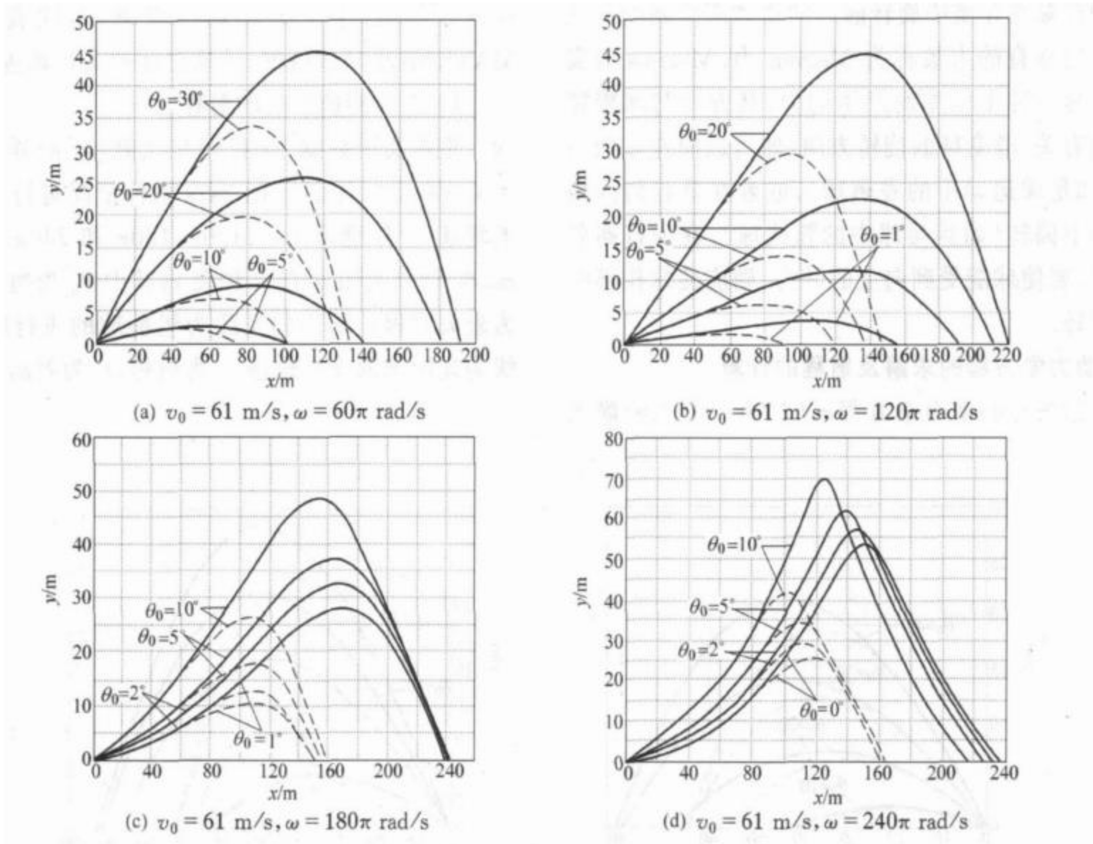

Fig. 4 Flight trajectory of the ball at initial velocity v_0=61 m/s.

Tab. 2 Distance result value

v_0/(m s^{-1})	ω/(rad s^{-1})	θ_0/(°)	s_m/m	
			smooth ball	rough ball
61.00	240 π	0°	160.50	233.50
	180 π	2°	145.40	243.20
	120 π	15°	140.10	220.00
	60 π	30°	130.90	192.50
31.09	240 π	5°	83.85	127.40
	180 π	20°	79.80	107.30
	120 π	30°	71.17	92.10
	60 π	40°	63.90	80.20

As can be seen from the above figure and table. A rough ball has a longer range than a smooth ball and a higher shot height than a smooth ball. The greater the rotational speed, the greater the lift, the higher the shot height, and the greater the difference between the shooting height of the rough ball and the smooth ball. Consider from the point of view of the maximum range. There will be an optimal ejection angle at the same speed and the higher the speed, the smaller the optimal ejection angle. At large initial velocity conditions, the ejection angle is much smaller than the ideal 45° and much smaller than the optimal ejection angle for other throwing events.

4.2.2 The effect of the sphere's own rotation on the range

To discuss the effect of angular velocity on range separately, the range of rough golf balls at ω=60π, 100π, 140π, 180π and 220π rad/s can be given at the throw angle θ_0=10°, v_0= 61 m/s respectively. From Figure 5 and Table 3, it can be seen that the influence of ball rotation on the range of the golf ball is very significant, and the range difference between the spinning ball and the non-rotating ball can even reach about 150m or more. Even the same ball spinning at different rotations will have a very different range. In contrast, when the ejection angle is small, the rotation has a greater effect on the range and less on the height of the shot. However, the speed of the ball is not as fast as possible, whether it is a smooth ball or a rough ball with the same initial speed and ejection angle as an optimal speed, too large a speed will reduce the range theoretically even spiral forward.

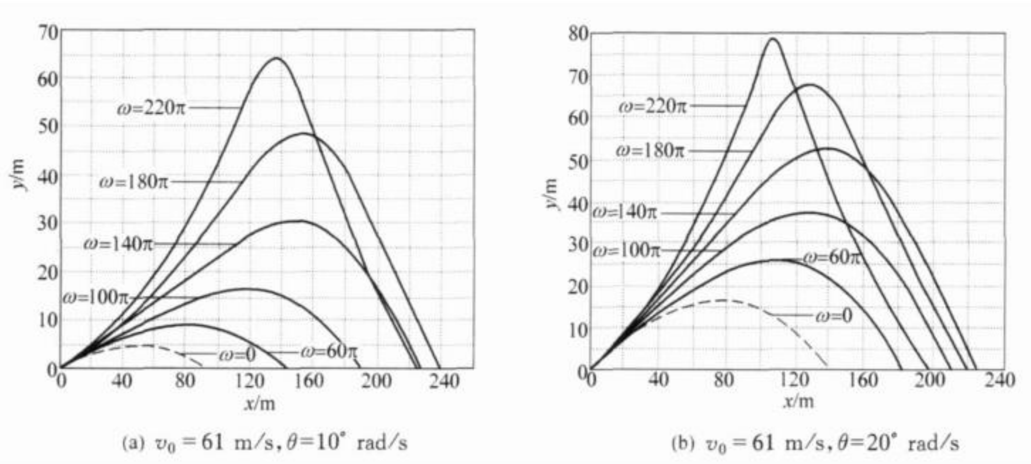

Fig. 5 Influence of different rotational speeds on ball flight.

Tab. 3 Distance result value at different angles

θ_0/(°)	ω/(rad s^{-1})	s_m/m	h_m/m
10°	0	91.75	4.74
	60π	141.80	8.94
	100π	188.00	16.13
	140π	227.00	30.07
	180π	239.00	48.38
	220π	226.00	63.86
20°	0	139.20	16.12
	60π	182.00	25.76
	100π	210.00	37.14
	140π	224.50	52.50
	180π	218.20	67.71
	220π	196.60	78.27

5. Conclusion

The fact that various balls, such as baseballs, golf balls, and soccer balls, bend as they spin through air shows the credibility of Magnus's principle and the laws governing the movement of a rotating body through a medium. It is helpful to the development of the aviation field and improve the performance of all kinds of ball games, and meet the needs of human beings to control the direction of object movement. This study adopted two methods: the first is to use MATLAB to solve the parameters, the second is to use computational algebra system (CAS) to simulate the trajectory. These two methods significantly improve the ability to solve trajectories in a variety of situations, such as different media and rotation speeds, thus expanding the scope and influence of the Magnus effect. The main highlight of this study on Magnus effect is the universality of the research method, which provides a new research path and research theory for the subsequent related research on control aerospace vehicles.

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