Determination of Drag and Lift Coefficients for a Spinning Baseball

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DETERMINATION OF DRAG AND LIFT COEFFICIENTS FOR
A SPINNING BASEBALL

A Thesis
Presented to the
Department of Mechanical Engineering
Brigham Young University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science

by

M. B. Parekh

May 1972
This thesis, by M. B. Parekh, is accepted in its present form by the Department of Mechanical Engineering of Brigham Young University as satisfying the thesis requirement for the degree of Master of Science.

Date
Sept 7, 1971

Typed by Katherine Shepherd
DEDICATED

To my parents
ACKNOWLEDGMENT

The author wishes to express his appreciation to

Dr. Richard D. Ulrich for his many hours of counsel and assistance.
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NOMENCLATURE

$C_D$  Drag coefficient

$C_L$  Lift coefficient

$D$  Drag force, lbf

d  Average diameter of ball, in.

g  Magnitude of acceleration due to gravity, $\text{ft/}\text{sec}^2$

$L$  Lift force, lbf

$N$  Revolutions per minute

$P$  Pressure, Psf

$P_d$  Dynamic pressure, in. of water

$R$  Radius of ball, in.

$\overline{R}$  Gas constant, $\text{ft-lb}_f/\text{lb}_m \, ^{\circ}\text{R}$

$Re$  Reynolds number

$S$  Projected area of ball, sq. in.

$T$  Absolute temperature, $^\circ\text{R}$

t  Time, sec

$V$  Wind velocity, $\text{ft/}\text{sec}$

$W$  Weight of ball, lb

$X_{1}$  Average horizontal distance from center line of shaft to the center of the baseball impression on the bottom of the test section while ball is either spinning in clockwise direction or at zero spin, in.
\( X_2 \) Average horizontal distance from center line of shaft to the center of the baseball impression on the bottom of the test section while ball is spinning in counterclockwise direction, in.

\( Y \) Vertical distance from center of the shaft to the bottom of the wind tunnel test section, in.

\( y \) Distance \( Y - R \), in.

\( \omega \) Angular velocity, radians per sec

\( \rho \) Density, slugs per cubic feet

\( \alpha \) Velocity ratio, \( \frac{R\omega}{12V} \)

\( \mu \) Dynamic viscosity, slug/ft-sec
CHAPTER I

INTRODUCTION

Few experiments have been carried out in the past to determine the effect of the lift and the drag forces on the trajectory of a ball used in any game. In a baseball game, it was reported that sometimes the ball took a sharp turn abruptly in the region of 15 to 20 feet from the home plate. This indicated a sudden change of the forces acting on the ball. The principal forces acting were as follows:

1. Weight of the ball.
2. Drag force acting in the direction parallel to the relative wind.
3. Lift force acting perpendicular to the relative wind.

The object of this study was to determine the effect of lift and drag forces on the baseball when it was spun about an axis lying in the vertical plane and perpendicular to the horizontal plane. The tests were carried out in a horizontal wind tunnel at a wind velocity in the range of 46 to 144 ft/sec. The ball was rotated at a velocity from 0 to 2000 r.p.m. Thus the measurements covered the entire range of conditions encountered in play.
CHAPTER II

LITERATURE SURVEY

As early as 1857, Lord Rayleigh (5)* conducted some tests on the irregular flight of a tennis ball, but it was only in the 1900's that Pannell gave some serious thought to the problem and tried to determine the relation between drag coefficient and Reynolds number. On comparison with the results obtained at later dates, one can say that his minimum value of the drag coefficient was higher than average.

Later Prandtl and Wieselsberger (7, 8) in their experiments laid more stress on the flow pattern around the sphere than on the absolute value of the drag coefficient. They also observed the effects of turbulence, discontinuity of flow, and surface roughness on the drag coefficient. Eiffel observed the transition regime to occur at a Reynolds number of $2 \times 10^5$ when he used two types of support pendulums and back spindles.

Crowley and Brown, of the National Advisory Committee for Aeronautics (NACA) (5), investigated the effects by towing spheres ranging from 2.95 to 14.95 inches in diameter by an airplane. The spheres were suspended from an airplane in flight and the test was

*Numbers in brackets indicate the reference number.
conducted at a high Reynolds number of $9 \times 10^5$. The minimum value of the drag coefficient was determined as 0.120 and the critical Reynolds number was $3.75 \times 10^5$.

**Standard Drag Curve**

A usually accepted curve of drag coefficient versus Reynolds number for a sphere is shown in Figure 1.

Extreme left side of the curve is a good agreement of Stoke's equation for the calculation of the drag of a sphere. As the Reynolds number increases further the inertia forces become predominant and hence, as expected, the value of the drag coefficient decreases. Following are the principal idealized conditions required to keep in mind while comparing the data with the standard curve:

1. The flow field in which a single sphere is moving is to be free from turbulence, since it has a great effect on the flow pattern and hence the pressure distribution. Consequently the drag coefficient is affected.

2. The flow field is to be continuous and infinite to eliminate wall effect.

3. The flow field is to be incompressible and homogeneous in properties.

The transition takes place when the drag coefficient is 0.3 and the Reynolds number is $3.85 \times 10^5$. The value of the critical Reynolds number varies from $1.5 \times 10^5$ to $4.0 \times 10^5$. In this region
Fig. 1. -- Comparison of sphere drag measurements at low speeds
the value of drag coefficient decreases from 0.47 to 0.1.

**Effects of Various Parameters on Drag Coefficients**

**Laminar sublayer**

Figure 2 indicates the pressure distribution around the sphere for subcritical Reynolds numbers. Flow past the sphere separates just behind the point of minimum pressure.

**Turbulent boundary layer**

Turbulent phenomena itself represents a continuous transport of momentum and hence resultant losses are higher than those of the laminar layer. The layer nearest to the surface of the sphere are boosted in velocity and momentum. Thus they are able to flow against the positive pressure opposed to their movement along the rear of the body. Therefore the flow separates even at 150° to 160°.

**Surface roughness**

The surface roughness affects the result at critical Reynolds number appreciably. Figure 3 shows the effect of roughness on the drag coefficient.

**Turbulence fluctuation**

Most of the experiments carried out in wind tunnels give entirely different results because of the turbulence present. It has been found that the critical Reynolds number varies from 1.5 to 4 \times 10^5.
Fig. 2. -- Pressure distribution around a sphere in a wind stream--experimental curves by Fage.

Fig. 3. -- Presentation of typical experimental results on the drag coefficient of the sphere in the critical range of Reynolds number.
Mach number effect

Figure 4 shows the effect of Mach number on the drag coefficient in a particular range of Reynolds number. A fairly good agreement of results has been found using different techniques to determine the effect of compressibility (1). Figure 1 compares the data obtained by different researchers with the standard curve.

Little work has been done in the past for determining the correlation of lift coefficient with Reynolds number for a spinning sphere. Maccol (6) used 2" diameter and 1/2" diameter steel balls with spindles. He also conducted the experiment on a 6" wooden ball. Air flow was maintained at 10 to 34 ft/sec and a three-dimensional velocity gauge was used to determine the velocity at a point. Figure 5 shows typical curves of his result with special indication of negative lift. Negative lift was observed when the velocity ratio $\infty$ was below 0.5. Though he did not explain the negative lift, he mentioned that turbulence might be the cause.

John M. Davis (7) carried out his experiments for a spinning golf ball at various wind velocities and spinning speeds in a horizontal wind tunnel. The ball was spun up to 5000 r.p.m. by a special spinning mechanism. He found the following equation for lift

$$L = 0.064 \left(1 - \exp\left(-0.00026N\right)\right) \text{ lb}$$

and the maximum value of lift and drag observed were 0.042 lb and
Fig. 4. -- Variation of sphere drag coefficient with Mach number
Lift and drag coefficients
L = dia. of sphere = 6 ins.
U = air speeds: • 10.0 f/s → 24.6 f/s
     • 14.6 f/s → 34.0 f/s
     • 19.6 f/s

Fig. 5.--Lift and drag coefficients for a rotating sphere
0.083 lb respectively at a wind velocity of 105 ft/sec and spinning velocity of 4000 r.p.m. He also observed the negative lift for a smooth ball at a wind velocity 105 ft/sec and spinning below 4000 r.p.m. He explained the phenomenon of negative lift with the help of the Bernoulli equation.

The Magnus effect on a spinning baseball was first studied by Lyman J. Briggs (2). The effect of spin and speed on the lateral deflection of a baseball has been measured by dropping the ball while spinning about a vertical axis through the horizontal wind stream of a 6-ft wind tunnel. Lateral deflection was found proportional to the spin and the square of the wind velocity. Maximum lateral deflection, when applied to a pitched ball in play, was ranging from 10 to 17 inches depending on the spin. The direction of the deflections of a rough ball is quite in accordance with what is predicted by the magnus effect. But with a smooth ball the direction is reversed. Wind speeds up to 150 ft/sec and spinning speeds up to 1800 r.p.m. were used for this experiment (see Figure 6).
Fig. 6.--Lateral deflection of a baseball, spinning about a vertical axis, when dropped across a horizontal windstream. These values are all for the same time interval, 0.6 sec, the time required for the ball to cross the stream.
CHAPTER III

TEST EQUIPMENT

Wind tunnel

A horizontal wind tunnel driven by a variable speed D.C. motor was used. The test section was 12 x 12 x 18 inches. The side walls of the test section were extended in either direction to fix up the spinning device. The side walls were made of transparent plastic and hence the trajectory of the ball could be seen while it was released. Two small holes were provided on top of the test section -- one to insert the pitot tube for measuring the dynamic pressure and another for the trigger. The maximum dynamic pressure that could be obtained in this wind tunnel was 4 inches of water.

Spinning device

Two electric motors were used to spin the baseball about an axis lying in the vertical plane and perpendicular to the horizontal plane. These motors were so connected that the ball could be rotated in either direction. The maximum spinning velocity obtained was 5000 revolutions per minute.

A small brass cone on the shaft of each motor was provided to hold the ball firmly. A small pin of 1/32 in. in diameter and 3/32 in.
in length was provided in the center of the shaft of each motor. These pins held the ball in such a way that the center of mass of the ball remained in the axis of rotation so as to diminish the vibration.

Each motor was connected with either end of the spinning device by a number of springs. As the trigger was pressed both the motors moved apart and the ball was released while it was spinning.

**Pitot tube**

A simple pitot tube was connected to an inclined manometer which measured the dynamic pressure, and hence the air velocity. The range of dynamic pressures that could be measured on this equipment were 0.00 to 4.0 inches of water with a least count of 0.01 inch of water.

**Strobotac**

This instrument was used to measure the rotational speed of the spinning ball.

**Pressure gauge and thermometer**

These two instruments were used to measure the atmospheric pressure and temperature.
Fig. 7. -- Test set-up for measurement of lift and drag coefficients of a spinning baseball.

Fig. 8. -- The baseball is held in the spinning device
CHAPTER IV

THEORY AND TEST PROCEDURE

When any object moves in a fluid or a fluid flows past any object, there is a pressure distribution around the object. This pressure distribution around the object causes aerodynamic forces which are summed up as lift and drag. Lift is the net force exerted on an object perpendicular to the fluid flow. Drag is the force which tries to oppose the motion of an object and acting in the direction parallel to the fluid flow. The magnitude of the lift and the drag forces depends on Reynolds number, acceleration, turbulence, rotational speed, Knudsen number, Mach number, wall effects, heat transfer, surface characteristics, and shape of an object.

This study was limited only to the effects of spinning and Reynolds number on the lift and drag forces on a baseball. The range of Reynolds number was from $0.55 \times 10^5$ to $1.75 \times 10^5$ and the range of spinning velocity was from 0 to 2000 r.p.m. These values cover the entire range of conditions encountered in play.

The wind tunnel used in this experiment was horizontal and hence the air flow was in the horizontal direction. Consequently, the drag force also acted in a horizontal direction and the lift force
acted upwards or downwards depending on the pressure distribution around the ball. Now, resolving the resulting force acting on the ball into the two--horizontal and vertical--components: the horizontal component equals the drag force and the vertical component equals \(-W + L\) (see Figure 10). The sign of the lift force depends upon the direction of spin and this can be easily understood from Figure 9.

When there was no spin the horizontal and the vertical distance traveled by the ball were proportional to the drag and the weight of the ball, respectively. As the ball started rotating, an additional vertical force acted which was ordinarily upwards for clockwise direction and downwards for counterclockwise direction as shown in Figure 9.

\section*{Derivation of the equations for lift and lift coefficient}

Referring to Figure 9 and applying Newton's Second Law of Motion: for clockwise direction:

\[
\frac{W}{g} \frac{d^2x_1}{dt_1^2} = D \tag{1}
\]

\[
\frac{W}{g} \frac{d^2y}{dt_1^2} = -W + L \tag{2}
\]

For counterclockwise direction:

\[
\frac{W}{g} \frac{d^2x_2}{dt_2^2} = D \tag{3}
\]

\[
\frac{W}{g} \frac{d^2y}{dt_2^2} = -W - L \tag{4}
\]
a. Spinning velocity zero

b. Clockwise direction
c. Counterclockwise direction

Fig. 9.--Forces acting on a sphere under different conditions
Fig. 10. -- Force diagram

+ for clockwise direction
- for counterclockwise direction
Vertical distance, \( y \), is the same for clockwise and counterclockwise direction.

Solving equation (1) for \( X_1 \), equation (3) for \( X_2 \), and equations (2) and (4) for \( y \), and simplifying,

\[
D = 2 \frac{W}{g} \frac{X_1}{t_1^2} \tag{5}
\]

\[
D = 2 \frac{W}{g} \frac{X_2}{t_2^2} \tag{6}
\]

\[
-W + L = 2 \frac{W}{g} \frac{y}{t_1^2} \tag{7}
\]

\[
-W - L = 2 \frac{W}{g} \frac{y}{t_2^2} \tag{8}
\]

From equations (7) and (8)

\[
t_1^2 = \frac{-W - L}{-W + L} t_2^2 \tag{9}
\]

Substituting the value of \( t_2^2 \) in equation (5),

\[
X_1 = \frac{D g}{2W} \left( \frac{W + L}{W - L} \right) t_2^2 \tag{10}
\]

Substituting the value of \( t_2^2 \) from equation (6),

\[
X_1 = \frac{D g}{2W} \left( \frac{W + L}{W - L} \right) X_2 \frac{2W}{D g}
\]

Therefore

\[
\frac{X_1}{X_2} = \frac{W + L}{W - L}
\]
Therefore \[ L = \frac{W (X_1 - X_2)}{(X_1 + X_2)} \text{ lb}_f \] (11)

But

\[ L = C_L \cdot q \left( \frac{S}{144} \right) \]

Therefore

\[ C_L = \frac{144 x W (X_1 - X_2)}{q x S (X_1 + X_2)} \] (12)

**Derivation of the equation for the drag force and drag coefficient**

Dividing equation (5) by equation (7),

\[ \frac{X_1}{y} = \frac{D}{-W + L} \] (13)

Similarly, from equations (6) and (8)

\[ \frac{X_2}{y} = \frac{D}{-W - L} \] (14)

Addition of equation (13) and (14) gives

\[ \frac{X_1 + X_2}{y} = \frac{D}{W - L} \left( 1 + \frac{W - L}{W + L} \right) \]

Substituting the value of \( L \) from equation (11) and simplifying

\[ D = \frac{-2 x W x X_1 x X_2}{y (X_1 + X_2)} \text{ lb}_f \] (15)
and hence the drag coefficient can be calculated from the value of the drag force

\[
C_D = \frac{D}{q \times (S/144)}
\]  

(16)

**Assumptions**

The following assumptions were made in deriving the equations:

1. Steady, continuous, incompressible flow existed.

2. The direction of spin did not affect the magnitude of the drag force.

3. The direction of spin did not affect the magnitude of the lift force, but the direction of this force was reversed.

**Test procedure**

Figure 8 shows that the ball was held in two brass cones of a spinning device which was attached to the test section. The ball was held in such a way that the center line of the shafts passed through the center of mass of the ball. A small pin in each shaft kept the ball in this position. The ball was spun about an axis lying in a vertical plane and perpendicular to the wind direction. The ball could be rotated in either direction as desired.

Before the ball was fixed in the spinning device, it was coated with some colored matter so that when it struck the surface
it left an impression on it. In this experiment chalk was used for the purpose.

Maintaining the desired air speed constant in the wind tunnel, the ball was spun at the desired velocity and then released from the spinning device into the wind tunnel test section. It covered a certain distance before striking the bottom of the test section. The distance traveled by the ball depended upon the magnitudes of the weight of the ball, lift force, and drag force.

Horizontal distance between the center line of the shaft and the center of the impression created by the ball on the bottom of the test section was measured when it was tested under a certain pressure head and a spinning velocity in the clockwise direction. For the same conditions, but reversing the direction of rotation, the horizontal distance is measured. The data in Table 1 show the different measurements under different conditions. The atmospheric pressure and temperature were measured to calculate the density of air. The average diameter and weight of the ball were also determined.
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<tr>
<th>No.</th>
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*See nomenclature.
CHAPTER V

RESULTS AND DISCUSSION

The results of this experiment are presented in tabular as well as graphical form. Table 2 and Figures 11 to 14 show various values of drag coefficient and lift coefficient under different values of Reynolds number and velocity ratio.

Discussion of the results

The curve of drag coefficient against Reynolds number for 0 spin is close to the standard curve. The curves of drag coefficient against Reynolds number at different spinning velocities show that spinning has an appreciable effect on the drag coefficient.

The curves of lift coefficient against Reynolds number also indicate appreciable effect on lift coefficient at a Reynolds number less than $1.0 \times 10^5$. However, the negative lift coefficient is observed at a low spinning velocity and at a subcritical Reynolds number. The value of the critical Reynolds number indicates the flow pattern changes from laminar to turbulent flow. Davies (3) has explained the negative lift with the help of the Bernoulli equation in his article on "The Aerodynamics of Golf Balls."

As in the case of an airfoil, as the angle of attack increases
# TABLE 2

DATA FOR DRAG COEFFICIENT, LIFT COEFFICIENT, AND REYNOLDS NUMBER
FOR A SPINNING BASEBALL

<table>
<thead>
<tr>
<th>No.</th>
<th>r.p.m.</th>
<th>V</th>
<th>( \alpha )</th>
<th>D</th>
<th>L</th>
<th>( C_D )</th>
<th>( C_L )</th>
<th>(Re ( \times 10^{-5} ))</th>
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<td>0.1704</td>
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<td>0.1048</td>
<td>0.3933</td>
<td>0.1193</td>
<td>1.749</td>
<td></td>
</tr>
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</table>
the lift coefficient increases and then stalls; the same pattern of the
curve was observed for the curve of lift coefficient against the velocity
ratio. For the same value of velocity ratio, the increase of Reynolds
number decreases the value of the lift coefficient.

Errors

The following probable errors are likely to affect the results:

1. Measurements of the horizontal distance: The probable
error of ± 3 percent may be present when the reading is above 3" and
± 7 percent when the reading is below 1/2". This error in the measure-
ments at low value of the reading affects the drag force and lift force
appreciably, and hence, the drag and lift coefficients.

2. Mass: The error in the determination of the mass of
the ball is less than ± 0.5 percent.

3. Wind velocity: Error in the measurement of the dynamic
pressure, atmospheric pressure, and the temperature can affect the
values. But this error may be less than ± 2.0 percent.

4. Diameter of the ball: The baseball is not of a uniform
spherical shape.

5. Vibration: Vibration is the main cause of inaccuracy at
a high spinning velocity because the centrifugal force is a function
of the square of the spinning velocity.

6. Spinning device: The presence of a spinning device in
the test section may alter the result slightly. However, comparing
the data obtained on zero spin with standard curve, the total error is not more than 10 percent at a low Reynolds number. Hence, the error may not be of great consequence.

Thus the overall error may not exceed more than 15 percent.
Fig. 11.--Effect of velocity ratio on drag coefficient at different Reynolds numbers.
Fig. 12.--Effect of Velocity Ratio on Lift Coefficient at Different Reynolds Numbers
Fig. 13.--Effect of Reynolds Number on Drag Coefficient at Different Spinning Speeds
Fig. 14. -- Effect of Reynolds Number on Lift Coefficient at Different Spinning Speeds
Data

Atmospheric pressure: 25.5 in. of Hg

Atmospheric temperature: 78°F

Coefficient of viscosity for air: $3.77 \times 10^{-7}$ Slug/ft sec

Gas constant for air: 53.34 ft-lb/lbm °R

Average diameter of baseball: 2.82 in.

Projected area of baseball: 6.256 sq. in.

Weight of baseball: 5-3/16 oz.

Vertical distance between the center of the shaft and the bottom of the test section of the wind tunnel: 8-3/16 in.

Dimensions of the test section of the wind tunnel: 12 x 12 x 18 in.

Maximum possible dynamic pressure obtained in the wind tunnel test section: 4 in. of water.
CHAPTER VI

CONCLUSIONS

1. The curve of the drag coefficient versus the Reynolds number at zero spin is close enough to the standard drag curve for a sphere.

2. As sufficient data are not available for comparison of the lift coefficient for a spinning baseball, part of the result is compared with Davies' (3) data on a golf ball and is within 20 percent accuracy.

3. In the range of Reynolds number from $0.55 \times 10^5$ to $1.0 \times 10^5$, there is a sharp change of values of the lift and drag coefficients, hence the lift and drag forces which may cause the "sharp curve" of the ball near home plate.
BIBLIOGRAPHY

2. Briggs. "Effect of Spin and Speed on the Lateral Deflection (Curve) of a Baseball; and the Magnus Effect for Smooth Spheres."


SAMPLE CALCULATION

Take data for no. 21 from Table 1.

Density

The density of air was 0.001944 slug/cu. ft.

Wind velocity

Bernoulli's equation for incompressible fluid flow is applied to calculate the wind velocity.

\[ V = \left( \frac{2 \times Pd}{g} \right)^{1/2} \]

\[ V = \left[ \frac{2}{0.001944} \left( \frac{1.5 \times 0.49 \times 144}{13.6} \right) \right]^{1/2} \]

Therefore, \( V = 89.5 \text{ ft/sec} \)

Velocity ratio

\[ \alpha = \frac{R \times \omega}{12 \times V} \]

\[ \alpha = \frac{1.41 \times 2 \times \pi \times 1000}{2 \times 89.5 \times 60} \]

\[ \alpha = 0.1376 \]
Drag force

Equation (15) is applied to determine the drag force.

\[
D = -2 \frac{W \cdot X_1 \cdot X_2}{y \cdot (X_1 + X_2)}
\]

\[
D = -2 \frac{0.3242 \times 2.667 \times 2.533}{-(8.19-1.41)(2.667+2.533)}
\]

\[
D = 0.1242 \text{ lbf}
\]

Lift force

Equation (11) is applied to determine the lift force.

\[
L = W \left( \frac{X_1 - X_2}{X_1 + X_2} \right)
\]

\[
L = 0.3242 \left( \frac{2.667 - 2.533}{2.667 + 2.533} \right)
\]

\[
L = 0.0084 \text{ lbf}
\]

Drag coefficient

\[
C_D = \frac{D}{\frac{1}{2} \cdot \frac{\rho \cdot V^2 \cdot S}{144}}
\]

\[
C_D = \frac{0.1242 \times 2 \times 144}{0.001944 \times (89.5)^2 \times 6.256}
\]

\[
C_D = 0.3679
\]
Lift coefficient

\[ C_L = \frac{L}{\frac{1}{2} \times \frac{\rho}{\rho_0} \times V^2 \times \left(\frac{S}{144}\right)} \]

\[ C_L = \frac{0.0084 \times 2 \times 144}{0.001944 \times (89.5)^2 \times 6.256} \]

\[ = 0.0247 \]

Reynolds number

\[ Re = \frac{V \times d \times \frac{\rho}{\rho_0}}{12 \times \mu} \]

\[ Re = \frac{89.5 \times 2.82 \times 0.001944}{12 \times 3.77 \times 10^{-7}} \]

\[ = 1.084 \times 10^5 \]
DETERMINATION OF DRAG AND LIFT COEFFICIENTS FOR
A SPINNING BASEBALL

M. B. Parekh
Department of Mechanical Engineering
M. S. Degree, May 1972

ABSTRACT

A literature survey of previous work was conducted to collect and review the information concerning the effect of spinning on the drag and lift coefficients of the baseball. The correlated data available were presented in graphical and tabular forms.

A spinning device was designed and built for the purpose. The effects of spin and wind velocity were studied by dropping the baseball while spinning about a horizontal axis through the horizontal wind stream of 12 x 12 x 18 in. wind tunnel test section. Tests were conducted for wind velocity up to 144 ft/sec and spinning velocity up to 2000 revolutions per minute.

The part of the result was compared with Davies' results on the golf ball. The results also explain why the ball takes a turn sharply near the home plate when the ball velocity is in the range of 30 to 70 miles per hour.

APPROVAL: