# Passing A Serve In Different Air Densities

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## I. Background

Volleyball was originally an outdoor-indoor game. Players who played the game outdoors had to deal with natural phenomena such as wet surfaces, wind, heat, cold, humidity and sun glare. When the game was brought totally indoors, most of the atmospheric variables were controlled to the point they had no effect on a player's performance. With the consistency of indoor conditions, most scientific inquiries have focused on the technical aspects of the player's performance and their conditioning. The atmospheric variables that were influential in outdoor play are now believed to be non-consequential in indoor games. The U.S.A. National Teams have been training in Colorado Springs for the last four years. During the last Olympics the Men's National Team performed well below their potential in Sydney, Australia. One of the skills performed well below par was identified to be passing the serve. The national office requested to conduct research examining the effect varying air density on the flight of the ball during the topspin serve. Considering the speed of the topspin serve at the men's international competition, it seemed unlikely that any considerable effect could be detected. Dr. Iradge Ahrabi-Fard, Professor and Head Volleyball coach at the University of Northern Iowa and Dr. Michael Roth, an on-campus colleague from the UNI Physics Department, were asked to conduct appropriate research into passing the serve in different air densities. Dr. Roth designed the study to investigate this concept.

The merit of this study is that its results can benefit the athletes who compete at different altitudes. If the flight of the ball changes considerably in different air densities with all other aspects of the serve and players held constant, the effect on passing this serve can be devastating. Previous investigations indicate that the passer doesn't see the ball within the last few feet of arm contact. Most of the training is reading the flight, moving to the area of passing, extending the arms early, and developing a kinesthetic feeling of predicting the area of contact before contacting the pass. A player who trains in a certain air density with a predicted ball trajectory develops certain expectations of the serve flight pattern. If this flight trajectory is different from the training condition, it may adversely affect the passer's ability to pass accurately.

## II. The Model

In modeling the flight of a volleyball it is crucial to identify the forces acting on the object so the equation describing its motion may be determined. In the simulations conducted in this study the differential equation for the ball's motion is

$$\frac{d\bar{v}}{dt} = -g\hat{z} - \frac{C_d \rho \pi r^2 v^2}{2m}\hat{v} + \frac{\rho \pi r^3 \omega v}{2m}\hat{\omega} \times \hat{v} + \frac{\rho}{\rho_b} g\hat{z}. \qquad (1)$$

The first term is the gravitational force. Here g is the acceleration of gravity at the surface of the earth, m is the mass of the ball and $\hat{z}$ is a unit vector in the vertical direction which, when coupled with the negative sign leading the term indicates mathematically that gravity acts downward. Typical first-semester physics courses use only this force to model projectile motion and hence afford students a solid understanding of two-dimensional kinematics.

In reality, however, such a model does not take into account the fact that the air the ball is passing through is a fluid and hence exerts both dynamic and static forces on an object passing through it. The most influential force from the air is drag resistance, expressed in the second term of Equation 1. Here ρ is the density of the air, r is the radius of the ball, $C_D$ is the drag coefficient, v is the speed of the ball and $\hat{v}$ is a unit vector if the direction of the ball's velocity which, when