Studying dynamics and kinematics of a soccer ball in a computer

Pedro Couto*
Universidade do Minho, Departamento de Física 4710-057 Braga, Portugal
pedro-couto@mail.pt

Abstract. *In Europe, football has fans all over the continent, both among adults and children. In school, the physics curriculum does not, in general, contain soccer as a subject that could be used as an example for studying the dynamics and kinematics of bodies. In this work we analyze, numerically, the three-dimensional motion of a soccer ball under real conditions, taking into account the effect of the atmosphere by including both the Magnus force and the air drag. We present an interactive simulation that solves the ball equations of motion, where a number of relevant variables can be controlled. Within our simulation it is easy to show why the trajectory is more or less curvilinear as well as the effect of the Magnus force on the range of the ball. By controlling the relevant variables we can induce interaction with students by opposing their expectations on a given real physical situation and the "experimental" result given by the computer. The simulation is suitable for students of different ages.*

Keywords. Computer simulations, Hands-on experiments, Soccer.

1. Introduction

One way of attracting students to science is using experiments to introduce new subjects. Physics is, no doubt, a topic of interests to everyone. At home, adults and children argue about the last game and analyze the player kicks.

To simulate the motion of soccer ball, we use a software, named *Modellus*, developed by Vítor Teodoro, João Vieira, and Filipe Clérigo from the *Faculty of Sciences and Technology of Universidade Nova de Lisboa (Portugal)*. Using this software it is possible create an interactive simulations that solves the ball's equation of motion. Within our computer code we can change all the initial conditions: position on the field, linear and angular velocities, atmospheric density, and ball's mass. Given the set of initial conditions we software computes the ball's trajectory taking into account gravity and the two forces existing due to the presence of atmosphere: the drag and the Magnus forces.

2. Physical model details

The drag force has the same direction as the ball's linear velocity, but opposite orientation. This force is the same felt by anyone having, say, its own hand outside the window of a moving car. The drag force has a non-linear dependence on the velocity. Studying the ball's motion using our code makes it possible for students to understand the effect of the drag force alone on the ball's trajectory. Also the code includes the so called drag crises: for velocities higher than approximately 24 m/s, the drag force, drastically decrease because the drag coefficient of the ball also decreases.

The Magnus force is related with the rotation of the ball around its symmetry axis, and it is perpendicular to both the linear and angular velocities. Within our model the orientation of the rotation axis is assumed constant with time, but its orientation arbitrary otherwise.

The Newton's equation of motion of a soccer ball is written as

$$m\frac{d^2\vec{s}}{dt^2} = \vec{F}_M + \vec{F}_g + \vec{F}_a \qquad (1)$$

where $\vec{F}_M$, $\vec{F}_g$, and $\vec{F}_a$ are the Magnus, the gravititational, and the drag forces, respectively. The analytical expressions for theses forces read

$$\vec{F}_M = \frac{1}{2}C_M.r.A.r.\vec{w}\times\vec{v} \qquad (2)$$

$$\vec{F}_A = -\frac{1}{2}C_A.r.A.v.\vec{v} \qquad (3)$$

$$\vec{F}g = m.\vec{g} \qquad (4)$$

where C_M, ?, A, r, $\vec{w}$, $\vec{v}$, C_A, m, and $\vec{g}$ are the Magnus coefficient, the atmosphere density, the ball's radius, the angular velocity, the linear velocity, the ball's mass, the free fall acceleration, respectively. Typical values for the physical parameters are: C_M~1, ?~1.2 kg/m^3, A~0.04 m^2, r~0.07 m, $|\vec{w}|$~40 rad/s, $|\vec{v}|$~30 m/s, C_A~0.5, m~0.43 kg. The combined effect of the Magnus, drag and gravitation forces leads to several different trajectories for the ball.

3. Description of the effects of the different forces

The effect of the drag force is simple to understand: it tends to reduce the ball's range and the ball's high. If only this force was present a soccer game would not have half of the excitement it has. In fact much of the excitement of the game comes from the existence of the Magnus force, which can have different orientations depending on how a ball is kicked. The kick defines the rotation axis. Depending on the orientation of rotation axis the behavior of the ball can be very different. In what follows we discuss two situations where the rotation axis has simple orientations, allowing us to hold a separate discussion on the effect of the Magnus force on the ball's range and on the ball's curvilinear trajectory. The first situation we consider is represented figure 1. In this case the axis of rotation is parallel to the soccer's field. This type of rotation is induced when the football's player kicks the ball in a point below the ball's center of mass. In this case an angular velocity in induced on the ball as shown in figure 1 by the curved arrow circulation the ball. The pressure's difference induced by rotation between the top and the button of the ball gives origin to the Magnus force. This force is oriented against the gravitation force and works as a lifting force, contributing for longer reach of the ball that the one expect on the basis of an ideal model, where the atmosphere is absent. It is quite interesting to note that, even with the drag force present, the range of the ball is large than that obtained from the ideal model (see figure 2).

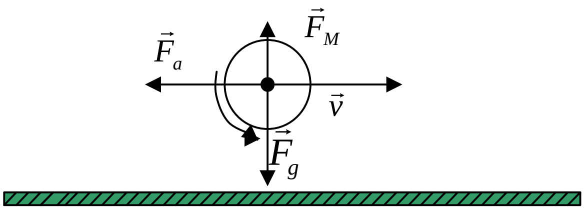

Figure 1.Graphic representation of the first situation (see text).

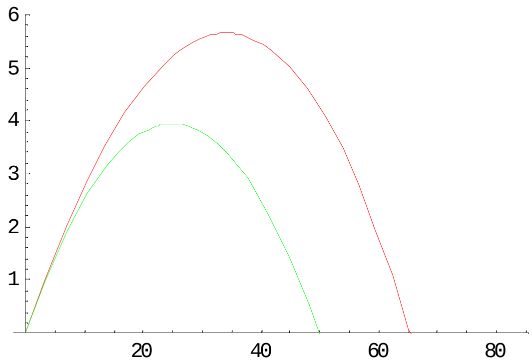

Figure 2.Trajectories of a soccer ball with (top line) the presence of the drag force and the lifting force coming from the Magnus effect; The lower line represents the trajectory of a ball with same initial condition, but here the atmosphere is absent. The axis unit is meter.

The other situation we consider is that of figure 3. In this case the rotation axis is perpendicular to the soccer field. In this case Magnus force has no longer the same direction of the gravitation force, but is parallel to the soccer's field, as represented is the right side panel of figure 3 (labeled as top camera view). The forces are represented in the same figures. This type of ration is induced on the ball when the player kicks it sidewise. In case represented in figure 3, we assumed the kick to have been applied on the right side.

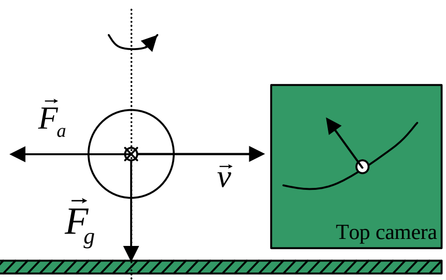

Figure 3.Graphic representation of the second situation (see text). The Magnus force is represented on the ball by a small crossed circle at its center, meaning that force is parallel to the soccer's field.

4. Pedagogical and didactical approaches

The new pedagogical ideas about teaching sciences at the elementary and secondary levels suggest that hands on experiments is the more effective way of attracting and motivating students for science. In some cases the implementation of such experiments is not an easy task. Many schools do not have the enough experimental equipments. Therefore the use of computer simulations can be a replacement of a real experiment can establish a compromise between doing an experiment or doing nothing. It is within these ideas that our computer code can help to fill the gap between the motivation students have in general for soccer doing a real experiment with a soccer ball. Although a real measurement of a ball's motion is in fact hard,we encourage teachers take a soccer ball into the classroom and ask students to test the kicks either before or after they have been simulated. Since the code allow us to turn on and off the forces we want and also to change the parameters at will, it possible to discuss in detail and in a controled way the effect of each of the «physical players» in this «game».

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