AC 2009-1345: SPORTS IN ENGINEERING: TWO HANDS-ON EXPERIMENTS

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Sports in Engineering: Two Hands-On Experiments

Abstract

A multidisciplinary team of faculty and students from two universities and a county college have developed a set of hands-on modules to introduce engineering students to mechanical, aerospace, and chemical engineering concepts and principles through their application to sports. The modules allow for students to explore topics such as aerodynamics, mechanics of materials and transport. In an aerodynamics module, the students study the effects of the rotation rate and the relative ball velocity on the lift and drag forces on a baseball. These forces play a key role in determination of the trajectory of the ball. In a mechanics module, concepts associated with the mechanics (modulus, stress, strain) of sporting materials are addressed. For these two modules a description of the development, use, and results in addition to feedback acquired from student surveys are presented.

Aerodynamics of Sportsballs

Ball games date back to ancient times and the earliest representations can be found in carvings in Egyptian temples dating from 1500BC. European monks played for recreation during religious ceremonies, but used their hands; and later the game became popular amongst noblemen and kings. Major Walter Wingfield invented equipment and a game that evolved into modern day tennis, a high-tech competitive sport that captivates millions of players and fans.

In many such sports, aerodynamics plays a key role in determining the pressure and shear stress distributions on the sports balls and sporting equipment and in turn affects the forces (lift and drag) that determine their motion [1]. As such, the objectives of this module are to explore the dependencies of the geometry, surface properties, and translational and rotational motion of sports balls and equipment on the lift and drag forces and measure these forces in a windtunnel for a range of representative flow speeds and rotation rates. These forces are then nondimensionalized and the lift and drag coefficients are determined as a function of nondimensional groups including the Reynold's number and the 'Spin Parameter'. The results are then compared to available data in the literature [2-6].

Equipment

1. Windtunnel: An educational windtunnel (model 1440) manufactured by Flotek (Fig.1) was used for all testing and provided a controlled, uniform air flow. The windtunnel is an open system and has a 12" x 12" x 36" test section. Air is drawn through a honeycomb flow straightener to ensure laminar flow at the entrance (right side) and exhausted through a blower motor mounted on left side of the tunnel. The air velocity through the rectangular test section is variable with a maximum speed of 90 mph. The air speed is computed using a pitot tube mounted at the entrance of the test section.

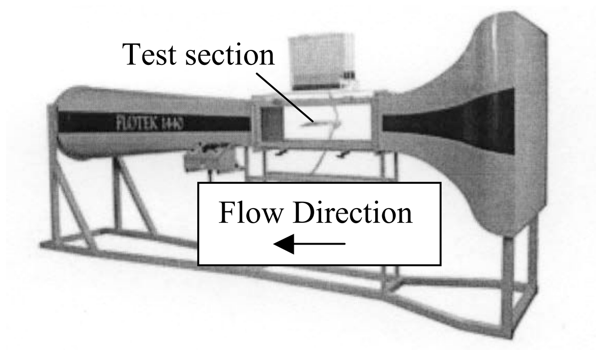
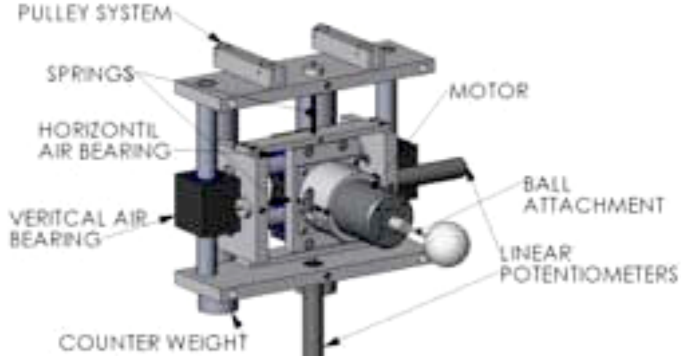
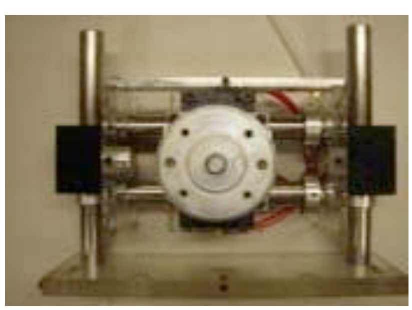


Fig.1: Model 1440 Flotek wind tunnel

2. Instrumented Apparatus: A custom test stand was designed, built and tested to support a variable-speed DC motor that is mounted such that it can "freely-float" in the horizontal (parallel to air flow) and vertical directions using air bearings that ride on precision ground stainless-steel shafts (Fig.2). The bearings are nominally pressurized with 551.5 kPa (80 psia) using shop air. An accurately machined shaft extension is mounted to the motor shaft and used to rotate a sports ball mounted at the opposite end of the shaft and positioned such that the center of the ball is at the center of the test section.



(a)



(b)

(c)

Fig.2: (a) a schematic of the test stand, instrumented assembly and variable-speed DC motor, (b) a front-view of the "freely-floating" fixture, (c) a golfball mounted on the shaft extension and positioned in the test section

Prior to testing, the entire assembly is counterbalanced with a spring and pulley system. A DC motor controller is then used to control the rotation rate of the ball (rpm) and load cells are mounted between the motor and frame assembly and measure the lift and drag forces (not shown in Fig.2). The full-scale range of the DC load cells were 111.2 N (25 lb) with voltage output calibrated at 0.27 mV/N (1.2 mV/lb_f).

Determination of the Drag and Lift Coefficients: For different rotation rates (rpm) and flow speeds, the magnitudes of the lift and drag forces are measured, converted to appropriate units and non-dimensionalized by the dynamic pressure ($1/2\rho V^2$) multiplied by the cross-sectional area (A) to determine the lift (c_L) and drag (c_D) coefficients, i.e.,

$$c_L \equiv \frac{L}{\frac{1}{2}\rho V^2 A} \quad \text{and} \quad c_D \equiv \frac{D}{\frac{1}{2}\rho V^2 A}$$

These nondimensional coefficients are then tabulated as a function of Reynold's number and a nondimensional parameter known as a 'Spin Parameter' (S), which is the ratio of the tangential velocity of the sportsball relative to its translational speed (V), i.e., $S = R\omega/V$; note that typical values of S range from 0 (no rotation) to 0.5 [5]. Interestingly, drag coefficients are relatively insensitive the spin parameter [6], yet the lift coefficient significantly increases with increasing spin parameter owed to the magnus effect. A representative plot of C_L versus S obtained by the students is shown in Fig.3 for a tennis ball at a constant rotation rate of 1920 rpm for different wind speeds ranging from 30-70 mph. The results were then compared to the values reported by Goodwill and co-workers [6] with very good agreement. These experiments clearly illustrate increasing lift with an increase in the spin parameter.

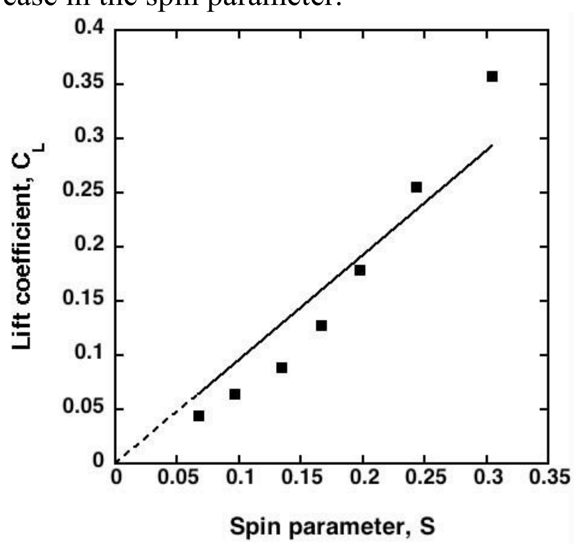


Fig.3: C_L vs. S for a tennis ball at 1920 rpm and different wind speeds. Results obtained by the students in an educational windtunnel

Mechanics of Materials

There have been many efforts to improve the materials with which sporting goods and equipment are made to improve performance. Sports ball, for example, were originally made with materials including hair, feathers, wool or cork often wrapped in cloth or leather. With the invention of the vulcanization process for rubber, players in sports such as tennis experimented with the new 'bouncy,' rubber balls. Rubber and foam were also incorporated into padding materials for American footballs as well as soccer balls and athletic shoe soles.

The objectives of this module are to conduct compression tests on different material samples used in sports, apply mechanics principles to determine stress, strain and modulus of elasticity, and evaluate the material properties and associated function.

Students work with a variety of elastomers, or rubber-like materials, which can undergo large deformations and still return to their original form after the loading is removed. Elastomers in sports are used to reduce shock and impact transmitted to the body. In athletic shoes, elastomers ease the impact of one's feet hitting the ground. Pads used in sports such as football or soccer reduce the impact from the hit or kick of another player by distributing the energy.

In our lab, students used a MTS elastomer test machine (Model 831.10) to apply a prescribed displacement history and compressively load different materials, including silicon elastomers, in the axial direction. TestStar software enabled the students to program a monotonic displacement history and collect force, displacement and time data, which was then exported to Excel. The students were then taught the concepts of stress (σ), strain (ε), Hooke's law and modulus of elasticity (E)

$$\sigma = \frac{\mathrm{F}}{\mathrm{A_s}} \quad (3) \qquad \varepsilon = \frac{\delta}{L} \quad (4) \qquad \sigma = E\varepsilon \quad (5)$$

where F is the applied force, A_s is the surface area, and L is the original length. Students measured the dimensions of the samples needed to compute stress and strain using the force and displacement data. Students were required to plot stress versus strain and determine the modulus of elasticity, which is the slope of the curve. An analogy was also made to springs and spring constants, which the students learned about in physical science or physics.

By determining the modulus of elasticity of the material, comparisons are then made among materials independent of their size and shape. Students compared the modulus to various other engineering materials such as steel, aluminum, rubber and wood and discussed particular applications for the materials that they tested and why they were appropriate. One of the materials that students tested was a silicon-based elastomer under quasi-static compressive loading to nearly 20%. From a representative stress-strain plot, shown in Figure 4, the students determined the linear modulus of elasticity to be 690 psi.

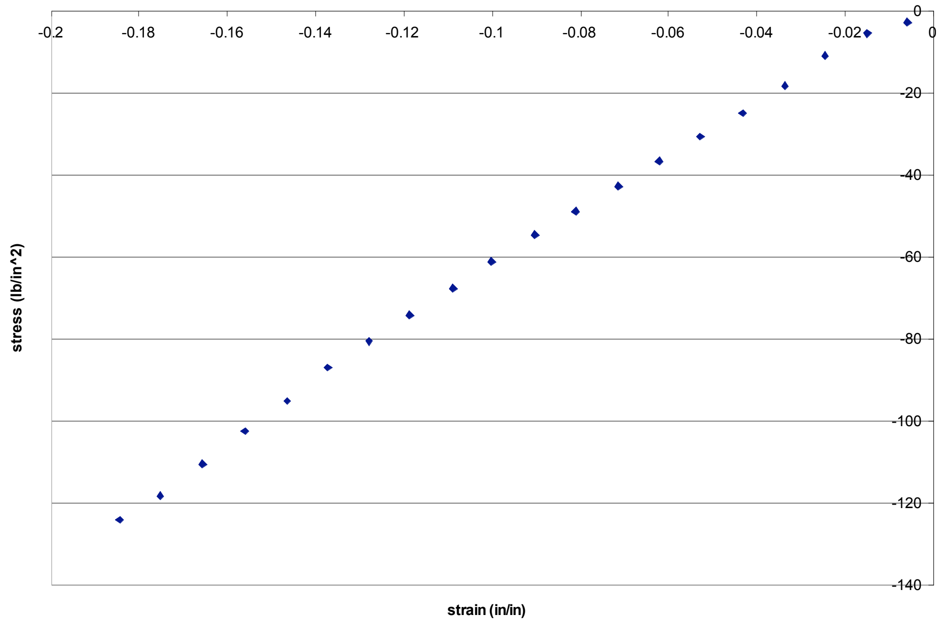


Fig.4: Stress versus strain for a silicon elastomer sample

Results

The aerodynamics module was used in courses at the four year institutions. The mechanics of materials module was used in courses at one of the four year institutions and the two year college. Both modules were favorably received at the institutions where they were used. Students from an intro to engineering (freshman) course at one of the 4 year institutions and from a mechanics of materials (second year) course at the 2 year college were given to assess the effect of the experiments on the level of student interest in engineering and in sports related to engineering. Table 1 lists the survey questions and the average score of each on a 5 point scale, where 1 is low and 5 is high.

Table 2 – Survey questions and results

Question	4 year university	2 year college
1) What is your interest level in engineering?	4	4.1
2) What is your interest level in engineering related to sports and sporting activities?	3.7	3.6
3) Please rate the quality of the instructions in your lab handouts.	4.1	3.6
4) How did the laboratory experiments affect your understanding of engineering concepts?	4	3.8
5) How did the laboratory experiments change your interest in engineering?	3.3	3.7
6) How did the laboratory experiments change your interest in sports engineering?	3.5	3.3
	n=15	n=18

The responses to the questions were favorable at both institutions. Students from the 4 year university rated questions 2, 3, 4, and 6 slightly higher than students from the 2 year college. This may be due to the fact that the 4 year students were all second semester freshmen. Students from the 2 year college rated questions 1 and 5 slightly higher. Since these students were in technology or engineering science programs, the modules may have increased their interest more than the freshmen who had already declared engineering majors. Also, the students in the 4 year institution were from a variety of different majors, so some students may have not have made a direct connection to the relevance to their discipline, yet the modules strengthened their appreciation for other disciples and broadened their exposure.

Conclusion

Two hands-on modules were presented from a set of several modules designed and developed to teach engineering principles in the context of sports with which the students are familiar. Students responded very favorably to the modules, and their level of interest in engineering and sports was increased. Future work will discuss other sports modules and assessment of student learning based on their use.

Acknowledgments

The authors thank the National Science Foundation for support under the CCLI program Grants DUE 0536307 and 0536229. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation or the college and universities of which the authors are affiliated.

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