It's a Birdie…It's a Shuttlecock…It's Badminton: The Physics Behind the Badminton Shuttlecock

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Abstract:

People often underestimate badminton as a sport because they conjure images of people casually hitting a shuttlecock. However, this sport is a brilliant combination of athletics and engineering. The extremely aerodynamically-stable design of the shuttlecock allows it to whiz past easily, but the combination of the materials used and the type of shot performed also affects the trajectory of the shuttlecock.

Article keywords: badminton, shuttlecock, aerodynamics

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Prepared on: May 3, 2013

Prepared for: WRIT 340 (Aubertin) Call for Papers

Introduction

"Smash that birdie!" was something I often heard during my high school career. No, we were not slaughtering helpless chickens. We were at badminton practice, and in badminton, the "birdie" is another term for the shuttlecock, "the ball of the game." Most people do not pay much detailed attention to the shuttlecock other than feverishly smashing it towards the opposing team. However, the seemingly simple design of the shuttlecock has many unique properties that have heavily influenced the game and rules of badminton.

Playing badminton requires not only athletic abilities but also an understanding of the laws of projectile physics. The design and material of the shuttlecock, can drastically affect its trajectory, influencing the dynamics of how a player strikes the shuttlecock. By studying the flight of shuttlecocks, researchers can design ones that have more consistent flight patterns or use cheaper materials to mimic high-quality feather shuttlecocks.

The Basics of Badminton

Originating in 19th century British India, badminton is a racquet sport played with two or four people on a rectangular court with a net in the center (Figure 1). The shuttlecock is the projectile used, and the game begins with one team hitting the shuttlecock into the air towards the opposing team. The game continues with each side hitting the shuttlecock back and forth (called a rally) until its path is interrupted. There are two types of interruption: a mistake (hit the shuttlecock twice or shuttlecock flies into

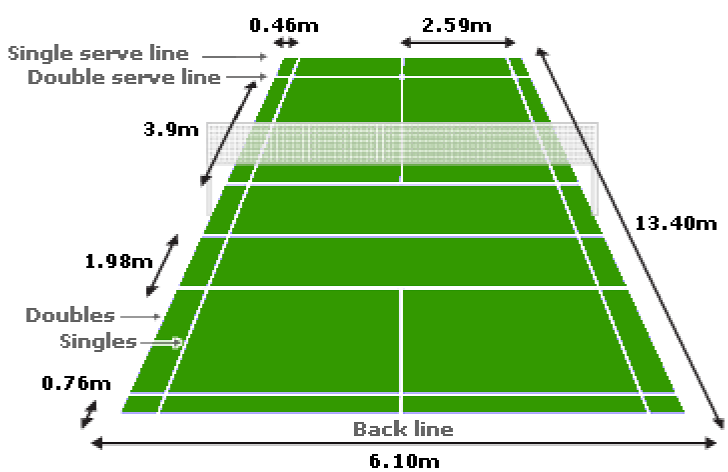

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Figure 1: The badminton court is rectangular with different boundaries for singles and doubles play.

the net or out of the court), or a winner (the shuttlecock lands on the opposing team's ground) [1].

There are four main types of shots in badminton: serve, net, smash, and high clear. The serve, which is a gentle hit of the shuttlecock, travels over the net and lands behind the serving line of the opposing side (Figure 2). Netting shots are similar to serves, but the player is right next to the net. A net shot is considered good if it barely travels over the net and drops on the opposing side's court almost immediately (Figure 3). The smash shot is where the player hits the shuttlecock hard with the racquet angled downwards; the goal of this "kill shot" is to have the shuttlecock hit the ground as soon as possible (Figure 4). Similar in initial velocity as the smash shot is the high clear. For high clears, the player instead angles the racquet upward when hitting the shuttlecock. A good clear shot would be one that travels to the end of the opposing side's court but still remains in-bounds (Figure 5).

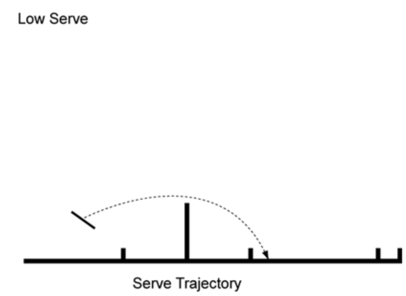

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Figure 2: A good serve travels over the net and lands slightly pass the serving line.

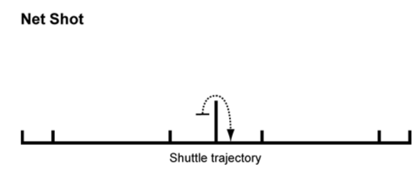

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Figure 3: A good net shot barely travels over the net.

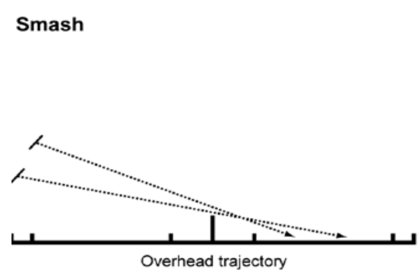

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Figure 4: A good smash shot travels at a very steep angle.

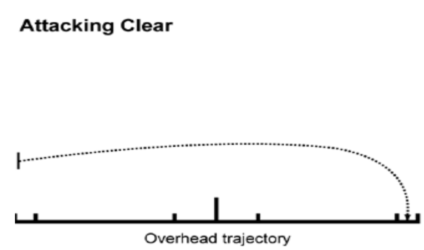

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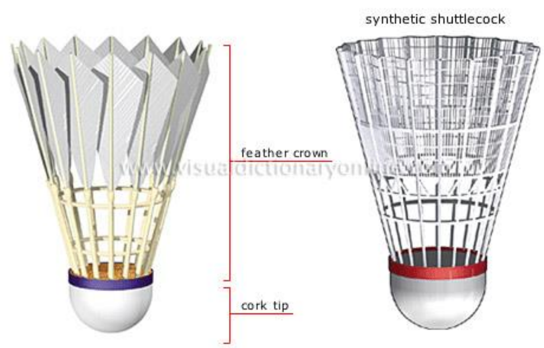
Figure 5: A good high clear shot lands at the end of the opposing side's court.

The Design of the Shuttlecock

The most importance piece of equipment in badminton would be the shuttlecock, which has gone through many different designs over the long history of badminton. Early shuttlecocks were made using a variety of materials and techniques. In 20th century France, people manufactured barrel-shaped shuttlecocks using chicken feathers. The feathers were inserted into the base with adhesive applied to keep them in place. Although the barrel shuttlecock was the first standardized design (as it could be replicated easily), its flight patterns were too random to be used for competition. The chicken feathers were also too brittle, so the barrel shuttlecocks had very short playing lives [2]. After years of experimenting, the chicken feathers were replaced by goose feathers, which were stronger and had much more consistent flight properties.

Gradual modifications have led to the modern conical-shaped design made of either goose feathers or plastic. A notable feature of the badminton shuttlecock is that it will always travel with its base first after hitting the racquet. The shuttlecock will re-orient itself upon impact, which makes badminton unique among projectile and ball sports. The conical shape of the shuttlecock also makes the shuttlecock highly aerodynamically stable (Figure 6). The shuttlecock travels at extremely high speeds upon hitting the racquet; the highest speed recorded was 332 km/h (206 mph) by Chinese player Fu Haifeng [3]. However, the speed decreases drastically after initial impact because the feathers or plastic skirt creates much drag. The shuttlecock travels in a skewed parabolic path instead of a symmetrical one as a result.



Plastic vs. Feather

Modern shuttlecocks are made of plastic or feathers, and there is an ongoing debate on which type is better. The plastic shuttlecocks are cheaper and have longer playing lives, but professional badminton players prefer the feather shuttlecocks because they feel that they give them more control.

To see which type of shuttlecock is indeed better, researchers from the Lafayette College in Easton, PA, conducted studies on four models of shuttlecocks of similar speed grade (two plastics and two feathers) from different manufacturers. From wind tunnel tests, it can be seen that the coefficient of drag is linearly proportional to the angle at which the shuttlecock is struck (i.e. the coefficient of drag increases as the angle increases). This finding applies to both plastic and feather shuttlecocks. It was also seen that the spin rate of feather shuttlecocks increases with increasing speed, whereas the spin rate of plastic shuttlecocks increases at first but tapers off. Plastic shuttlecocks spin less at high speeds because the plastic skirts deform under those conditions. The deformation of the skirts also explains why plastic shuttlecocks exhibit less drag compared to feather ones at high speeds [4].

Using simulation software, the researchers also examined the trajectories of these shuttlecocks for specific shots: serve, net, smash, and high clear. For serves, the high-quality plastic and the high-quality feather models reached the ground only 0.01 second apart. However, the plastic shuttlecock landed 0.23 meters shorter and reached a maximum height 0.02 meters shorter compared to that of the feather shuttlecock. This experiment was repeated with the low-quality plastic model, and the range difference was even greater. Similar trends were noted when the experiment was run for net shots: plastic shuttlecocks have shorter ranges compared to feather shuttlecocks of the same quality, and low-quality plastic shuttlecocks are worse in mimicking high-quality feather shuttlecocks.

For smash shots, on the other hand, both the high-quality and low-quality plastic shuttlecocks demonstrated longer ranges than the high-quality feather shuttlecock. However, the high-quality plastic model had the shortest flight time followed by the high-quality feather model and the low-quality plastic model. For high clear shots, the high-quality feather model landed

0.06 second earlier than the high-quality plastic model. In addition, the low-quality plastic model displayed a completely different flight path that is about 1 meter shorter than the others.

In a separate study conducted by a group of researchers in Taiwan, it was determined that the air drag force is proportional to the square of the shuttlecock velocity [5]. This finding supports the Lafayette College study since smash shots have very short flight times. Based on these two studies on shuttlecock trajectory, the high-quality plastic shuttlecock was the closest in performance to the high-quality feather shuttlecock. Depending on the kind of shot, the plastic or feather model is the better choice. The plastic model is better for smash shots (it had the shortest flight time), but it also has a shorter range compared to the feather model for other types of shots. The ideal shuttlecock would be durable and has short flight times and long ranges.

The Future of Shuttlecocks

Based on these studies, both plastic and feather shuttlecocks of the same quality have their own benefits. Plastic shuttlecocks are cheaper and more durable, but feather shuttlecocks provide longer ranges and more stable speeds. However, feather shuttlecocks are becoming more expensive because of the labor-intensive production process. The feathers are hand-plucked and sorted by hand in factories (feathers from the right and left wings have to be separated because they have different orientations). After the shuttlecocks are made, they are individually tested for speed grades and stored for a period of time for re-testing before distribution [6]. Lastly, feather shuttlecocks are usually replaced after two games in professional settings, leading to high turnover rates. The ideal case would be using plastic shuttlecocks that behave the same as feather shuttlecocks.

To make the production of shuttlecocks cheaper and more efficient, engineers are working hard to develop synthetic shuttlecocks that have the same performance as feather shuttlecocks. A Japanese sporting goods company recently introduced a synthetic model that has individual feather-shaped pieces attached to the base [7]. Unlike plastic shuttlecocks, these synthetic shuttlecocks do not have plastic skirts (Figure 7). They do not exhibit deformation at high speeds, so they have more consistent speeds than regular plastic models. Nevertheless, these synthetic models do not mimic feather shuttlecock performance perfectly. Engineers (and badminton players alike) are hopeful that a synthetic shuttlecock model capable of mimicking feather shuttlecocks will be available in the future.

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Figure 6: The individual "feathers" are actually made of synthetic material.

Conclusion

Badminton is often looked down upon as a garden sport, but it is actually a bridge between athletics and science. Players need to have the athletic abilities as well as understanding of physics to determine where they should aim or receive the shuttlecock. While the performance of the shuttlecock has improved drastically since badminton first began, there is still much room for advancement. The challenge for engineers is to develop a shuttlecock that combines the benefits of both synthetic and feather models. This goal may take many more years of research, but engineers are working hard to see that day come.

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This webpage provides information on the new synthetic shuttlecock that can mimic feather shuttlecock performance fairly well.