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# Determining The Best Badminton Starting Service By Using Projectile Motion

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**Abstract**: Badminton is a racquet sport in which players drive a shuttlecock across a net with racquets. There are two forms of starting service in badminton namely the forehand long service and forehand short service. This research will focus on all types of facilities, with the initial height of the service position varying. This research aims to improve shuttlecock starting operation by reducing the amount of time the shuttlecock spends in the air. The projectile motion equation applied is a vector version of Newton's Second Law of Motion, which is aimed at singles players. Using the projectile motion principle, the result will determine the type of starting service that will result in the serviced shuttlecock spending the least amount of time in the air. Since the shuttlecock only spends 1.19983 seconds in the air at a $52^{\circ}$ trajectory angle, it can be concluded that forehand short service is the best form of badminton starting service. As a result, it's clear that the higher the starting service spot, the less time the shuttlecock spends in the air. Hence, badminton players should practice forehand short service. In addition, the best trajectory angle made with the sideline is preferable for the best form of badminton starting service.

**Keywords**: Badminton starting service; forehand short service; forehand long service; newton's second law of motion; projectile motion; trajectory angle.

## 1 Introduction

The badminton starting service is a crucial part of the game as it is the ground for players to initiate the best shot to begin the game. As the service more than often sets the tone of the game, the strength of service will decide the control of the game to some extent. In competitive badminton games, there are two types of starting service namely the forehand long service and forehand short service. In comparison to the forehand long service, the forehand short service skill masks the body movement and unobservant shuttlecock positioning. The shuttlecock flies just over the net on a very flat trajectory and hits the service box. Moreover, the forehand short service is often used when the player is under an opponent's pressure. The forehand short service is indeed a valuable skill for both singles and doubles games. Additionally, the tactic of slicing and without backswing, this service offers more opportunities as the opponent has to play a tight net return to raise the shuttlecock if it is delivered correctly at the top of the net. In both cases, the server either gets a drop or smash advantage.

In gaining a winning strategy, an effective shuttlecock starting service is crucial. The aim of the game is to score points by forcing the shuttlecock to the opponent's side of the court. One prevalent strategy to achieve this is by the use of a server. An effective service will either result in a point, due to the shuttlecock not being returned or weakly returned, allowing them to use this as an advantage. Furthermore, one of the significance of an efficient service is to determine the best badminton starting service by reducing the amount of time spent by the shuttlecock in the air [1]. Based on [2] the overall badminton court's measurement, it is concluded that the measurement is 46.67 feet by 22.33 feet (13.4 metres by 6.7 metres); thus, each side of the court measures is 20.33 feet by 20.33 feet (6.1 metres by 6.1 metres). In addition, the standard height of the badminton net is 5.09 feet (1.55 metres) for both men and women players respectively.

Evidentially, various mathematical methods are used to solve a problem that involves the motion of an object such as differential equations and projectile motion [3]. In addition, [4] and [5] stated that projectile motion is influenced by two independent motions which are the vertical motion and horizontal motion.

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A shuttlecock service model is designed and used to evaluate the service so that the shuttlecock is able to reach the target position in the shortest amount of time after crossing the net [6]. The forces acting on the shuttlecock must be described in mathematical terms to form a model. The force due to gravity is considered to be the most significant force in the order of its impact upon the shuttlecock [7]. In this research, the air resistance and aerodynamic effects acting on the shuttlecock are assumed to be ignored [8, 9].

For badminton, projectile accuracy (shuttlecock) is important even if the shuttle normally does not land as the opponent intercepts it before it can hit the court floor [10]. [11] designed and developed a model to describe the trajectory of a badminton shuttlecock and use it to explore the impact of serve height in light of the Badminton World Federation's new serve regulation. The new regulation requires all players to launch the shuttlecock below a height of 1.15m, as opposed to the previous rule, which required the shuttlecock to be launched under the server's rib cage [11]. Based on [6] it notes that different approaches, conventional and modern methods, are used to create analytical solutions. The objective of their study is to provide a formula with quadratic air resistance to create the trajectory of the projectile motion.

Next, [12] applies motion analysis software to determine the reaction time for different deception types during smash. It considers the smash as the most important strike during a badminton match. Besides, the projectile motion is also used in volleyball with a spin by exploring how effectively the Magnus effect is integrated into a model of the ball's motion [13]. The projectile motion is also used in the game of tennis, in which when the ball is smashed or launched, it moves in a projectile motion. The ball is thought to have both a vertical and horizontal component of velocity during projectile motion, which explains the distance and height the ball travels [14]. Similarly, the motion of a baseball also includes the creation of fundamental functional dependences of the motion, determining the best throwing angle for maximum range, constructing a family of projectile trajectories, and determining the vertical asymptote of projectile motion [15].

According to [16], highlighted that there are two types of shuttlecocks. The shuttlecocks are feathered shuttlecocks and synthetic shuttlecocks. The researchers asserted that a shuttlecock produces high aerodynamic drag and a sharp flight trajectory. Subsequently, [17] researched the improvements in the badminton short service test among students of Islamic Education at Riau Islamic University. More importantly, short service is done by directing the shuttlecock with the aim of the two opposing target plots that are from the right corner to the right of the opposing field and the left-to-left corner of the opposing field.

Furthermore, starting service is an important shot when playing a game of badminton doubles [18]. The short service is played by launching the shuttlecock over the net as low as possible and return of the service received by the duo pairs which enables the player to be in a position to perform an offensive return and move to the attack. Therefore, the shots enable the players to garner more points.

Henceforth, this research focuses on single games and aims to find the best start-up service for badminton by determining the minimum time spent by the shuttlecock in the air. Consequently, the best type of starting service can be determined which differs in the initial starting service height of the shuttlecock. The result of this research can be used to improve serving skills in the future. Several criteria that have been considered in the study are the initial starting service height of the shuttlecock, the shuttlecock's trajectory angle made with the sideline, and also the distance beyond the net where the shuttlecock lands. [19, 20] deliberated that the suitable angle for throwing a shuttlecock is ranged from $35^\circ$ to $55^\circ$ and the range of angle is applicable for all types of sports therefore, the same range of angle is used for the analysis. Based on the initial point obtained, the initial height for forehand long service is 0.9 metres in relation to the player's arm's length and the initial service height for forehand short serve is 1.35 metres [2]. The states by [21] that one of the ways to minimize the time the shuttlecock spends in the air is to make the shuttlecock land just over the net. Therefore, the distance where the serviced shuttlecock lands are set to 1.98 metres.

This paper is presented in four sections whereby the first section is the introduction and related works of badminton services by using several mathematical techniques. Subsequently, section two discusses in detail the research methodology. Thereafter, the research results and discussion are deliberated in section three whereas section four concludes with the contribution of this research and further work.

## 2 Material and Methods

In this section, the research methodology is discussed thoroughly. In order to set up the research analysis, all the variables involved in the calculation are defined based on the top view of a badminton court, and the schematic view of the badminton trajectory angle. Figure 1 shows the top view of a badminton court, and the variables used are shown in Table 1:

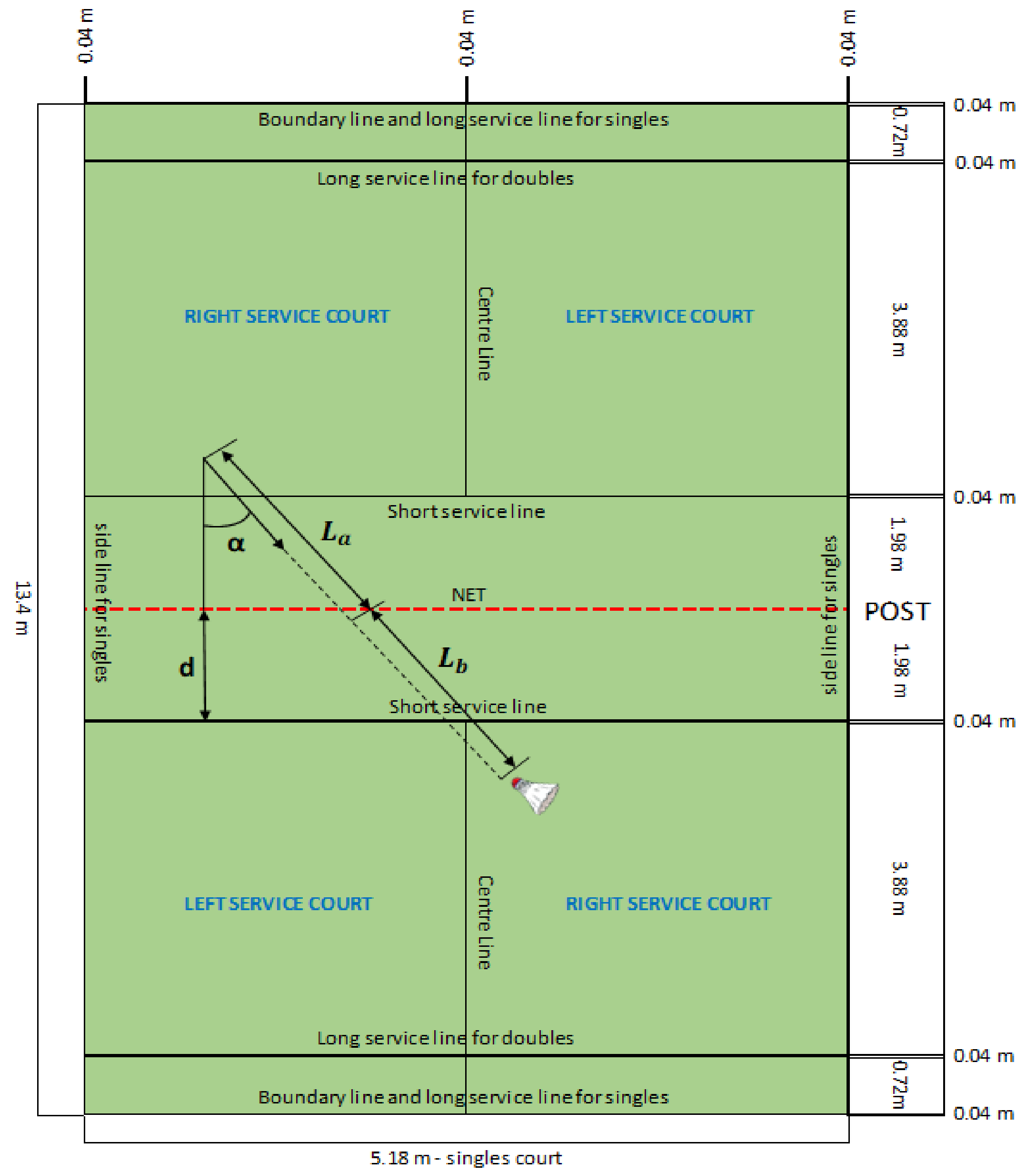

Figure 1: The Top View of a Badminton Court.

Table 1: Variable Used on View of a Badminton Court.

| Variable | Description |
|---|---|
| $L_a$ | The distance from the service location to the net, along the direction the badminton is serviced |
| $L_b$ | The arbitrary distance from the net to where the shuttlecock lands on the other side of the court along the direction the is serviced |
| $d$ | The distance beyond the net where the shuttlecock lands |
| $\alpha$ | The angle the badminton trajectory makes with the side-line |

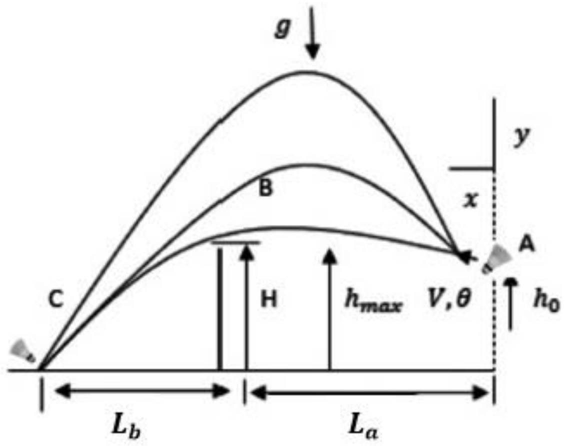


Figure 2: The Schematic View of Badminton Trajectory Angle.

Meanwhile, Figure 2 based on [21], shows the schematic view of the badminton trajectory angle, and the variables used are shown in Table 2:

Table 2: Variable Used on View of a Badminton Trajectory Angle.

| Variable | Description |
|---|---|
| $g$ | The acceleration due to gravity (gravity, $g = 9.8m/s^2$) |
| $H$ | The height of the net |
| $h_{max}$ | The maximum height reached by the shuttlecock |
| $h_0$ | The initial starting service height of the shuttlecock |
| $V$ | The initial starting service velocity of the shuttlecock |
| $\theta$ | The initial angle the shuttlecock makes with the above horizontal line |
| Point $A$ | The starting service location |
| Point $B$ | The location just above the net, through which the shuttlecock passes |
| Point $C$ | The location on the court where the shuttlecock lands |
| $(0, h_0)$ | The origin of this system |
| $(x, y)$ | The coordinate system is defined with the positive $x$ and $y$-axis pointing in the direction shown |
| $t$ | Time the shuttlecock spends in the air |

***A Projectile Motion Equation***

In order to achieve the objective of this research, the mathematical model of projectile motion is chosen. This research focuses on singles games and with the assumption that the air resistance and aerodynamic effects acting on shuttlecock are ignored. Besides that, this research takes into consideration of two start-up services which are forehand long services and forehand short services. Relatively, both type of services will differ in the initial height of the starting service location. Hence, in order to conduct the analysis, several parameters are required to be modified and fixed as follows:

i. Value of gravity, $g$ is constant ($g = 9.8m/s^2$)
ii. Value of $d$ is fixed ($d = 1.98\ m$) from the court dimension referring Figure 1.
iii. Value of $H$ is fixed ($H = 1.55\ m$) from the court dimension referring Figure 1.
iv. Value of $a$ varies from $35^{\circ}$to $55^{\circ}$ from [4].
v. Value of $h_0$ varies; from the normal player arm's length [2].

a) Case I (forehand long service: $h_0 = 0.9\ m$).
b) Case II (forehand short service: $h_0 = 1.35\ m$).

***B The Basic Concepts of Projectile Motion***

The concept of a projectile motion starts from Newton's Second Law of Motion [22]:

$$F = ma \tag{1}$$

where,
$F$ is the net force acting on the object,
$m$ is the mass of the object,
$a$ is the acceleration of the object.

Therefore, listed are the following modelling assumptions:

i. The mass, $m$, of the object, is constant.
ii. The only force acting on the object after it is launched is the gravity force. (Air resistance and aerodynamic effects acting on the badminton are ignored).
iii. The object remains sufficiently close to the Earth so that the constant force of gravity can be assumed.

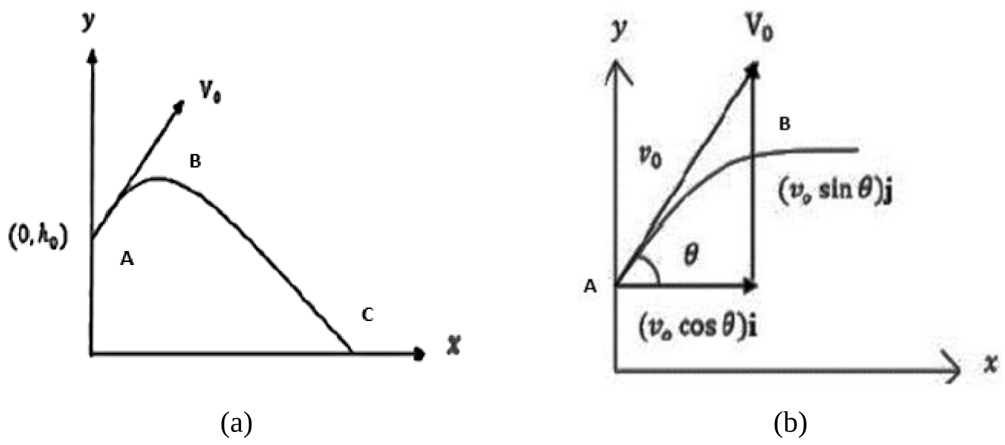


Figure 3: (a) The Initial Position and the Direction of the Shuttlecock and (b) the Graph of the Initial Velocity Vector of the Shuttlecock.

Based on the equation for projectile motion [22] and [23]:
Note that, $x$ and $y$ denote the position of the shuttlecock at any trajectory and $t$ is time in seconds.

i) $x$ displacement of badminton (distance travelled along the $x$-axis with respect to time $t$) is:

$$x = (V\ cos\theta)t \tag{2}$$

ii) $y$ displacement of badminton (distance travelled along the $y$-axis with respect to time $t$) is:

$$y = (V\ sin\theta)t - \frac{1}{2}gt^2 \tag{3}$$

In order to eliminate parameter $t$, combine (2) and (3). Then substitute $t$ into equation (3), then the equation is defined as:

$$y = (tan\theta)x - \frac{gx^2}{2(V\ cos\theta)^2} \tag{4}$$

The above is the equation of a parabola in terms of $x$ and $y$ and the general form of parabola equation is:

$$y = ax^2 + bx, \tag{5}$$

where $a = -\frac{g}{2(V\ cos\theta)^2}$, and $b = tan\ \theta$
such that

$$V^2 = -\frac{g}{2a(V\ cos\theta)^2}, \tag{6}$$

$$V = \sqrt{(-\frac{g}{2a(V\ cos\theta)^2})}, \quad \text{and} \tag{7}$$

$$\theta = tan^{-1}\ b \tag{8}$$

### *C Calculation in Identifying the Type of Starting Service that Gives the Minimum Time the Shuttlecock Spends in the Air*

The constant $a$ and $b$ can be solved for $t$ in terms of parameter $L_a$, $L_b$, $H$ and $h_0$ using simultaneous equation method based on the coordinates of Point $B$ and Point $C$ relative to the coordinate system $(x, y)$.

Based on Figure 2, the coordinates of Point $B$ and Point $C$ are given by:

$$\text{Coordinate of Point B: } (L_a, H - h_0), \tag{9}$$

$$\text{Coordinate of Point C: } (L_a + L_b, -h_0). \tag{10}$$

where $L_a = \frac{6.7}{cos\ a}$ and $L_b = \frac{d}{cos\ a}$.

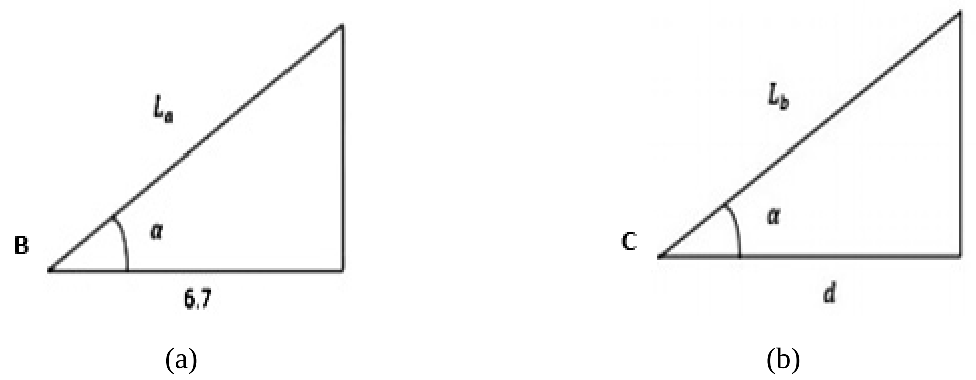


Figure 4: The Angle View for $L_a$ in (a) and $L_b$ in (b).

Figure 4 is extracted from Figure 1 to show the derivation of $L_a$ and $L_b$. Thereafter, to calculate the time that the shuttlecock spends in the air, rewrite Eq. (2) becomes:

$$t = \frac{x}{V\,cos\theta} \tag{11}$$

where
$x$ is the distance travelled by the shuttlecock, represented by $L_a + L_b$.

Hence, the time that the shuttlecock spends in the air can be calculated by:

$$t = \frac{L_a + L_b}{V\,\cos\theta} \tag{12}$$

## 3 Results and Discussion

***A Type of Starting Service and the Time the Shuttlecock Spends in the Air***

### i. Case I: Forehand Long Service

The research analysis involves two types of starting service in shuttlecock namely the forehand long service and forehand short service. Forehand long service is a technique of starting service where players just use their arm strength to service the shuttlecock and the optimum height for forehand long service is 0.9 meter.

Figure 5 illustrates the graph representing the changes of $a°$ with respect to time, $t$, where the change of time, $t$, depends on the value of the badminton trajectory angle makes with the sideline, $a°$. The graph indicates the best angle of service or also known as the trajectory angle of the badminton, $a°$, which is at 47° because it generates the minimum time the shuttlecock spends in the air, recording at 1.24842 seconds. On the other hand, the maximum time the shuttlecock spends in the air is 1.24843 seconds, which is generated by trajectory angle, $a°$, at 54°.

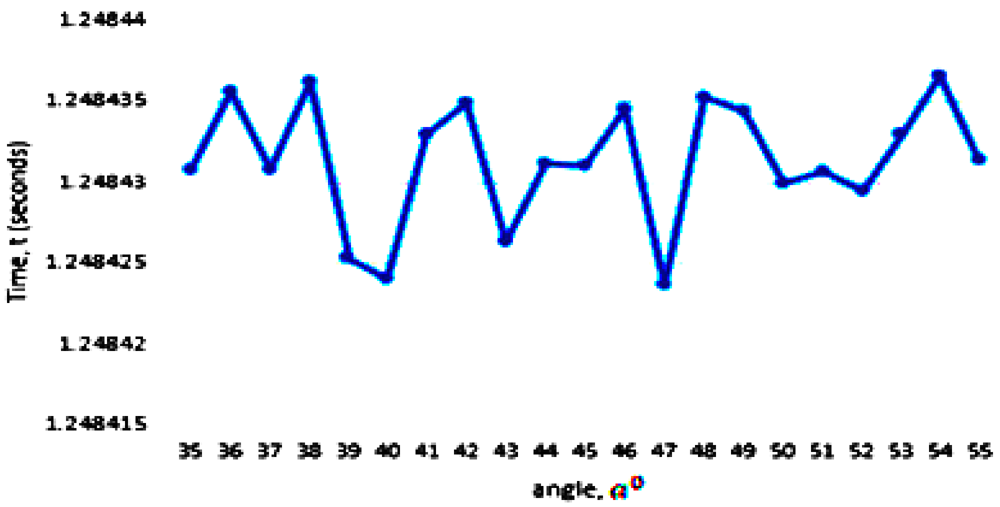


Figure 5: The Graph of Changes of $a°$ with respect to Time, $t$.

### ii. Case II: Short Service

In order to score points, the servicing team needs to find the best service so that the opposite team will be unable to return the service. Therefore, the best service of a shuttlecock start-up service can be achieved by minimizing the time spent by the shuttlecock in the air.

Figure 6 depicts the graph of changes of $a°$ with respect to time, $t$, for forehand short services. From the graph obtained, the change of time depends on the value of the shuttlecock trajectory angle made with the sideline, $a°$. It indicates that the best service angle, $a°$, is at $52°$ that generates the lowest time the shuttlecock spends in the air which is only within 1.19983 seconds. Contrarily, the service angle, $a°$ at $54°$ generates a maximum time which is 1.19985 seconds.

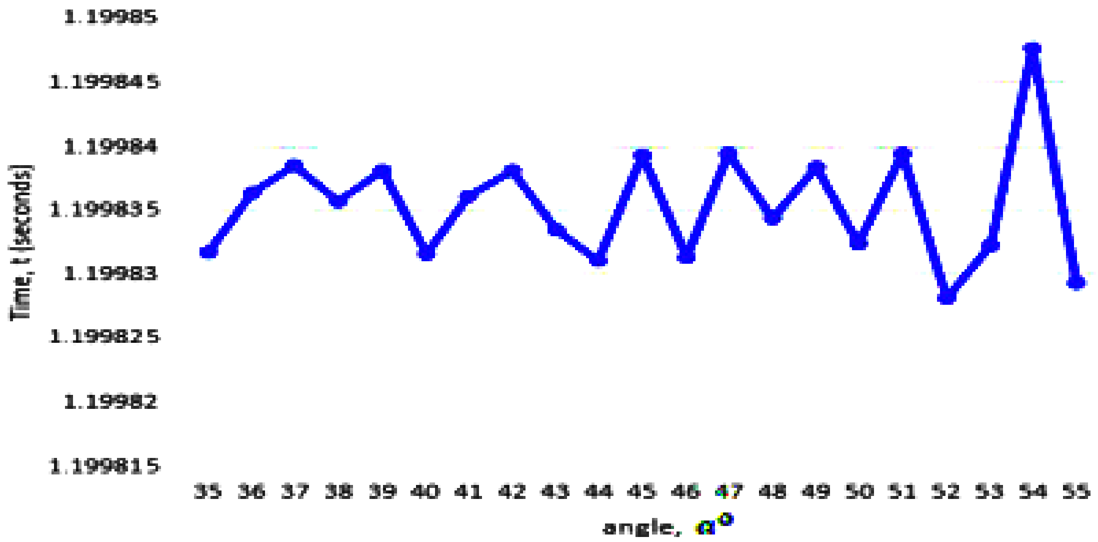


Figure 6: The Graph of Changes of $a°$ with respect to Time, $t$.

The graph for forehand long services and forehand short services shows that a waveform curve due to the cosine formula used in the equation.

By comparing both results of the forehand long service and forehand short services, as detailed in Table 3, it is clear that there is a significant difference between the two types of starting services. Forehand long service which is initially serviced at a height of 0.9 metres generates the minimum time the shuttlecock spends in the air within 1.24842 seconds.

In contrast, a forehand short service initially serviced at a height of 1.35 metres will generate a time of only 1.19983 seconds the shuttlecock spends in the air. Based on the result analysis, it can be concluded that the initial service height affects the time the shuttlecock spends in the air.

Therefore, the best start-up service technique between the two types of service which tends to boost the start-up badminton service is the forehand short service, since it generates a minimum and least time for the serviced shuttlecock to spend in the air compared to the forehand long service.

Table 3: Comparison Results of Forehand Long Service and Short Service.

| | **Forehand long service** | **Forehand Short service** |
|---|---|---|
| Initial height (metres) | 0.9 | 1.35 |
| Angle for minimum time (degree) | 47 | 52 |
| Minimum time (seconds) | 1.24842 | 1.19982 |
| Angle for maximum time (degree) | 54 | 54 |
| Maximum time (seconds) | 1.24845 | 1.19985 |

***B The Best Badminton Trajectory Angle Makes with the Sideline.***

Based on the result of forehand long and forehand short service comparison, additional important information can be further analysed and obtained. The results are obtained to determine that the best trajectory angle, $a°$, for the best starting service type, which is forehand short service, is at $52°$. It is generated based on the initial service height of the shuttlecock, $h_0$, versus the distance travelled by the shuttlecock along with the court, D.

In reference to the previous section, the length of a one-sided badminton court is 6.7 metres which means that the length of a standard badminton court is 13.4 metres. The servicing team requires to optimize the start-up service skill so that the opposite team will be unable to return the service, thus increasing the teams' score point. However, the team has to ensure that the serviced shuttlecock does not exceed the end line.

Recapitulating on the result obtained from the changes of $a°$ with respect to time, $t$, the best type of start-up service is short service since it generates the minimum time that the shuttlecock spends in the air which is merely 1.19983 seconds, that generates a trajectory angle of $52°$. Figure 7 illustrates the view of the short service trajectory angle made with the sideline for the best-serviced shuttlecock. Besides that, Figure 7 shows the best angle of forehand long service, $a°$, which is at $47°$ because it generates the minimum time the shuttlecock spends in the air, recording at 1.24842 seconds. On the other hand, the maximum time the shuttlecock spends in the air is 1.24843 seconds, which is generated by trajectory angle, $a°$, at $54°$.

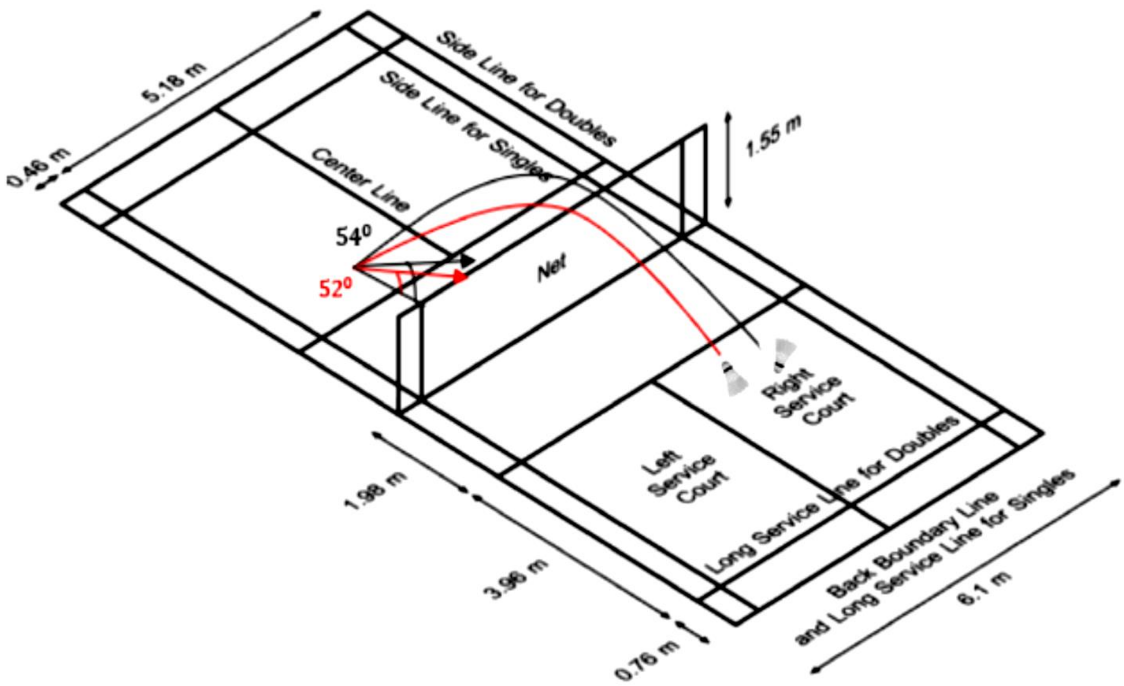


Figure 7: The View of Short Service Trajectory Angle Made with the Sideline.

## 4 Conclusion

In summary, this study focused on the singles games and examined the fact on type of shuttlecock service which will be able to provide the minimum time spent by the shuttlecock in the air. Based on the results, it is concluded that the forehand short service has the least time as compared to the forehand long service in the air.

Constructively, the shorter time the shuttlecock spends in the air makes it difficult for the opposing team to return the shuttlecock, which will also offer an extra point service to the servicing team. In addition, another important assumption was made in the research whereby the trajectory angle of the shuttle service did not hit the terminal line of the court. The research uses trajectory angles between 35° to 55° to obtain the results. Ultimately, the best trajectory angle that does not hit the terminal line of the court is 52° with a time of 1.19983 seconds based on the outcome obtained. Hence, in order to maximise the start-up skills of badminton players, the research has revealed that badminton players are required to strengthen their short service skills.

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