The Swing of a Cricket Ball – A Computational Study

Chowdhury Mahbub Ashraf [+] , SM Tareque Saifullah, Maglub Al Nur

Dept. of Mechanical Engineering, Bangladesh University of Engineering & Technology, Dhaka-1000, Bangladesh

Abstract. The mystery of cricket ball swing has fascinated the bowlers and batsmen as well as spectators and cricket critiques from the very first appearance of the game. This nonlinear flight is mainly due to the aerodynamic properties of the cricket ball which has been investigated by many researchers in the last three decades. While conducting a lot of experimental studies, their main interest was to figuring out the factors and conditions affecting the swing. However, a lot of features responsible for both conventional and reverse swing are yet to be known. In this study, rather than performing experimental study, a computational approach is undertaken to investigate the effects of different parameters on the swing of the cricket ball. The newly developed and widely used CFD (Computational Fluid Dynamics) tools and their commercial packages have been applied in this study and the effect of seam angle, bowling speed and surface roughness are considered. This study explains the conventional swing and finds out the critical combination of the above parameters to produce reverse swing with an old ball.

Keywords: Conventional swing, reverse swing, side thrust, surface roughness.

1. Introduction

Cricket is one of the most popular and widely watched games around the world. Though it was believed to be originated in Britain, its popularity has moved outside the British colonial countries now a day. In cricket, a ball this bowled by a bowler to a batsman. Both the bowler and batsman have different objectives. Batsman tries to hit the ball hard to score as many points (runs) as possible by saving the stumps and bowler tries to deceive the batsman by changing the flight and direction of the ball forcing him to play a wrong stroke. While projecting through the air, the cricket ball experience a pressure differential across it due to its structure, thus associated aerodynamics play a significant role in the motion of the ball.

The swing generated by the fast bowlers amazes the spectators as well as the researchers. The reason of swing of tennis and golf balls [1, 2] was known from the beginning as those balls travel under Magnus effect (the rotation of the ball along its own axis). However, spin of the ball could not explain the entire mystery of cricket ball swing. The first scientific investigation to find out the reasons of cricket ball swing was carried out by Cooke [3] where he tried to explain this with the help of boundary layer theories. Since then, people like Lyttleton [4], Mehta and Wood [5] have published several theories to explain this well observed phenomenon.

Later, experimental investigations were carried out by Barton [6], Bentley *et al.* [7], Mehta *et al.* [8] and Wilkins [9] to investigate different factors that affect the amount of swing experienced by the ball while it is in air. Already existing theories of cricket ball swing were also verified by flow visualization experiments by Mehta *et al.* [8]. Sayers and Hill [10] also conducted experimental studies considering the Magnus effect with other parameters to calculate the drag and lift force while ball is in air. Mehta [11, 12] later summarized all his findings on the aerodynamics of cricket ball as well as other sports balls.

In the mid-1980s, a new phenomenon about the cricket ball swing started to emerge which is known as 'reverse swing'. As the factors of conventional swing were yet to be revealed at that time, reverse swing created a lot of interest among researchers who were working with the conventional swing. The concept of reverse swing was first explained and discussed by Bown and Mehta [13]. Recently, Lock *et al.* [14] conducted flow visualization experiments demonstrating the reverse swing of cricket ball while Sawyers [15]

[+] Corresponding author. Tel.: +880-1714174564
  E-mail address: mahbub.ashraf@gmail.com

tried to measure the amount of reverse swing. The researchers of RMIT University Australia have also undertaken a large project to analyze various parameters responsible for cricket ball swing. This project will be carried out both experimentally and computationally.

Although computational modeling has become an integrated part in fluid dynamics research, most of the studies performed until today on cricket ball swing are experimental. Our study takes the advantage of computational tools available today and uses a commercial CFD (Computational Fluid Dynamics) package to analyze cricket ball aerodynamics. This paper demonstrates the design and simulation procedure and explains the results obtained through simulation in support of existing theories of cricket ball swing. As a basic step towards using computational modeling, the effect of only three parameters namely seam angle, speed and surface roughness are considered and their effect on swing are discussed.

2. Mechanism of Swing: Conventional Vs. Reverse

Swing is the sideways movement of the ball while it travels through the air towards the batsmen. While swing in tennis and golf ball is mainly due to its spinning (Magnus effect), swing in cricket ball is due to the asymmetric flow caused by the presence of seams. A cricket ball generally has six rows of seam, three rows in either hemisphere, with 80-90 stitches encircling the whole ball. The stitches are generally 1 mm of high (Fig. 1).

Fig. 1: Cricket ball

The reasons behind the swing in the cricket ball can be explained easily with the help of simple fluid dynamics theories. If the ball is delivered at a seam angle to the initial line of flight, the laminar flow over the ball is converted to turbulent flow on one side of the ball due to the presence of the seam while other side remains laminar. This asymmetric flow over the ball creates a pressure differential and the ball experiences a side thrust which deviates from its original line of flight and produces swing. This is called 'Conventional Swing' which is achieved by maintaining laminar flow on the non-seam side and turbulent flow on the seam side facing the batsmen.
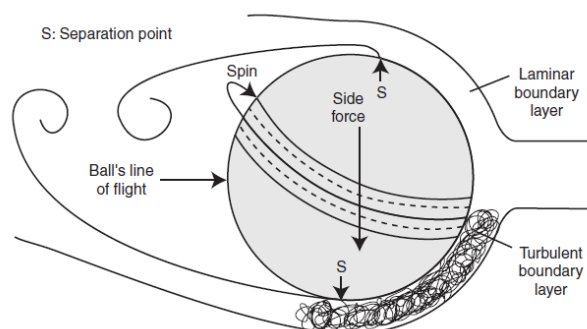

Fig. 2: Schematic of flow over a cricket ball for conventional swing (Mehta[12])

Fig. 2 shows the mechanism described for conventional swing. As the flow on the seam side facing the batsman turns to turbulent, the boundary layer associated with it separates later than the laminar boundary layer due to its increased energy causing a pressure differential across it, and thus causing the swing.

In the mid 1980's, the bowlers started to produce a newer version of swing bowling, especially with the old ball. It was popularly termed as 'Reverse swing' as it swings in the reverse direction of the conventional swing having the same seam orientation. Though both the way to produce the reverse swing and its mechanics were unknown to many of the people, yet few bowlers continued to deliver such swings with great ease.

At the beginning, as the reverse swing is generated with the old ball only, it was initially believed that, to produce reverse swing, one side of the ball should be smooth and other side should be rough. The mechanism of producing reverse swing with old ball is shown in Fig. 3.
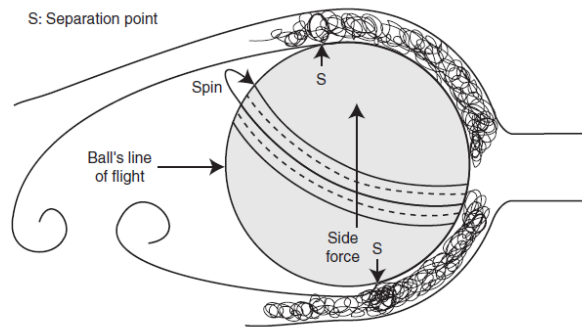

Fig. 3: Schematic of flow over a cricket ball for reverse swing (Mehta[12])

To generate reverse swing with an old ball, the non-seam side facing the batsman should be rough while the seam side should be smooth. Similar to the conventional swing, the seam trips the flow from laminar to turbulent, but this time the flow in the non-seam side also becomes turbulent due to its higher surface roughness. If the turbulent air flow in the seam side separates earlier than the turbulent flow on the other side, the pressure differential now acts on the opposite side giving rise to reverse swing. Traditionally, reverse swing occurs when half of the ball is has been naturally worn significantly. In most cricket matches, the phenomenon of reverse swing occurs after 40 or more overs (one over consists of a set of six bowled balls). Though the mechanism for a reverse swing is complex and still not fully understood due to the degree of ball's surface roughness and required seam alignment angles with the mean direction of the flight, the bowlers still try wholeheartedly to maintain the smoothness of one particular side.

Later, it was also found that, reverse swing could also be generated with the new ball with higher bowling speed where high velocity of wind causes turbulent flow over both sides of the ball. However, the advantage of using older ball is, one can still obtain the reverse swing with relatively lower speed.

3. Generating the Computational Model

A lot of experimental studies have been performed to investigate the drag coefficient on the ball and to visualize the flow over the ball. However, a mathematical model for the flow over the ball is yet to be developed, thus there is no significant amount of numerical studies on this topic.

In this paper, a numerical approach is taken to investigate the amount of side thrust on the ball by developing a 2D computational model of the system. As the governing mathematical equation is unknown, this virtual model is simulated using commercial package software where one can solve different fluid dynamics and heat transfer problems by setting some boundary and initial conditions.
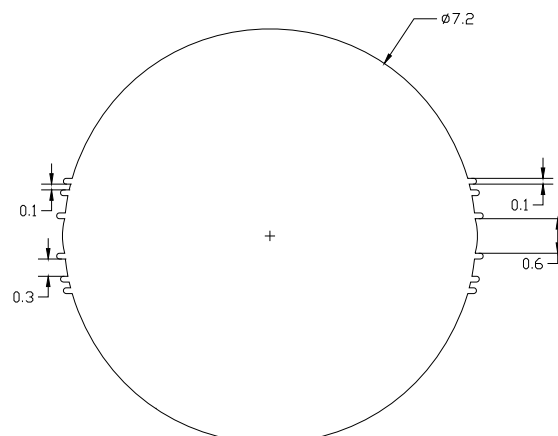
3.1. Drawing the 2D model in CAD

Fig. 4: 2D drawing of the cricket ball (All the dimensions are in cm)

The 2-dimensional cross-sectional view of the cricket ball is first drawn in CAD software using the standard dimensions that are used in international games.

Standard dimensions are given below with the drawing:

- Ball diameter : 7.2 centimeter
- Seam width and height : 1 millimeter
- No of seams in each half of the ball : 3

This model is then transferred to a commercial package to generate mesh.

3.2. Generating Mesh and Defining Boundaries

The next step is to generate mesh in the area of interest and define proper boundary conditions. A concentric circle of 5 times of the ball diameter is drawn in AutoCAD. The area between the ball and the outer circle is the region of analysis where mesh has to be generated.

3.2.1 Mesh Specification

- Element : Quad
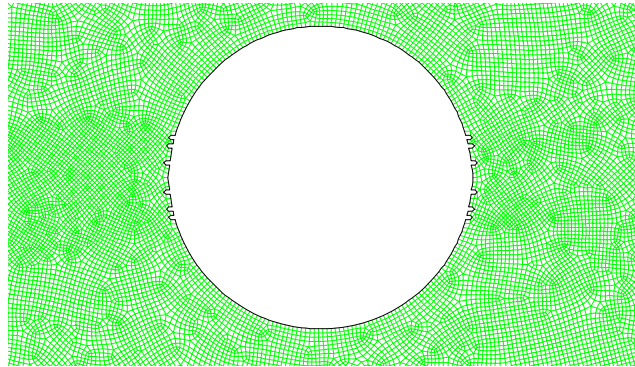- Type : Pave
- Spacing : Interval size of 0.001

Fig. 5: Portion of the Generated Mesh

3.2.2 Defining Boundaries

Firstly all the boundaries of interest are named according to Fig. 6. Then types of the boundaries are defined based on which boundary conditions could be applied.
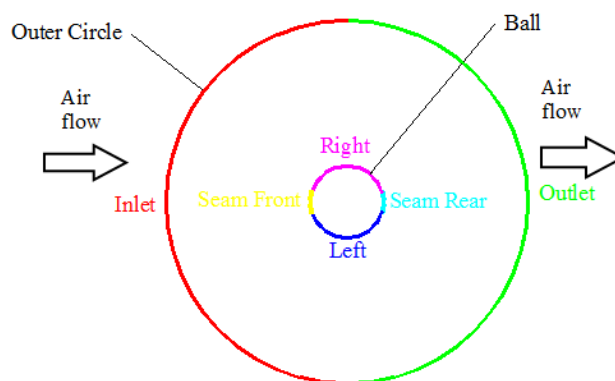

Fig. 6: Defining the boundaries for assigning boundary conditions

The boundary types are fixed in such a way that different initial and boundary conditions could be set easily. At the inlet boundary, as we need to fix the bowling speed i.e wind speed, this boundary is marked as velocity inlet. At outlet, the pressure is atmospheric. All the other boundary types are 'wall' where parameters like surface roughness could be introduced.

Table. 1: Type of Boundaries

Name of the Boundary	Type of the Boundary
Inlet	VELOCITY_INLET
Outlet	PRESSURE_OUTLET
Right	WALL
Left	WALL
Seam Front	WALL
Seam Rear	WALL

3.3. Simulating the Model

As the model is now ready to simulate, the first step is to check the volume of the grids those have been generated. If the volume of all the grids are positive, then the mesh is appropriate for simulation. The fluid material is defined as air with density 1.225 kg/m^3 and viscosity 1.7894×10^{-3} N-s/m^2. The material of the ball is defined as 'leather' with density 900 kg/m^3. The pressure is normal atmospheric pressure of 101.325 kPa.

The next step is to set the boundary conditions. At the inlet boundary, the air velocity which is the same as the bowling speed is fixed. As the swing is generally produced at relatively higher speed, five different high bowling speeds of 27.5, 30, 33, 36 and 40 m/s are considered. At the outlet, the gauge pressure is set to zero.

Surface roughness is set to zero for both the 'left' and 'right' boundaries to consider it as a new ball. For the old ball with one rough surface, the roughness height of the 'left' boundary is fixed at 0.0001m. Both the 'Seam Front' and the 'Seam Rear' are given a roughness height of 0.0005m for both the new and old ball.

After running the simulation, values of total pressure at different points over the surface of the ball is obtained for each cases with different bowling speeds, seam angles and surface roughness. Using these data, total pressure distribution curves for each half surface divided horizontally are plotted . The differece between those two curves provide the amount of pressure differene experiencd by the ball which in turn converts to the side thrust when multiplied by the area of the ball.

4. Results

The pressure contours found after simulation shows the evidence that the seam trips the boundary layer of the lower surface into turbulence. The laminar boundary layer on the upper surface separates relatively early compared to the turbulent layer on the lower surface. By virtue of its increased energy, the turbulent boundary layer, separates later (further back along the ball surface) compared to the laminar layer and so a pressure differential results downward side force. This force which is responsible for the swing in air can be termed as 'side thrust'.

Fig. 7 illustrates the amount of side thrust experienced by the new ball due to various seam angles at different bowling speeds. As expected, the amount of swing increases with the increase of both bowling speed and seam angle.
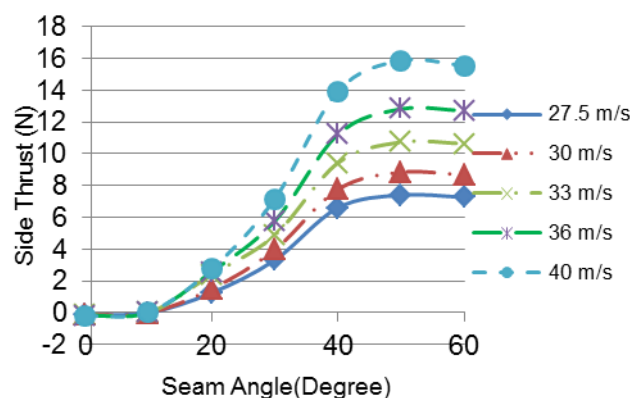

Fig. 7: The effect of seam angle on the side thrust experienced by new ball at various bowling speeds (both side shiny); Seam angle varied from 0-60 degrees with 10 degree interval for five different bowling speeds of 27.5, 30, 33,36 and 40 m/s

Due to almost symmetric flow separation, there is no significant side thrust experienced by a new shiny ball for a seam angle between 0-10 degrees at any speed. Once the seam crosses this barrier, it becomes more efficient in obstructing the flow and trips the boundary layer from laminar to turbulent, thus causing asymmetric flow separation resulting in greater side thrust. However, there is no further effect of seam angle on side thrust if seam angle crosses a certain limit, which is 40 degrees. This trend is observed for all five different bowling speeds. In this case, , the seam no longer plays the role of tripping the laminar flow since the flow separates before reaching the seam. Thus, the maximum amount of swing can be achieved between 20-40 degree seam angles at different bowling speeds.
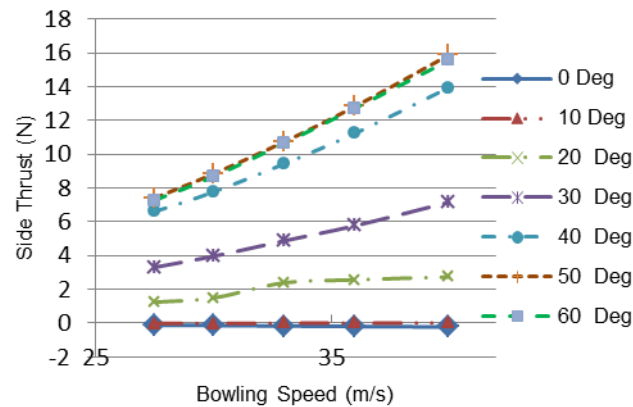

Fig. 8: The effect of bowling speed on the side thrust experienced by new ball at various seam angles (both side shiny); Seam angle varied from 0-60 degrees with 10 degree interval for five different bowling speeds of 27.5, 30, 33, 36 and 40 m/s

Fig. 8 ensures the claim made in the previous paragraph as the ball does not experience sufficient amount of side thrust with a seam angle between 0 to 10 degrees at any bowling speed. As the seam angle goes over 10 degrees, the side thrust increases almost linearly with the increase of bowling speed. Due to higher bowling speeds, increased turbulence is initiated in the seam. As the amount of swing is directly proportional the bowling speed, fast bowlers generate more swing than the slow bowlers. Again, the curves for 50 and 60 degree seam angle almost overlap which indicates that the effect of seam angle reduces as it goes beyond 40 degrees.
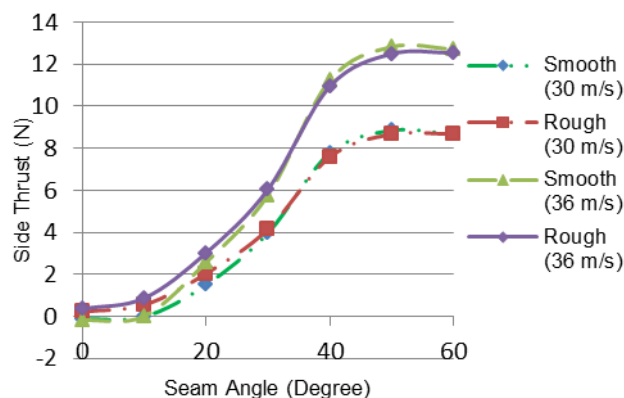

Fig. 9: Effect of surface roughness on the swing of the cricket ball; for the new ball, both the surface is smooth for the new ball and for the old ball, the left surface is rough, bowling speeds of 30 and 36 m/s is considered

It has been widely believed that, the balls with one rough and one smooth surface produce more swing than new balls. That is why the fast bowlers are seen trying hard to maintain the smoothness of one particular surface as the game progresses.

In Fig. 9, the side thrust experienced by a both side smooth ball and one side (left surface) rough ball is compared. For the same speed, the one side rough ball will exhibits greater swing than a both side smooth ball for seam angle of 0-10 degrees. It has been discussed earlier that the seam does not create a significant

amount of turbulence in this range. Thus, the reason for this higher amount of swing at this range of seam angle is mainly due to the surface roughness as the surface roughness causes more turbulence at that side other than the seam itself.

As the seam angle increases over 10 degrees, the seam starts to play the dominant role to cause the turbulence thus decreases the difference between the amounts of swing obtained in smooth and rough ball. This trend is similar both for lower (30 mps) and higher (36 mps) speeds. As the seam angle increases further over 30 degrees, the effect of surface roughness diminishes and the seam angle becomes solely responsible for the swing. At this higher seam angle, new smooth balls will exhibit more swing than the old rough balls. This concludes that, to obtain higher amount of swing with the new ball, the seam angle should be higher while higher swings can be achievable with old balls at low seam angles.
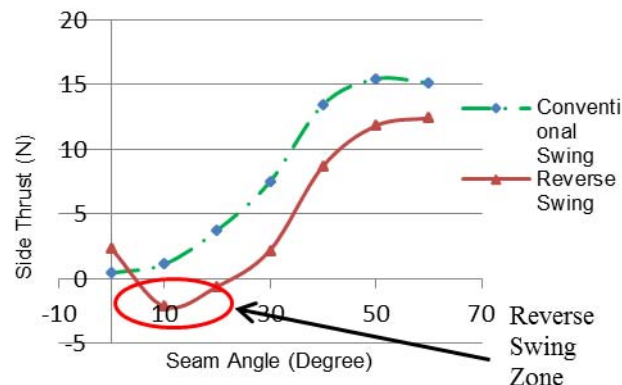

Fig. 10: Generation of reverse swing compared to conventional swing at bowling speed of 40 m/s; in the marked region, reverse swing will produce instead of conventional swing

Reverse swing has always been a mysterious phenomenon to cricket critiques. In reverse swing the ball swings in a direction opposite (or reversed) to that expected based on conventional cricketing wisdom and accepted aerodynamic principles. Few bowlers are able to bowl those, yet the dynamics behind it was quite unknown. This study observes that a critical combination of bowling speed, seam angle and surface roughness could produce reverse swing.

To generate reverse swing, it is essential to have a rough surface in the non-seam side facing the batsman. The rough surface on the non-seam side produces more turbulence than the turbulence created by the seam for a definite range of seam positions. Now, the pressure is higher at the left side which causes the ball to swing in the direction which is opposite to the direction of conventional swing.

In Fig. 10, side thrust vs. seam angle curves for two balls having surface roughness in either side is shown. In the seam angle range of 7-20 degree, the side thrust experienced by the ball having surface roughness on the non-seam side is negative that is now the thrust is in a direction from left toward the right. As a result, the ball will experience reverse swing instead of conventional swing though the orientation of seam generally produces conventional swing. From Fig. 10, maximum reverse swing for 40 m/s bowling speed will occur at a seam angle of 10-12 degrees.

As the seam angle of the ball increases, the turbulence caused by the seam on the smooth side becomes dominant which reduces the effect of roughness on the non-seam side, thus the reverse swing phenomenon no longer exists. At these higher seam angles, the ball exhibits conventional swing but the amount of swing reduces due to the cancellation of force caused by the turbulent flow on both sides.

As mentioned earlier, some fast bowlers still achieve reverse swing with the new ball at relatively higher speed. However, reverse swing is certainly possible at lower speeds with an older ball and our data completely explain this phenomenon.

5. Conclusion

This paper clearly demonstrates the effect of bowling speed, seam angle and the surface roughness on the amount of swing in the cricket ball. Findings of this study are quite interesting. Swing behaviors are very much dependent on the mentioned factors and the amount of swing and its direction can be predicted by these factors. The computational modeling and simulation approach carried in this study clearly shows the

pressure difference caused by the asymmetric flow over the ball. In the simulation, the flow over the non-seam side remains laminar and separates earlier than the turbulence flow on the seam side which supports the theory behind the swing. This study can guide a bowler to achieve maximum swing with his bowling speed.

One of the major findings of this study is, it uncovers the mystery of reverse swing and figures out the critical combination of those three parameters considered in this study to produce reverse swing. Knowing this combination a fast bowler can really surprise the batsmen with reverse swing.

Swing of the ball also depends on the bowling style of the bowler, the environmental conditions like humidity and the rotation of the ball with respect to its own axis (Magnus effect). Further improvements of this study could be possible by taking account of such parameters.

6. Acknowledgements

7. Reference

[1] L. Rayleigh. On the irregular flight of tennis ball. *Mess. Math*. 1877, **7**:14-16.

[2] J. J. Thompson . The dynamics of the golf ball. *Nature.* 1910, **85**: 2151-2157.

[3] J. C. Cooke The boundary layer and the seam bowling. *The Mathematical Gazette.* 1955, **39**: 196-199.

[4] R. A. Lyttleton . The swing of a cricket ball. *Discovery*. 1957, **18**: 186-191.

[5] R. D. Mehta, and D. H. Wood Aerodynamics of the cricket ball. *New Scientist.* 1980, **87**: 442-447.

[6] N. G. Barton. On the swing of a cricket ball in flight. *Proceedings of the Royal Society London.* 1982, **379**: 109-131.

[7] K. Bentley, P. Varty, M. Proudlove and R. D. Mehta. An experimental study of cricket ball swing. *Imperial College Aero Technical Note.* 1982, pp. 82-106.

[8] R. D. Mehta, K. Bentley, M. Proudlove and P. Varty. Factors effecting cricket ball swing. *Nature*. 1983, **303**: 787-788. doi: 10.1038/303787a0

[9] B. Wilkins. The bowler's art. *A & C Black Publishers. London*, 1991.

[10] A. T. Sayers, and A. Hill. Aerodynamics of the cricket ball. *Journal of Wind Engineering & Industrial Aerodynamics*. 1999, **79**: 169-182. doi: 10.1016/S0167-6105(97)00299-7

[11] R. D. Mehta. Aerodynamics of sports ball. *Annual review of Fluid Mechanics*. 1985, **17**: 151-189. doi: 10.1146/annurev.fl.17.010185.001055

[12] R. D. Mehta. An overview of cricket ball swing. *Sports Engineering*. 2005, **8**: 181-192,

[13] W. Bown W, and R. D. Mehta. The seamy side of swing bowling. *New Scientist*. 1993, **139**: 21-24

[14] G. D. Lock, S. Edwards, and D. P. Almond. Flow visualization experiments demonstrating the reverse swing of a cricket ball. *Sports Engineering and Technology*. 2010, **224**: 191-199.

[15] A. T. Sawyers. On the reverse swing of a cricket ball- modeling and measurements. *Proc. IMechE, Part C: J. Mechanical Engineering Science*. 2001, **215**: 45-55.