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CFD Analysis of Reverse Swing of Cricket Ball

Dhruvin V Shah [1], Arpit N Patel[2], Darshan N Panchal[3], Arnab J Ganguly[4]

[1]*Assistant Professor, Department of Aeronautical Engineering, SVIT-Vasad dhruvinshah.aero@svitvasad.ac.in*

[2]*Assistant Professor, Department of Aeronautical Engineering, SVIT-Vasad arpitpatel.aero@svitvasad.ac.in*

[3]*Student, Department of Aeronautical Engineering, SVIT-Vasad darshanpanchal24@gmail.com*

[4]*Student, Department of Aeronautical Engineering, SVIT-Vasad arnab10893.ajg@gmail.com*

Abstract-*Aerodynamics plays a prominent role in defining the behavior of a cricket ball that is struck or thrown through the air. Our main interest lies in the fact that the ball can often deviate from its initial straight path resulting in a curved flight path. Lateral deflection in flight, commonly known as swing is well recognized in cricket, tennis, soccer and baseball. The lateral deflection is produced by swinging the ball about an axis perpendicular to the line of flight, which gives rise to the "MAGNUS EFFECT". The model for simulation of reverse swing of cricket ball is designed in "CATIA V5 R21" which is meshed in "ICEM CFD 15(ANSYS)" and the analysis is carried out in "ANSYS FLUENT"*

Keywords-*CFD; Reverse Swing; Cricket Ball; Magnus Effect; Side Force*

I. INTRODUCTION

The essence of swing bowling is to get the cricket ball to deviate sideways as it moves through the air towards or away from the batsman. The asymmetry of the ball is encouraged by the constant polishing of one side of the ball by members of the fielding team, while allowing the opposite side to deteriorate through wear and tear. With time, this produces a marked difference in the aerodynamic properties of the two sides. Both turbulent and laminar airflow contribute to swing. Air in laminar flow separates from the surface of the ball earlier than air in turbulent flow, so that the separation point moves toward the front of the ball on the laminar side. On the turbulent flow side it remains towards the back, inducing a greater lift force on the turbulent airflow side of the ball. The calculated net lift force is not enough to account for the amount of swing observed. Additional force is provided by the pressure gradient force.

When the ball is new, the seam is used to create a layer of turbulent air on one side of the ball, by angling it to one side and spinning the ball along the seam. This changes the separation points of the air with the ball; this turbulent air creates a greater coverage of air, providing lift. The next coverage and as there is a difference in air velocity, the static pressure of both sides of the ball are different and the ball is both 'lifted' and 'sucked' towards the turbulent airflow side of the ball.

When the ball is older and there is an asymmetry in roughness the seam no longer causes the pressure difference, and can actually reduce the swing of the ball. Air turbulence is no longer used to create separation point differences and therefore the lift and pressure differences. On the rough side of the ball there are scratches and pits in the ball's surface. These irregularities act in the same manner as the dimples of a golf ball: they trap the air, creating a layer of trapped air next to the rough side of the ball, which moves with the surface of the ball. The smooth side does not trap a layer of air. The next

layer of air outward from the ball will have a greater velocity over the rough side, due to its contact with a layer of trapped air, rather than solid ball. This lowers the static pressure relative to the shiny side, which swings the ball. If the scratches and tears completely cover the rough side of the ball, the separation point on the rough side will move to the back of the ball, further than that of the turbulent air, thereby creating more lift and faster air flow. This is why a slightly older ball will swing more than a new ball. If the seam is used to create the turbulent air on the rough side, the tears will not fill as quickly as they would with laminar flow, dampening the lift and pressure differences. Reverse swing occurs in exactly the same manner as conventional swing, despite popular misconception. Over time the rough side becomes too rough and the tears become too deep - this is why golf ball dimples are never below a certain depth, and so "conventional" swing weakens over time; the separation point moves toward the front of the ball on the rough side. When polishing the shiny side of the ball, numerous liquids are used, such as sweat, saliva, sunscreen, hair gel (which bowlers may apply to their hair before a game) and other illegal substances like Vaseline (applied to the clothing where the ball is polished). These liquids penetrate the porous surface of the leather ball. Over time the liquid expands and stretches the surface of the ball (which increases the surface area meaning more lift) and creates raised bumps on the polished side, due to the non-uniform nature of the expansion. The valleys between the bumps hold the air in the same manner as the tears on the rough side. This creates a layer of air over the shiny side, moving the separation point towards the back of the ball on the shiny side. The greater air coverage is now on the shiny side, giving rise to more lift and faster secondary airflow on that side. This is therefore lower static pressure on the shiny side, causing the ball to swing towards it, not away from it as in conventional swing.

A. Reverse Swing

Normal swing occurs mostly when the ball is fairly new. As it wears more, the aerodynamics of the asymmetry change and it is more difficult to extract a large amount of swing. When the ball becomes very old—around 40 or more overs old—it begins to swing towards the shine. This is known as reverse swing—meaning a natural out swinger will become an in swinger and vice versa. In essence, both sides have turbulent flow, but here the seam causes the airflow to separate earlier on one side. The result is always a swing to the side with the later separation, so the swing is away from the seam.

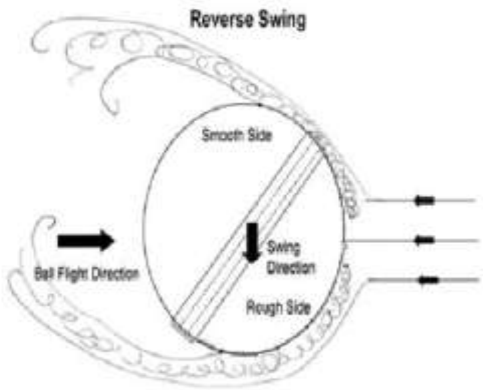


Figure 1 Direction of Reverse Swing

Reverse swing tends to be stronger than normal swing, and to occur late in the ball's trajectory. This gives it a very different character from normal swing, and because batsmen experience it less often, they generally find it much more difficult to defend against. It is also possible for a ball to swing normally in its early flight, and then to alter its swing as it approaches the batsman. This can be done in two ways one for the ball to reverse its direction of swing, giving it an 'S' trajectory: the other is for it to adopt a more pronounced swing in the same direction in which the swing is already curving; either alteration can be devastating for the batsman. In the first instance, he is already committed to playing the swing one way, which will be the wrong way to address swing which is suddenly coming from the opposite direction: in the second instance, his stance will be one which is appropriate for the degree, or extent, of the expected swing, and which could suddenly leave him vulnerable to LBW, being caught behind, or bowled.

B. GOVERNING EQUATIONS

Computational Fluid Dynamics is a science of predicting fluid flow, heat and mass transfer, chemical reactions, and related phenomenon by solving numerically the set of governing numerical equations.

Continuity Equation

$$\frac{D\rho}{Dt} + \rho\nabla.\vec{V} = 0 \qquad (1)$$

Momentum Equation

$$\rho\frac{Du}{Dt} = -\frac{\partial \rho}{\partial x} + \frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z} + \rho f_x \qquad (2)$$

Energy Equation

$$\frac{\partial \rho u}{\partial t} + \frac{\partial \rho u^2}{\partial x} + \frac{\partial \rho uv}{\partial x} + \frac{\partial \rho uw}{\partial x} = -\frac{\partial p}{\partial x} + \frac{\partial}{\partial x}\left(\lambda \nabla.V + 2\mu\frac{\partial u}{\partial x}\right) + \frac{\partial}{\partial y}\left[\mu\left(\frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}\right)\right] + \frac{\partial}{\partial z}\left[\mu\left(\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x}\right)\right] + \rho f_x \qquad (3)$$

C. CFD PROCEDURE

As mentioned earlier, there are a number of CFD packages available, however all these codes are structured around a numeric algorithm used to model fluid flow problems. The numeric algorithm is made up of three elements:-

Pre-Processing

The pre-processor consist of input of flow problems into the CFD program. This step includes such activities as definition of the geometry, generation of the grid, defining of the fluid properties and specification of boundary condition

Solver

This is the numerical method used to solve the fluid flow problems. One of the most widely validated techniques is the Finite Volume Method. Domain is discretised into a finite set of control volumes. General conservation equations for mass, momentum and energy are solved on this set of control volumes.

Post-Processing

This stage allows for the analysis and presentation of the data produced by the solver. This usually includes geometry and grid display, vector plots, contour plots, particle tracking and animation. It is the second of these stages, the solver stage, which is the most complicated and is highly dependent on the computing power available it is during this stage that the CFD software solves the set of differential equations associated with the flow, these include the Navier-Stokes equations and the Continuity Equation This is especially true for the case of turbulent flows In principle the Navier-Stokes equations apply equally in both laminar and turbulent cases, however the detail associated with turbulent flow is small scale and is far beyond the capabilities of current generation computers.

II. GEOMETRY

Geometry of the project is designed by using CAD software CATIA (Computer Aided Three-Dimensional Interactive Application)-V5R21 which is multi-platform CAD/CAM/CAE commercial software.

Diameter of Ball	74mm
Thickness of seam	1mm
Width of seam	20mm
Width of Control Volume	5D
Height of Control Volume	5D
Length of Control Volume	7D

Table 1 Dimensions of cricket ball

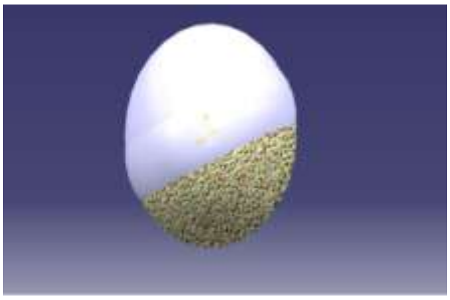


Figure 2 Ball with 0.3mm Roughness

III. Meshing

The ball has now reached to the level of meshing which is carried out in ICEM CFD 15 with a course unstructured tetrahedral mesh. The total number of elements obtained after meshing were approximately 158339.

Total Elements	159339
Total Nodes	29225
Min:	-0.220672 -0.185 -0.234215
Max:	0.412929 0.185 0.345215

Table 2 Mesh Info

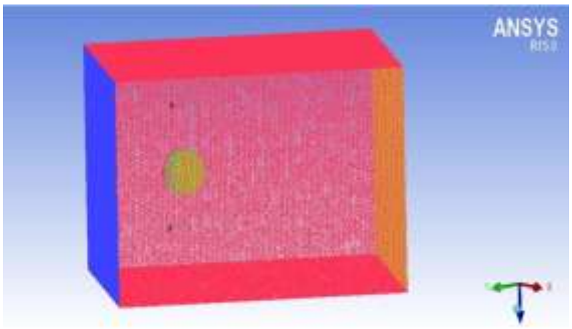


Figure 3 Wireframe view of mesh

IV. Solution Setup

General	Pressure –based, Transient Analysis
Model	Viscous-Detached Eddy Simulation(DES)
RANS Model	Spalart Allmaras
Material	Fluid-Air

Table 3 Solution setup parameters

V. Boundary Conditions

Inlet	Type	Velocity-inlet
	Velocity magnitude	33m/s
	Temperature	300K
Outlet	Type	Pressure-outlet
Box	Type	Wall
	Wall Motion	Moving Wall
	Shear Condition	Specified Shear
Ball	Type	Wall
	Wall Motion	No slip

Table 4 Boundary conditions

VI. Results and Discussions

The maximum pressure is created at the leading edge of the ball while a wake region is created at the trailing edge. The flow is separated early at the rough surface i.e. at the bottom of the ball while there is a late separation at the top of the ball having smooth surface

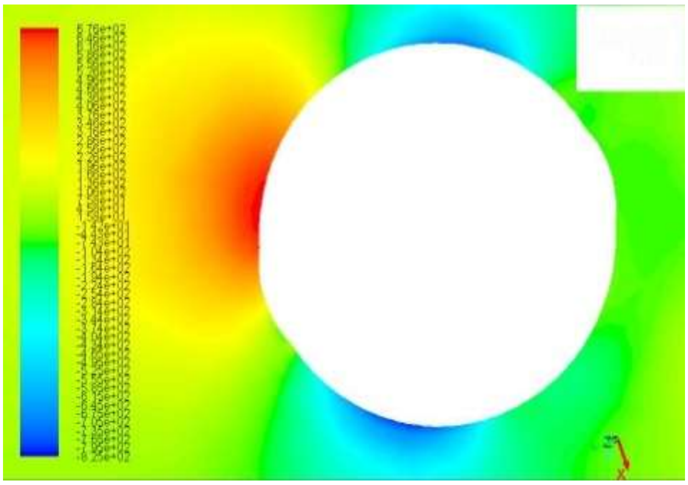
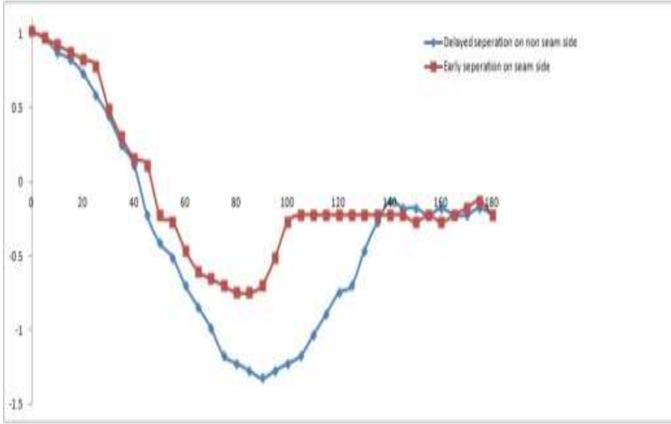


Figure 4 Static pressure variation



Plot 1 Variation of Cp v/s Angle from Stagnation point

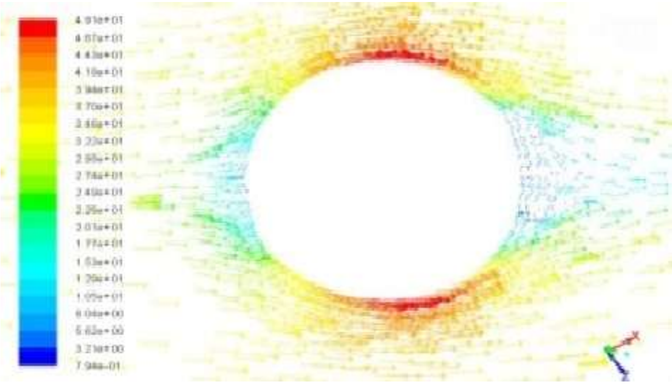


Figure 5 Behavior of velocity vectors

Above figure shows the behavior of velocity vectors for the flow over the surface of the ball. The purpose of showing the velocity vectors is to see the behavior of the ball striking the surface, flowing over it and finally leaving at the trailing edge creating a wake region

The pressure coefficient variation at different angles from the point of stagnation for 0.3mm roughness height is shown as below:

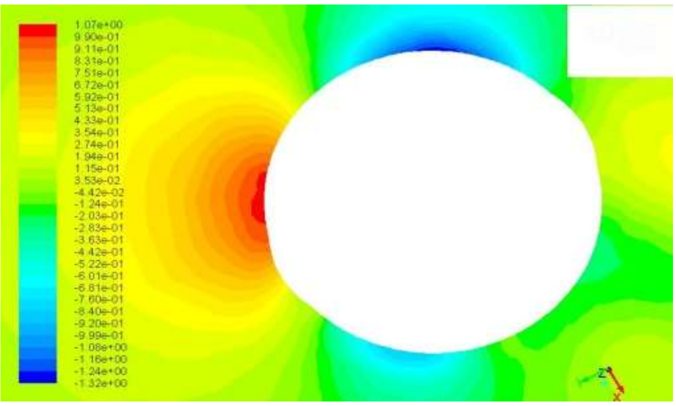


Figure 6 Pressure coefficient variations

VII. Conclusions

The reverse swing of cricket ball was satisfactorily simulated for different values of roughness height for ball. Reverse swing was found to occur when seam side of ball underwent turbulent separation and non seam side underwent laminar separation. The separation point lies in range of 90-110° for seam side and 130-150° for non seam side or smooth side.

The present simulation can have a limitation as far as modelling of seam is concerned. The manufacturing variability in shape of ball was neglected.

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