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Research Article

Analysis of footballs to study their overall performance using design parameters and explain the knuckling effect using CFD

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Abstract

The design of a football entails consideration of various aerodynamic parameters to optimize its flight characteristics inclusive of surface roughness, number of panels, panel shapes, seam angles etc. The layout of football has advanced from the standard 32-panels to the 6 panels with different panel shapes. The primary objective of this study is to determine the influence of the surface roughness design parameter of selected and designed balls a smooth sphere, 32 panels football and FIFA 2014 football Brazuca on their aerodynamics, which is assessed by the flight traits such a drag force, drag coefficient and lift coefficient in CFD Analysis. The end result of these effects with and without surface roughnesses are defined within side the paper and are used to give an explanation and apprehend the reasons behind the unusual phenomenon of knuckling effects of footballs.

Keywords: Drag Coefficient, Football, Lift coefficient, Number of panels, Surface roughness

1. Introduction

When it comes about football matches, football itself is one of the most overlooked factors. The most common exciting factor is that football has through many modifications over the years. The excitement rises among fans across the world with today's game of the Fédération Internationale de Football Association (FIFA) World Cup tournament. People were inquisitive about aerodynamics and aviation for thousands of years, while NASA is known for space science and airplanes; it additionally likes solving more down-to-earth problems. While NASA isn't in the business of designing or testing balls, they show an interest in advancing development in such a sport to offer a possibility to provide an explanation for the principles of aerodynamics to students and individuals by presenting them with something they are able to relate to. These remarkable changes in football's design parameters have piqued the curiosity of researchers to study their effects on the aerodynamics. To begin with, the work of Alam, Chowdary, Moria and Fuss suggests the study of the aerodynamics of 32 panels and 14 panels using the arrangements of experiments in the wind tunnel which graphically represents the drag force and the coefficient taking into account the seam angle of the balls[3]. Similarly, analysing five non-spinning FIFA accepted soccer balls in the same configuration and prediction of their trajectories by Goff, Hobson, Asai and Hong explained the effect of knuckling with respect to Reynolds number and hydrodynamic boundary layers[5]. Even though the paper could incorporate the basic parameters that the flow is dependent on, it lacks the consideration of ball design traits.

Recent work by Hasan, Haider and Naimuddin has concluded that CFD analysis can be conveniently used instead of experimental work and gave full initiative to complete the project with simulation software as the results and the like were compared in a wind tunnel experiment[9].

In a majority of these studies, the primary layout elements that depend on present day football design has now no longer been taken into consideration whilst while experimenting or while mentioning a have a look at which could assist in analyzing the unpredicted course of balls and has failed to clarify the motives that control the flight of the ball in phrases of football properties and know-how the modern enhancement and cutting-edge upgrades added from the conventional 32 panel ball. This study focuses on simulation techniques to examine flight and factors influencing it. In this work, we record the effects of critical parameters like the surface roughness and quantity of panels which can be successfully taken into consideration and convey the presently derived football designs. We investigate the drag force and lift force of balls and smooth sphere with surface roughness under the knuckling speed in assessment to provide an explanation for the flight characteristics and to analyze the knuckling effect.

2. Methodology

Design

The required models were designed in Autodesk Fusion 360 with the desired dimensions and appearance. The design of the football changes in number, shape and surface roughness of the panels, all the footballs have the standard properties 'size 5' dimensions diameter 22cm, circumference 68cm. The first design was a smooth sphere with white leather-based as material. The traditional 32 panel has a round truncated icosahedron and it consists of 12 regular pentagons and 20 regular hexagons which are externally stitched. These panels are given the equal synthetic white and black leather as the sphere. The first thermally bonded ball became the Teamgeist in 2006 FIFA with decreased no of panel of 14, then came the 2010 Jabulani with 8 panels and the Brazuca ball, that is thermally bonded with reduced no. of panels of six which improves the consistency, introduced in 2014 FIFA world cup by Adidas rectifying maximum of the aerodynamic problems confronted in Jabulani.

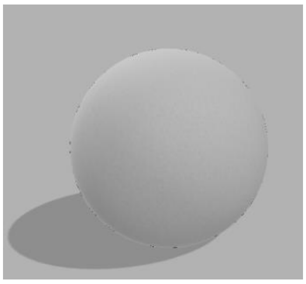


Fig. 1 Smooth sphere

Fig. 2 Traditional football

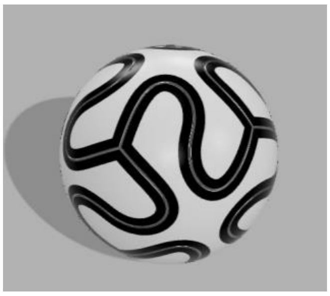
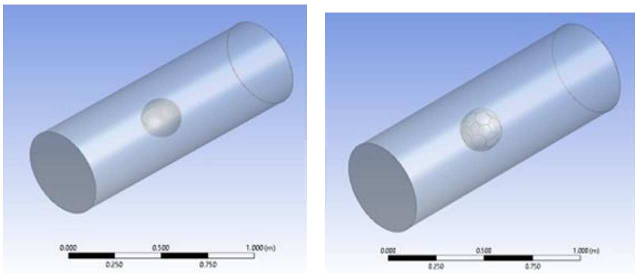


Fig. 3 2014 Brazuca ball

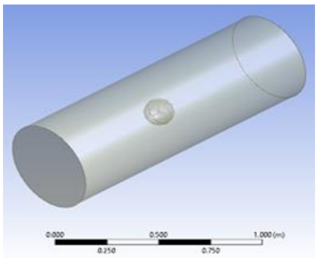
Meshing

After modeling the footballs in Autodesk Fusion 360, the 3D model of football is imported into Ansys Workbench Version 2019 R1. The fluid domain around the balls is modeled as enclosure and discretized in Ansys with tetrahedral elements. The shape of the domain is cylinder to be able to resemble a wind tunnel and two side surfaces are called as inlet and outlet, the lateral surface as the wall of the enclosure that holds the ball in the middle of each side. Placing the surface of the ball, diameter d, at 34d from the inlet, 34d from the outlet and 1.1d from the sides of the domain was found to be sufficient. The mesh generated in Ansys mesh editor has 110869 elements and 22094 nodes for the sphere, 51966 nodes and 267726 elements for the conventional football 2561245 elements and 579403 nodes for Brazuca. The given boundary conditions are:

1. Inlet- The inlet of the cylinder is taken as the velocity inlet
2. Outlet- The outlet of the cylinder is taken as the velocity outlet
3. Lateral surface- It is considered as stationery wall
4. Ball- ball is considered as stationery in the middle of the wind tunnel



(a) Smooth sphere (b) 32 panel



(c) 6 Panel ball

Fig. 4 Enclosure of the designed balls

Simulation

The flow is in-compressible and unsteady. The governing equations used are Continuity equation and momentum equation and the selected model is K- Epsilon standard model and Realizable wall function settings for turbulent flow region. The discretization scheme applied for Momentum is a second order upwind scheme, used for acquiring the second-order accuracy and Pressure, a second order and turbulent kinetic energy second order upwind scheme. The velocity applied is 32m/s which are the initial speed range for knuckling to happen. The considered surface roughnesses are 0.11, 0.55 and 2.75 at a height of 0.5mm. 100 iterations for initialization and 250 iterations for calculation were given during the process.

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho v) = 0$$

$$\frac{\partial(\rho u)}{\partial t} + \nabla.(\rho u \overline{\nabla}) = -\frac{\partial p}{\partial x} + \frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z} + \rho f_x$$

$$\frac{\partial(\rho v)}{\partial t} + \nabla.(\rho v \overline{\nabla}) = -\frac{\partial p}{\partial y} + \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{zy}}{\partial z} + \rho f_y$$

$$\frac{\partial(\rho w)}{\partial t} + \nabla.(\rho w \overline{\nabla}) = -\frac{\partial p}{\partial z} + \frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \tau_{zz}}{\partial x} + \rho f_z$$

3. Result And Discussion

The CFD analysis tool was found to be a powerful tool for the comparative analysis of soccer ball aerodynamics, even though there were some limitations with the software capabilities and the available computational resources. The most suitable and accurate meshing and solving techniques that were chosen for the analysis of soccer balls were combined together into an analysis tool, which used the solving parameters for the real footballs.

Influence of number of panels

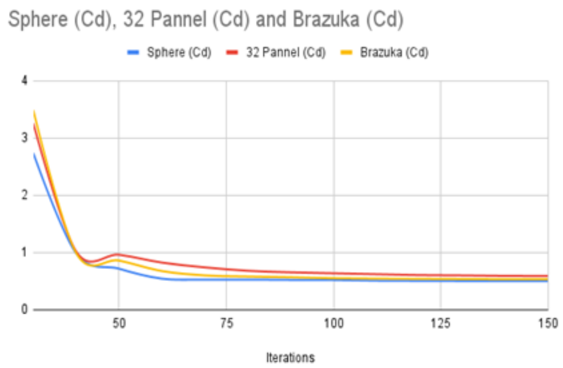


Fig. 5 Cd Vs Iteration

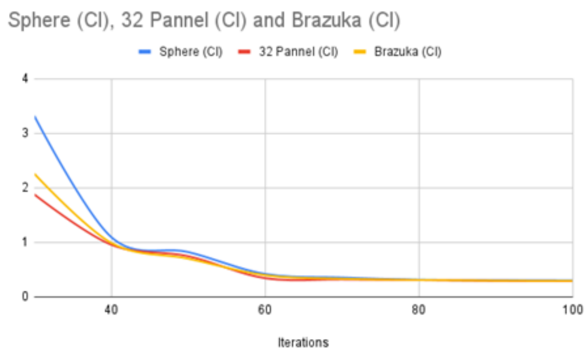


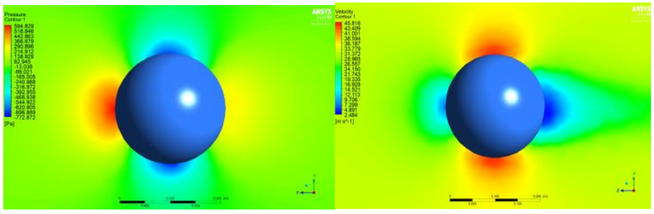
Fig. 6 Cl Vs Iteration

When a smooth ball is struck over a velocity of 70mph with very little spin, the ball has a tendency to move laterally because the drag coefficient drops and the lift coefficient slightly increases. As an end result the ball gets volatile in midair and the trajectory of the ball turns into unpredictable even by the person hitting the ball. The graph on account of the CFD simulation of the three balls, smooth sphere, 32 panel football and brazuca of six panels after 150 iterations is shown. The x axis shows the number of iterations and the y axis shows the drag coefficient, Cd. The inlet condition is 32m/s which are the average speed of knuckling impact to take place (70mph). Since the primary result is to analyze the aerodynamics of the ball is obtained without considering the surface roughness, therefore the number of panels offers major importance here. No external surface roughness is applied to the sphere, 32- panel ball and Brazuca in simulation to eliminate the additional influence of surface roughness. For the first few iteration the Cd values are unexpectedly high after which generally tend to lower gradually. From the 100th iteration after the value converges it becomes constant throughout.

In a study by Morshita, Homma it was experimentally determined that the Cd of a smooth sphere is 0.6[2]. The value of Cd for smooth sphere is 0.5038, conventional football with 32 panels is 0.591 and brazuca with 6 panels is 0.533 was obtained from the analysis. The result obtained agrees with the study of Oggiano and Saetran who graphically represented the drag coefficient of an ideal sphere as in between 0.5 and 0.6[7]. By Barber,Asai stating that the values of Cd were generally lower than in the experiment because the effects of the flow interaction[8].

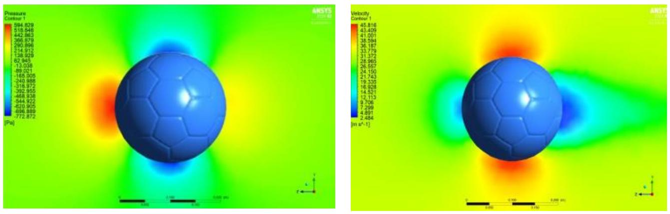
between the ball and its support device could not be fully taken into account, justifies the above results. The influence of this design parameter is negligible with laminar flow, and shows deviation as soon as turbulence is reached. From this graph, the ball with 32 panels has the highest drag coefficient, followed by Brazuca and smooth sphere. The Cd of Brazuca is 5% and 32 panel ball is 17% larger than that of sphere. This shows that an increase in no. of panels leads to an increase in the drag coefficient. The number of panels also includes the length of the seam so that the number of panel is proportional to the seam length i.e, increase in drag coefficient is also depended upon the seam length. The lift acts perpendicular to the motion of the direction of the ball. It is a force on a soccer ball that can be used to loft or dive the ball that is it aids the striker to kick by giving an elevation. Using experimental data, Choppin measured that Cl value of a least spinning sphere is between 0.23

and 0.29[1]. From the graph, the values determined are 0.247 for sphere, 0.231 for 32 panel and 0.236 for brazuca. This shows that there is slight deviation from the smooth sphere and then values remain almost constant. The Cl of brazuca is 5% lesser and 32 panel ball 7% is lesser than that of sphere. Hence, it can be seen that as the number of panel changes, the variation in the coefficient of lift is relatively less significant than the coefficient of drag. In summary, drag is the property of an object that keeps it in the air, and lift is a property which allows an object to elevate from the ground and helps in its trajectory. Whenever the air resistance decreases the lift effect is impaired.



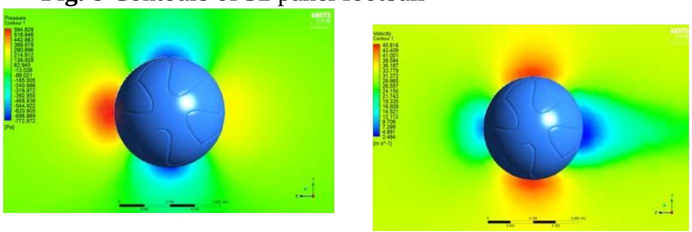
(a) Pressure contour (b) Velocity contour

Fig. 7 Contours of smooth sphere



(a) Pressure contour (b) velocity contour

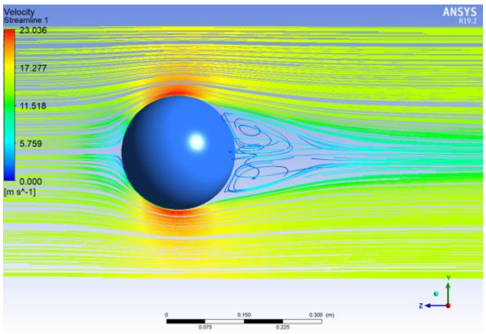
Fig. 8 Contours of 32 panel football



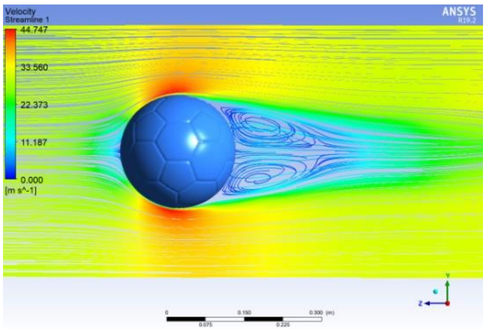
(a) Pressure contour (b) velocity contour

. **Fig 9** Contours of 6 panel brazuca

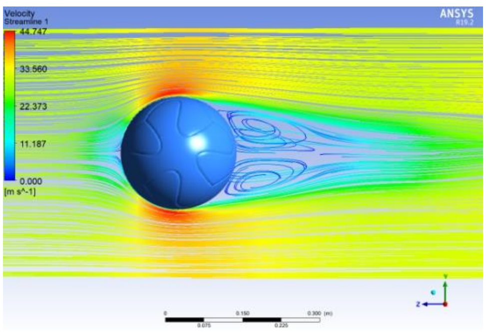
The velocity contour in Ansys fluent is one of the methods by which the velocity sectioning can be graphically obtained. This method helps us to clearly visualize the variation of 41velocity on the surface of the object that is being analyzed. The quality of velocity contour is dependent on meshing quality, mesh size and the governing equations. Different colors represent different fluid velocity. Faster fluid flow is represented by reddish shades and the slower flows by bluish shade. The free flowing fluid will be at the specified inlet velocity and will generally be in a greenish shade. Whenever there is an obstruction in front of the direction of wind flow , the velocity of the flow changes and so does the color contour. In this project we have provided the velocity contours of smooth sphere, 32 panel football, Brazuca and also sphere with surface roughness. As the flow of fluid is from the z direction, the front view of the contour is taken for better understanding and comparison. Firstly a plane was generated on the ZY plane that bisects the sphere into two equal halves. The contours are generated on this plane. The two dimensional representation of the velocity contour clarifies the variation of velocity along the surface of the balls. For the smooth sphere, the curvature of the surface and the absence of any roughness results in a calmer variation in velocity. The inlet fluid flow strikes the frontal portion of the ball and slows down significantly whereas on the sides the curved surfaces cause an increase in the velocity. The curved surface creates an additional distance to be travelled by the fluid. As the time is constant, the fluid flowing on the surface close to the sides of the spear has to travel some additional distance. Mathematically this increases the speed of the flow in the particular case. From the contour we can also observe that as the distance from the ball and the flow is more the velocity increase is considerably lesser, creating a lighter reddish yellow color patch around the sides of the ball. At the rear end of the ball there is a limited air flow, thus showing a low velocity region just behind it. The velocity gradually builds up as the flow from the sides converges. In the case of brazuca, the surface roughness is higher than that of the sphere due to its panels. These panels create an additional drag that in turn brings a small change on the contour. For a 32 panel ball the number of panels and the stitch to ball area ratio are high. This creates a more effective surface friction resulting in the difference in the contour. In addition to the velocity contour, Pressure contour is also added in this project. This is in order to visualize the variation of pressure across the surface of different balls. The pressure contour is very much 42connected to the velocity contour. Pressure and velocity are inversely proportional to each other. If pressure increases, the velocity decreases to keep the algebraic sum of potential energy, kinetic energy, and pressure constant. Similarly, if velocity increases, the pressure decreases to keep the sum of potential energy, kinetic energy, and pressure constant. In mechanics, the relation between pressure and velocity is given by Laplace correction for Newton's equation for the velocity. As per Bernoulli's equation also, pressure is inversely related to velocity. Therefore the pressure contour shows an opposite set of colors when compared with the velocity contour.



(a) Smooth sphere



(b) 32 panel football



(c) Brazuca ball

Fig. 10 Streamlines of footballs

A streamline is a line that is tangential to the instantaneous velocity direction as velocity is a vector, and it has a magnitude and a direction. Since the velocity at any point in the flow has a single value, streamlines cannot cross and the flow cannot go in more than one direction at the same time. Except at points where the velocity magnitude is zero, such as 44at a stagnation point. This method helps us to clearly visualize the variation of velocity and its direction on the surface of the object that is being analyzed. The quality of streamline is also dependent on meshing quality, mesh size and the governing equations. The streamlines also represent the vortex formation at the rear end of the ball. In Fluid dynamics, a vortex is a region in a fluid in which the flow revolves around an axis line, which may be straight or curved. Vortex is a phenomenon that occurs when a gas or a liquid moves in circles. At the center is a vortex line that the matter swirls around. They are formed when there is a difference in the velocity of what surrounds the line. At the rear end of the ball there is a stagnation region where the velocity of the fluid is very small and the fluid flowing from the sides of the ball is relatively faster. In the case of pressure also there is a difference in both the regions. The above mentioned changes can be clearly seen on the Velocity and pressure contours respectively. This causes the formation of vortices and can be visualized by a two dimensional side view of a plane generated streamline. As there is no surface roughness for a smooth sphere the vortices formed are relatively weaker. For the brazuca the vortex is stronger and for the 32 panel football it is the strongest.

Influence of surface roughness

In the previous result it can be seen that with the number of panels, the 32 panel football has greater value of drag coefficient and justifies this, but the 32 panel ball has practically no surface roughness. In the past years football was a much more a slower game, so considering surface roughness wasn't an important factor. After the 1990s, the importance of the ball as such was looked upon and in 2006 the first football without 32 panels was introduced. The importance of surface roughness is to eliminate the knuckling effect by keeping the ball and speeds in a turbulent region. The evolution of football thus began and the design reduced the number of panels to optimise the design, ease the manufacturing process and to ensure consistency.

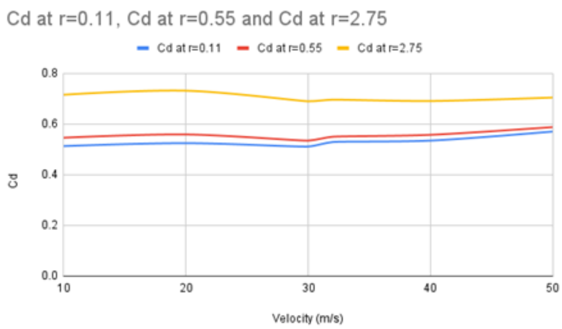


Fig. 11 Cd Vs Velocity

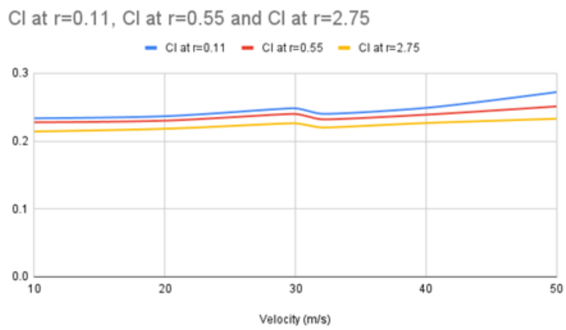


Fig. 12 Cl Vs Velocity

In this analysis, the surface roughness factors were 0.11, 0.55, and 2.75 applied to the periphery of a regular sphere. The roughness height was taken as 0.5mm as mentioned by Hong, Asai which is the most common roughness dimples [11]. From the graph 7 it is inferred that at the point of 32m/s, the Cd is 0.5289 for 0.11, 0.5498 for 0.55 and 0.6961 for 2.75. We can conclude that roughness with 0.11 is 4% more than the Cd of smooth sphere. Similarly roughnesses 0.55 is 9% and 2.75 is 38% more. Then it is determined from figure 8 that Cl for 0.11 is 0.240, 0.232 for 0.55 and 0.224 for 2.75 at 32m/s. From these values it can be summarized that simply increasing the surface roughness doesn't bring an impact on lift coefficient. Using surface roughness beyond a certain value will increase the lift, making it difficult for the striker to kick the ball. When the speed increases over 50m/s, the Cd tends to increase. Smoother as the surface gets less will be the drag and when surface gets rougher the drag increases and the effect of lift increases slightly. Due to these additional depressions on the surface of smooth sphere, the air flow is turbulent. The interaction between the irregularities of the surface with the turbulent flow creates eddies in the valleys of the dimples. This increases the drag of the ball allowing it to stay in air for a longer time thus reducing the effects of lift. Surface roughness can also be a problem for the ball flight, as too much drag creates more lift force for the ball. Therefore, the surface roughness factor has to be in balance such that the natural movement of football does not get affected.

The knuckle ball is when the ball does not spin while flying through the air. Spin gives the ball stability as it moves, and without it, the shot will snake through the air, suddenly changing directions and making it nearly impossible for the goalkeeper to predict it through at any given speed of 70mph to 80mph. Such speed is known as the knuckling velocity where the ball experiences the knuckling impact. Knuckling effect increases whenever there is less no. of panels and the given surface roughness is insufficient to create drag that negatively affects the aerodynamics of the ball, the drag is drastically reduced and the effect of lift is distorted, creating an imbalance. Because of this effect, the trajectory itself cannot be predicted even by the person kicking the ball and creates an uncertainty that gives the person an unfair advantage. The above results show that applying the surface roughness to footballs even to balls having less no. of panels reduce the knuckle effect. In figure, between the 32m/s to 35m/s, i.e. the speed at which the ball moves during the movement, it can be seen that the drag coefficient remains almost constant under surface roughness. Similarly in figure it is found that shortly after the point of 32m/s, there is sudden dip in the value of Cl and then remains almost constant throughout. Thus we can conclude that the ball Brazuca with less no. of panels with surface roughness act like a perfect sphere with optimum drag and lift without the knuckling giving a predictable trajectory in comparison. The official football of 2010 FIFA tournament, Jabulani, had a number of flaws and was criticized for the geometry and seams of the ball; it had a relatively high drag due to knuckle effect, so the ball remained stable in the midair and travel at high speeds. Therefore the design of Brazuca formed in the consecutive world cup has rectified all these problems with even decreased panels from 8 to 6 and increased balanced surface roughness giving it a predictable trajectory.

4. Conclusion

In this study, the impact of surface roughness and number of panels of the footballs on aerodynamics and flight characteristics had been evaluated via way of means of numerical simulation with the usage of Ansys Fluent on three balls, a smooth sphere, 32 panel ball and Brazuca which has different number of panels, panel shapes, seam length and surface roughness. The effects are as compared with a starting speed of knuckling effect. The first end result wherein the CFD of the sphere, 32 and Brazuca is analyzed without surface roughness shows the significance of the number of panels. The number of panels increases drag force and lift increases, so that 32 panels have the highest drag in comparison, but in modern design with reduced panels it seems a necessity to add roughness to a surface. Increase in surface roughness will increase the drag coefficient. Brazuca suggests the outcomes as that of a perfect sphere whilst there is surface roughness on much less number of panels increasing the drag force with best lift. With the above conclusions the knuckling effect is explained. In the future, footballs designs may encounter these kinds of problems wherein it is able to be solved by varying the surface friction factor of the surface along with making the decrease or increase in panels

References

[1] Choppin, " Calculating football drag profiles from simulated trajectories", International sports engineering association (ISEA) 16: 189-194, 2013

[2] Etsuo Morishita and Toshiki Homma, "Experimental and theoretical aerodynamics of a sphere in engineering education", Proceedings of the AAEE2019 Conference brisbane., Australia, 2019.

[3] Firoz Alam, Harun chowdary, Hazim moria and franz konstaanin fuss, "A comparative study of football aerodynamics 8th conference of the international sports engineering association" ,ISEA. Procedia engineering 2 (2010): 2443-2448, 2010

[4] Firoz Alam, Harun chowdary, Marl stemmer, Zilong wang, Jie yang, "Effects of surface structure on soccer ball aerodynamics", 9th conference of the international sports engineering association, ISEA.Australia. Procedia engineering 34 (2012): 146- 151, 2012.

[5] John Eric Goff, Chad michael Hobson, takeshi Asai, sungchan Hong "Wind tunnel experiments and trajectory analyses for five non spinning soccer balls", 11th conference of the international sports engineering association, ISEA. Procedia engineering 147:32-37, 2016.

[6] John eric Goff, sungchan Hong And Takeshi Asai, " Influence of surface properties on soccer ball trajectories", proceedings, 2020

[7] luca Oggiano, Lars saetran, "Aerodynamics of modern soccer balls" 8th conference of the international sports engineering association(ISEA), Procedia engineering 2 2473- 2479, 2010

[8] S. Barber, S.B. Chin, M.J. Carre, " Sports ball aerodynamics: a numerical study of the erratic motion of soccer balls", Computer Fluids. 38(2009) 1091- 1100, 2009.

[9] Suhaib Hasan, Talha Hasan Sayyed Haider, Naimuddin, "Experimental analysis of ve locity distribution over a sphere placed in wind tunnel and its comparison by CFD", International journal of scientific and engineering research. volume 8.Issue 7, Faridabad, 2017.

[10] SungChan Hong and takeshi asai, "aerodynamics of knuckling effect shot using kick-robot", International journal of applied sports science, vol23, 406-420, 2011.

[11] Hong, Asai.,"Aerodynamic effects of dimples on soccer ball surfaces", Elsevier., 2017

[12] Takeshi Asai, Kazuya seo, Yousuke sakurai, shinichiro ito, Sekiya Koike, Masahide murakami, "A study of knuckling effect of soccerball", The engineering of sport 7 vol-1 2014.