AERODYNAMIC PARAMETERS FOR DESCRIPTION OF FLIGHT OF ROTATING VOLLEYBALL

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Abstract: This work deals with description of effect of revolutions on the flight of a rotating volleyball with airstream in defined side angle of attack. The description is based on results of measurements in an aerodynamic tunnel. The flight is described by using dimensionless aerodynamical characteristics such as coefficients of Drag, of Lift and of Side force and coefficients of moments – Roll, Pitch, Yaw with parameters of Reynolds number $Re$, spin $s$ and side angle of attack $\beta$. The real conditions of flight of a volleyball, which were simulated ($Re = 1.5 – 3.8 \times 10^5$) all fall within the region of critical $Re$. All collected results are prepared to be used in the system of 3D ballistic equations. The system of ballistic data and from the experiment can solve all types of flights of a volleyball including the special cases: influence of side wind, flight of ball without rotation.

Description of experiment: The experiment was performed in 1.8 m diameter wind tunnel with open test section (the intensity of turbulence was $1\%$) in the Aerospace Research and Test Establishment, Department of Aerodynamics, Prague, Czech Republic. The main aim of the measurement was to describe all forces and moments acting on the ball flying in the medium. Therefore six strain gauges (accuracy of 1% of measured forces) were used: two for lift force $F_2$, three for drag $F_1$ and one for side force $F_3$. All values, forces $F_1$, $F_2$ and $F_3$ and all moments $M_y$, $M_z$, $M_x$ were evaluated according to simple equations (schema of the experiment is in Fig. 1.):

- Drag: $F_2 = F_3 + F_4 + F_5$
- Side force: $F_3 = F_6$
- Roll: $M_y = F_6\cdot a - F_2\cdot a$
- Pitch: $M_z = (F_5 + F_4)\cdot b - F_2\cdot c$

Measurements conditions:
- air-flow velocity: $v = < 10 – 25 >$ m/s
- revolutions: $n = 0 – 12.5$ rps
- Reynolds number: $Re = 1.5 – 3.8 \times 10^5$

where the reliability $R^2 = 0.4799$. Dispersion of the population of $C_L$: $Var(C_L) = 0.0994$, standard deviation of the population of $C_L$: $s = 0.0967$. It is clear from Fig. 5 that the trend of the population is rising in the interval of spin number $0 < s < 0.6$. For higher values of spin the trend stagnates. The effect of spin on coefficient of Lift $C_L$ is not linear.

Measurements:
In the case of flight of ball without rotation phenomena called knuckling effect appears. It is characterized by unpredicted changes in the path. The effect was noticed in the results of experiment. For further evaluation statistical approach was chosen: medians of six independent tests were calculated to coefficient of Lift, Drag, Side force. It is visible in Fig. 3 that result of Drag is according the expectation (according to smooth sphere) while Lift and Side force results are very close to zero (in the area of uncertainties of the results). This confirms unpredictability of the phenomenon – of knuckling effect.

Influence of revolutions $n$ on transition – in the case of side angle of attack $\beta = 0^\circ$ the effect of Reynolds number and revolutions on coefficient of Drag $C_D$ shows that revolutions cause reduction of $C_D$ (Fig. 2 – red area) for lower Reynolds numbers (lower $Re$ means here: lower half of the investigated interval of Reynolds number $Re < 2.8 \times 10^5$). This phenomena can be explained by the different shape of wake behind the sphere, which is caused by rotation of the ball.

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Influence of revolution – defined by spin $s$ on Lift was studied. The vector of velocity was divided in the case of $\beta = 0^\circ$, only perpendicular component of vector $v$ causes the Magnus effect which results into Lift (principle of superposition was used). The population of results of $C_L$ is depicted in the Fig. 5. The trend of the effect of spin on coefficient of Lift was statistically calculated and it is described by polynomial of third grade – dotted line in Fig. 5.

In the case of flight of ball without rotation phenomena called knuckling effect appears. It is characterized by unpredicted changes in the path. The effect was noticed in the results of experiment. For further evaluation statistical approach was chosen: medians of six independent tests were calculated to coefficient of Lift, Drag, Side force. It is visible in Fig. 3 that result of Drag is according the expectation (according to smooth sphere) while Lift and Side force results are very close to zero (in the area of uncertainties of the results). This confirms unpredictability of the phenomenon – of knuckling effect.

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