# Description of experimental setting: volleyball in the wind tunnel

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**Abstract**

Observation of forces acting on rotating volleyball in the flight is a main task of this presented paper. Therefore, experimental setting is proposed based on requirements: 1. all three forces (Drag, Lift, Side force) and moments (Roll, Pitch, Yaw) need to be measured, 2. volleyball has to rotate in defined revolutions, 3. side angle of attack must be adjustable. All main features of experimental settings are summarized in this paper. All devices used in experiment are introduced. Methodology of experiment procedure is also described in the article. Experiment was performed in regions of velocities v = (10 – 25) m/s, revolutions n = (0 – 12.5) rps and side angles β = 10°, 20°, 30°, 40°and 45°. First results are presented and following steps of project are recommended.

*Keywords:* aerodynamics, revolution, drag, lift, side force, moment, volleyball,

## 1. Introduction

Measuring of forces acting on the volleyball in flight is a project, which started at CTU in Prague, Department of Fluid dynamics and Thermodynamics in the year 2009 in the Bachelor thesis. Firstly it was description of the phenomena of volleyball service, definition of boundary and initial conditions, study of flight from the video and in calculation by using 2D ballistic equations, presented in [1]. Secondly in diploma thesis [2] first experiment to measure drag and lift of the volleyball was set up in the laboratories of Department of Fluid Dynamics and Thermodynamics and 3D ballistic equations were introduced. One conclusion of diploma thesis said, that tunnel used in the laboratories of Department of Fluid dynamics and Thermodynamics is not correct for this specific measurement. In the next stage of the project, more sophisticated solution must have been used, new experiment must be built up.
Low speed wind tunnel with 1.8m diameter in the test section of Aerospace Research and Test Establishment, Department of Aerodynamics was used. Experiment set up was built for measurements of lift and drag forces. Experimental set up is visible in the Fig. 1. Results of dependences of coefficient of drag $C_D$ vs. Reynolds number and coefficient of lift $C_L$ vs. spin were presented in [2] and [3].

Measurement of drag and lift was performed, but description of all forces acting on volleyball was not complete. Side force must be add in the setting and also moments acting on the ball should be observe. Third performed experiment setting is based on scheme, which was firstly introduced in [4]. Description of the setting of the experiment is presented in this article.

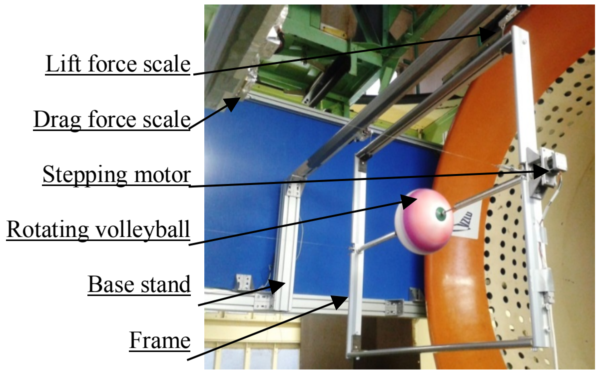


*Figure 1: Description of setting of the first experiment - only drag and lift, 2014, source [3]*

## 2. Scheme of measurement

Basic task of the setting is to make complete description of forces acting on a volleyball in the flight including turning of side angle of attack. Requirements of the setting of experiment specifically:
1. all three forces (Drag, Lift, Side force) and moments (Roll, Pitch, Yaw) need to be measured,
2. volleyball has to rotate in defined revolutions,
3. side angle of attack must be adjustable.

The setting scheme is visible in the Fig. 2. Forces and moments are calculated according simple equations (1) to (6):

- Drag:
$$F_D = F_3 + F_4 + F_5 \quad (1)$$
- Lift:
$$F_L = F_1 + F_2 \quad (2)$$
- Side force:
$$F_S = F_6 \quad (3)$$
- Roll:

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$$M_X = F_1 \cdot a - F_2 \cdot a \tag{4}$$

- Yaw:

$$M_Y = F_4 \cdot f - F_3 \cdot f \tag{5}$$

- Pitch:

$$M_Z = (F_3 + F_4) \cdot b - F_5 \cdot c \tag{6}$$

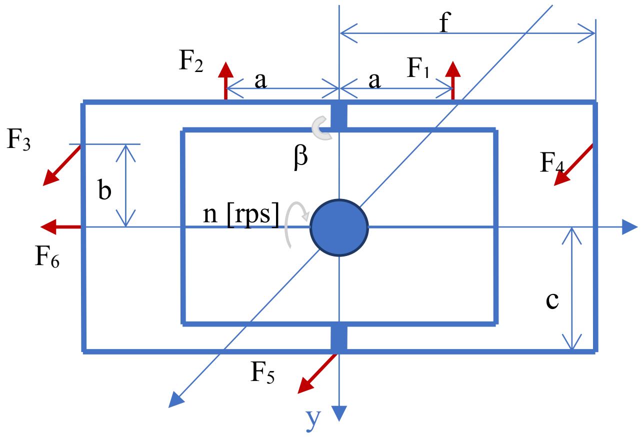


*Figure 2: Scheme of experimental setting*

## 3. Description of experiment

Based on scheme defined in Chapter 2, description of devices used for experiment follows.

### 3.1 Wind tunnel

Open circuit atmospheric wind tunnel with continuous run (1.8M LSWT), which is in the laboratory of VZLU Aerospace Research and Test Establishment, Department of Aerodynamics was used. Wind tunnel circular test section of 1.8 m dia x 1.75 m in length. Maximum velocity of air-

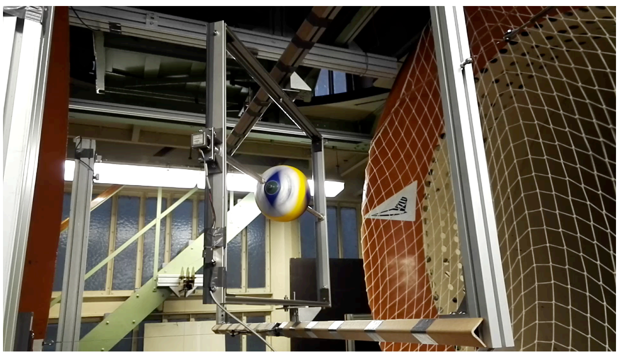

*Figure 3: Test section of low speed wind tunnel with installed stand for volleyball*

stream is 55 m/s. Test section of the wind tunnel is shown in the Fig. 3. Characteristic turbulence intensity is 0.5%. Maximum deviation of local velocity from mean velocity is less than 0.5%, all facts are from source [5].

### 3.2 Frame for volleyball

Frame, which holds the volleyball in the air stream is depicted in the Fig. 4, first proposal of this device was introduced and frame was constructed in [6]. The frame holds the stepping motor and allows the volleyball to rotate.

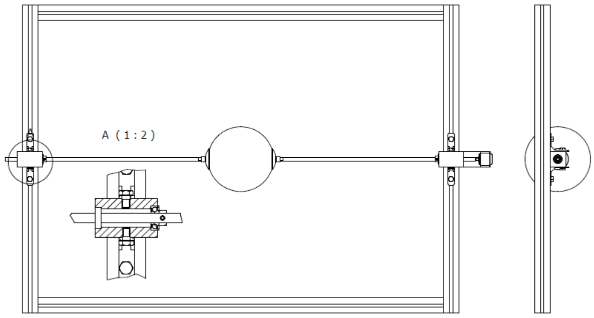


*Figure 4: Construction draft of a frame for holding the volleyball in the airstream*

### 3.3 Outer frame

Due to request: turning side angle of attack the additional outer frame was built around the original frame. Connection of two frames was ensured by small plate, which is visible in the Fig. 5. This connection enables to set exact side angle of attack, as requested in the assignment. Forces acting on the volleyball are measured by connection of outer frame to strain gouges (strain gouges are firmly mounted to the base stand), as it is proposed in the scheme in the Fig. 2.

*Figure 5: Connective plate, which enables to set different angle of side attack up*

### 3.4 Stepping motor

Function of stepping motor is to initiate revolutions of volleyball. Stepping motor Microcon SL17 – 0301 was chosen, technical details are in [7]. Motor is connected to the rotating axe at the frame, as it visible in the Fig. 6. Stepping motor is controlled by signal from the driver: M415B, Micro Microstepping Driver from Leadshine Technology Co., Ltd., Fig. 7. All detailed information about the driver is in [8].

### 3.5 Strain gauges

Six of the Zemic load cell model L6D were used for measuring forces. Class of accuracy of the cells is C3. Cells were connected to the base frame, as it is visible in the Fig. 8. Position of the load cells was precisely found by using planar laser – device Bosch GLL 3-80 P Professional. Connection between the strain gauges and outer frame was made by strings.

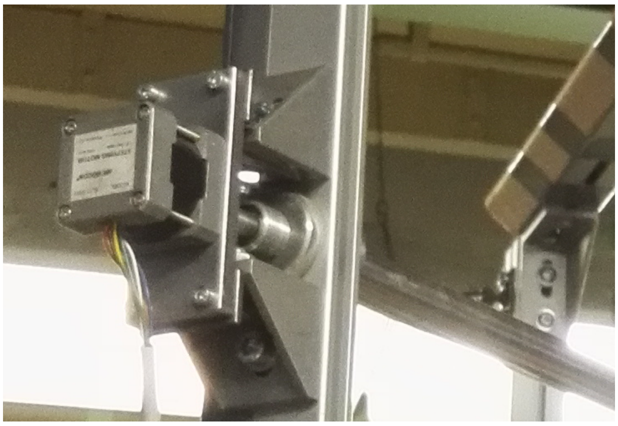

*Figure 6: Connection of stepping motor Microcon SL17 - 0301 to axe of rotation at the frame*


*Figure 7: Microstep Driver M415B*

*Figure 8: Zemic load cell model L6D, measurement of position by planar laser.*

### 3.6 Software

Signal was processed by special developed program in software Labview. Values of quantities are collected three times for one defined conditions over 3 seconds sampling period. Further processing was done in Matlab software.

## 4. Methodology

### 4.1 Conditions of experiment

- Air density: $\rho = 1.2135$ kg / m$^3$.
- Average temperature: t = 9°C (T = 282, 15 K),
- Kinematic viscosity: $\nu$ = 14,6831 x $10^{-6}$ m$^2$s$^{-1}$ was calculated according Sutherlands equation, defined in equation (7) and equation (8):

$$\mu = \mu_0 \frac{T_0 + C}{T + C} \left(\frac{T}{T_0}\right)^{\frac{3}{2}}, \tag{7}$$

$$\nu = \frac{\mu}{\rho}, \tag{8}$$

where $\mu$ is a dynamic viscosity [N.s/m$^2$], reference temperature $T_0$ = 291.15 K, C is Sutherland's constant, for air C = 120 K, reference viscosity $\mu_0$ = 18.27 x $10^{-6}$ N.s/m$^2$ and $\rho$ is density [kg/m$^3$].

Based on previous observations [1 - 4], measured values of quantities for experiment were defined:

- Measured air stream velocities:
  v = 10; 15; 17; 19; 21; 25 m / s,
- controlled ball revolutions:
  n = 0; 5; 6.25; 7.5; 8.75; 10; 11.25; 12.5; rps,
- set of side angles of attack:
  $\beta$ = 0°; 9.92°; 20.56°; 30.70°; 41.15°; 47.08°.

Observed ball: Mikasa VLS 300, determined for beach volleyball. Diameter of the ball is: d = 0.22 m.

Based on velocity and ball dimensions, Reynolds number can be counted according to equation (8):

$$Re = \frac{vd}{\nu}, \tag{8}$$

where $\nu$ is kinematic viscosity. Range of Reynolds numbers: Re = 1.5 – 3.8 x $10^5$.

### 4.2 Calibration

Independent calibration of each cell was done. Six constants were resulting from the calibration, each for one cell. Constants are used to calculate voltage vs. force.


*Figure 9: Connection of loading cell with hinge for calibration*

### 4.3 Measurement procedure

Measurement of the forces acting on the volleyball in the airstream was performed according following procedure:

1. Frame is fixed in the position – definition of side angle of attack β. Starts from β = 0°.
2. Setting of the velocity of airstream in the tunnel test section. It is necessary to wait for stabilization of the velocity, controlled by the software. Starts from v = 10 m / s.
3. Setting of revolutions of the volleyball by stepping motor. Starts from n = 0 rps.
4. Measurement of all revolutions for v = const. and β = const. After changing all revolutions n, step 5. follows.
5. Change of velocity, one step higher. Back to steps 3. and 4. Final airstream velocity was defined to v = 25 m / s.
6. Change of setting of angle β. Up to β = 47.08°.

Firstly forces acting on the frames were measured without the ball. Different side angles of attack β and velocities v were measured without installed volleyball – revolutions of empty axe was neglected. Secondly all procedure was done with ball in the frame and steps 1. to 6. were fulfilled.

## 5. First results

Aerodynamic quantities, such as drag $F_D$, lift $F_L$ and side force $F_S$ were evaluated from measured data and coefficients $C_D$, $C_L$, $C_S$ were counted according to equations (10 - 12):

- Drag coefficient:

$$C_D = \frac{8F_D}{\rho v^2 \pi d^2}, \qquad (10)$$

- Lift coefficient:

$$C_L = \frac{8F_L}{\rho v^2 \pi d^2}, \qquad (10)$$

- Side force coefficient:

$$C_S = \frac{8F_S}{\rho v^2 \pi d^2}, \qquad (10)$$

Dependence of coefficient of drag $C_D$ on revolutions n and Reynolds number Re is presented in Fig. 10 for side angle β = 47.08°. Dependence of coefficient of lift $C_L$ for angle β = 47,08° in Fig. 11 shows that increasing revolutions n increases lift coefficient also. Side force coefficient $C_S$ increases with velocity increase in the case of side angle of attack β = 47.08°, as visible in Fig. 12.

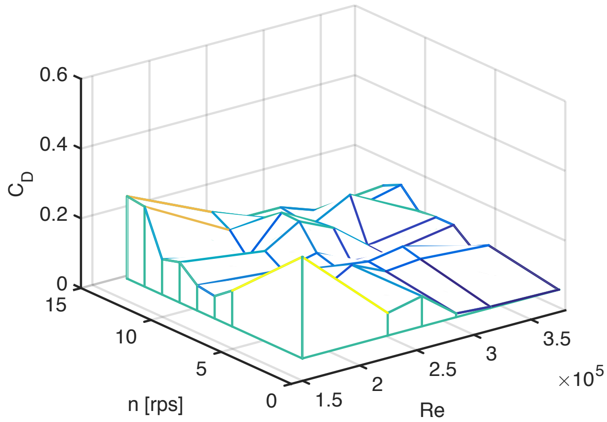


*Figure 10: Coefficient of drag, β = 47.08°*

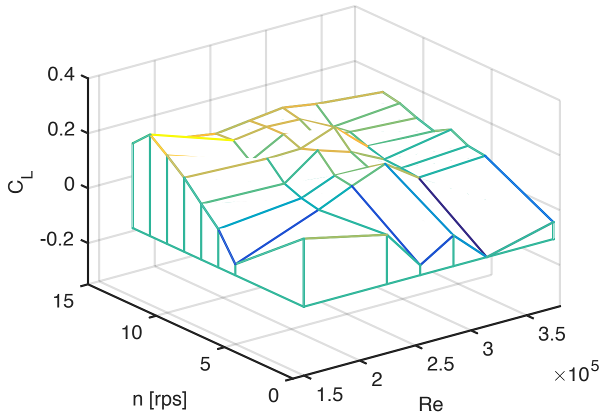


*Figure 11: Coefficient of lift, β = 47.08*

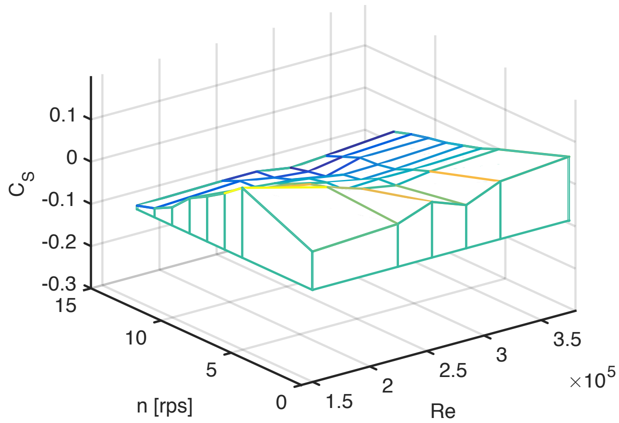


*Figure 12: Coefficient of side force, β = 47.08*

## 6. Conclusion

Experiment was prepared in the wind tunnel. All devices used in preparation of experiment, such as frame, outer frame, stepping motor, strain gauges are briefly described in the paper. Methodology of the experiment and procedure is also described in the article. In Section 5 first achieved results are presented.
Further evaluation of results for all observed velocities, revolutions and side angle of attack will be done. In evaluation of results uncertainties of all quantities will be calculted.


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## Nomenclature

| | |
|---|---|
| $C_D$ | coefficient of drag (1) |
| $C_L$ | coefficient of lift (1) |
| $C_S$ | coefficient of side force (1) |
| $C_{Mx}$ | coefficient moment about axis x (1) |
| $C_{My}$ | coefficient moment about axis y (1) |
| $C_{Mz}$ | coefficient moment about axis z (1) |
| d | diameter (m) |
| $F_D$ | drag (N) |
| $F_L$ | lift (N) |
| $F_S$ | side force (N) |
| $M_X$ | Moment of Roll (Nm) |
| $M_Y$ | Moment of Pitch(Nm) |
| $M_Z$ | Moment of Yaw (Nm) |
| v | air stream velocity (m/s) |
| β | side angle of attack (°) |
| ρ | density (kg/m$^3$) |
| μ | dynamic viscosity (N.s/m$^2$) |
| ν | kinematic viscosity (m$^2$/s$^{-1}$) |

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