

Complete Description of Forces Acting on a Flying Beach Volleyball

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Abstract. Complete description of all forces acting on a flying Beach Volleyball was made based on measurements in the wind tunnel. Forces (drag, lift and side force) were measured for different angle of attack β which varies from 0° to 47° . Velocity region was from 10 to 25 m/s and revolution region was from 0 to 12.5 rps. Moments (Roll, Yaw, Pitch) were detected. Results are described by means of non-dimensional numbers, such as Reynolds number Re , spin s , drag C_D , lift C_L and side force C_S coefficients. Differences in results of C_D , C_L and C_S were detected for various angle β and are further described in the article. Conclusions of the investigation can be utilized 1st by ball producers for practical use in development, 2nd for sport Methodist to build more exact methodology for Beach Volleyball, 3rd in basic and applied aerodynamic research.

1 Introduction

Forces acting on rotating sport ball (as well as any other body in flow) which is in the wind tunnel test section are three, drag force F_D , lift force F_L and side force F_S . Three moments are acting on balls in the flow in a non-symmetric case of flow “Roll” M_X , “Yaw” M_Y , “Pitch” M_Z .

Experimental data of forces acting on the flying rotating sphere were measured in different studies and were published in articles [1], [2], [3], [4], [5] and others. Different approaches were used. Free observation of rotating spheres, which are thrown into water is one approach [1], second describes trajectory of flight of a volleyball in real conditions [4] and others [3] measured forces acting on the volleyball fixed in a special stand in an aerodynamic wind tunnel test section. Wind tunnel measurements can describe with forces acting (forces and moments) on a rotating sphere, therefore a right set-up is required.

The measurement set-up, which can measure all three components of force and all three components of moments, is described in next chapter, Description of Experiment. The results of the realized measurements are presented in the article.

2 Description of Experiment

The experiment was conducted in a 1.8 m-diameter low-speed wind tunnel in the laboratories of Aerospace Research and Test Establishment in Prague. The set-up principal is visible in Figure 2. Forces were measured by

6 dynamometers, two in direction of the lift force F_L , three in direction of the drag F_D and one in direction of side force. Air-flowing velocities of $v = <10 - 25>$ m/s were observed. Reynolds number of measurement is in the range of $1.5 - 3.8 \times 10^5$. The ball was rotating in these revolutions: $n = <0, 12.5>$ rps.

Non dimensional parameters such as Reynolds number Re and the spin s are calculated according to the equations (1) and (2):

$$Re = \frac{vd}{\nu}, \quad (1)$$

$$s = \frac{\pi nd}{v}, \quad (2)$$

where v is velocity [m/s], d is diameter of the ball [m], ν is kinematic viscosity [m^2/s], n is revolution [rps]. Spin is a nondimensional expression of movement in the boundary condition and in the fluid. Meanwhile Strouhal number is criterium of impulsive and inertial forces. Values of Reynolds number are shown tab. 1.

Table 1. - Reynolds number values

v [m/s]	10	15	17	19	21	25
Re	152	228	259	289	320	381
[-]	420	630	120	600	090	060

The spin number is in the range $s = (0 - 0.85)$.

Revolutions were conducted and measured by a “stepping motor” and in this article are conducted as a

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independent value and recalculations of the spin number are not performed. All the values were recorded by the Labview program and evaluated afterwards by using a Matlab based program.

An experimental set-up is depicted in figures 1. and 2.

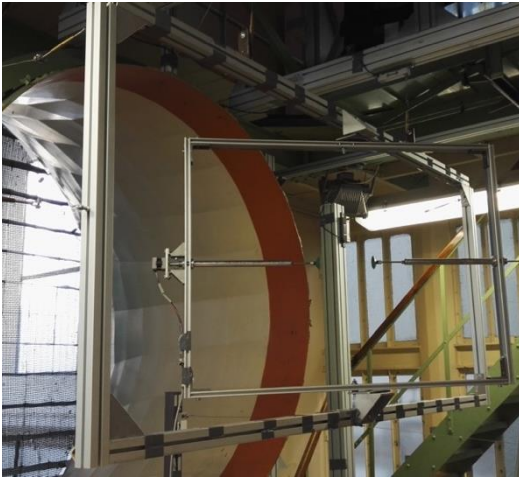


Fig. 1. Special stand for measurement of all 3 forces without volleyball



Fig. 2. Special stand for measurement of all 3 forces with rotating volleyball

Influence of moments and influence of side forces must be taken in consideration for a complete description of the situation. This experimental set up enable an observation by measurement of forces and moments acting on a rotating sphere in different angle of the airstream – β : axis of a rotating ball is not just normal to the airstream, but has also a defined angle ($\beta = 0 - 45^\circ$).

Forces and moments are calculated according to the equations (3) - (8):

- Drag:

$$F_D = F_3 + F_4 + F_5 \quad (3)$$

- Lift:

$$F_L = F_1 + F_2 \quad (4)$$

- Side force:

$$F_S = F_6 \quad (5)$$

- Roll:

$$M_X = F_1 \cdot a - F_2 \cdot a \quad (6)$$

- Yaw:

$$M_Y = F_4 \cdot f - F_3 \cdot f \quad (7)$$

- Pitch:

$$M_Z = (F_3 + F_4) \cdot b - F_5 \cdot c \quad (8)$$

From kinematic scheme, which can be seen in Figure 3, is defined in a complete picture of forces (F_D, F_L, F_S) and torques (M_X, M_Y, M_Z) acting on the rotating volleyball. Based on the kinematic scheme, the real stand and frame were constructed and installed in a wind tunnel test section, depicted in Figure 2. The measurement is prepared.

Forces acting on the special stand without volleyball were measured firstly and then characteristics of the volleyball in the stand were measured in the same conditions (v and n) as in the experiment – in purpose to deduct influence of the stand. Volleyball characteristics: I. must be spherical, II. circumference is in the range of 650 – 670 mm, III. weight of 260 – 280 g, IV. internal pressure 0,300 – 0,325 kg/cm². The volleyball MIKASA VLS 300 was measured.

3 Results

Results of coefficients C_D, C_L, C_S and moments M_X, M_Y, M_Z are depicted at figures 4. – 21.

4 Discussion

Basic principles are observed in the figures of results:

1. Drag coefficient for $\beta = 0^\circ$ (Fig. 4.). Dependence of Drag coefficient for $n = 0$ rps shows that results include region of critical Reynolds number (according to theory critical Reynolds number smooth sphere $Re_{CR} = 300\ 000$, [6]). Drag coefficient firstly decreases to critical region and increases in turbulent region.
2. With increasing revolutions area of critical Re moves (Fig. 4.). Revolutions apparently have impact on drag force – increasing revolutions decrease the drag. This phenomena will be studied and described more detailed in further articles.
3. Lift coefficient increases with increasing revolutions, as in [7].
4. Influence of the rotation n and angle of attack β is evident on each dependences.
5. Strict concept of symmetry is not confirmed in the observation. Theoretically lift force (coefficient C_L) should be equal to zero for $n = 0$ rps.

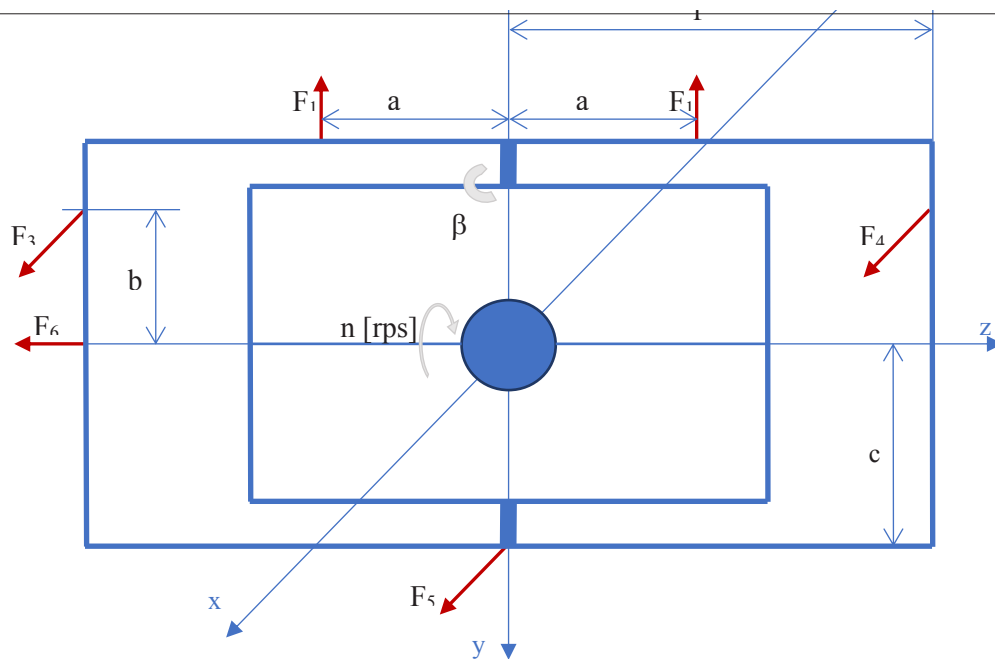


Fig. 3. Force scheme for the set-up

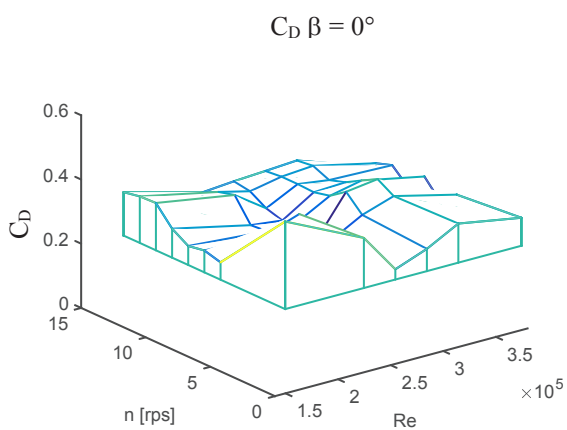


Fig. 4. Drag coefficient $C_D \beta = 0^\circ$

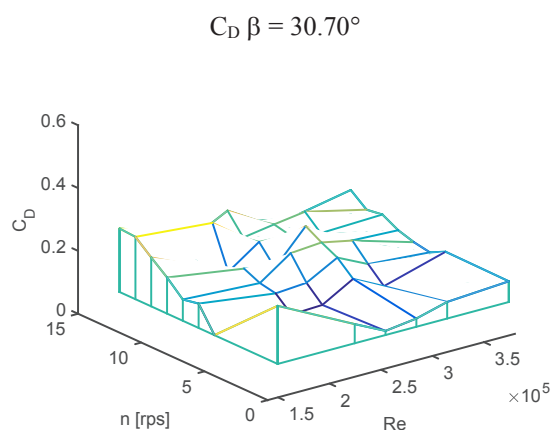


Fig. 6. Drag coefficient $C_D \beta = 30.70^\circ$

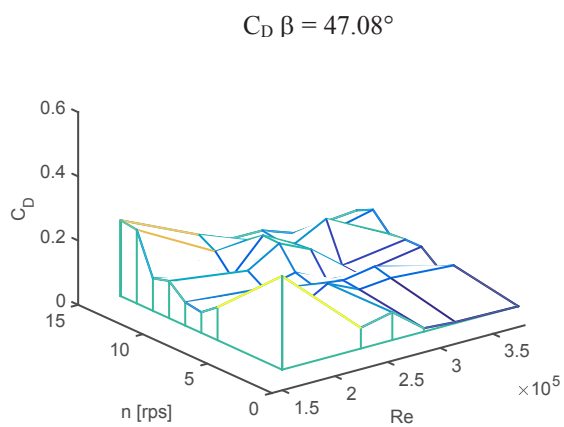


Fig. 5. Drag coefficient $C_D \beta = 47.08^\circ$

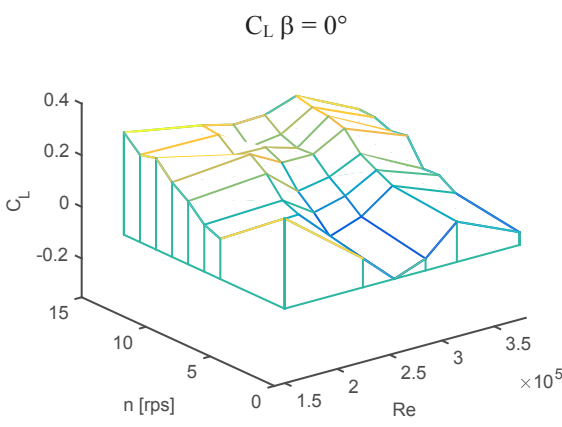


Fig. 7. Lift coefficient $C_L \beta = 0^\circ$

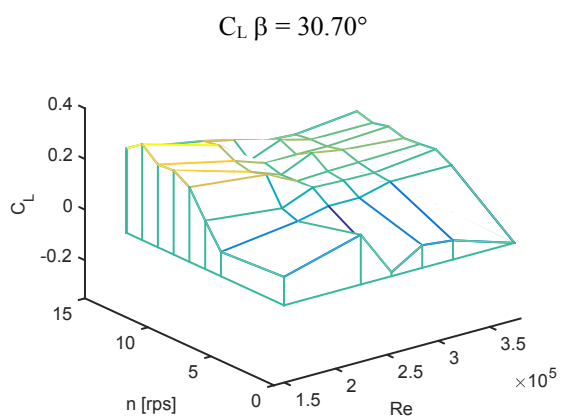


Fig. 8. Lift coefficient $C_L \beta = 30.70^\circ$

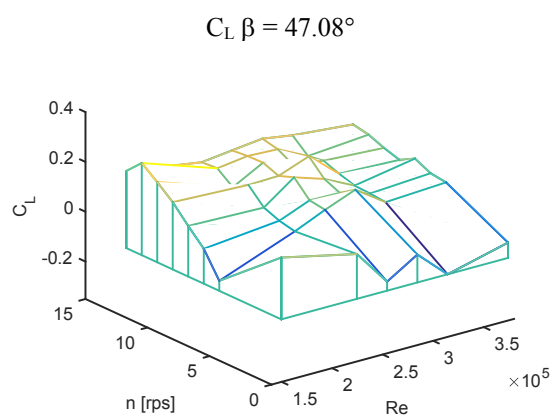


Fig. 11. Lift coefficient $C_L \beta = 47.08^\circ$

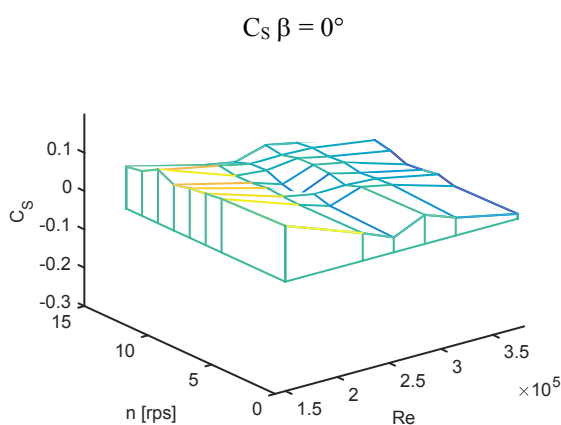


Fig. 9. Side force coefficient $C_S \beta = 0^\circ$

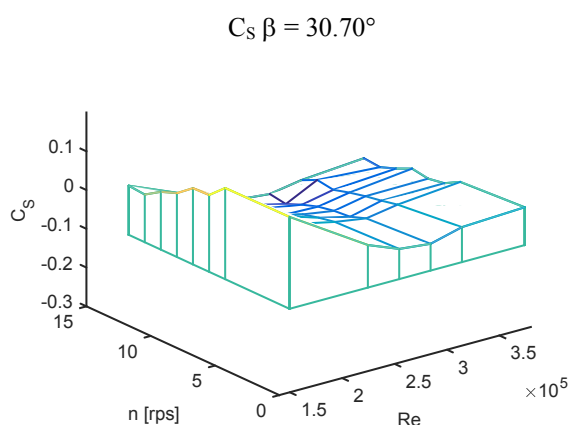


Fig. 12. Side force coefficient $C_S \beta = 30.70^\circ$

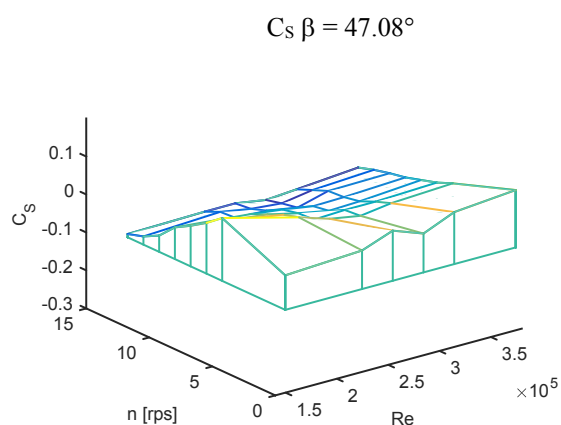


Fig. 10. Side force coefficient $C_S \beta = 47.08^\circ$

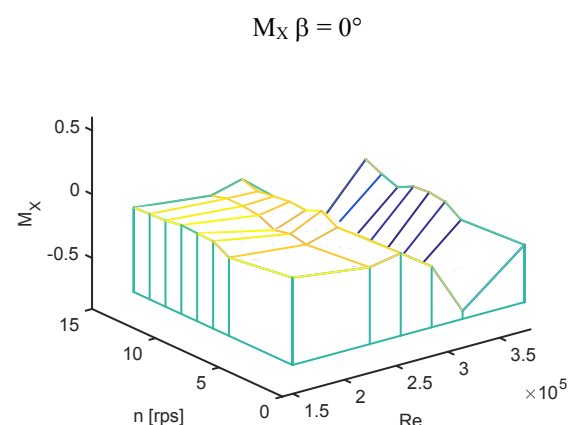


Fig. 13. Moment $M_X \beta = 0^\circ$

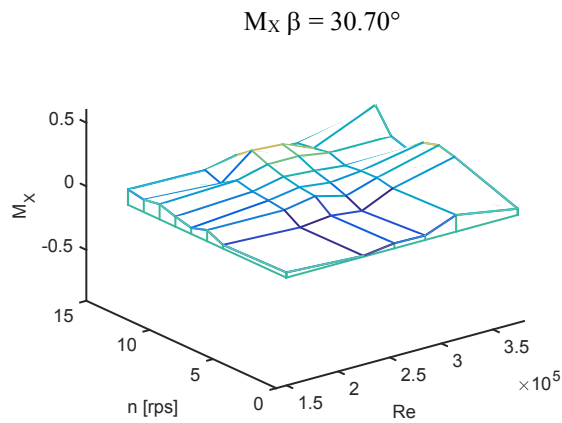


Fig. 14. Moment $M_X \beta = 30.70^\circ$

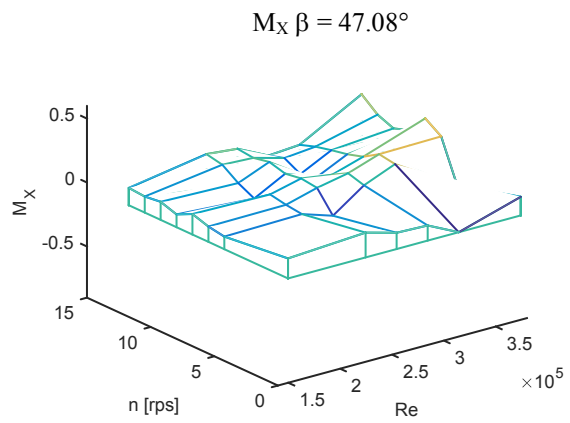


Fig. 17. Moment $M_X \beta = 47.08^\circ$

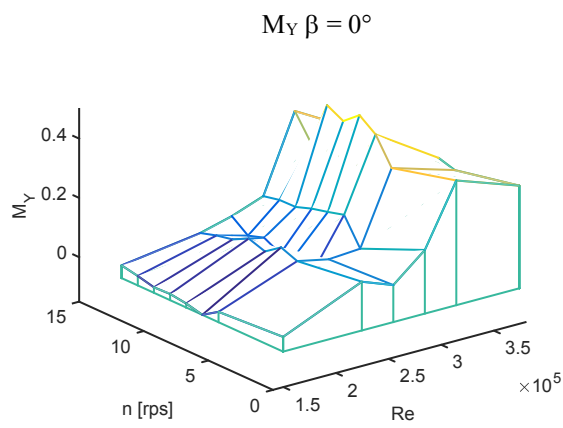


Fig. 15. Moment $M_Y \beta = 0^\circ$

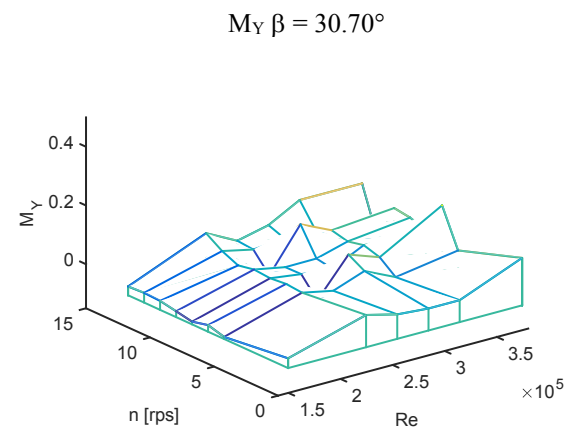


Fig. 18. Moment $M_Y \beta = 30.70^\circ$

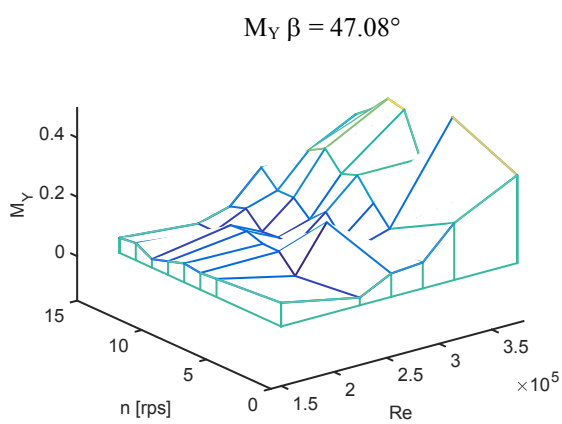


Fig. 16. Moment $M_Y \beta = 47.08^\circ$

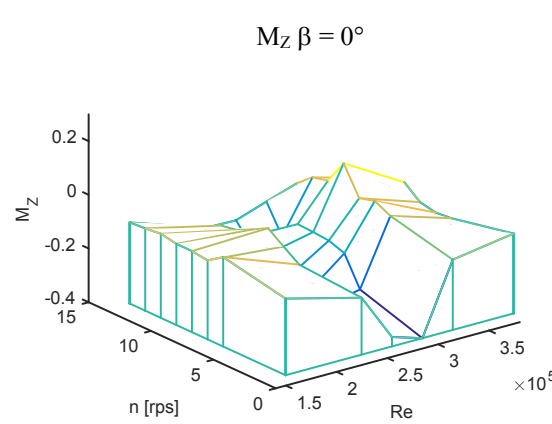


Fig. 19. Moment $M_Z \beta = 0^\circ$

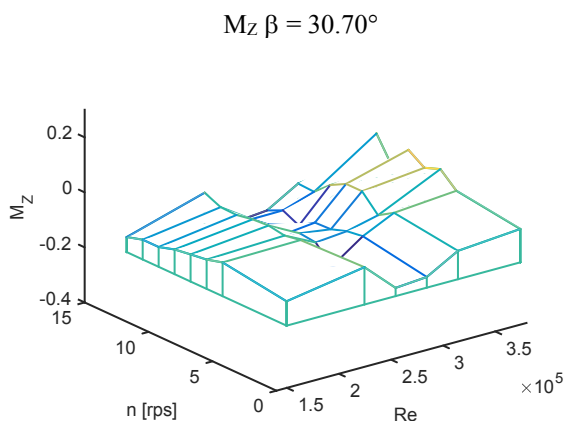


Fig. 20. Moment M_Z $\beta = 30.70^\circ$

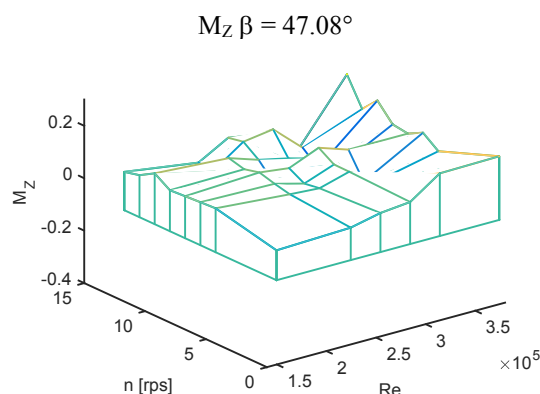


Fig. 21. Moment M_Z $\beta = 47.08^\circ$

5 Conclusions

Experimental set up of volleyball, which rotates in two planes in the wind tunnel was made and experiment was performed. Results are shown in the Section 3 Results. Basic principles, which are evident from results were described in the Section 4 Discussion. Results will be studied more thoroughly. Based on the principles described in Discussion, main conclusion is made:

1. detailed results study will be made,
2. measurement uncertainties must be counted and described,
3. moments coefficients will be counted and results will be described,
4. aerodynamic characteristic C_L vs. C_D will be described.

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