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Measurement of Surface Roughness of Volleyball

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Abstract: Main investigations are focused to measurements of all forces and moments acting on the rotating volleyball, such as drag FD, lift FL, side force FS, moment of roll MX, pitch MY and yaw MZ. Based on previous first results roughness of surface is an important quantity to study. Description of measurement of surface roughness of volleyball is presented in the article. Devices used in the measurement are noted. Results of the measurement are discussed and meaning of the results for aerodynamic forces acting on volleyball is taken in consideration.

Keywords: *aerodynamics; measurement; roughness; volleyball.*

1. Introduction

Measurement of all forces (drag FD, lift FL and side force FS) and moments (Roll MX, Pitch MY and Yaw MZ) acting on rotating volleyball in the flight is a main topic of the research. Tests were prepared in low speed wind tunnel in laboratories of Department of Aerodynamics, VZLU Aerospace Research and Test Establishment, Prague. Experiment is described in [1]. First results of the experiment, published in cooperation with University of Tsukuba [2], [3] and also previous investigations, article [4] showed that effect of surface roughness might be an important quantity for aerodynamic forces such as drag, lift and side force in the region of critical flow past volleyball.

Effect of roughness of surface on drag of the sphere in the airstream is well known in aerodynamics since Hörner 1935 [5]. This effect is visible in the Figure 1, there are depicted results of Achenbach 1974 [6]. As it is visible in the Figure 1, the higher roughness (defined in the Figure 1 by ratio k/d, where d is diameter and k is parameter of roughness) causes the earlier (lower Reynolds number Re) transition from laminar to turbulent flow.

Aim of this part of work is to measure surface's roughness of two different volleyballs. Comparison of aerodynamic characteristics of two measured balls is presented and discussed in the paper.

Furthermore comparison of aerodynamic characteristics of volleyball and sphere with rough surface (data from Achenbach [6]) is discussed.

2. Description of measurement

Aerodynamic characteristics, which define flight of bodies in the air are intensively effected by surface roughness. Roughness of surface must be defined by precise measurement.

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2.1 Devices

Machine: MarTalk
Sliding unit: DriveUnit. PGK 20
Probe: MFW-250:2 (#1855)   - 2.0%

2.2 Measured objects – volleyballs

Two different volleyballs were measured. Balls are shown in the Figure 2 (a) and (b).

- *Mikasa VLS 300 – ball for beach volleyball,*
- *Mikasa MVA 200 – ball for volleyball.*

2.3 Procedure

1. Ball was placed in to the measuring space of the machine – as visible in the Figure 2 (c),
2. Machine sliding unit was manually set to the approximate starting position,
3. Sensor position was set by software – shown in Figure 2 (d),
4. Measurement was performed – according the software settings – sensor travelled over selected part of the volleyball.

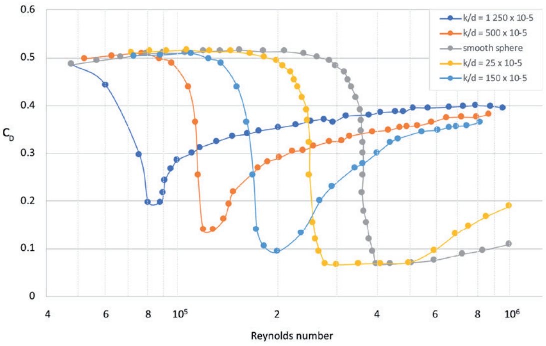


Fig. 1: *Coefficient of drag C_D vs. Reynolds number Re, parameter is roughness of surface k/d, source Achenbach [6].*

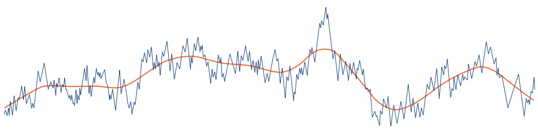
2.4 Measured quantity

Measuring device is able to measure following quantities:
A) roughness,
B) waviness,
C) parameters of profile – combination of roughness and waviness.

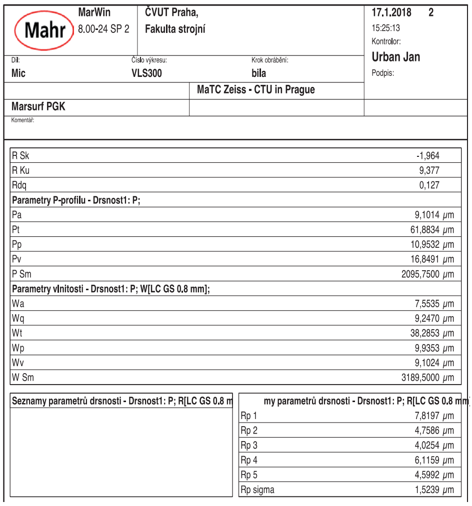
Based on EN ISO 4287 [7] parameter *Pt* is described: "The primary profile (P-profile) is the profile resulting from electronic low-pass filtering of the measured profile with a cut-off wavelength λS. This process removes the shortest wavelength components that are judged not relevant to a roughness measurement. The parameters are designated P and evaluated within the sampling lengths. In Figure 3(a) this is equal to the evaluation length *ln* (the total length of the surface pro le recorded)."

For the purpose of aerodynamic forces parameter of profile Pt is most important one. In aerodynamic evaluation of surface roughness of sphere ratio *k/d* is used. Where *d* is a diameter of sphere and *k* responds to *Pt* parameter description.

Fig. 2: **(a)** *Beach Volleyball Mikasa VLS 300.* **(b)** *Volleyball Mikasa MVA 200.* **(c)** *Setting of the ball and sliding unit of measuring machine to the position.* **(d)** *Probe position on the surface of the volleyball.*



(a)



Mahr MarWin 8.00-24 SP 2 | ČVUT Praha, Fakulta strojní | 17.1.2018 2 15:25:13

Kontrolor: Urban Jan
Podpis:

Díl: Mic | Číslo výkresu: VLS300 | Krok obrábění: bila

MaTC Zeiss - CTU in Prague

Marsurf PGK

Komentář:

R Sk	-1,964
R Ku	9,377
Rdq	0,127
Parametry P-profilu - Drsnost1: P;	
Pa	9,1014 µm
Pt	61,8834 µm
Pp	10,9532 µm
Pv	16,8491 µm
P Sm	2095,7500 µm
Parametry vlnitosti - Drsnost1: P; W[LC GS 0.8 mm];	
Wa	7,5535 µm
Wq	9,2470 µm
Wt	38,2853 µm
Wp	9,9353 µm
Wv	9,1024 µm
W Sm	3189,5000 µm

Seznamy parametrů drsnosti - Drsnost1: P; R[LC GS 0.8 m

my parametrů drsnosti - Drsnost1: P; R[LC GS 0.8 mm	
Rp 1	7,8197 µm
Rp 2	4,7586 µm
Rp 3	4,0254 µm
Rp 4	6,1159 µm
Rp 5	4,5992 µm
Rp sigma	1,5239 µm

(b)

Fig. 3: **(a)** *Profile of surface - definition of Pt profile.* **(b)** *Example of part of the protocol of measurement - Mikasa VLS 300 – in Czech.*

Tab. 1: *Results of primary profile Pt measurements.*

	Pt (μm) first	Pt (μm) second	Pt (μm) third	Pt (μm) average	d (m)	k/d
VLS 300	88.12	61.88	55.78	**68.59**	0.24	28.58 x 10^{-5}
MVA 200	59.98	37.08	178.80*	**48.89**	0.218	22.34 x 10^{-5}

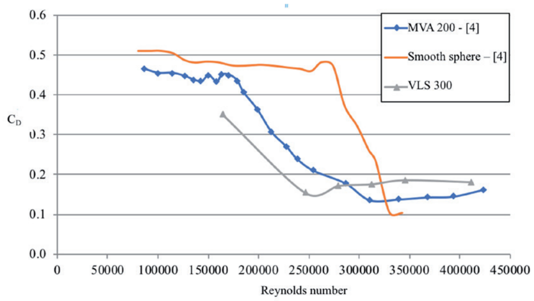


Fig. 4: *Comparison of drag of VLS 300 and MVA 200 vs. Reynolds number.*

3. Results and Discussion

Three measurements of each ball were performed. Protocol of each measurement was prepared by the Mahr device software. Complete description of surface properties and characteristic coefficient (according ISO 4287) is in the protocol. Important part of the example of protocol is in the Figure 3 (b). In the protocol are on the right side defined all quantities of roughness, waviness and profile parameters, on the right side real profiles measured by probe are shown - firstly roughness, secondly profile parameter and thirdly waviness.

Important results of primary profile *Pt* are collected in the Table 1. Average results are in the fifth column, Pt for VLS 300 is *Pt* = 68.59 (μm), while for MVA 200 *Pt* = 48.89 (μm). In aerodynamics is important, as mentioned above in the 1. Introduction, ratio *k/d* – this is in the last column. Measurement confirmed, that surface of volleyball.

Mikasa VLS 300 is with roughness ratio *k/d* than Mikasa MVA 200. Therefore earlier transition to the turbulent flow regime is expected in the case of ball VLS 300.

Comparison of aerodynamic drag is shown in the Figure 4, source [3] and [4]. Drag of two discussed volleyballs and smooth sphere is depicted vs. Reynolds number. Results of experiment refer to Figure 1, Achenbach 1974: the higher roughness of surface the earlier (lower critical Reynolds number) starts transition on the surface of sphere.

Coefficient of drag C_D is defined in equation (1) and Reynolds number is defined in equation (2):

$$C_D = \frac{8F_D}{\rho v^2 \pi d^2}, \tag{1}$$

$$R_e = \frac{vd}{\nu}, \tag{2}$$

where F_D (N) is drag, ρ is density (kg/m^3) of air, v is velocity (m/s), d is diameter of the ball (m), *d* is kinematic viscosity (m^2/s), n is revolution (rps).

Comparison of measured values with sphere with rough surface is in Table 2, Reynolds critical number, which is defined by C_D = 0.3 (source [5]), is chosen as a quantity for comparison. In table 2 is visible, that critical Reynolds number Re_{CRIT}. decreases with increasing roughness of surface of the sphere. Values summarized in the Table 2 confirm, that measurement of surface roughness was accurate.

Based on values of ReCRIT. of measured volleyballs, was expected that surface roughness (defined by ratio *k/d*) of measured volleyballs is higher than *k/d* = 25 x 10^{-5} and lower than *k/d* = 150 x 10^{-5}. This expectation was not accomplished in the case of MVA200, could be caused by dimples on the surface of MVA200. Results of Re_{CRIT}. of both investigated volleyballs is lower than expected according to Achenbach [6], rough surface sphere. Seams (as visible in Figures 2) on the surface of volleyball is explanation of speeding up transition on the surface

Tab. 2: *Values of transition, defined by critical Reynolds number (C_D = 0.3) according to surface roughness. Values of Re_{CRIT}. are stated according to Asai [4], Achenbach [6] and Figure 4.*

	Smooth sphere *k/d* = 0	Sphere *k/d* = 25 x 10^{-5}	MVA200 *k/d* = 22.34 x 10^{-5}	VLS300 *k/d* = 28.58 x 10^{-5}	Sphere k/d = 150 x 10^{-5}
ReCRIT	300 000	260 000	214 000	186 000	170 000

of volleyballs.

4. Conclusions

Aerodynamic characteristics of volleyball are intensively effected by surface roughness, that is a reason, why practical measurement of balls surface roughness was performed.

Parameter of profile *Pt* was selected as the most appropriate for aerodynamic purposes. Measurement of roughness of surface of two different volleyballs was performed. Results show, that surface of volleyball "Mikasa MVA 200" is smoother than surface of "Mikasa VLS 300".

Results of [3] were proved in comparison to Achenbach, 1974: Roughness of surface moves the transition zone to lower Reynolds numbers. Results of the measurement will be further used in the work for explanation of drag on different volleyballs.

According to critical Reynolds number measured volleyballs were compared to sphere with roughness [6]. All results are summarized in table 2. Results show, that transition on volleyballs is in lower *Re* than would be expected according to Figure 1, Achenbach [6]. Seams on the surfaces seem to be reason of the earlier transition from laminar to turbulent flow.

Acknowledgments

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Biographical notes

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Ing. Jan Urban, *1989, PhD student, graduated 2015 at Department of machining, processplanning and metrology, Faculty of Mechanical Enginnering, Czech Technical University in Prague. Most relevant article: Urban J., Dvořák R., Beránek L., Optimierung der Qualitätskontrolle bei Koordinatenmessgeräten hinsichtlich der Messproduktivität [DE] (Optimization of quality control of coordinate measuring machines with regard to measuring productivity), conference STC at CTU in Prague 20.4.2017, Prague, Czech Republic.*