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EXPERIMENTAL INVESTIGATION OF BOUNDARY LAYER SEPARATION INFLUENCE OF PRESSURE DISTRIBUTION ON CYLINDER SURFACE IN WIND TUNNEL ARMFIELD C15-10

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ABSTRACT
Aerodynamics, as branch of fluid mechanics studies relative motion of air around the body from theoretical and experimental aspect. Those two approaches will not give same results if using theoretical laws based on ideal process, because experimental investigation is presentation of real process. Wind tunnel is an instrument that can be used for experimental investigation. Boundary layer separation influence testing results of cylinder surface pressure distribution, gained by experimental investigation in wind tunnel ARMFIELD C15-10, are presented in this paper. Obtained experimental results are compared with theoretical results, and on the basis of that data certain conclusions are brought.
Keywords: Experimental aerodynamics, wind tunnel, pressure distribution, boundary layer separation, cylinder

1. INTRODUCTION
Aerodynamics is a branch of fluid mechanics that studies relative motion of air in interaction with body. It is divided on theoretical and experimental aerodynamics. Theoretical aerodynamics is based on the laws of fluid mechanics and mechanics of solid body. Experimental aerodynamics is based on experimental investigations, and one of the ways of experimental investigation is by the help of wind tunnel. In this paper, using wind tunnel investigation of pressure distribution around cylinder is done, before comparison of theoretical and experimental results.

2. WIND TUNNEL AND PRESSURE DISTRIBUTION ON CYLINDER SURFACE
Wind tunnel is instrument which can be used for experimental investigation of air flow around different geometrical shapes bodies. In real process the body is moving trough the steady air, but in wind tunnel model is positioned and air is moving around it. Same effect is accomplished as in real process taking care about fulfilling specific criteria of dynamical similarity. Figure 1. shows the wind tunnel ARMFIELD C15-10 on which the testing is executed, [1].

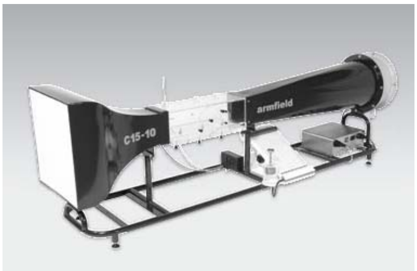

Figure 1. Wind tunnel ARMFIELD C15-10

Cylinder with smooth surface, of 30 mm diameter and 140 mm length, is selected as testing object in wind tunnel. Measuring points or tappings are distributed on upper surface of cylinder with 20° spacing, as shown in figure 2.

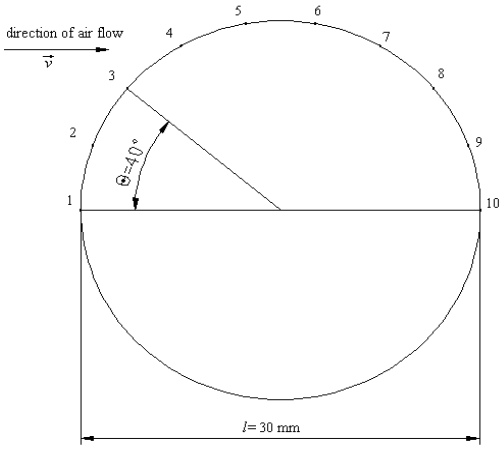

Figure 2. Position of measuring points on cylinder surface

To complete the testing, cylinder was investigated two times with same air speed, where second time cylinder was rotated for 180° angle. In that way pressure distribution is gained on lower cylinder surface. Investigation is done for three different air speeds, i.e. 11.48, 17.13 i 22.88 m/s. Value of Reynolds number for these air speeds is in range from $2 \cdot 10^4$ to $5 \cdot 10^4$.

3. THEORETICAL GROUNDS

In theory, if the cylinder is placed perpendicular to a steady stream of air, air speed on cylinder surface, with assuming no losses, is

$$v_{cil} = 2v \sin \Theta , \qquad ...(1)$$

where: v_{cil} - speed in point on surface of cylinder, m/s,

θ - angle between the radius to the measuring point and the free stream flow direction, °,

v - free stream velocity of air, m/s.

Free stream velocity of air in wind tunnel is known data, gained from the sensor on side wall of working section. This sensor measures the value of dynamic pressure, and air speed is calculated by the following equation

$$v = \sqrt{\frac{2g\Delta h}{\rho_{air}}},\qquad ...(2)$$

where: g - effect of gravity (g=9,81 m/s^2), m/s^2,

Δh - value of dynamic pressure, mmH_2O,

ρ_{air} - density of air (ρ_{air}=1,211 kg/m^3), kg/m^3.

The equation (2) is dimensionally homogeneous if the value Δh is inserted directly in unit of mmH_2O, because the value of water density (ρ_{man}=ρ_{water}=1000 kg/m^3) is left out from this equation. Using Bernoulli equation, theoretical value of surface pressure at the point on cylinder can be calculated

$$p + \frac{\rho v^2}{2} = p_{cil} + \frac{\rho v_{cil}^2}{2},\qquad ...(3)$$

where: p - static pressure in wind tunnel working section, Pa,

p_{cil} - surface pressure in point on cylinder, Pa.

The static pressure is calculated as difference between total, in this case atmospheric pressure and dynamic pressure. Atmospheric pressure is know data, measured using barometer or obtained from the internet from weather pages. Using equation (1) in equation (3), theoretical pressure distribution on cylinder surface can be found

$$p_{cil} = p + \frac{\rho v^2}{2}\left(1 - 4\sin^2\Theta\right).\qquad ...(4)$$

The simplified form of equation (4) is given in equation

$$p_{cil} = p + k\rho v^2,\qquad ...(5)$$

where coefficient k for certain angles is presented in table 1.

Table 1. Values of factor k for diferent angles

Angle (°)	0 180	20 200	40 220	60 240	80 260	100 280	120 300	140 320	160 340	180 360
k	0,5	0,266	-0,326	-1	-1,44	-1,44	-1	-0,326	0,266	0,5

4. RESULTS ANALYSIS

Table 2. is representation of experimental results obtained by measuring in wind tunnel and calculated theoretical results, for air speeds of 11.48 and 22.88 m/s, and figure 3. shows comparison of theoretical and experimental results for air speed of 17.13 m/s, [2]. Reynolds number is calculated with following equation

$$\mathrm{Re} = \frac{\rho v d}{\mu},\qquad ...(6)$$

where: d - cylinder diameter, m,

μ - viscosity for air (μ=1.8·10^{-5} Pas), Pas.

Table 2. The experimental results of pressure distribution around cylinder

Air speed m/s	11,48				22,88			
Static pressure Pa	99920				99683			
Re	23182				46179			
	Upper surface		Lower surface		Upper surface		Lower surface	
Point on cylinder surface	Measured pressure	Predicted pressure	Measured pressure	Predicted pressure	Measured pressure	Predicted pressure	Measured pressure	Predicted pressure
H1 Pa	99999	100000	99819	100000	99991	100000	99216	100000
H2 Pa	99965	99963	99818	99963	99852	99852	99200	99852
H3 Pa	99881	99868	99816	99868	99506	99476	99204	99476
H4 Pa	99801	99760	99817	99760	99193	99049	99226	99049
H5 Pa	99807	99690	99819	99690	99220	98770	99236	98770
H6 Pa	99813	99690	99811	99690	99229	98770	99221	98770
H7 Pa	99806	99760	99806	99760	99228	99049	99206	99049
H8 Pa	99813	99868	99886	99868	99216	99476	99533	99476
H9 Pa	99812	99963	99965	99963	99203	99852	99860	99852
H10 Pa	99804	100000	99998	100000	99182	100000	99991	100000

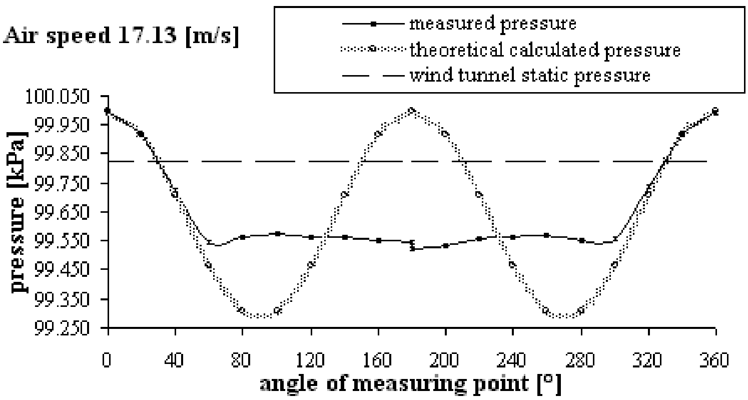

Figure 3. Diagram for the air speed of 17.13 m/s, with theoretical and experimental curve

5. CONCLUSION

Pressures on cylinder surface obtained by investigation in wind tunnel and those based on theoretical fundaments with no losses are similar but only in small area of cylinder surface. Changes are occurred in point of stall, at which separation of boundary layer begins. In practice point of stall position depends on the value of Reynolds number. For $Re<3\cdot 10^5$ point of stall occurs in 81° angle, and for $Re>3\cdot 10^5$ boundary layer separates at 125°, [3]. Since the investigation of pressure distribution is done for 20° spacing, it is not possible to precisely determine point of stall, but boundary layer separation can be noticed, and because of that influence theoretical and experimental results don't match.

6. REFERENCES

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