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SCIENTIFIC EXPERIMENTS PERFORMED BY STUDENTS. A BENEFIT FOR THE EDUCATIONAL PROCESS*

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Abstract. This paper describes how an aerodynamic experiment is performed and reveals the fact that using a device made out of ordinary materials found in households, it is possible to determine: the speed of an air jet, the geometric dimensions of the objects used or the form factor. One can also determine the displacement of an object towards the equilibrium position at different temperatures and locations on the globe. It is pointed out that although we are not in the position to achieve all the practical conditions for the experiment, we can extrapolate the theoretical results. It is also emphasised the fact that in carrying out a scientific experiment one should take into account all the variables, not only the one which is analyzed. The experimental results are important, as well as the benefits acquired by an educational process based on a modern didactic approach oriented towards this subject of study.

Key words: aerodynamic experiment, creativity, education.

1. INTRODUCTION

Since ancient times, people have been preoccupied with the study of fluid mechanics. Jean Le Rond d'Alembert† (1717–1783) was also concerned with the study of the aerodynamic force [1]. He studied the movement of a sphere and showed that an overpressure zone appears in its front and a decompression zone in its back. The resistance force which appears when the object moves through the fluid is due to the difference between the front and the back of the pressure forces.

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† (Nov. 17th, 1717, Paris, France – Oct. 29th, 1783, Paris, France). He was a mathematician, scientist, philosopher and writer. In 1743 he published a treatise on dynamics containing "d'Alembert's principle", relating to Isaac Newton's laws of motion. He developed partial differential equations and published the findings of his research on integral calculus.

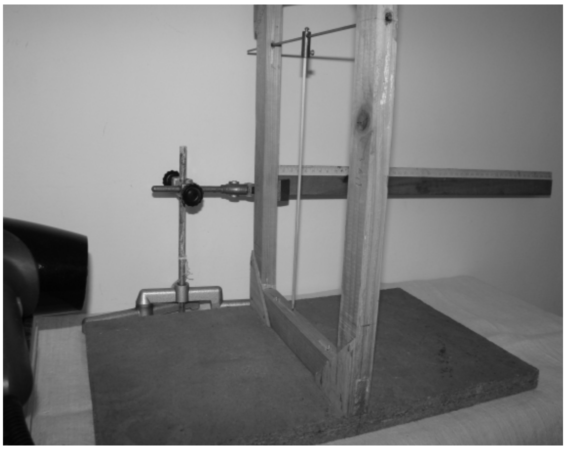
The resistance force due to air viscosity is small compared with the resistance forces generated by pressure. The experiments carried out in aerodynamic tunnels showed that the resistance with which the air opposes to the movement of the object has the form: $F = \frac{CS\rho v^2}{2}$, where C is the form coefficient, S is the surface area obtained by projecting the object onto a perpendicular plane on speed vector, called apparent contour, ρ is the air density at the moment of the experiment, v is speed, the ½ factor is being used out of theoretical considerations [2, 3]. In the book “Fluid Dynamic Drag”, written by Sighard Hoerner [4], form factors are analyzed for various objects. The movement of the objects in the fluids was also presented on http://aerospaceweb.org/ [5]. A simulation entitled “Fluid Mechanics” was created in order to make it possible to visualize the effect of an object movement on the current lines of the fluid [1].

The aim of this paper was to simulate the effect of the movement of an object on the current lines of the fluid. In this case one can determine the parameters of flow for various objects, the speed of an air jet, the geometric dimensions of the objects used or the form factor. One can also determine the displacement of an object towards the equilibrium position at different temperatures and locations on the globe. Was analyzed the relationship between the displacement of the object and the speed of the airflow and the calibration of the experimental device was made, too.

The paper is structured in five sections. Section 2, entitled “Experimental device and work method”, presents the experimental device and the mathematical relationships that students used in the experimental data processing. Section 3, entitled “Results of the experiments”, introduces the data obtained by carrying out the proposed experiments, their processing and interpretation. Section 4 is intended to highlight the causes of the measurement errors and some methods that can be used in the future experiments to reduce these errors. The paper concludes with the benefits that these experiments bring to the educational process both from the scientific and didactic points of view.

2. EXPERIMENTAL DEVICE AND WORK METHOD

A simple device made of household materials was employed in the experiments. This device allows determining the form coefficient and it can also emphasize the friction force existing between the object and air. With this device students can also determine the factors affecting the value of aerodynamic force [6, 7].



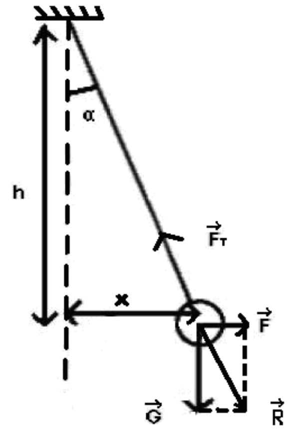


Fig. 1 – Experimental device.

The experimental device consists of a support base and a wooden frame. The object is fixed on a very light wooden bar, severally bound with a horizontal axis which can move easily, so as the friction be minimal. The horizontal axis is provided on the exterior with an indicator that moves in front of a horizontal ruler. If the air jet coming from the blower is directed to the object, it will move until the aerodynamic force of friction and the object weight and the one of the bar reach a resultant force along the support bar. By measuring x, h and the mass of the object and of the bar can establish the resistance force which appears at the movement of the object through the air. F represents the aerodynamic force, G represents the weight of the object, x is the deviation read on the ruler and h is the vertical distance from the point of support to the position of the ruler. To determine all the parameters the following relations were used and which are represented in Fig. 1 (right side), [6].

$$\text{tg}\alpha = \frac{x}{h} = \frac{F}{G}. \tag{1}$$

$$F = \frac{Gx}{h} = \frac{mgx}{h} = \frac{(CS\rho v^2)}{2}, \tag{2}$$

$$v = (\frac{2mgx}{CS\rho h})^{1/2}. \tag{3}$$

The value for the air density is: $\rho_{\text{air}} = 1.2928\ \text{kg/m}^3 \approx 1.30\ \text{kg/m}^3$.

3. RESULTS OF THE EXPERIMENTS

Some other objects were used and the results were verified again to make sure that these results are consistent with the previous ones (Constantin L.V., 2007) [6]. In order to achieve that, a cylinder placed vertically and horizontally and a cube were used.

The results obtained for the 1600W, 1500W and 1400W blowers can be read in the Tables 1, 2 and 3 [8–14]. The speed of the airflow is constant regardless of the object used during the experiments. The speed was accurately calculated because the speed values obtained on various stages (with simple geometric shapes) were almost similar and the form coefficients were fit for the geometry of the object.

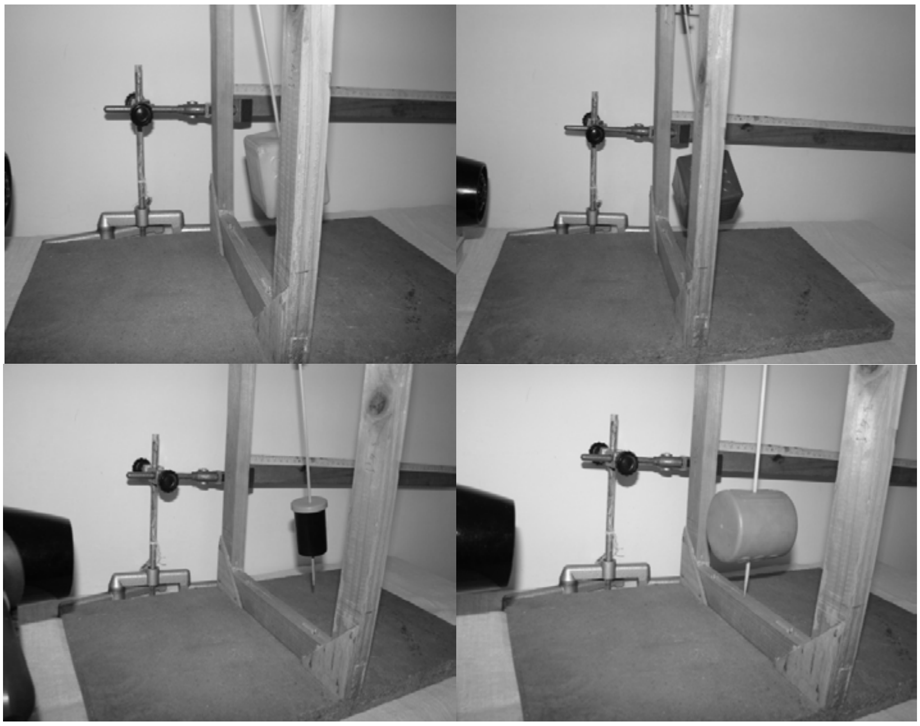


Fig. 2 – Some of the objects employed in experiments.

For the cylinder with $m = 5.00\text{g}$, the value *C* was determined from the chart being known that: $\frac{L}{R} = 3 = \frac{4.50\text{cm}}{1.50\text{cm}}$. For the cylinder with $m = 27.00\text{g}$, the *value C* was determined from the chart being known that: $\frac{L}{R} = 2 = \frac{5.60\text{cm}}{2.80\text{cm}}$.

Table 1

Experimental results for the 1600W blower [6]

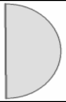
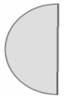
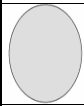
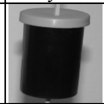
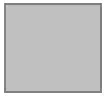
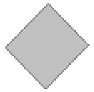
Object	Disk	Hemisphere	Hemisphere	Sphere	Vertical cylinder	Horizontal cylinder	Cube	Tilted cube	Vertical cylinder	Horizontal cylinder
										
h(cm)	19.00	19.00	19.00	19.00	19.00	19.00	19.00	19.00	19.00	19.00
m(g)	1.00	6.00	6.00	10.00	5.00	5.00	27.00	27.00	27.00	27.00
x(cm)	18.80	5.80	1.80	0.80	4.10	2.90	3.70	2.80	2.20	2.50
v^2(m/s)^2 with the mass rod correction	25.34	25.91	26.48	25.27	25.58	25.51	25.26	25.09	25.93	25.99
C	1.32	1.12	0.34	0.24	0.65	0.88	1.05	0.80	0.63	0.91
R(cm)	2.00	2.00	2.00	2.00	1.50	1.50			2.80	2.80
L(cm)					4.50	4.50			5.60	5.60
L/R					3.00	3.00			2.00	2.00
l(cm)							5.70	5.70		
S(cm)^2	12.56	12.56	12.56	12.56	13.50	7.07	32.49	32.49	31.36	24.62
Formula S	πR^2	πR^2	πR^2	πR^2	$2RL$	πR^2	l^2	l^2	$2RL$	πR^2
m_r(g)	1.76	1.76	1.76	1.76	1.76	1.76	1.76	1.76	1.76	1.76
v(m/s)	5.03	5.09	5.15	5.03	5.06	5.05	5.03	5.01	5.09	5.10
$\bar{v}$(m/s)										5.06 ± 0.03

Table 2

Experimental results for the 1500W blower

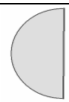
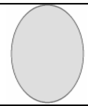
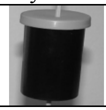
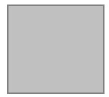
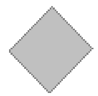
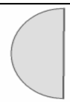
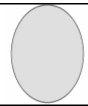
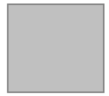
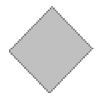
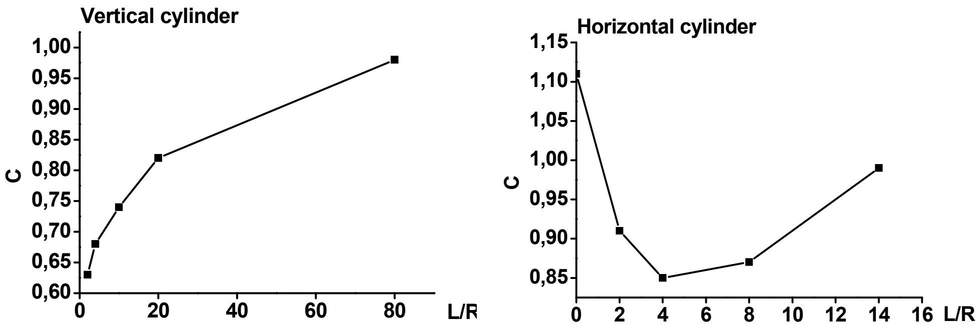
Object	Disk	Hemisphere	Hemisphere	Sphere	Vertical cylinder	Horizontal cylinder	Cube	Tilted cube	Vertical cylinder	Horizontal cylinder
										
h(cm)	19.00	19.00	19.00	19.00	19.00	19.00	19.00	19.00	19.00	19.00
m(g)	1.00	6.00	6.00	10.00	5.00	5.00	27.00	27.00	27.00	27.00
x(cm)	13.50	4.10	1.25	0.60	3.00	2.10	2.10	2.80	1.60	1.80
$v^2(\text{m/s})^2$ with correction of the mass rod	18.20	18.32	18.39	18.95	18.71	18.48	18.43	18.82	18.86	18.71
C	1.32	1.12	0.34	0.24	0.65	0.88	1.05	0.80	0.63	0.91
R(cm)	2.00	2.00	2.00	2.00	1.50	1.50			2.80	2.80
L(cm)					4.50	4.50			5.60	5.60
L/R					3.00	3.00			2.00	2.00
l(cm)							5.70	5.70		
$S(\text{cm})^2$	12.56	12.56	12.56	12.56	13.50	7.07	32.49	32.49	31.36	24.62
Formula S	πR^2	πR^2	πR^2	πR^2	$2RL$	πR^2	l^2	l^2	$2RL$	πR^2
m_r(g)	1.76	1.76	1.76	1.76	1.76	1.76	1.76	1.76	1.76	1.76
v(m/s)	4.27	4.28	4.29	4.35	4.33	4.30	4.29	4.34	4.34	4.33
$\bar{v}$(m/s)										4.31 ± 0.03

Table 3

Experimental results for the 1400W blower

Object	Disk	Hemisphere	Hemisphere	Sphere	Vertical cylinder	Horizontal cylinder	Cube	Tilted cube	Vertical cylinder	Horizontal cylinder
										
h(cm)	19.00	19.00	19.00	19.00	19.00	19.00	19.00	19.00	19.00	19.00
m(g)	1.00	6.00	6.00	10.00	5.00	5.00	27.00	27.00	27.00	27.00
x(cm)	8.00	2.30	0.70	0.35	1.70	1.20	1.50	1.20	0.90	1.00
v^2(m/s)^2 with correction of the mass rod	10.78	10.27	10.30	11.06	10.60	10.56	10.24	10.75	10.61	10.39
C	1.32	1.12	0.34	0.24	0.65	0.88	1.05	0.80	0.63	0.91
R(cm)	2.00	2.00	2.00	2.00	1.50	1.50			2.80	2.80
L(cm)					4.50	4.50			5.60	5.60
L/R					3.00	3.00			2.00	2.00
l(cm)							5.70	5.70		
S(cm)^2	12.56	12.56	12.56	12.56	13.50	7.07	32.49	32.49	31.36	24.62
Formula S	πR^2	πR^2	πR^2	πR^2	$2RL$	πR^2	l^2	l^2	$2RL$	πR^2
m_r(g)	1.76	1.76	1.76	1.76	1.76	1.76	1.76	1.76	1.76	1.76
v(m/s)	3.28	3.20	3.21	3.33	3.26	3.25	3.20	3.28	3.26	3.22
$\bar{v}$(m/s)										3.25 ± 0.03



a b

Fig. 3 – *C=f (L/R)* for vertical cylinder (a) and for horizontal cylinder (b).

Determinations were conducted for three blowers with wattages of 1600, 1500 and 1400, in order to analyze the relationship between object displacement *x* and speed of the airflow *v*. Charts $x = f(C)$ were also made for each of the three blowers. It was observed that, as in the limits of the experimental errors, the character of the curve is maintained, so the calibration of the device was made correctly. The use of a much lower-wattage blower was also attempted. In this case it is to notice that the aerodynamic force value greatly decreases because the displacement of the high-mass objects is not noticeable and therefore measurements cannot be properly performed. Using a higher-power blower makes it possible to observe that the value of the aerodynamic force increases greatly. The displacement of the objects becomes very large and cannot be measured correctly because in this case there is a great increase in the angle between the rod on which the object is fixed and the vertical axis of the experimental device. This angle cannot vary greatly because the object would be outside the range of the airflow from blower.

In the graph representation $x = f(C)$ it can be seen that fitting is done with a fourth-degree function $\left(y = ax^4 + bx^3 + cx^2 + dx + e, \quad a,b,c,d,e \in R\right)$. Fitting is done as the graph $x = f(C)$ represents a calibration of the experimental device. Thus by measuring the displacement *x* of an object the form coefficient can be determined (for irregular-form objects) and, knowing the form coefficient, the displacement of the object from the theoretical point of view can be determined.

In the graph representation $x = f(v)$ it can be seen that fitting is done with a second-degree function ($y = ax^2 + bx + c$, $a,b,c \in R$). Fitting is performed to check whether the displacement of the object is directly proportional with the square velocity of the airflow. The experimental results verify the theory [6].

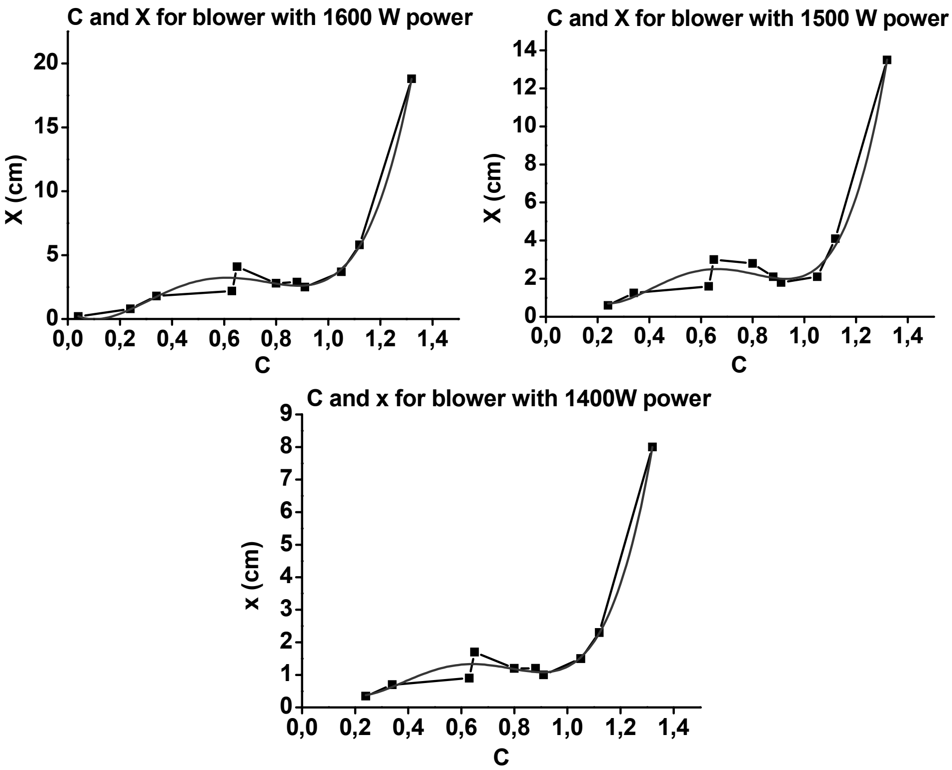


Fig. 4 – *x=f (C)* for blower with power 1 600W, 1 500W and 1 400W.

$$x = \frac{CS\rho h v^2}{2mg}. \quad (4)$$

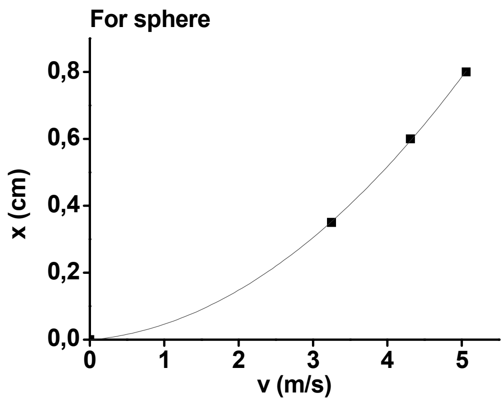


Fig. 5 – *x = f(v)* for sphere.

The size of the objects involved in the experiment can be determined as well. Using the average speed of the air flow $\bar{v} = 5.06 \pm 0.03\text{m/s}$ and measuring the x displacement of the object, the apparent contour of the object can be calculated.

$$S = \frac{2(m_C + m_t)gx}{v^2 C\rho h}. \tag{5}$$

For the cube: $x = 3.70\ \text{cm}$, $S = 32.05\ \text{cm}^2$, $l = 5.66\ \text{cm}$. For the sphere: $x = 0.80\ \text{cm}$, $S = 12.40\ \text{cm}^2$, $R = 1.99\ \text{cm}$. Students could not do the calculation for all objects used, as the assignation of the value of the apparent contour would not allow it for all geometric shapes of the object. The students overcame this drawback by using a graduated cylinder, so they were able to determine the volume of the object. Then, using other mathematic rules, they calculated the other geometric sizes of the objects. For the horizontal cylinder, $m = 27.00\ \text{g}$, $x = 2.50\ \text{cm}$, $S = 24.99\ \text{cm}^2$, $R = 2.82\ \text{cm}$, $V = 138.00\ \text{cm}^3$, although $L = 5.52\ \text{cm}$. For the vertical cylinder, $m = 27.00\ \text{g}$, $x = 2.20\ \text{cm}$, $S = 31.76\ \text{cm}^2$, $V = 138.00\ \text{cm}^3$. This means that $R = 2.77\ \text{cm}$, $L = 5.73\ \text{cm}$. There is a good ratio between the theoretical results and the experimental ones. Students learn how to find solutions in order to overcome the difficulties and develop relations of friendship, collaboration and appreciation of work values. They also remember and recap the concepts of geometry.

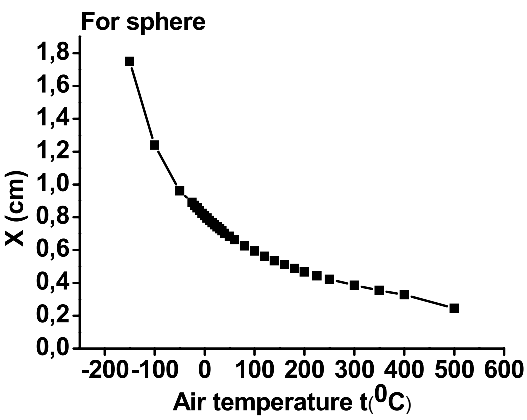


Fig. 6 – *x=f (t)* for sphere.

Knowing the airflow density value established by considering the temperature and having the speed of the airflow, the sphere displacement towards the equilibrium position for various temperatures can be calculated and the graph: $x = f(t)$ can be obtained. This way, the sphere displacement according to the temperature can be determined. For these calculations the sphere was preferred, because spherical objects are the most unlikely to generate errors due to their perfect symmetry and to the fact that these objects keep their shape regardless of the rod tilt. It is noted that with increasing temperature, the sphere displacement becomes smaller, tending to nil. It has also been observed that the value of x displacement lowers whereas the temperature raises. At extreme temperatures, in reality, the displacement from equilibrium position of the objects cannot be measured because the experimental device would deteriorate.

This can be explained if one takes into account the gas expansion. This expansion regards volume. The gas has constant pressure and mass $V = V_0(1+\alpha\Delta t)$, where V stands for the gas volume at temperature t and V_0 stands for the gas volume at temperature t_0. $\alpha = \frac{\Delta V}{V_0 \cdot \Delta t}$ is the coefficient of isobar expansion of the gas. $\rho = \frac{m}{V}$, $\rho_0 = \frac{m}{V_0}$ so $\rho = \frac{\rho_0}{1+\cdot\alpha\cdot\Delta t}$. The gas density decreases with increasing temperature, thus the hydrodynamic force is reduced. $F = \frac{CS\rho v^2}{2}$. This way the displacement x of the object decreases.

The theoretical and the experimental results obtained for the value of x displacement at various temperatures regarding several objects with known shapes are presented in Table 4.

Table 4

The theoretical and the experimental results obtained for the value of displacement x at various temperatures

$t(^0C)$	Sphere theoretical values	Sphere experimental values	Cube theoretical values	Cube experimental values	Disk theoretical values	Disk experimental values
40	0.70	0.70	3.23	3.30	16.36	16.10
30	0.73	0.80	3.36	3.40	17.01	16.70
20	0.75	0.70	3.47	3.50	17.59	17.50
10	0.78	0.80	3.60	3.70	18.21	17.90
0	0.81	0.80	3.73	3.70	18.88	18.80

For some geometric objects for which the displacement from the equilibrium position is very small, this variation depending on the temperature are within the error limits accepted in experiments, so they cannot be taken into account. This is also the case of sphere.

Considering that the value of gravity acceleration depends on the height and on the position on the globe, the displacement of the sphere can be determined anywhere in the world.

Table 5

g(m/s^2) and x(cm) for sphere

g(m/s^2)	x(cm)
$g_{Equator} = 9.79$	0.8279
$g_{Romania} = 9.81$	0.8262
$g_{Pole} = 9.83$	0.8245

The linear representation $x = f(g)$ is not accurate as we should also think of the temperature variations on the globe. Thus students note that in an experiment there may be many variables that must be considered [3, 5].

4. ERROR CAUSES AND METHODS TO MINIMIZE THEM

The error causes were:

● consideration that the airflow is constant along its path so that airflow speed is practically independent of the distance blower - object

● using a blower of too high or too low wattage (a hair dryer can be used)

● neglecting the change in the apparent contour with tilt of the rod

● inability to measure with certainty the distance on which the object moves because the indicator may oscillate around this position due to the air flow

● neglecting the mass of the rod (m_r)

● the usage of objects of various shapes, which can modify the assumed constant flow of air or the temperature and humidity that can change the air viscosity

● the air density may have a different value from the one used in determinations because the air may have a different composition from the conventional one

● using inappropriate weighing/ measuring devices

● error calculation may occur through the elimination of decimal fractions or rounding

The errors can be diminished if:

● the airflow passes through a cylinder (a rolled piece of cardboard, for example) which allows the movement of the rod and also prevents the divergence dispersal of the airflow, so that the speed remains constant all along the tube. If all the measurements are performed from a constant distance between the object and the head of the blower, the error rate diminishes

● several measurements be conducted in which the students may be able to use various blowers

● for a spherical object the modification of the apparent contour with tilt of the rod does not matter, but, nevertheless, for irregular or highly symmetrical objects this effect should be considered.

● a sensor be used in order to monitor the movements of the indicator

● the correction of the mass rod be used:

$$v^2 = \frac{2(m + m_r)gx}{CS\rho h}. \qquad (6)$$

Rods be made of low-density wood $\rho_r = 0.92\ \mathrm{g/cm^3}$ and geometric sizes: length $L_r = 25.00\ \mathrm{cm}$ and diameter $d_r = 3.00\ \mathrm{mm}$, so that each has a mass $m_r = 1.76\ \mathrm{g}$. The correction related to transverse area of the rod: the whole area transverse rods $25.00 \times 0.30 = 7.50\ \mathrm{cm^2}$. That area itself is negligibly small, but the only thing that (really) matters is the area included in the airflow. In these experiments the exposed area of the rod is considered negligible

- adequate devices to measure air density, temperature be used
- appropriate weighing devices be used
- several sets of measurements be carried out.

Teacher and students together have discovered these error causes that can affect the quality of the experimental data. By doing the experiment more than once, in groups, with several objects, they have understood the phenomenon and updated their theoretical knowledge, they have developed their practical abilities and discovered new causes for measurement errors. However, we have demonstrated that, regardless of the geometric shape, theoretical and real-life conditions were obeyed within the error limit, of course.

5. CONCLUSIONS

From the scientific point of view, this experiment underlines the fact that using a created device, we can determine the speed of the airflow, the geometric sizes of the objects employed and their shape factor. It has been shown that between the displacement of the object and the airjet speed from the blower there is a second-degree polynomial dependence. We can also determine the displacement of the object from equilibrium position at various temperatures or positions on the globe. It is emphasized that, although, we sometimes cannot practically benefit from all the proper conditions for an experiment, it can extrapolate the theoretical results. Furthermore, the students have understood that during a scientific experiment they must take into account all the variables, not only the one that is analyzed.

From the didactic viewpoint, after carrying these experiments out, students have once again understood that "*Nobody comes into the world as a wise man, everything is achieved through hard work*." In other words, it may be said that students must 'climb up' their way through personal effort towards knowledge. "*We do not inherit wisdom, we must discover it all by ourselves through a personal journey that cannot be skipped or made for us by someone else*", as Marcel Proust wrote.

The teacher only assumes the role of the guide in each student's personal journey. This role is extremely important in shaping up the students' destinies. The teacher must be consciously and deeply involved in the development of the high-quality educational process. This goal can be reached if education focuses on the student, if there is a curricular diversity within the institution. This way, the practical facet of all activities and the appropriate theoretical knowledge allow the increase in the student's motivation for learning!

"In the future, the student will be an explorer", says Marshall Mc Luhan. In order to become one, they have to be aware of the importance of learning through research, of the importance of connecting various subjects of study.

Last, but not least, students learn how to ask questions, examine and discuss scientific issues that influence their lives. Studying this work and other ones appreciated for major contributions brought to the development of the educational physics [15 - 21], students will be responsible people, able to socially integrate.

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