Leonardo's anemometer

RELATION OF

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Introduction

The anemometer we have accomplished is similar to the prototype present at the Museum of Science and Technology Leonardo da Vinci in Milan. Our exhibit, just like the one in Milan, consists of an anemoscope (indicator or pointer of the wind direction) which is not present in the original drawings of Leonardo. Nevertheless Leonardo drew the anemoscope separated from the anemometer. Therefore the close functional correlation of the two components justifies the choice of joining them in the exhibit.

The anemometer was produced, together with other machines of Leonardo in a didactic module in the ambit of the Formative Offer Plan (P.O.F.) at the Galileo Ferraris Institute in Naples during the 2005-2006 school year. About fifteen grade 9 and 10 students participated in this module. The main purpose of this module (just like the other ones done in the preceding scholastic years) is to supply young students with a concrete image of Science and not only an abstractly formal one. We are convinced that this can be reached by developing the teaching of Science even in a historical perspective. The achievement of this work made the students do research on Leonardo and his anemometer, in the planning of the prototype and making it with their own hands.

In doing so the students not only developed technical and scientific skills and competence but also the possibility to live Science. To accomplish the didactic aim of the module in full, the course was completed giving the exhibit useful equipment to guide simple experiments in the science laboratory and thus attaining specific scientific learning objectives.

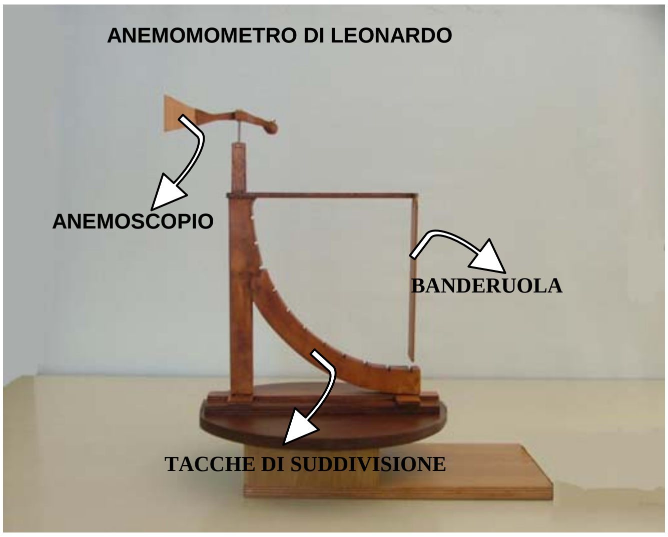
This was done in two different ways:

- The exhibit was equipped with additional elements and measuring scales to lead quantitative experiments.
- An electronic simulation of Leonardo's anemometer was done in order to describe the reaction of the equipment and carry out quantitative expectation.

In the following paragraphs we have a brief description of the two above mentioned points.

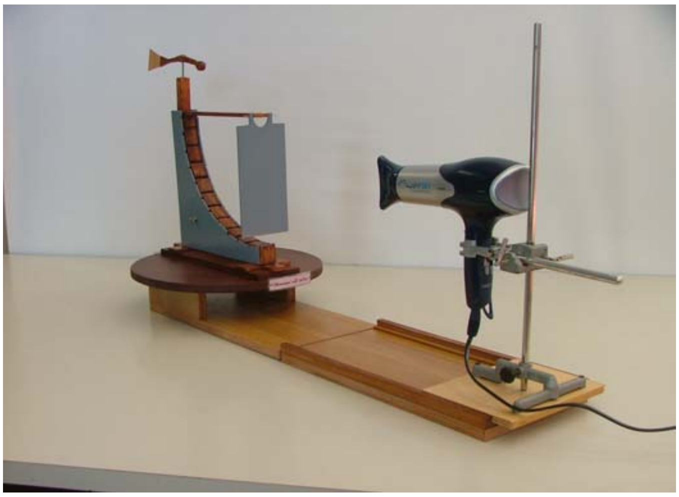
Quantitative experiments with Leonardo's anemometer

The exhibit in picture 1 consists of a gradual scale for the reading of the inclination of the banderol (determined by wind pressure) and the velocity of the wind. To obtain this purpose without damaging the original aspect of Leonardo's anemometer new parts were added to the apparatus. These added parts were differently coloured (grey) so as to immediately recognize them. The velocity of the wind was obtained by using the digital anemometer. Moreover banderols of different areas and mass were made, to verify how the inclination of the banderol depends on these two sizes. The wind was obtained by using a hair-dryer. In picture 2 we have the equipment with all its added parts. The accomplished experiments are:



Picture1

- The determination of the inclination of the banderol depending on the velocity of the wind;
- The determination of the inclination of the banderol depending on the mass of the banderol;
- The determination of the inclination of the banderol depending on the function of the area of the same banderol.



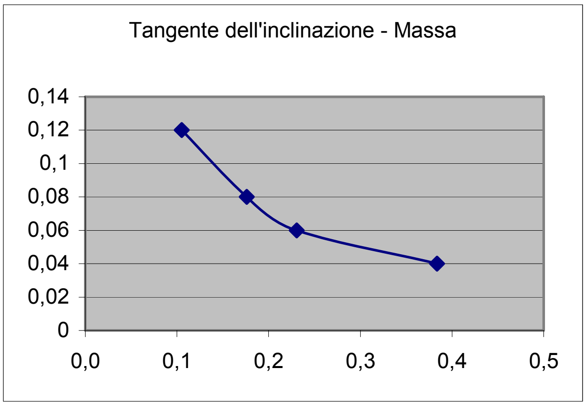
Picture 2

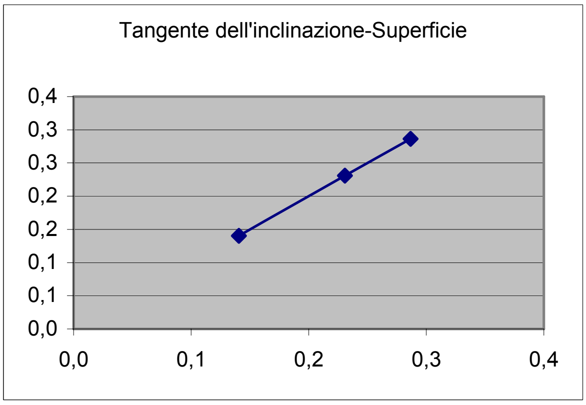
In the first experiment a banderol was chosen (in practice the mass and area were fixed) and the velocity of the wind was varied by modifying the distance of the hair-dryer from the banderol. The wind speed carried out was measured by a digital anemometer, situated in the place of the banderol. Instead in the second and third experiment, the position of the hair-dryer was fixed being the velocity of the wind and so we modified the mass of the banderol and then the area, substituting the original banderol with the other intentionally prepared ones.

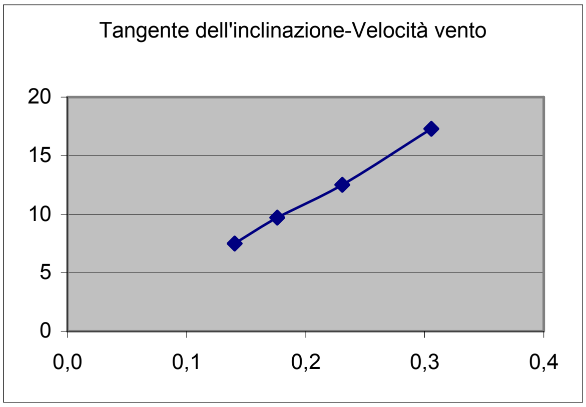
The obtained results are summarized in the following chart.

PHON IN 1ª SPEED

N	Distanza del fon dalla banderuola dell'anemometro (cm)	Massa (kg)	Superficie (m^2)	Velocità del vento (Km/h)	Angolo di inclinazione sperimentale (°)
Variazione dell'inclinazione della banderuola al variare della sua massa					
1	22	0,04	0,02	12,5	21
2	22	0,06	0,02	12,5	13
3	22	0,08	0,02	12,5	10
4	22	0,12	0,02	12,5	6
Variazione dell'inclinazione della banderuola al variare della sua superficie					
1	22	0,06	0,03	12,5	16
2	22	0,06	0,02	12,5	13
3	22	0,06	0,01	12,5	8
Variazione dell'inclinazione della banderuola al variare della velocità del vento					
1	11	0,06	0,02	17,3	17
2	22	0,06	0,02	12,5	13
3	33	0,06	0,02	9,7	10
4	44	0,06	0,02	7,5	8







PHON IN 2ª SPEED

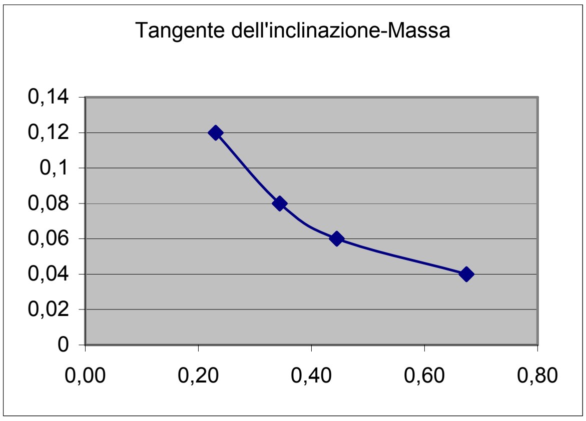
N	Distanza del fon dalla banderuola dell'anemometro (cm)	Massa (kg)	Superficie (m^2)	Velocità del vento (Km/h)	Angolo di inclinazione (°)
Variazione dell'inclinazione della banderuola al variare della sua massa					
1	22	0,04	0,02	18,7	34
2	22	0,06	0,02	18,7	24
3	22	0,08	0,02	18,7	19
4	22	0,12	0,02	18,7	13

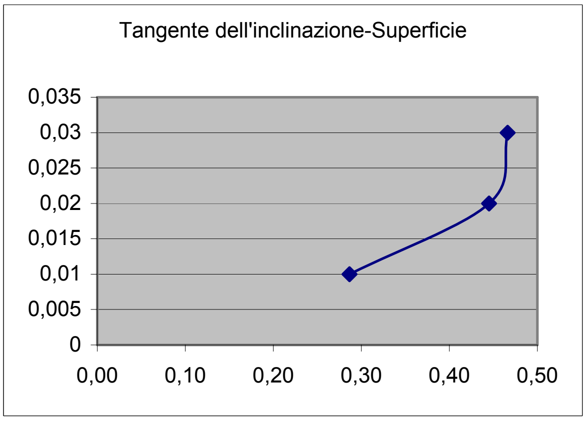
Variazione dell'inclinazione della banderuola al variare della sua superficie

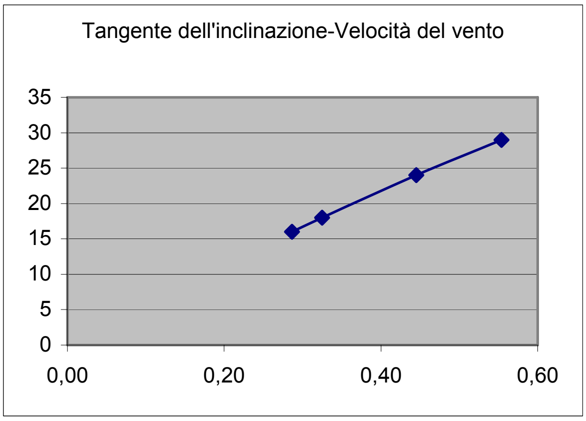
1	22	0,06	0,03	18,7	25
2	22	0,06	0,02	18,7	24
3	22	0,06	0,01	18,7	16

Variazione dell'inclinazione della banderuola al variare della velocità del vento

1	11	0,06	0,02	25,6	29
2	22	0,06	0,02	18,7	24
3	33	0,06	0,02	14,4	18
4	44	0,06	0,02	11,7	16







The graphs report the tangent of the angle of the banderol's inclination depending on the variation of its mass, area and wind speed. The graphs very precisely indicate, except for the encircled spot that:

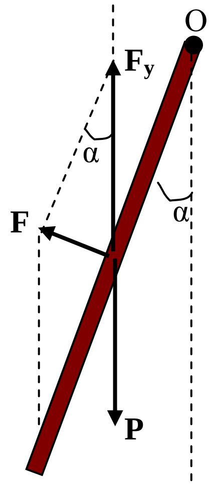
- The tangent of the inclination of the banderol is inversely proportional to its mass;
- The tangent of the inclination of the banderol is directly proportional to its area;
- The tangent of the inclination of the banderol is directly proportional to the velocity of the wind.

The introduction of the tangent of the banderol's inclination and its correlation with the mass, area and wind speed indicated by the experimental data are justified by the mathematical model that governs the phenomenon.

In particular the last condition makes one understand that the wind flux achieved is in a laminar condition: in fact the dependence of the tangent of the banderol's inclination with the velocity is linear; whereas in a stormy condition the dependence would be to the power of two.

The Simulation of Leonardo's Anemometer

To carry out the simulation of the anemometer we used an Interactive Physics 2000 software made by MSC Working Knowledge® that reproduced two dimensional mechanical and electromagnetic phenomena.
One needs to determine a mathematical model in order to correctly forecast the real behaviour of the anemometer and precisely the inclination of the banderol with the wind thrust at a determined speed.
In a preliminary way we fixed theoretical conditions so as to verify the equilibrium. For this purpose we schemed the banderol of the anemometer as in the diagram below, that is like a object fixed down at O. The external forces acting on the banderol are the force F in a normal condition at the surface determined by the wind and its weight P. For the equilibrium we can change the force F into a vertical force (F_y) and into a parallel one at the banderol's surface. This last force is surely annulled by the reaction of the belt O that prevents translation.



The equilibrium of the banderol must result:

$$F_y = P \tag{1}$$

Now let's determine F_y . The experiment with the hair-dryer demonstrates that the force caused by the wind is directly proportional to the area of the banderol and the velocity of the wind. Therefore it results as:

$$F = c\ S\ V \cos \alpha$$

in which there is a constant proportionality, S is the area of the banderol and V is the velocity of the wind. assuming the wind thrust as a viscose regime thus meaning that the resistance of the means used depends on the velocity and not on the velocity at the power of two. The cosine of the inclination of the banderol is shown in the expression because we must bear in mind that the wind direction is horizontal while the area is inclined as regards to it at an angle equal to α . Now determining F_y with a simple trigonometric relation and substituting the equilibrium relation (1), then substituting P with mg (with mass of the banderol we finally obtain the following:

$$m\ g \sin\alpha = c\ S\ V\ \cos \alpha \tag{2}$$

or alternatively

$$\text{tang}\ \alpha = c\ S\ V / mg$$

that is perfectly coherent with the graphs of our experiment. In order that the simulation established in the relation (2) gives linear results like those in the experiment, the coefficient results the same at about 0.6.
The following charts show the data obtained in our experimental simulation.

PHON IN 1ª SPEED

N	Distanza del fon dalla banderuola dell'anemometro (cm)	Massa (kg)	Superficie (m^2)	Velocità del vento (Km/h)	Angolo di inclinazione sperimentale (°)	Angolo di inclinazione nella simulazione (°)	Δ

Variazione dell'inclinazione della banderuola al variare della sua massa

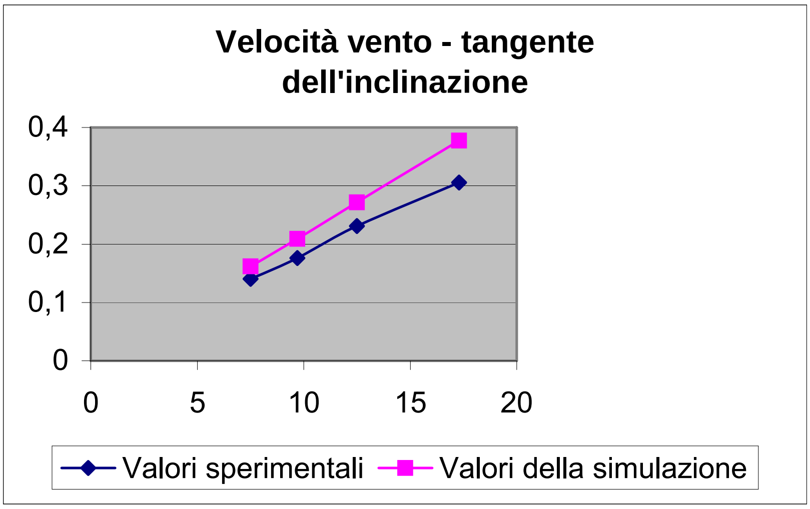
1	22	0,04	0,02	12,5	21	15,2	2,2
2	22	0,06	0,02	12,5	13	22,2	1,2
3	22	0,08	0,02	12,5	10	11,4	1,4
4	22	0,12	0,02	12,5	6	7,7	1,7

Variazione dell'inclinazione della banderuola al variare della sua superficie

1	22	0,06	0,03	12,5	16	22,2	6,2
2	22	0,06	0,02	12,5	13	15,2	2,2
3	22	0,06	0,01	12,5	8	7,8	0,2

Variazione dell'inclinazione della banderuola al variare della velocità del vento

1	11	0,06	0,02	17,3	17	20,7	3,7
2	22	0,06	0,02	12,5	13	15,2	2,2
3	33	0,06	0,02	9,7	10	11,8	1,8
4	44	0,06	0,02	7,5	8	9,2	1,2



N	Distanza del fon dalla banderuola dell'anemometro (cm)	Massa (kg)	Superficie (m^2)	Velocità del vento (Km/h)	Angolo di deflessione sperimentale (°)	Angolo di deflessione nella simulazione (°)	Δ

Variazione dell'inclinazione della banderuola al variare della sua massa

1	22	0,04	0,02	18,7	24	22,2	1,8
2	22	0,06	0,02	18,7	34	31,6	2,4
3	22	0,08	0,02	18,7	19	16,9	2,1
4	22	0,12	0,02	18,7	13	11,4	1,6

Variazione dell'inclinazione della banderuola al variare della sua superficie

1	22	0,06	0,03	18,7	25	31,5	6,5
2	22	0,06	0,02	18,7	24	22,2	1,8
3	22	0,06	0,01	18,7	16	11,4	4,6

Variazione dell'inclinazione della banderuola al variare della velocità del vento

1	11	0,06	0,02	17,3	17	20,7	3,7
2	22	0,06	0,02	12,5	13	15,2	2,2
3	33	0,06	0,02	9,7	10	11,8	1,8
4	44	0,06	0,02	7,5	8	9,2	1,2

PHON IN 2ª SPEED