PAPER AIRPLANES LAUNCH

5, 4, 3, 2, 1 … BLASTOFF!

Alexandre Costa (Escola Secundária de Loulé)
Ana Luísa Gonçalves (Agrupamento de Escolas Dra Laura Ayres)
Paulo Ribeiro (Escola Secundária de Loulé)

PLACE AND DATE OF RELEASE:

The aircraft launch will take place in a wide and closed space of the partner schools, between 18th and 27th April 2016.

INTRODUCTION

The movement of the paper airplanes is described by the action of the three forces and the Laws of Newton. Figure 1 shows the free-body diagram of a paper airplane in an upward trend, positioning the weight ($\vec{P}$), the force of normal reaction ($\overrightarrow{R_n}$) and the frictional force ($\overrightarrow{F_a}$). The forces $\overrightarrow{R_n}$ and $\overrightarrow{F_a}$ have aerodynamic origin, ie, the interaction with the atmosphere, and depend on the velocity of the air. The frictional force is related to the air resistance.

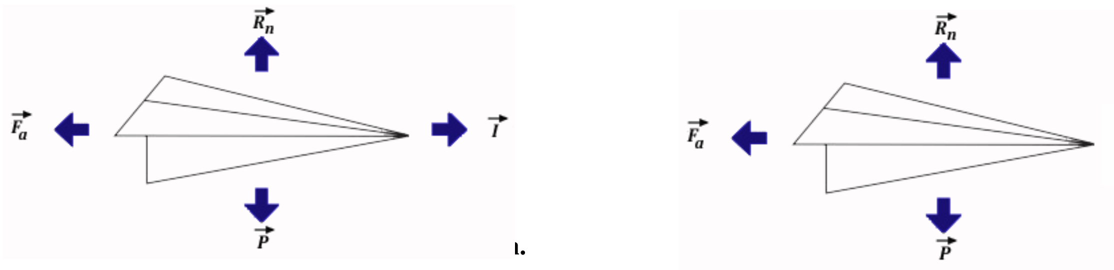

Figure 1:Diagram of free body of a paper airplane: a. During the boost phase; b. During flight.

For the study of the mechanics of flight of paper airplanes analyze shall be experimentally the trajectory of these aircraft. In general, the trajectory of a paper airplane launched horizontally with a speed $\vec{v_x}$, will follow a parabolic behavior as shown in Figure 2.

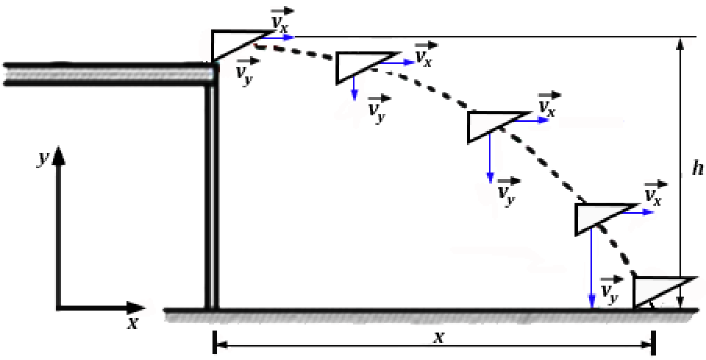

Figure 2: Flight illustration in a horizontal launch a paper airplane. Immediately after the pulse has only the speed component in the x-axis.

The path described in Figure 2 is the result of the action of the vertical forces $\vec{P}$ and $\vec{R_n}$ and initial horizontal velocity $\vec{v_x}$.A vertical speed $\vec{v_y}$ increases from zero initial value (horizontal launch) due to the vertical acceleration $\vec{a_y}$ caused by the difference between $\vec{P}$ and $\vec{R_n}$. Considering the strength $\vec{F_a}$ negligible for paper airplanes, and therefore the speed $\vec{v_x}$ constant and equal to and $\vec{v_0}$, kinematics explains the trajectory using equations [1] and [4].

$$\boldsymbol{a_x = 0} \qquad \textbf{[1]}$$

It is known that:

- according to the horizontal component we have $\mathbf{x = v_0}\boldsymbol{t}$ ***[2]***
- according to the vertical component we have $\boldsymbol{y = y_0 - \frac{1}{2} a_y t^2}$ **[3],** wherein $y_0 = h$.

Knowing that, when the paper aircraft reaches the ground has y = 0, substituting y in expression **[3],** it follows that:

$$\boldsymbol{a_y = 2h\frac{v_x^2}{x^2}} \qquad \textbf{[4]}$$

By equation **[4],** knowing the mass of the airplane (the mass of a sheet of paper with the rubber band and clip), the value of launching speed v_0 and measuring the corresponding hex values of h and x, high of launch and reach, respectively, are obtained experimentally the value of the vertical acceleration, which can be used to characterize the value of the normal reaction force involved by **[8]** equation.

The resultant of the forces $(\vec{F_r})$ has only component in the y-axis, since the friction is negligible so has vectorially

$$\vec{F_r} = \vec{F_g} + \vec{R_n} \qquad \textbf{[5]}$$

That is, it has been intensities

$$F_r = F_g - R_n \ \textbf{[6]}$$

$$ma_y = mg - R_n \ \textbf{[7]}$$

$$\boldsymbol{R_n = m(g - a_y)} \quad \textbf{[8]}$$

To carry out the launches with paper airplanes and obtain the values of reach, height and speed of delivery, will be used the model shown in Figure 3.

Figure 3: Model for launching paper airplanes

The objective of the model is to launch the aircraft horizontally, so that the value of the casting speed can be within the existing constraints, as controlled as possible. Thus, use shall be an elastic band that functions as propeller of the aircraft, and in that a clip attached to a stapling action, as illustrated in the experimental procedure. The procedure aims to obtain a rough estimate of the initial speed of the airplane (v_0) from the flight range. The accuracy of this estimate is strongly conditioned by the difficulty to establish accurately the point of impact of the aircraft with the ground.

From equation **[3]**, it can be inferred that, after release, the aircraft will reach the ground ($y = 0$) at instant $\boldsymbol{t} = \sqrt{\frac{2h}{a_y}}$. **[9]**

From equation **[2]**, which has $v_0 = \frac{x}{t}$ **[10]**.

Thus, replacing t from equation **[9]** into equation **[10],** we will have that:

$$\boldsymbol{v_0} = \sqrt{\frac{g}{2h}}\cdot \boldsymbol{x} \quad \textbf{[11]}$$

Thus, knowing the release height (h), the measurement range (x) to determine the release rate of the launcher (v_0) by **[11]** equation.

EXPERIMENT OBJECTIVES

- Motivating students to the teaching of physics in day-to-day, recognizing the role that science has;
- Study the dynamics of flying paper airplanes;
- To construct and interpret the scope of the graph (x) as a function of flight time (t), $x = f(t)$;
- To construct and interpret the scope of the graph (x) as a function of the initial velocity $x = f(v_0)$;
- Construct and interpret the function of flight time graph of launch speed $t = f(v_0)$;
- Recognizing the mutual influence between the Society, Science and Education;
- Promote team spirit and sharing between all actors in this process.

MATERIAL USED

- 1 launch pad (measurement ruler as shown in Figure 3);
- 2 simple elastic;
- 1 sheet of paper;
- 1 Clip n.º2;
- 1 staples No. 24/6;
- 1 stapler;
- 1 pencil.

EXPERIMENTAL PROCEDURE

PART I - General rules of uniformity. (Video video support in the TwinSpace)

1. The paper sheet is standard A4 size (297 × 210mm) and 80g / m2.
2. The paper airplanes are the DART model and have to be built according to the provided origami.
3. On the paper airplane, mark 7 cm at the bottom, from the nozzle to the center of the plane and put a straightened paper clip and run as follows (Figure 4):

Figure 4 – Clip and Staple

4. It is not allowed to tear, paste and cut beyond shown in 3.
5. The aircraft must be launched by a single student without any help and from a launch line marked on the launch pad.
6. Students must have their feet on the ground during the launch.
7. All tests must take place in a covered enclosure without any wind.
8. No acrobatics are allowed.
9. Each student is entitled to one try.

PART II - Flight dynamics of paper airplanes and experimental measurement of flying paper airplanes. (*See video support in the TwinSpace*)

1. Measure the mass of the aircraft (g).
2. Place the launch pad at a height of 1.20 m above the ground.
3. Place the plane horizontally, properly attached to elastic, and the tips of the thumb and index finger hold on the tail without touching the wings.
4. Stretching the plane through the "elastic" propellant to 40.0 cm mark.
5. Launch the plane.

6. Measure the distance d2, in meters, with a tape measure from the platform end to the first point where the plane touches the ground or any object (see Figure 5).
7. The measurement of the total distance, d (which is the range x), will be carried away from the launch line (the point where the elastic is no tension) to the platform end, d1, d2 plus the distance. (In the database is already included in the measurement d1, since the platform has been normalized).
8. Recording the flight time with a chronometer (ms) from the time the aircraft departs paper hand the student to land. If contacting any object must be repeated because this test is not relevant since the plane does not reach the distance range.

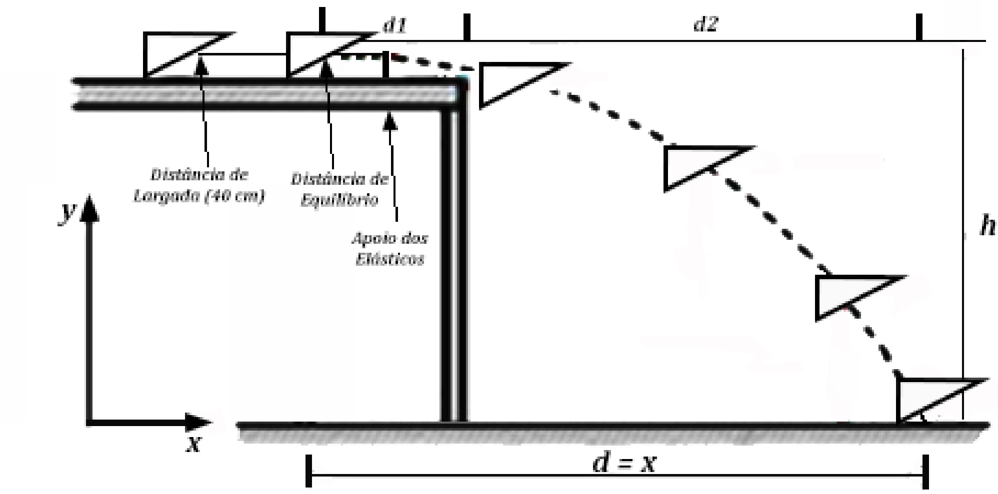

Figure 5. Explanation of distances to be measured during the tests.

Extra bonus: Build the DART model using an A3 sheet, an A5 and A6. Checks what happens to reach. You will have a bonus for the chart range depending on the area ($x = f(A)$). Considers the A4 area equal to A. As marks the areas of the other?

PART III - Free-throw paper airplane.

1. Proceed together the free release of the paper airplane, in open field, use two elastic coupling and a pencil according to Figure 6.

Figures 6a e 6b- Free launching of the airplane.

PART IV - Scientific Exploration

1. To construct and interpret the scope graph of the range (x) as a function of flight time (t), $x = f(t)$, indicating the meaning of the ratio x/t and checking whether there is some regularity in the graph.
2. After the introduction, in the database, the data recorded make the analysis of the graph $x = f(v_0)$;
3. After the introduction, in the database, the data recorded make the analysis of the graph $t = f(v_0)$;
4. Proceed to the analysis of results and conclusion.

COMPILATION OF RESULTS

The results of range (cm) and the flight time (ms) should be registered in the database provided in order to carry out a scientific analysis of the obtained graphs, the graphs in particular $\mathrm{x} = \mathrm{f}(\mathrm{v}_0)$ e de $\mathrm{t} = \mathrm{f}(\mathrm{v}_0)$.

BIBLIOGRAPHIC REFERENCES

- Anderson, D., Heberhardt, S. (2006). *Como os aviões voam.* http://www.sbfisica.org.br/fne/Vol7/Num2/v13a08.pdf. Accessed in January 2016.
- Delatorre, R.G., Becker,M.P., Victorette,A.W.D.B, Steffen,B., Mikowski,A., Souza,M.S.K., Soethe,V.L. (2013). *A física no voo de aviões de papel: Uma abordagem prática e experimental para o ensino de física e de conceitos aerodinâmicos*, COBENGE 2013-LXI Congresso Brasileiro de Educação em Engenharia, Brasil.

- Chen,K., Lai,W. (2013) *Paper Plane Aerodynamics*, Yongchang Qian Advisor, Xiamen Foreign Language School Ed., China. Available in *ymsc.tsinghua.edu.cn:8090/down/1.pdf*
- Farnudi, A. (2010). "Paper Planes", *Journal of the International Association of Physics Students*, n.1, 12. Disponível em *www.iaps.info/media/jiaps-2010-1.pdf.*
- Henk.T. (1996). *The Simple Science of Flight*, MIT Press, USA.
- Studart, N., Dahmen, S. (2006). *A Física do Voo na Sala de Aula.* http://www.sbfisica.org.br/fne/Vol7/Num2/v13a07.pdf. (Accessed in January 2016)
- Johns, R.H. (1971) "Scaling and Paper Airplanes", *The Physics Teacher*, 9, 541
- Vieyra, R.E., Springer,T., Gipson,L., Werries,M., Schultz,J. (2011). *Aeronautics for Introductory Physics*, Edited by NASA Aeronautics and the American Association of Physics Teachers, USA. Available in www.aeronautics.nasa.gov/pdf/aero-intro-physics.pdf.