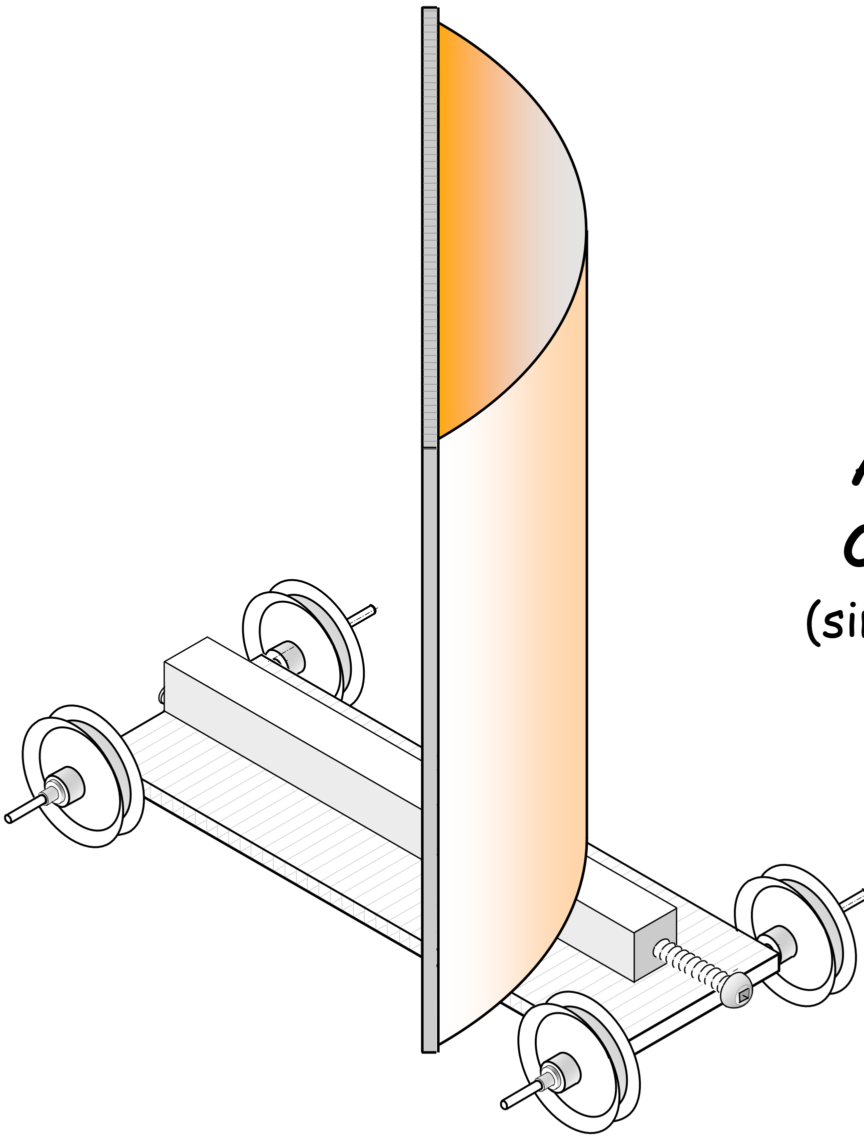
centre de développement pédagogique
pour la formation générale en science et technologie

Working document



AEOLUS' CHARIOT
(simplified LES)

TEACHER AND TTP GUIDE

January 2012

Table of contents

FOR TEACHING AND TECHNICAL PERSONNEL

NOTE	This LES was designed within the framework of training sessions. It may require adaptation before being used with students.

Uniformly accelerated motion

Directed laboratory (Uniformly accelerated mobile)

Example for Data Table 1 — **Mass (g) =** 42.39

n°	Distance Éperon - Transducteur (cm)	U(V) #1	U(V) #2	U(V) #3	U(V) Moy.
1	0,9	0,034	0,034	0,033	0,034
2	3,5	0,140	0,140	0,141	0,140
3	6,1	0,229	0,227	0,217	0,224
4	8,6	0,302	0,295	0,293	0,297
5	11,3	0,362	0,349	0,356	0,356
6	13,7	0,457	0,442	0,461	0,453

Analyse the results

Analyse your data

Question 1
The voltage is increasing in relation to the distance between the spur and the transducer.

Question 2
When we release the mobile from a higher position, it hits the transducer with greater speed. Greater speed generates greater voltage.

Question 3
Yes, we would have obtained the same results. We would also have found that the voltage increases in relation to the distance between the spur and the transducer.

Draw your conclusions

Question 4
It is possible to do so from the measured voltages.

Calibrating the piezoelectric transducer

Notes

- An "Excel" spreadsheet is available on the CDP website to make the calibration easier. See: http://www2.cslaval.qc.ca/cdp/pages/documentation.html
- The graph obtained from this calibration allows you to see the relationship between a voltage read and a given mechanical energy. Though this relationship can be made directly on the graph, mathematical treatment leading to the equation will give more precise results.

Precautions to take to ensure greater accuracy in calibrating

- Start the calibration with the marble 3 cm. high.
- Ensure that the marble always hits the transducer in the center.
- Ensure that there are no parasitic vibrations on the assembly. A part of the voltage generated could then be attributed to this vibration.
- Remove any 120V CA supplied devices from the immediate area. Electromagnetic induction could be captured by the control box of the transducer circuit.

- **Use the same multimeter and measurement scale throughout the calibration and experiment. In addition, since the sampling frequency of multimeters varies from one model to another, some models may perform better than others. In our experiment, we used ABRA's DM-9700 model (see image at right).**

  http://www.abra-electronics.com/products/DM-9700-Digital-Multimeter.html

Example of analysis results for the calibration of the transducer

Analyse your data

Question 1

When the marble is held back by the electromagnet, its energy is in the form of potential gravitational energy.

Question 2

For the calculation of the potential energy, see table below.

Summary of data tables 2 and 3

Éole simplifié (transducteur piézoélectrique)

Étalonnage

Entrez vos valeurs expérimentales dans les cadres rouges.

Masse de la bille d'acier : 13,77 *g*

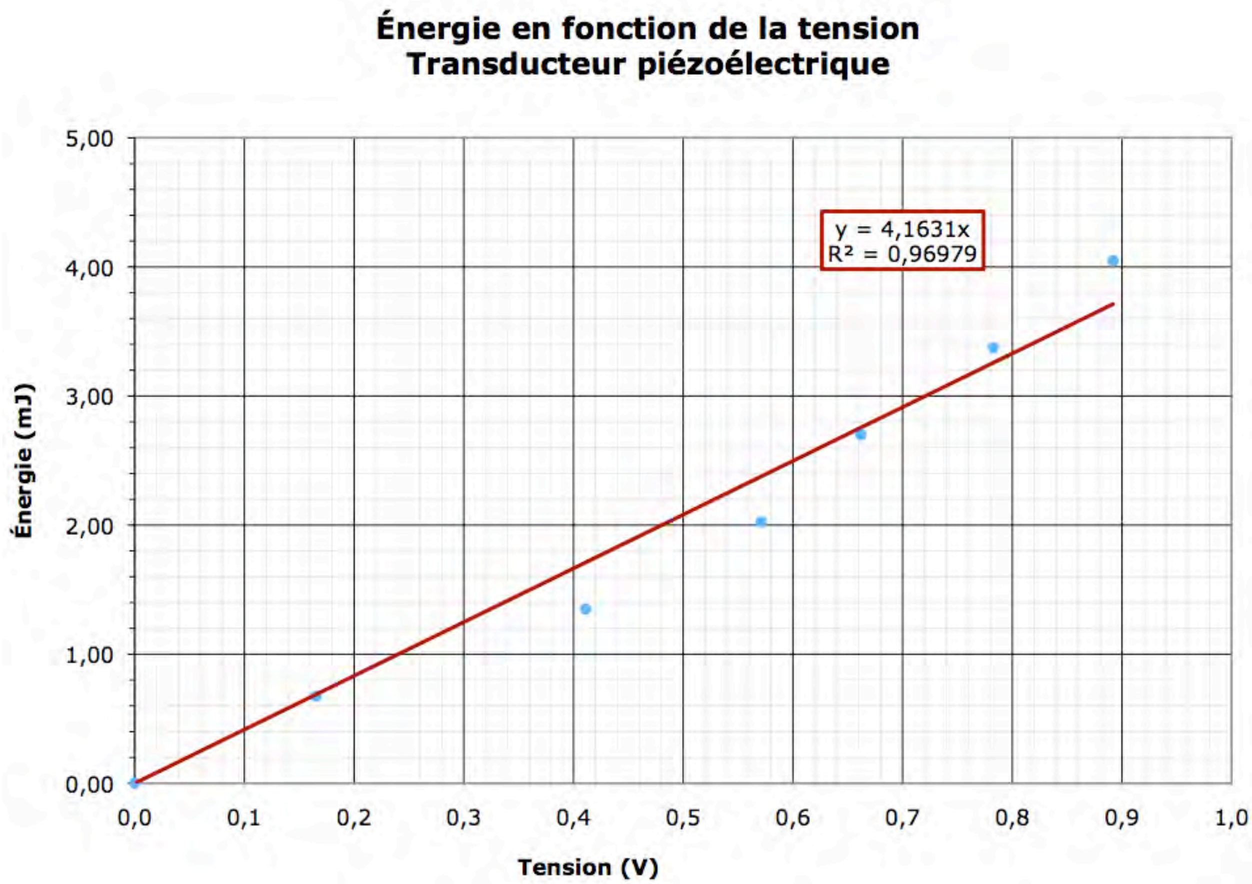
Accélération gravitationnelle : 9,8 m/s2

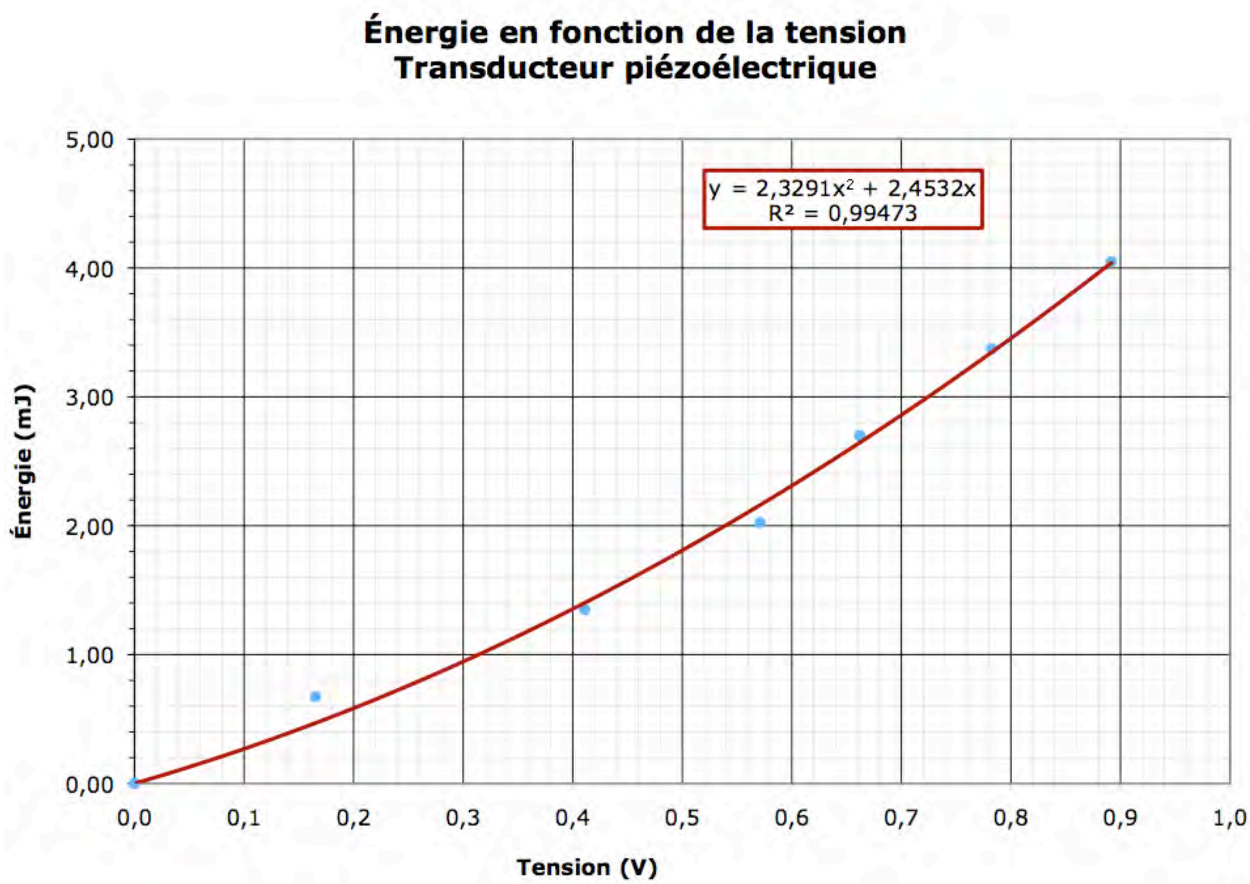
Hauteur (cm)	Tension (V) Essai #1	Tension (V) Essai #2	Tension (V) Essai #3	**Tension (V) Moyenne**	**Énergie (mJ)**
3,00	*0,928*	*0,859*	*0,888*	0,892	**4,048**
2,50	*0,813*	*0,777*	*0,758*	0,783	**3,374**
2,00	*0,674*	*0,643*	*0,669*	0,662	**2,699**
1,50	*0,553*	*0,552*	*0,608*	0,571	**2,024**
1,00	*0,423*	*0,400*	*0,410*	0,411	**1,349**
0,50	*0,154*	*0,168*	*0,174*	0,165	**0,675**
0,00	*0,000*	*0,000*	*0,000*	0,000	**0,000**

Analyse your data (continued)

Question 3

See the graphs on the following page.


Énergie en fonction de la tension
Transducteur piézoélectrique
y = 4,1631x
R² = 0,96979
5,00
4,00
3,00
2,00
1,00
0,00
0,0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
1,0
Énergie (mJ)
Tension (V)


Énergie en fonction de la tension
Transducteur piézoélectrique
y = 2,3291x² + 2,4532x
R² = 0,99473
5,00
4,00
3,00
2,00
1,00
0,00
0,0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
1,0
Énergie (mJ)
Tension (V)

Highlight the trends

Question 4
Looking at the graphs from the previous page, we note that the parabola follows the experimental data more closely. The sum of the distances between the experimental points and the curve is smaller in the case of the quadratic function. The coefficient of determination R^2 is also greater for the second degree function.

Question 5
See the equations present on the graphs on the previous page.

Question 6

Summary table	
Type of energy (or labour)	At a given time
Potential gravitational energy	When the marble is held by the electromagnet
Kinetic energy	Just before the marble hits the crystal
Labour	When the crystal is distorted
Electrical energy	When an electrical current is generated

Draw your conclusions

Question 7
Every time the transducer generates voltage, a quantity of energy can be associated to it using the graph or the equation of the chosen model.

Kinematic study of the uniformly accelerated mobile

Question 1

See columns 2 and 3 of the results table 4 below.

Question 2

See column 4 of the results table 4 below.

Question 3

$\{E_k = \frac{1}{2}\, m \bullet v^2 \Rightarrow v = \sqrt{(2\, E_k / m)}\}$
See column 5 of the results table 4 below.

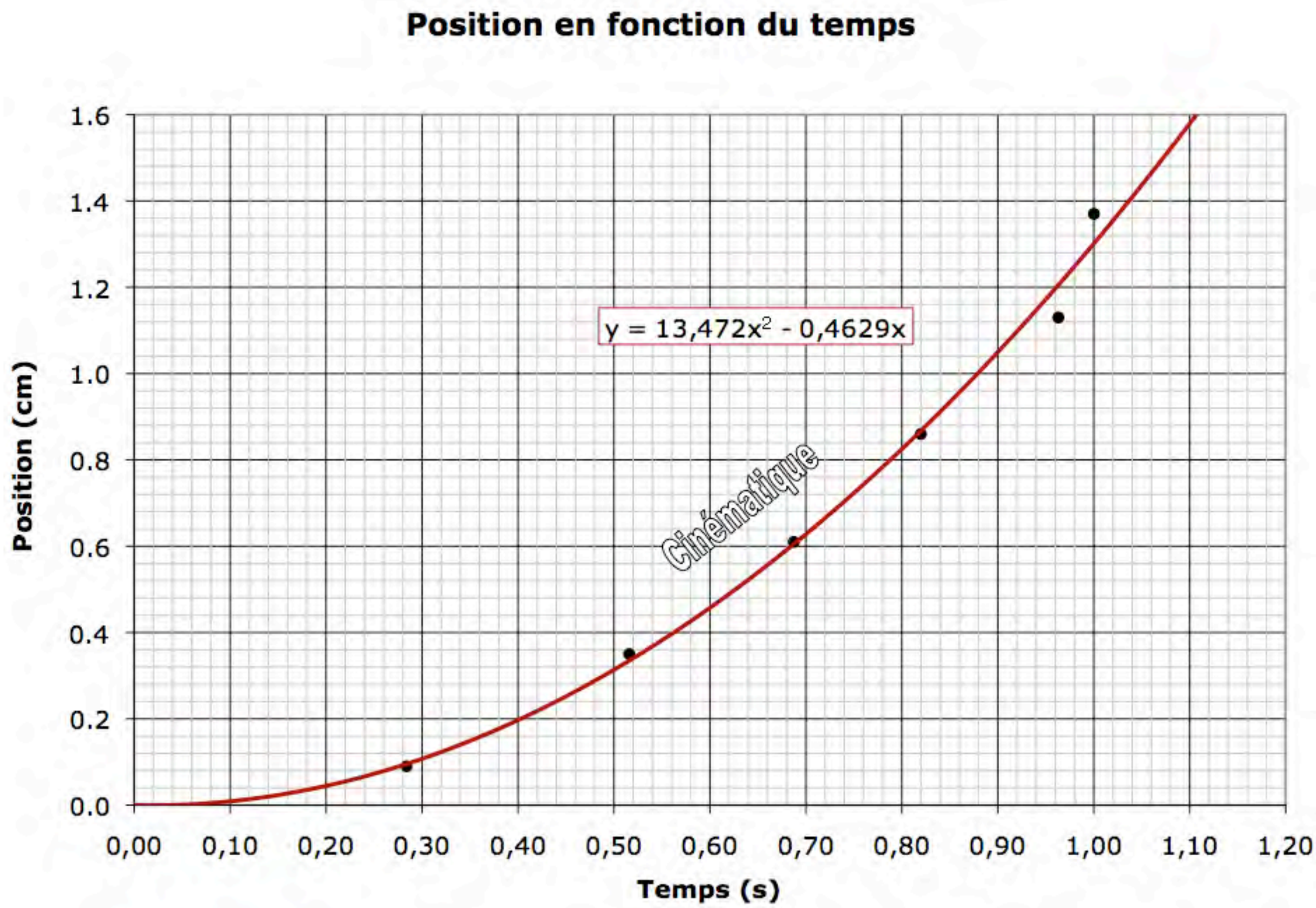
Question 4
See column 6 of the results table 4 below.

Question 5
Simplified equation: $x = \frac{1}{2}\, v \cdot t$

Question 6
See column 7 of the results table 4 below.

Example for results table 4 (uniformly accelerated mobile - kinematic)						
This section is drawn from the six small collisions carried out				If we had simulated a single descent for the mobile		
Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7
Collision number	**Distance spur — transducer (cm)**	**Average voltage (V)**	**Kinematic energy (mJ)**	**Speed v (cm/s)**	**Position x (cm)**	**Time t (s)**
1	0.9	0.034	0.085	6.3	0.9	0.28
2	3.5	0.140	0.390	13.6	3.5	0.52
3	6.1	0.224	0.668	17.7	6.1	0.69
4	8.6	0.297	0.933	21.0	8.6	0.82
5	11.3	0.356	1.167	23.5	11.3	0.96
6	13.7	0.453	1.591	27.4	13.7	1.00

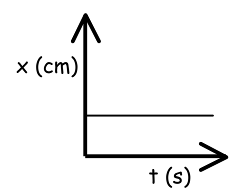
Question 7



Question 8

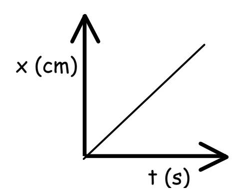
There is a parabola on the graph.

Question 9



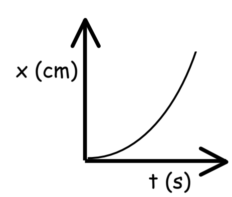
On the graph at right, the position is constant. The observed object is therefore immobile, its position unchanging. It is a given that its speed is nil.

Question 10



On the second graph at right, the position changes regularly in relation to time. The observed object is therefore in motion. We can even affirm that it is moving at constant speed, since its position changes at a constant rate.

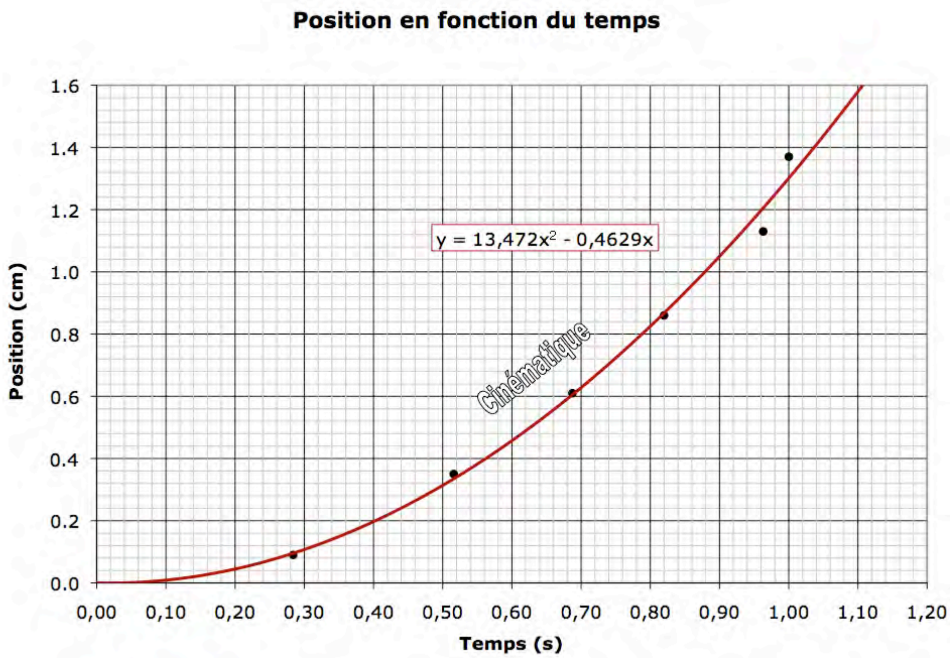
Question 11



On the last graph, the position changes faster and faster as time goes on. The observed object therefore is moving at ever greater speed. We can therefore affirm that the object is accelerating.

Question 12

The graph of the mobile in relation to time is the same as the one seen in Question 11. We can therefore affirm that the position of the mobile changes in relation to time, that its speed is increasing, and that it is accelerating.



Dynamic study of the uniformly accelerated mobile

Find angle θ.

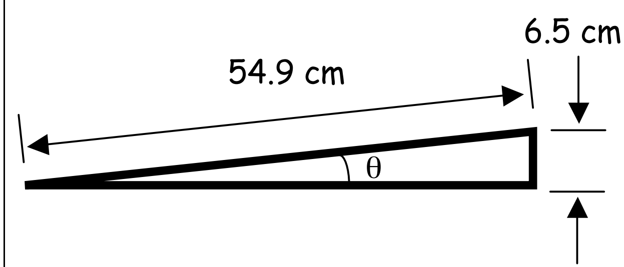
Sin θ = opposite side / hypotenuse

θ = arc Sin (opposite / hypotenuse)

θ = arc Sin (6.5 cm / 54.9 cm)

θ = arc Sin (0.118)

θ = 6.80°



Calculate the gravitational force $\vec{F_g}$

$$\vec{F_g} = m \bullet \vec{g}$$

$$= 0.0424 \text{ Kg} \cdot 9.8 \text{ m/s}^2$$

$$= 0.416 \text{ N}$$

Calculate $\vec{F_r}$ **considering the right triangle.**

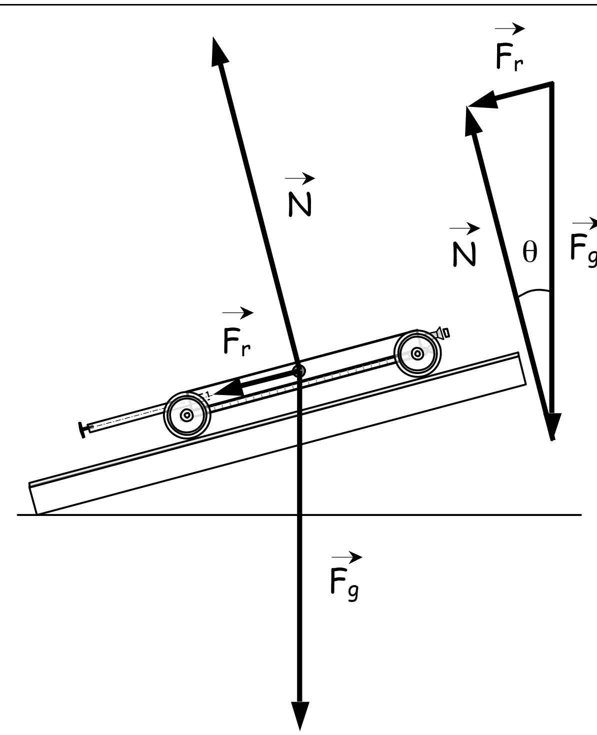
Sin θ opposite side / hypotenuse

Sin θ = F_r / F_g

F_r = F_g Sin θ

F_r = 0.416 N • Sin 6.80°

F_r = 0.049 N



Question 1

The theoretical acceleration of the mobile on the inclined plane is:
$F_r = m \bullet a \Rightarrow a = F_r / m \Rightarrow a = 0.049 \text{ N} / 0.0424 \text{ Kg} \Rightarrow a = 1.16 \text{ m/s}^2$

Question 2

Recopy column 7 (time) from Results table 4 into Results table 5 below.

Results table 5 (uniformly accelerated mobile - dynamic)							
n°	**0**	**1**	**2**	**3**	4	5	6
Time, t (s)	**0**	0.28	0.52	0.69	0.82	0.96	1.00
Speed, v (cm/s)	**0**						
Position, x (cm)	**0**						

Question 3

Example of the calculation of speed of the mobile starting from acceleration.

$v = v_0 + at \Rightarrow v = at \Rightarrow v = 1.16\ m/s^2 \bullet 0.28\ s \Rightarrow v = 0.362\ m/s \bullet 100\ cm / 1\ m$
$\Rightarrow v = 32\ cm/s$

Results table 5 (uniformly accelerated mobile - dynamic)							
n°	**0**	**1**	**2**	**3**	4	5	6
Time, t (s)	**0**	0.28	0.52	0.69	0.82	0.96	1.00
Speed, v (cm/s)	**0**	≈32	≈60	≈80	≈95	≈111	≈116
Position, x (cm)	**0**						

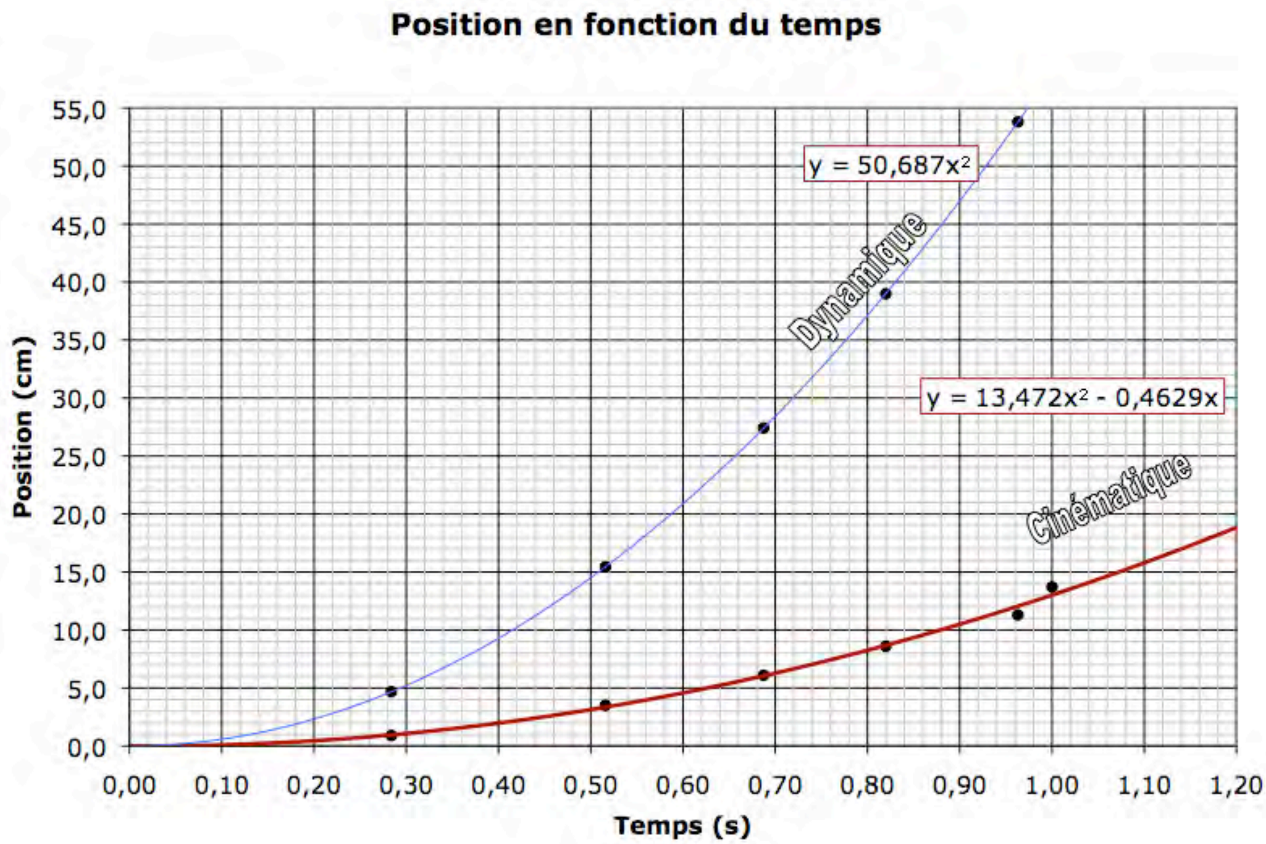
Question 4

Example of calculation of the position of the mobile for each time.

$x - x_0 = \frac{1}{2} (v + v_0) t \Rightarrow x = \frac{1}{2} v \bullet t \Rightarrow x = 0.5 \bullet 32\ cm/s \bullet 0.28\ s \Rightarrow x = 4.5\ cm \approx 5\ cm$

Results table 5 (uniformly accelerated mobile - dynamic)							
n°	**0**	**1**	**2**	**3**	4	5	6
Time, t (s)	**0**	0.28	0.52	0.69	0.82	0.96	1.00
Speed, v (cm/s)	**0**	≈32	≈60	≈80	≈95	≈111	≈116
Position, x (cm)	**0**	**≈5**	≈16	≈28	≈39	≈53	≈58

Question 5



Question 6

The "dynamic" curve moves upwards more quickly.

Question 7

The mobile has traveled a greater distance in the case of the "dynamic" curve. For example, after .5 seconds, the kinematic study shows a position at ≈3 centimetres, compared with ≈15 centimetres for the dynamic study.

Question 8

If we consider the last two points on the curves to calculate a variation rate, we find a much greater variation rate for the "dynamic" curve. The final speed is therefore greater in the dynamic study.

Question 9

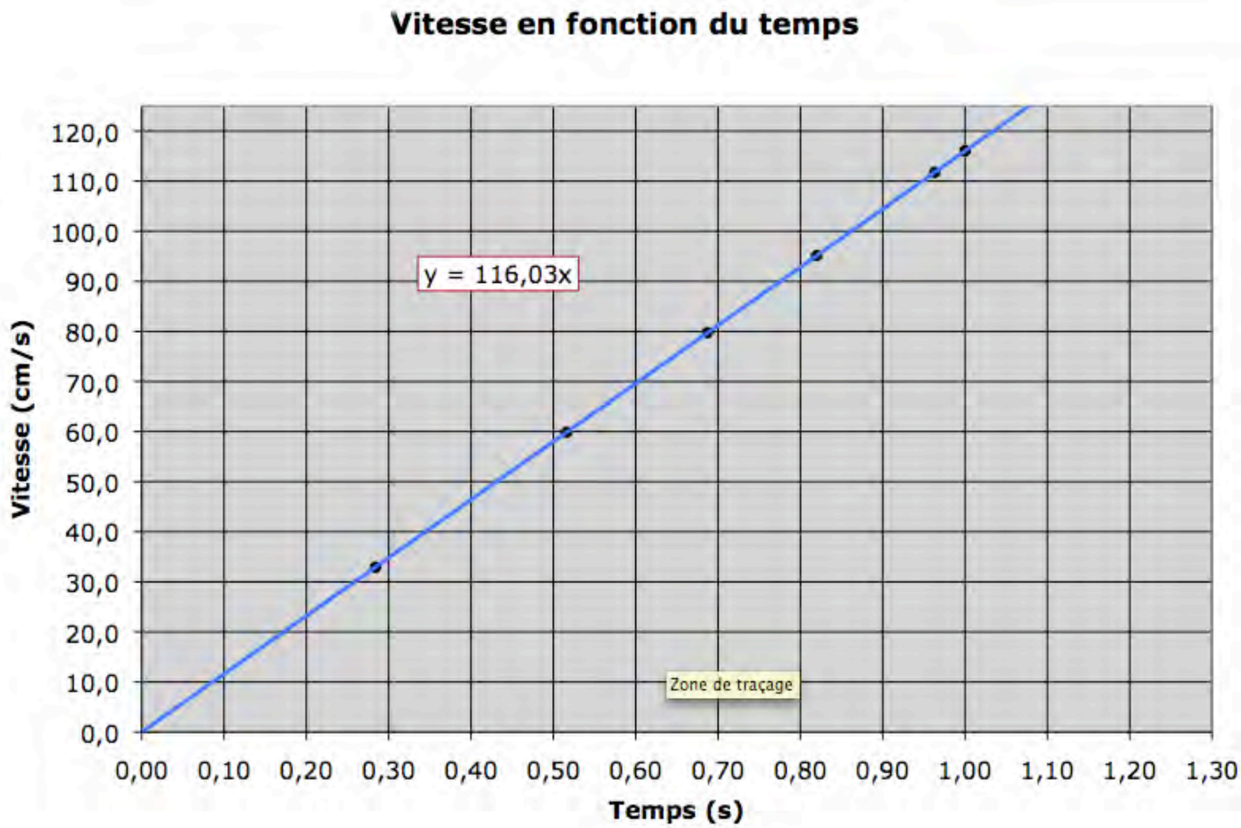
The parabola is distinctly more curved in the case of the dynamic study, so the mobile accelerates more quickly.

Question 10

In the case of the dynamic study, no friction is taken into account. It is a more theoretical way of seeing things.

Question 11

From Results table 5, here is the graph of the speed of the mobile in relation to time.



Question 12

Speed is increasing steadily, always at the same rate, which is why the line is straight.

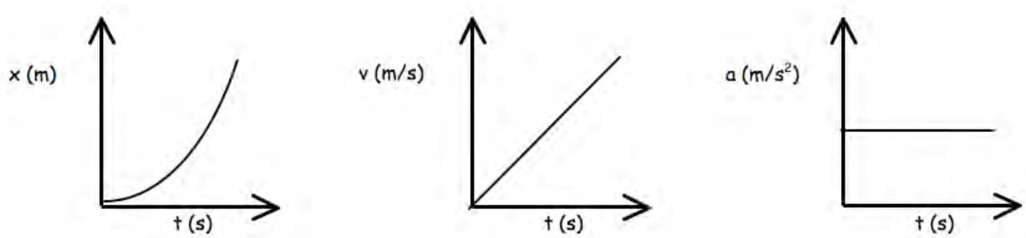
Question 13

We are seeing uniformly accelerated motion. If the acceleration had changed, we would have seen a curve rather than a straight line.

Question 14

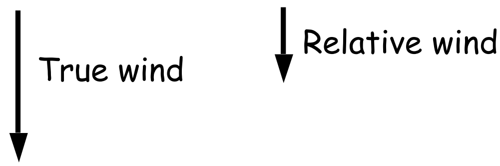
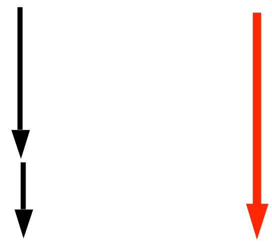
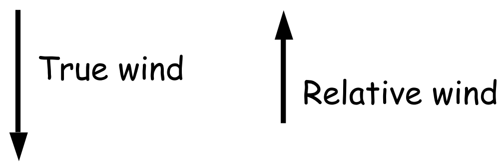
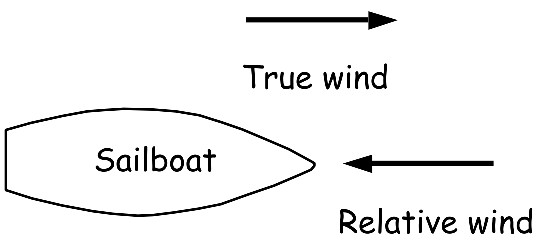
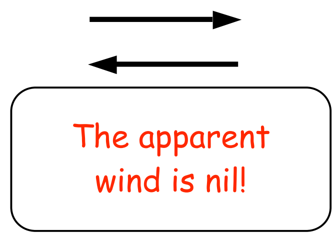
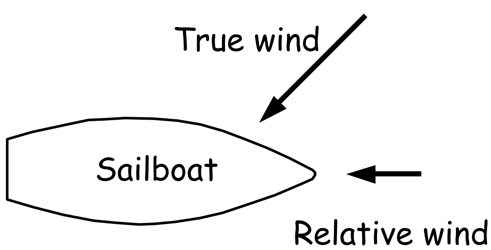
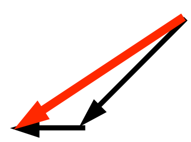
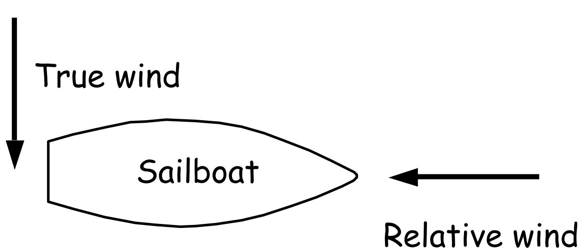
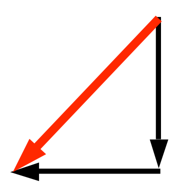
The rate of variation of the straight section of this graph corresponds to the acceleration of the mobile. Here, the acceleration is about 116 cm/s^2 or 1.16 m/s^2.

Question 15



Basic notions about sailing

Exercises about winds

From these two wind vectors,	find the resulting vector, the apparent wind.
	
	
	
	
	

Directed laboratory (dynamics of Aeolus' chariot)

Data table 6 (dynamic Aeolus' chariot)				
Point of sail	**U (V) Trial n° 1**	**U (V) Trial n° 2**	**U (V) Trial n° 3**	**Average voltage (V)**
Running wind	0.220	0.265	0.237	0.241
Beam reach	0.176	0.157	0.141	0.158
Close hauled	0.019	0.012	0.013	0.015
Distance spur — transducer Δs (cm)			3.7	
Mass of Aeolus' chariot (g)			71.26	

Questions 1 and 2 (see Results table 7 below)

Question 3 Example of the calculation for the running wind.

$W = F \cdot \Delta s \Rightarrow F = W/\Delta s \Rightarrow F = 0.725 \text{ mJ} / 3{,}7 \text{ cm} \Rightarrow F = 0.000725 \text{ J} / 0.037 \text{ m}$

$\Rightarrow F = 0.020 \text{ N}$

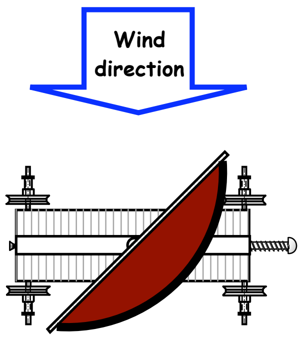
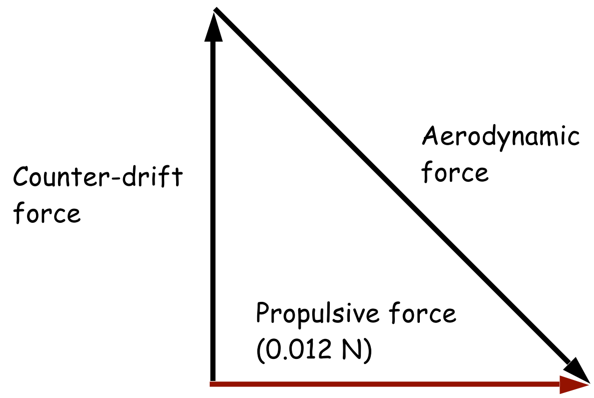
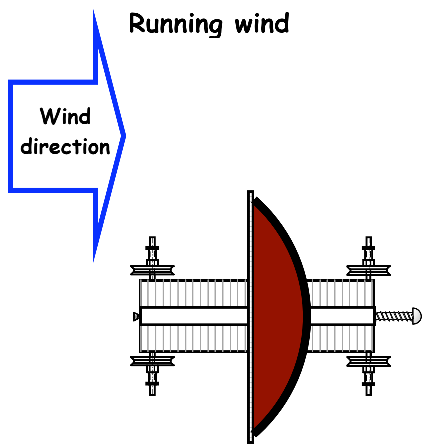
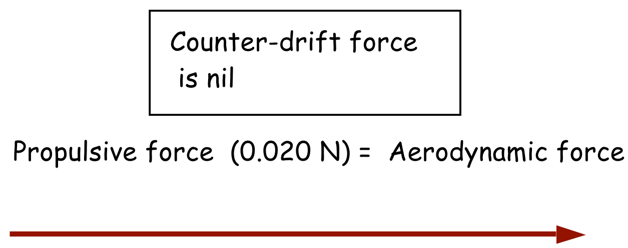
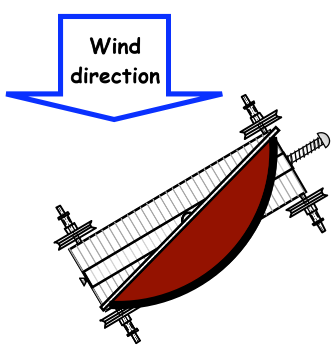
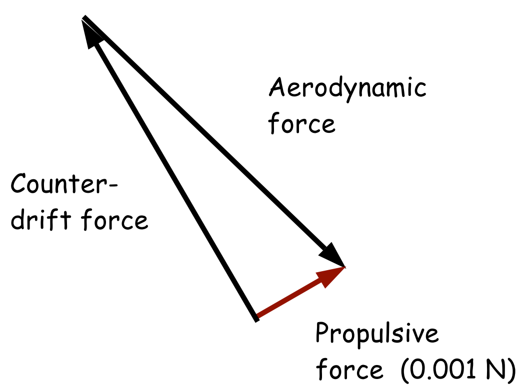
Question 4 Example of the calculation for the running wind.

$F = m \cdot a \Rightarrow a = F/m \Rightarrow a = 0.020 \text{ N} / 71.26 \text{ g} \Rightarrow a = 0.020 \text{ N} / 0.07126 \text{ kg}$

$\Rightarrow a = 0.28 \text{ m/s}^2$

Results table 7 (dynamic Aeolus' chariot)					
Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
Point of sail	**Average voltage (V)**	**Energy (mJ)**	**Labour (mJ)**	**Effective force (N) (propulsive)**	**Acceleration (m/s^2)**
Running wind	0.241	0.725	0.725	0.020	0.28
Beam reach	0.158	0.446	0.446	0.012	0.17
Close hauled	0.015	0.036	0.036	0.001	0.01

Question 5

Since you know the direction of the three forces, and the strength of the propulsive force, (size of the resulting vector), determine, graphically, the strength of the two other forces.	
Illustration of the situation	Graphical vector addition
Beam reach 	
Running wind 	
Close haul (60°) 	

Question 6
The propulsive force is greatest when there is a running wind. It is less when it is close-hauled.

Question 7
According to what we see here, it would seem that a running wind would make us move fastest, since the wind pushes us in the same direction as we are traveling.

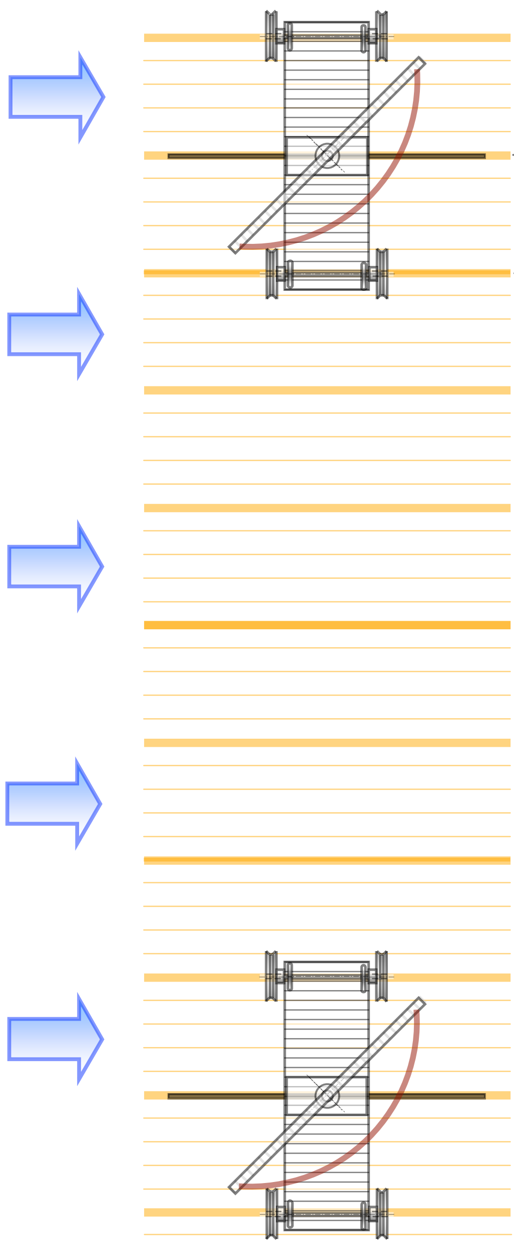
Question 8
When the chariot is face to the wind and its rigid sail is in the same axis as the boat, there is still an aerodynamic force perpendicular to the sail. In fact, since the sail is rigid, Bernoulli's principle still applies. A counter-drift force is also present, directed exactly opposite to the aerodynamic force. In this case, you can see that there is no resulting force to push the chariot forward.

Kinematic analysis of Aeolus' chariot

The video is available at: http://www2.cslaval.qc.ca/star/Char-d-eole

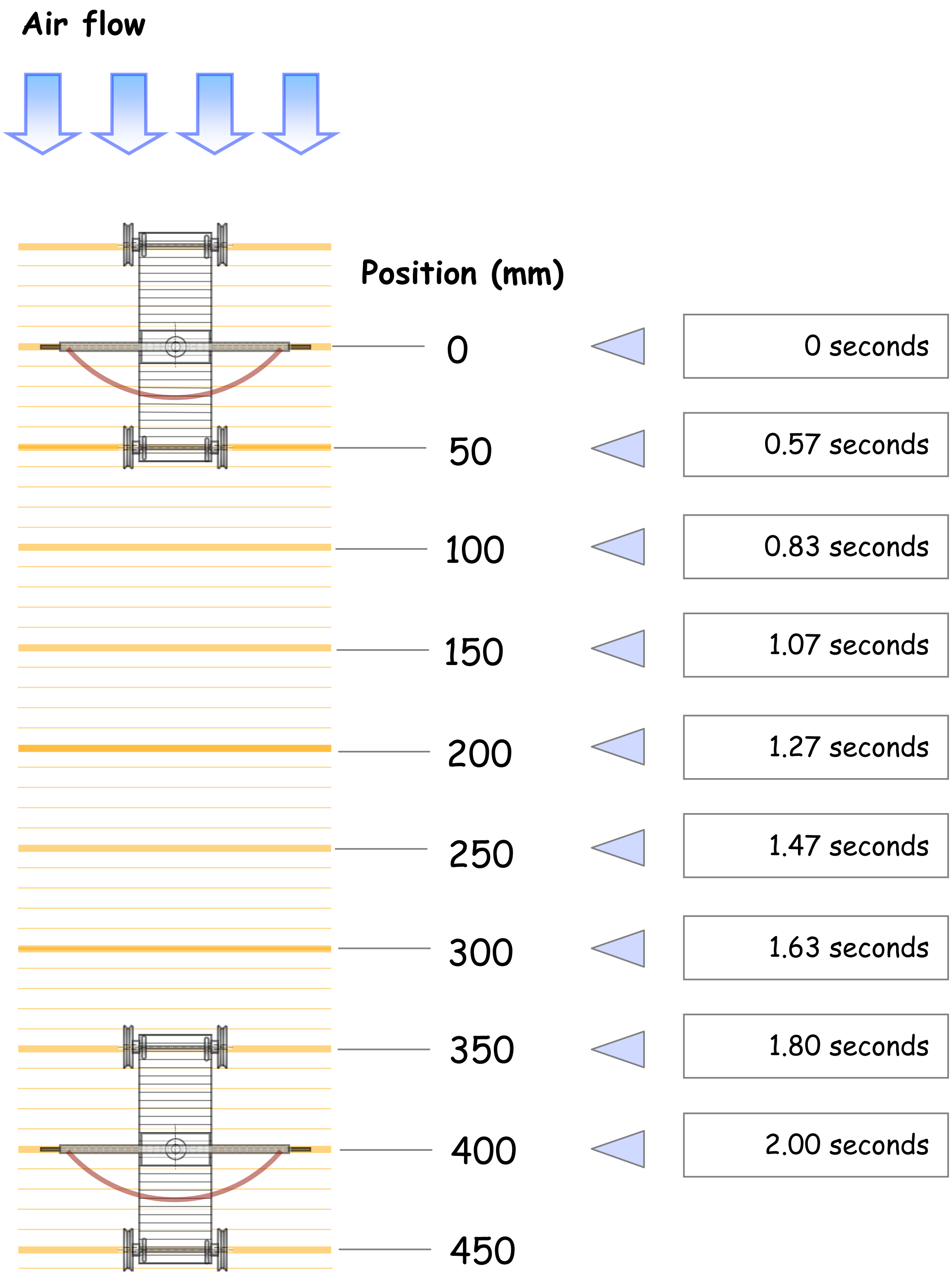
Time recording in relation to position for beam reach point of sail

Air flow

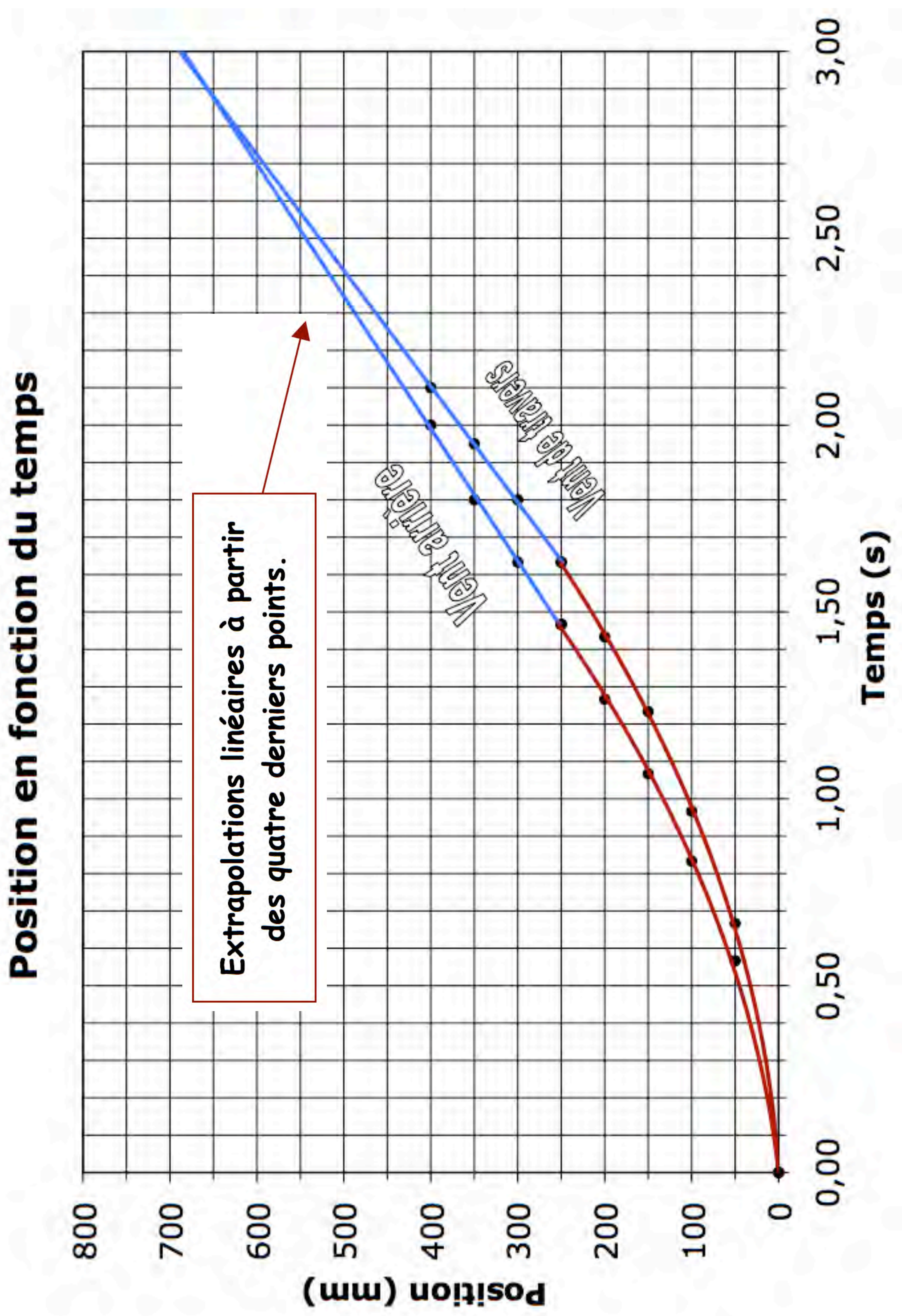


Position (mm)	
0	0 second
50	0.67 seconds
100	0.97 seconds
150	1.23 seconds
200	1.43 seconds
250	1.63 seconds
300	1.80 seconds
350	1.95 seconds
400	2.10 seconds
450	

Time recording in relation to position for running wind

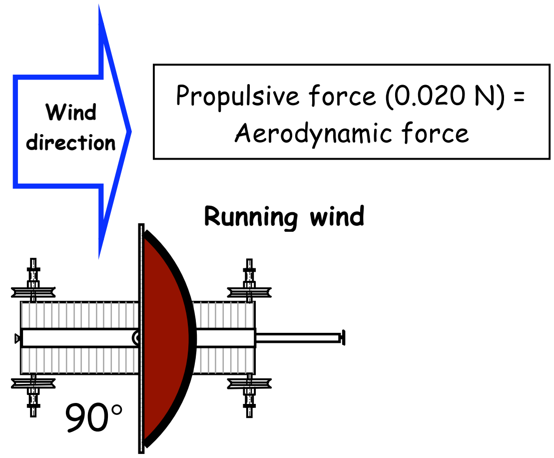


Graphical analysis for the points of sail



Which point of sail allows for the greatest acceleration?

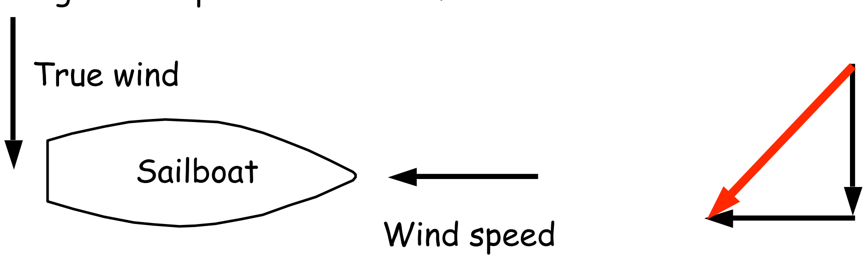
The parabolic section of the curve (in red) is most curved in the case of a **running wind.** This indicates that acceleration is greatest at this point of sail. This corroborates the measurements taken during the dynamic study of Aeolus' chariot. We noticed then that the effective (or propulsive) force was greater when we had a running wind.



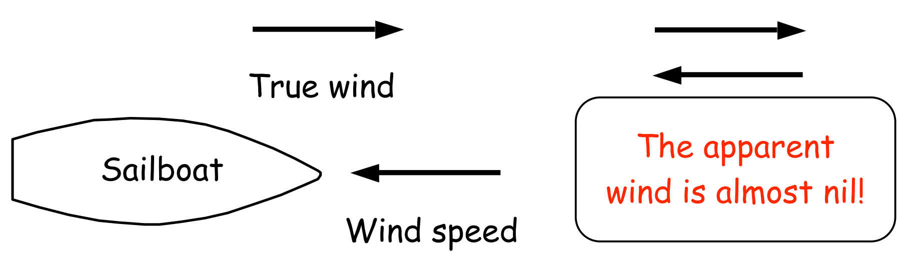
Which point of sail allow for the greatest speed?

After a few seconds, the chariot reaches a constant speed. At that point, the propulsive force equals the force of friction from the wheels. Since the resulting force is nil, there is no longer acceleration. That's why a linear extrapolation is carried out on the last three experimental data for each curve (see blue curved section on the graph). By observing these extrapolations, we notice that there is a greater rate of variation in the case of a beam reach wind. This indicates to us that the final speed is greatest at this point of sail. This observation was not obvious when we did the dynamic study of Aeolus' chariot because the chariot never got the chance to accelerate enough. Remember, the spur-transducer distance was only about 3 cm.

The reason for which we reach greater speed with a beam reach wind is that the apparent wind keeps its strength at this point of sail. The propulsive force generated at this point of sail therefore stays very vigorous.



With a running wind, the chariot accelerates and almost reaches the speed of the wind. At that point, the apparent wind becomes almost nil and the propulsive force, miniscule.



Webography

Boat images

http://www.gettyimages.ca/detail/75491338/Dorling-Kindersley-RF

http://www.gettyimages.ca/detail/85594808/Dorling-Kindersley-RF

http://www.gettyimages.ca/detail/88663220/De-Agostini-Picture-Library

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History

http://fr.wikipedia.org/wiki/Caravelle_%28navire%29

Rigid-sail trimaran

http://www.youtube.com/watch?v=6zQYatrcqPY

http://bmworacleracing.com/en/yacht/index.html