INCLINED PLANE REMOTE LABORATORY

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Content

1 Objectives and level of complexity

Through the practical sessions proposed in this document and that make use of the remote laboratory Inclined Plane provided by the Federal University of Santa Catalina (Brazil), the following objectives can be met:

1. Observe and analyse the behaviour of a freely dropping target.
2. Understand and characterize the rotation and translation movements of an object that rotates and/or slides through a plane whose inclination can be configured by the user.

The use of this remote laboratory has a low level of complexity, while the analysis and conclusions drawn from the data collected from experimentation have a medium level of difficulty, since they require the study and understanding of complex physical concepts.

2 The Lab

The Inclined Plane Remote Laboratory offered by the Federal University of Santa Catalina (Brazil) consists mainly of a plane on which a ball can be released.

This plane can be controlled remotely to incline it at different degrees, from -15° to 90° and be able to experience both the principle of free fall and the decomposition of forces experienced by a mass in an inclined plane.

The laboratory consists of the following elements:

1. A ball of 38 mm diameter and a mass of 33 g.
2. A device that allows the ball to be held in its original position
3. 56 cm plane on which the ball is released. The friction of this plane is negligible.
4. A set of motors that allow the plane to be tilted at any angle setup by the user.
5. Set of sensors that allow measuring the passing time of the ball at 6, 16, 26, 36, 46 and 56 cm.
6. Tilt angle indicator.
7. Falling time indicator expressed in milliseconds

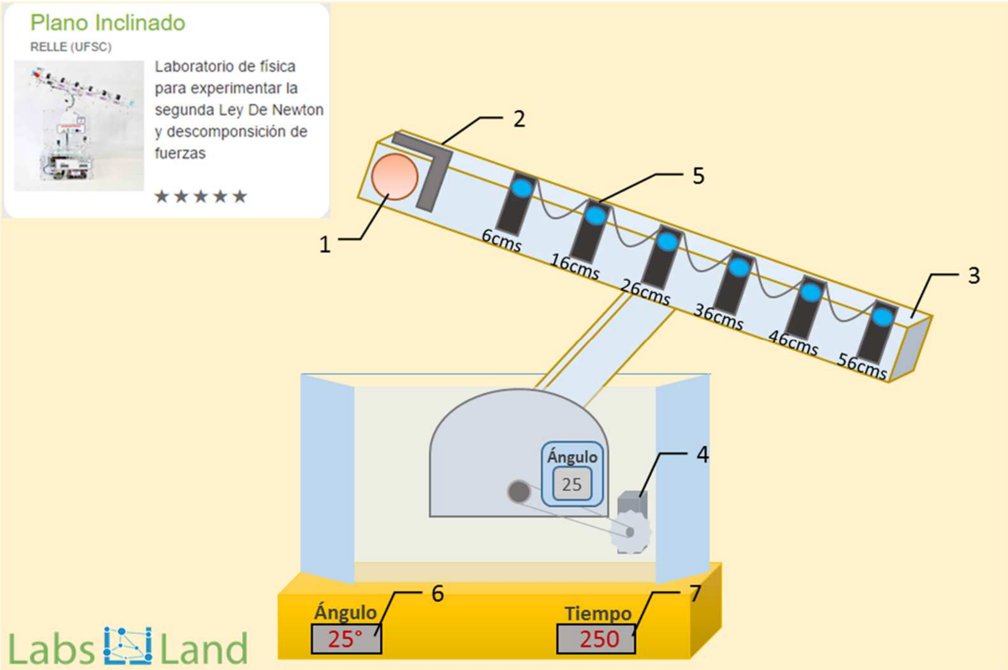

Figure 1. Inclined Plane Remote Lab Schema

The client's user interface is quite intuitive and simple to use. Just consider the following steps:

1. Before throwing the ball, user must place it in its initial position. After each launch, the plane will always be positioned at -15.
2. Select the tilt degree you want to experiment with and press "*Start experiment now*". Remember that, if you want to experiment with the principle of free fall, you must select 90°.
3. Once the inclined plane adopts the desired position, press the ball will be released and you will see how the ball slides or falls from the starting position.
4. Observe the passing times of the ball through the sensors located at 6, 16, 26, 36, 46 and 56 cm.

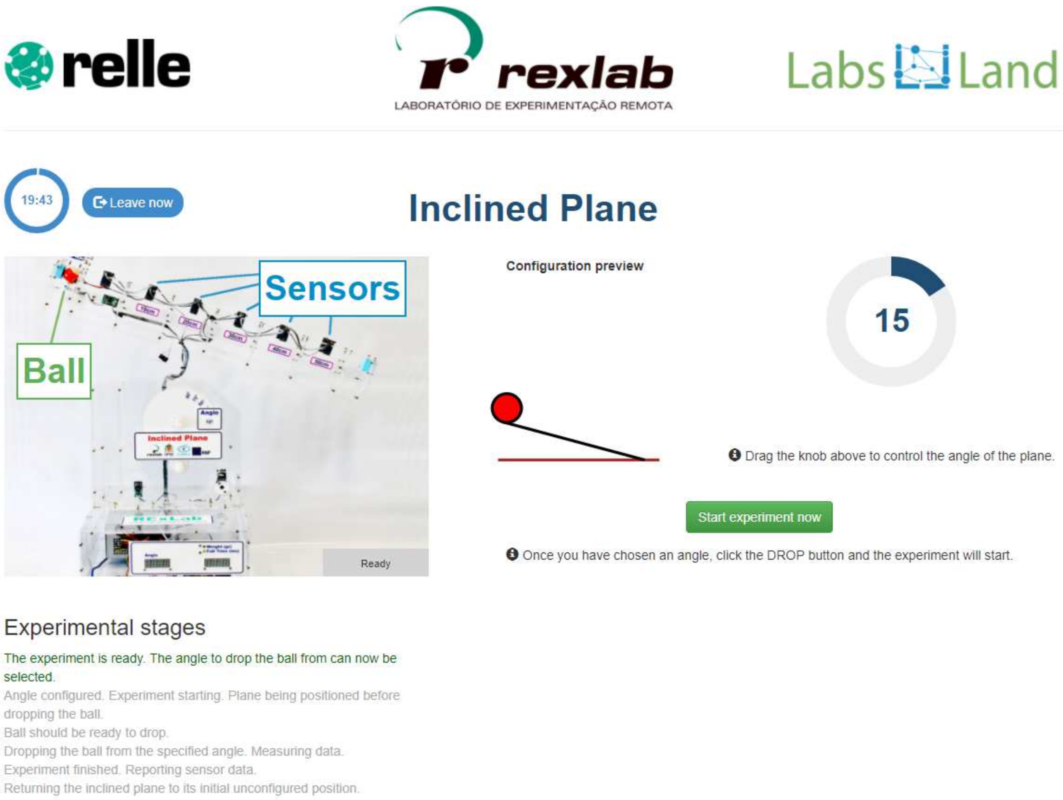

Figure 2. Interfaz de usuario del Laboratorio Remoto del Plano Inclinado

3 Hypothesis that may arise during the experiment

As you can see, depending on the degree of inclination to which we configure the plane of the experiment, the ball will move, slide or fall in different ways.

On this experiment we can play with a multitude of variables: the speed of the ball, its acceleration, the gravity acceleration, the time it takes to travel a certain distance, and so on.

Thus, bearing in mind that we can analyse both the free fall of the ball and the **principle of energy conservation**, the questions we can try to answer with this experiment are:

1. Assuming free fall movement, can we check the acceleration value of the ball? Is it the same as gravity?
2. What theoretical velocity value will the ball reach when it travels 56 cm from the plane when it is configured at different degrees of inclination?
3. In the above case, what is the difference between the velocity calculated theoretically considering translation and rotation movements and the velocity calculated theoretically assuming only translation?

4. To what degrees of inclination should we consider the ball's rotation motion and what degrees of inclination can we consider it negligible?

On these questions, the hypotheses that can be formulated in this laboratory are almost automatic:

- If the tilt is greater than 45°, then the two movements, rotation and translation, must be taken into account. (You must change the slope value according to your results)
- If the inclination is less than XX° then it is necessary to consider the two movements, rotation and translation. (this hypothesis is in principle contradictory to the other, i. e. at least one is erroneous)
- If the ball takes XX seconds to travel 20 cm then it takes twice as long to travel 40 cm (this can be repeated for other distances).
- If the fall is free (90°) then the value obtained for acceleration is the value of gravity.
- If the inclination is doubled then the time is reduced/increased by half/double.
- If the fall is free and the mass changes then the acceleration/gravity does/doesn't change.
- If the fall is free and the height changes then the acceleration/gravity does/doesn't change.

Remember that when you write a hypothesis it is not relevant whether it seems true or not, it is only relevant if it can become an experiment. In other words, if in Scenario 1 there is doubt between increasing or decreasing, one of them is chosen, for example "increases", and experimented to accept the hypothesis or refute it.

All these questions you can try to answer by experimenting with the remote lab, performing the following experiments.

4 Experiments to validate responses to the hypotheses put forward

The development of the experiments simply consists of choosing a pitch, releasing the ball and observing the behavior. In addition, however, the experiment requires two additional points: gathering information and analysing it.

The collection of information has a significant influence on the analytical capacity. Thus, a correct tabulation of the data allows to "see" the most relevant data clearly. In addition, it is sometimes very interesting to represent these data graphically, since the analysis is more visual. Using a spreadsheet makes experimental work much easier.

There are two main problems with data collection: lack of order and lack or excess of data. Few data collection makes correct analysis impossible, but sometimes the opposite situation occurs, as an excess of data may not allow analysis (trees do not show the forest).

In this case there are several data to collect: the starting inclination and the time needed to travel the distance, but should we collect the time for each sensor? Sometimes it is useful to collect all the information and then extract and graph (or not) the information considered most useful.

90°	Sensor 1	Sensor 2	Sensor 3	Sensor 4	Sensor 5	Sensor 6
Distance (m)	0,06	0,16	0,26	0,36	0,46	0,56
Time (s)						
XX°	Sensor 1	Sensor 2	Sensor 3	Sensor 4	Sensor 5	Sensor 6
Time (m)	0,06	0,16	0,26	0,36	0,46	0,56
Tiempo (s)						
XX°	Sensor 1	Sensor 2	Sensor 3	Sensor 4	Sensor 5	Sensor 6
Distance (m)	0,06	0,16	0,26	0,36	0,46	0,56
Time (s)						

Table 1. Example table for collecting information during an experiment

The following are several experiments that you can carry out to check the operation of the remote laboratory and compare the results obtained with the theoretical analysis of each case.

4.1 Experiment 1. Analysis of the free fall of an object.

Through this experiment we want to observe and analyse what happens when we let an object fall freely from a height 'h'. To do this we will follow the following steps:

1. Access the Labsland site with our username and password.
2. Access the Inclined Plane Remote Lab of the Federal University of Santa Catalina (Brazil) and follow the indicated steps

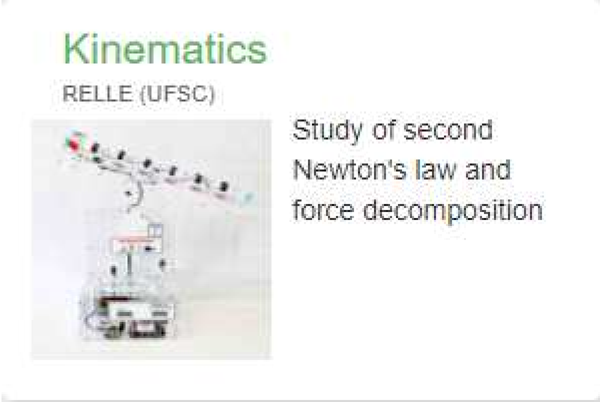

Figure 3. Access the Inclined Plane Remote Lab of the Federal University of Santa Catalina (Brazil)

3. Once inside, we find the control interface where we can configure the degree of inclination. Remember that after experiment, the plane will go back always to its initial position at -15º.

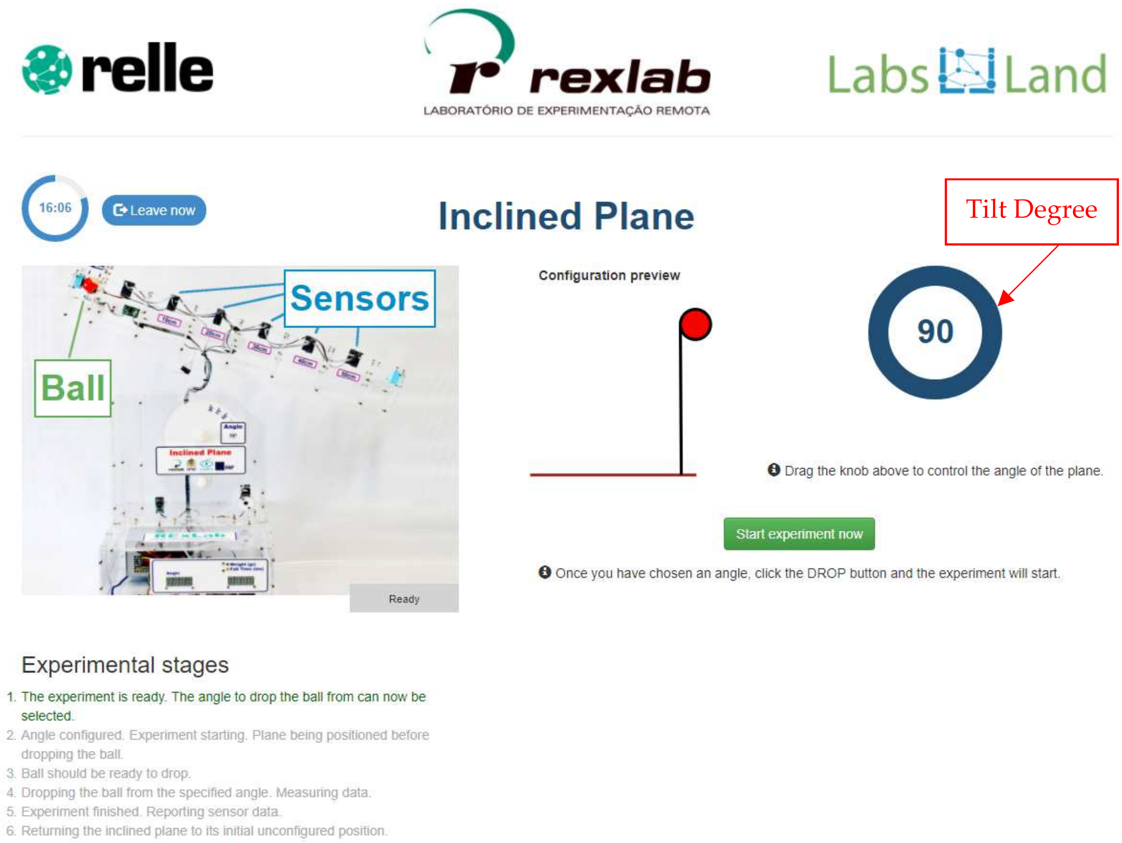

Figure 4. Set up the inclined plane to 90º

4. Once the tilt degree is setup, we can click at *"Start Experiment Now"*. Then, we can observe how the plane acquires the setup position and the ball is released. The measures of the sensors are shown in the attached table. Each steps of the experiment are indicated on the left side of the interface.

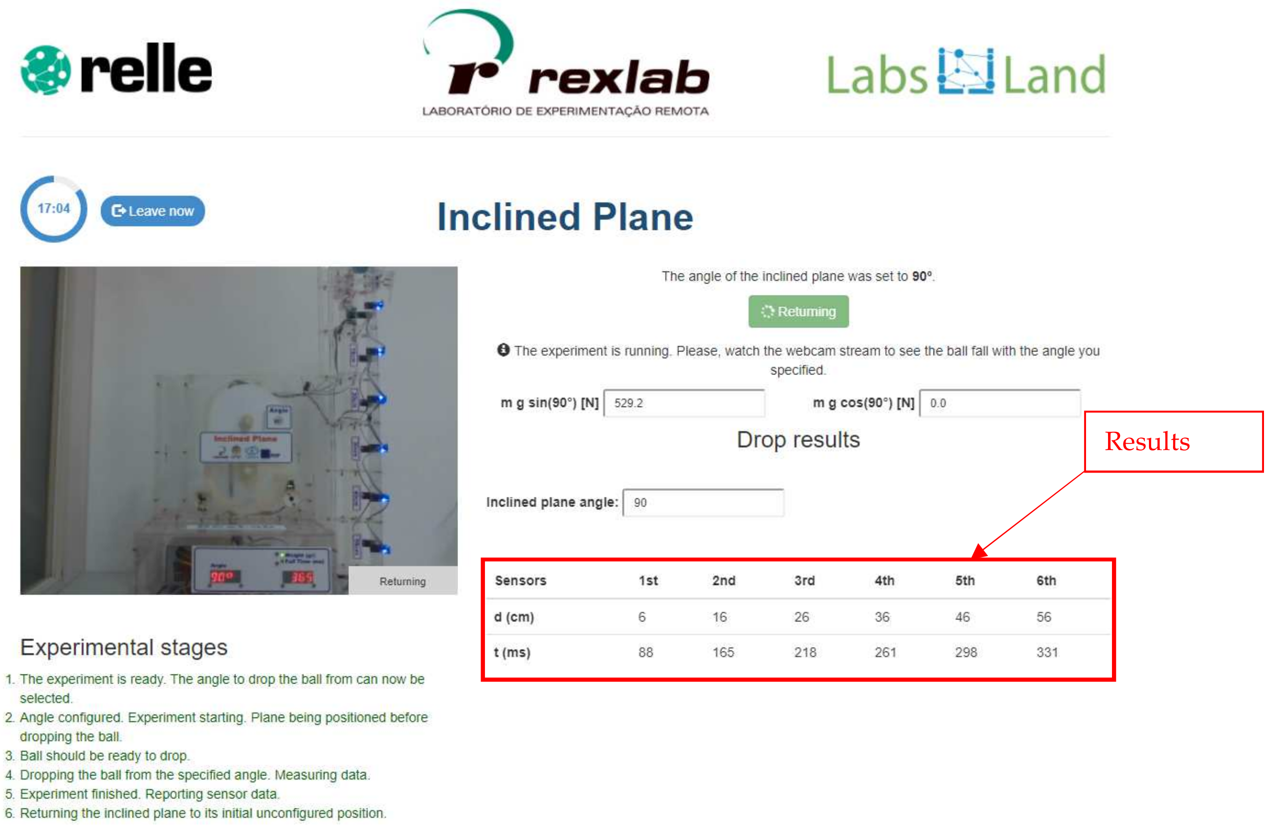

Figure 5. Obtained results for an inclination of 90º.

5. **Analysis of results**. For this we can take as an example Table 1, which we can complete with the passage times through these distances calculated theoretically and assuming that the acceleration of gravity is 9.8m/s2.

   To do this, we can use the following expression:

$$h = e(t) = \frac{1}{2} \cdot a \cdot t^2$$

   solving the equation for the time, and knowing that the distance 'h' is the one where the sensor is placed, we can obtain that

$$t = \sqrt{\frac{2 \cdot h}{9{,}8}} \rightarrow h = 0{,}56m \rightarrow t = \sqrt{\frac{2 \cdot 0{,}56}{9{,}8}} = 0{,}338s$$

   As an example, we see that if taken d=56cms, the time it should take to fall is 338ms, while the remote lab gives us a value of 331ms. Note that you are experimenting with a real (not virtual or simulated) computer, so there can always have small variables that affect the measurement, such as the sensors are not placed exactly 10cms away from each other, but 10.5cms, or the delay since the ball is released and start counting time.

In the same way, we can calculate the difference between the measured value and the theoretical value and calculate the error %.

90°	Sensor 1	Sensor 2	Sensor 3	Sensor 4	Sensor 5	Sensor 6
Distance (m)	0,06	0,16	0,26	0,36	0,46	0,56
Measure time(s)	0,088	0,165	0,218	0,261	0,298	0,331
Theoretical time (s)	0,110	0,180	0,230	0,271	0,306	0,338
Error (s)	-0,022	-0,015	-0,012	-0,010	-0,008	-0,007
Error (%)	20%	8%	5%	4%	3%	2%

Table 2. Analysis of results for measurements obtained with the plane configured at 90°.

6. Conclusions. We can see how the remote laboratory (remember that it is real) offers measurements with a very low error rate for each of the sensors.

A very interesting exercise is to repeat the same experiment several times and check **the accuracy and precision of the measurements** obtained (we will tell you more in the conclusions section in this regard). You can use a shared document in Google Drive to do this and see how the values can change and also analyse statistical values such as the mean of the values obtained, their variance, their deviation, etc.

4.2 Experiment 2. Inclined plane at 15°

In this experiment we will analyse how the ball moves when we set up the inclined plane to 15°. This exercise will allow us to determine whether the ball rolls and moves, i. e. whether while falling down the plane it also rotates on itself or whether the rotation movement can be neglected. To do this we will follow these steps:

1. Starting from step 3 of the previous experiment, we will configure the plane to 15°.
2. Once the ball is positioned at the desired inclination, we proceed to observe the ball and record the readings offered by the sensors.

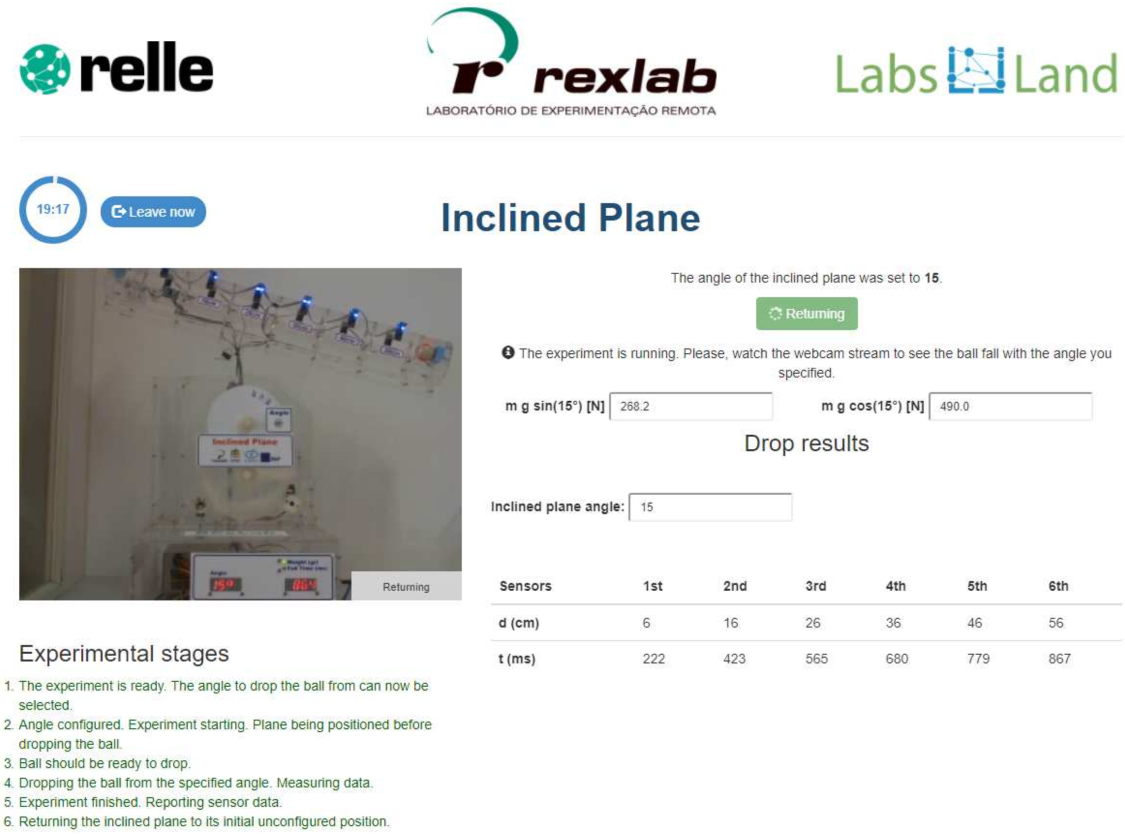

Figure 6. Plane set at 15° and results obtained after releasing the ball

3. **Analysis of results**. For this we will take Table 1 as a reference, filling it with the values obtained from the experiment and the theoretical ones. To make these calculations, and since the objective of the experiment is to determine whether the ball's rotation and translation movement should be taken into account as it descends, we proceed to calculate the theoretical times assuming that both movements are made and assuming that only translation movement occurs.

   As an example, we will calculate the time it takes the ball to travel 5cms when the angle of inclination is 15°.

   If we only suppose **translation movement**, the velocity that the ball would acquire when travelling a distance "d" is given as:

$$v' = \sqrt{2 \cdot g \cdot d \cdot \sin \alpha} = \sqrt{2 \cdot 9{,}8 \cdot 0{,}56 \cdot \sin 15} = 1{,}685 m/s$$

   Then, we can calculate the acceleration of the ball during the fall and finally, the time it takes to travel the 56 cms:

$$v^2 = 2 \cdot a \cdot d \rightarrow a = \frac{1{,}685^2}{2 \cdot 0{,}56} = 2{,}536\, m/s^2$$

$$v = a \cdot t \rightarrow t = \frac{v}{a} = \frac{1{,}685}{2{,}536} = 786\, ms$$

Considering the **translation and rotation movement** of the ball, the speed it reaches when travelling the 56cms, will be equal to:

$$v = \sqrt{\frac{10}{7} \cdot g \cdot d \cdot \sin\alpha} = \sqrt{\frac{10}{7} \cdot 9{,}8 \cdot 0{,}56 \cdot \sin 15} = 1{,}424 m/s$$

And finally, following the same steps above, we can determine the acceleration and the time it takes for the ball to travel 56cms:

$$v^2 = 2 \cdot a \cdot d \rightarrow a = \frac{1{,}424^2}{2 \cdot 0{,}56} = 1{,}811\, m/s^2$$

$$v = a \cdot t \rightarrow t = \frac{v}{a} = \frac{1{,}424}{1{,}811} = 786\, ms$$

If we use a program such as Excel, we can calculate these values for each of the sensor positions, obtaining the following table:

15º	Sensor 1	Sensor 2	Sensor 3	Sensor 4	Sensor 5	Sensor 6
d (m)	0,06	0,16	0,26	0,36	0,46	0,56
Theo. veloc. without rotation (m/s)	0,5517	0,9009	1,1485	1,3514	1,5276	1,6855
Acceleration without rotation (m/s²)	2,5364	2,5364	2,5364	2,5364	2,5364	2,5364
Theo. Time without rotation (sg)	0,2175	0,3552	0,4528	0,5328	0,6023	0,6645
Theo. veloc. with rotation (m/s)	0,4663	0,7614	0,9706	1,1421	1,2910	1,4245
Acceleration with rotation (m/s²)	1,8117	1,8117	1,8117	1,8117	1,8117	1,8117
Theo. Time with rotation (sg)	0,2574	0,4203	0,5357	0,6304	0,7126	0,7863
Time measured in the remote lab (s)	0,222	0,423	0,565	0,680	0,779	0,867
Error without rotation (s) (mea-theo)	0,0045	0,0678	0,1122	0,1472	0,1767	0,2025
Error without rotation (%) (error/theo)	2,06	19,09	24,78	27,63	29,35	30,47
Error with rotation (ms) (mea-theo)	-0,0354	0,0027	0,0293	0,0496	0,0664	0,0807
Error with rotation (%) (error/theo)	-13,74	0,65	5,46	7,87	9,32	10,27

Table 3. Analysis of results for measurements obtained with the plane configured to 15°

4. **Conclusions**. Analysing Table 3, we can observe how if we compare the values obtained in the laboratory for the passing times through each of the sensors with the theoretical values obtained assuming that there is and not rotation movement of the ball during the descent, the least error occurs when it is considered that the ball rolls while moving through the inclined plane.

As in the previous experiment, a very interesting exercise is to repeat several times the same experiment and check the accuracy and precision of the measurements obtained (we will tell you more in the section of conclusions in this regard). You can use a shared document in Google Drive to do this and see how the values can change and also analyse statistical values such as the mean of the values obtained, their variance, their deviation, etc.

4.3 Experiment 3. Inclined plane at 60°

In this experiment we will analyse how the ball moves when we set up the inclined plane to 60°. This exercise will allow us to determine whether the ball rolls and moves, i. e. whether while falling down the plane it also rotates on itself or whether the rotation movement can be neglected. To do this we will follow these steps:

1. Starting from step 3 of the previous experiment, we will configure the plane to 60°.
2. Once the ball is positioned at the desired inclination, we proceed to observe the ball and record the readings offered by the sensors.

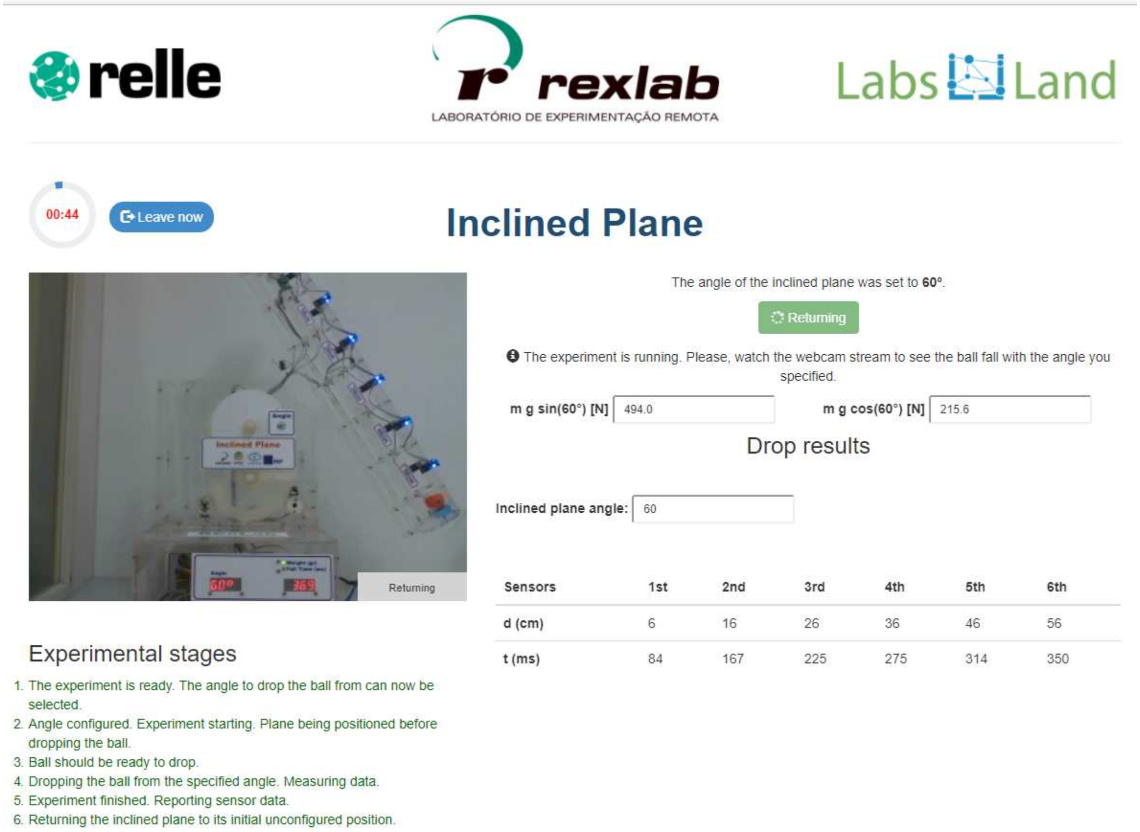

Figure 7. Plane set at 60° and results obtained after releasing the ball

3. **Analysis of results**. For this we will take Table 1 as a reference, filling it with the values obtained from the experiment and the theoretical ones. To make these calculations, and since the objective of the experiment is to determine whether the ball's rotation and translation movement

should be taken into account as it descends, we proceed to calculate the theoretical times assuming that both movements are made and assuming that only translation movement occurs.

As an example, we will calculate the time it takes the ball to travel 5cms when the angle of inclination is 60°.

If we only suppose **translation movement**, the velocity that the ball would acquire when travelling a distance "d" is given as:

$$v' = \sqrt{2 \cdot g \cdot d \cdot \sin \alpha} = \sqrt{2 \cdot 9{,}8 \cdot 0{,}56 \cdot \sin 15} = 1{,}685 m/s$$

Then, we can calculate the acceleration of the ball during the fall and finally, the time it takes to travel the 56 cms:

$$v^2 = 2 \cdot a \cdot d \rightarrow a = \frac{1{,}685^2}{2 \cdot 0{,}56} = 2{,}536\, m/s^2$$

$$v = a \cdot t \ \rightarrow t = \frac{v}{a} = \frac{1{,}685}{2{,}536} = 786\, ms$$

Considering the **translation and rotation movement** of the ball, the speed it reaches when travelling the 56cms, will be equal to:

$$v = \sqrt{\frac{10}{7} \cdot g \cdot d \cdot \sin \alpha} = \sqrt{\frac{10}{7} \cdot 9{,}8 \cdot 0{,}56 \cdot \sin 15} = 1{,}424 m/s$$

And finally, following the same steps above, we can determine the acceleration and the time it takes for the ball to travel 56cms:

$$v^2 = 2 \cdot a \cdot d \rightarrow a = \frac{1{,}424^2}{2 \cdot 0{,}56} = 1{,}811\, m/s^2$$

$$v = a \cdot t \ \rightarrow t = \frac{v}{a} = \frac{1{,}424}{1{,}811} = 786\, ms$$

If we use a program such as Excel, we can calculate these values for each of the sensor positions, obtaining the following table:

60º	Sensor 1	Sensor 2	Sensor 3	Sensor 4	Sensor 5	Sensor 6
d (m)	0,06	0,16	0,26	0,36	0,46	0,56
Theo. veloc. without rotation (m/s)	1,0092	1,6480	2,1008	2,4720	2,7943	3,0831
Acceleration without rotation (m/s²)	8,4870	8,4870	8,4870	8,4870	8,4870	8,4870
Theo. Time without rotation (sg)	0,1189	0,1942	0,2475	0,2913	0,3292	0,3633
Theo. veloc. with rotation (m/s)	0,8529	1,3928	1,7755	2,0892	2,3616	2,6057
Acceleration with rotation (m/s²)	6,0622	6,0622	6,0622	6,0622	6,0622	6,0622
Theo. Time with rotation (sg)	0,1407	0,2298	0,2929	0,3446	0,3896	0,4298
Time measured in the remote lab (s)	0,084	0,167	0,225	0,275	0,314	0,350
Error without rotation (s) (mea-theo)	-0,0349	-0,0272	-0,0225	-0,0163	-0,0152	-0,0133
Error without rotation (%) (error/theo)	-29,36	-14,00	-9,10	-5,58	-4,63	-3,65
Error with rotation (ms) (mea-theo)	-0,0567	-0,0628	-0,0679	-0,0696	-0,0756	-0,0798
Error with rotation (%) (error/theo)	-40,30	-27,31	-23,18	-20,20	-19,40	-18,57

Table 4. Analysis of results for measurements obtained with the plane configured to 60°

4. **Conclusions**. Analysing Table 4, we can see how if we compare the values obtained in the laboratory for the passing-time through each of the sensors with the theoretical values obtained assuming that there is and not rotation movement of the ball during the descent, the least error occurs when it is considered that the ball does not roll while moving through the inclined plane.

As in the previous experiment, a very interesting exercise is to repeat several times the same experiment and check the accuracy and precision of the measurements obtained (we will tell you more in the section of conclusions in this regard). You can use a shared document in Google Drive to do this and see how the values can change and analyse statistical values such as the mean of the values obtained, their variance, their deviation, etc.