Laboratory guide of the "Acceleration and Inertial Frames" experiment

A) Introduction

We will analyze the motion of two gliders on an air track, which initially are stationary and leaning against, but not connected, to each other. These two gliders are launched together by means of an elastic band attached to the rail. A string is attached to one of the carts, passes over a pulley and has a weight attached to the other end, in order to accelerate this glider in the opposite direction to its initial motion. Thus, after the launch, only the other glider continues in uniform motion.

The objective of this experiment is to determine the acceleration of a body in different frames of reference: the laboratory and the glider moving with constant velocity.

B) Analysis procedure

B1. Watch the videos of the experiment. The gliders will be identified by the letters L and R as they appear on the left or the right in the images. Pay attention to the motion of glider R and try to describe it as it would be seen by a camera fixed to glider L.

Imagine the following experiment. You are in a bus in uniform motion when a car, moving with the same speed and direction at one side of the bus, starts breaking smoothly; in this precise moment, your friend is on the sidewalk, in the same line of the car and the bus. The car walks away from you much slower than with respect to your friend on the sidewalk. Moreover, you see the car going backwards, while your friend sees it moving forward. Then you and the person determine the acceleration of the car in relation to your places, the bus and the sidewalk, respectively. ***Think about the measured acceleration values in the two reference systems, and ask yourself if they will be equal or different, and in the same direction or not***." This question does not need to be answered immediately, but it is expected to induce to reflect on the obtained results and the objective of the experiment.

B2. Read, in the images of the set assigned to you, the positions (x) at each instant (t) and build a table with this data, in both frames of reference, i.e. measure $x_{L(S)}$, $x_{R(S)}$ and $x_{R(L)}$, the first two on the measuring tape fixed to the air track and the last one on the ruler attached to the glider L.

For this, we recommend that you follow the position of the glider L, $x_{L(S)}$, through its lower right corner on the measuring tape fixed to the air track. The position $x_{R(S)}$ of the glider R must also be measured using the fixed measuring tape, this time observing its lower left corner. Now, $x_{R(L)}$ must be measured from the ruler attached to L. Note that the glider R has a tape on which two vertical marks have been made. Choose one of them and always measure the position by the same mark. Record the standard deviation of the position in the table, but ignore the uncertainty in time.

Keep in mind that the focus of the study is to relate the motion of glider R to the laboratory frame of reference, described by the coordinate $x_{R(S)}$, with the motion relative to the Left glider, $x_{R(L)}$, measured on the ruler.

B3. Plot the position as a function of time with the values obtained in the item B2 – Spreadsheets call this type of drawing a *scatter plot*. Points should suggest smooth curves; if you notice discrepant points, reread these points in order to confirm or correct these values.

B4. The average speed over a time interval [t_{i-1}; t_{i+1}] is a good approximation of the velocity at the mean time $t'_i = \frac{t_{i-1} + t_{i+1}}{2}$. In this experiment, the time interval between consecutive frames is always the same, hence the average instant $t'_i = t_i$. Thus, calculate the speed of the gliders relative to the laboratory, $v_{L(S)}$ and $v_{R(S)}$, as well as the speed of glider R with respect to glider L, $v_{R(L)}$, using the general formula:

$$v(t_i) = \frac{x(t_{i+1}) - x(t_{i-1})}{t_{i+1} - t_{i-1}}$$

Observe that x must be replaced by $x_{L(S)}$, $x_{R(S)}$ or $x_{R(L)}$ when calculating the speed of the left or right glider, respectively.

B5. Calculate the standard deviation of each of the velocities from the previous item by the formula:

$$\sigma_v = \frac{\sqrt{2}\ \sigma_x}{t_{i+1} - t_{i-1}}$$

equal for all times, since the intervals between successive images are equal for all instants. Evaluate σ_x as half of the smallest division you can read on the position measuring instrument. Note that σ_x is different for each of the frames of reference – the reading on the measuring tape is more accurate than on the ruler attached to the glider R.

B6. Determine the speeds of gliders L and R relative to the laboratory frame of reference, $v_{L(S)}(t_i)$ and $v_{R(S)}(t_i)$, and that of glider R, in relation to the moving frame (cart L), $v_{R(L)}(t_i)$.

B7. Plot the velocity versus time with the values obtained in item B5. Also add the uncertainty bars (which Excel calls error bars), whose sizes correspond to the standard deviations calculated on these items.

B8. Fit trend lines to the 3 speed data sets. Evaluate the standard deviations of the accelerations as

$$\sigma_a = \frac{\sigma_v}{T}\sqrt{\frac{12}{N}}$$

where N is the number of data points and T is the time difference between the last and first analyzed images. The Auxiliary Guide "Uncertainty in the inclination of a tendency line", which can be found in the tab http://www.fep.if.usp.br/~fisfoto/guias.php, explains the origin of this formula but in this report the focus is not on that.

B9. Compare the accelerations of the glider R in the two frames of reference, and verify that the acceleration of the glider carrying the moving ruler is, within the uncertainties, compatible with zero.

C) Report preparation procedure

C1. *Identification*: include the names of all team members, class and identify the dataset you analyzed.

C2. *Experimental Description:* describe, in your own words, the experimental arrangement – gliders, measuring tape, weight, etc., and their respective characteristics. Tell how the gliders were launched. Explain which objects and properties of the arrangement made it possible to obtain data about the physical quantities on which the analysis presented below will be based.

C3. *Data Obtained*: present a table with all measured and calculated quantities (time, position and speed of each glider in relation to the laboratory frame of reference and in relation to the frame of reference of glider L). Show the graphs from item B3, and record the names of the curves that are implied by the sets of points.

C4. *Obtained Results:* Present the graphs from item B9. Highlight the results obtained for the accelerations in the two frames of reference, in items B8 and B9. Check that the quantities are in the proper units and represented with the proper number of significant figures.

C5. *Discussion:* Explain how a constant acceleration produced the back-and-forth motion of cart R. Compare the graphs obtained and, from that, answer the motivating question in item B1. Confirm your interpretation of these graphs by comparing the accelerations measured in the two frames of reference adopted (Laboratory and glider L). Could you compare the accelerations, as you did in item B9, by analyzing the graphs in item B3 differently than you did in items B4-B8? Explain how.

C6. *Conclusion*. What is the concept or physical law or subject addressed in the theory that this experiment is intended to demonstrate?