INDIAN INSTITUTE OF TECHNOLOGY GANDHINAGAR

ME 206

STATICS & DYNAMICS

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Experiment-3

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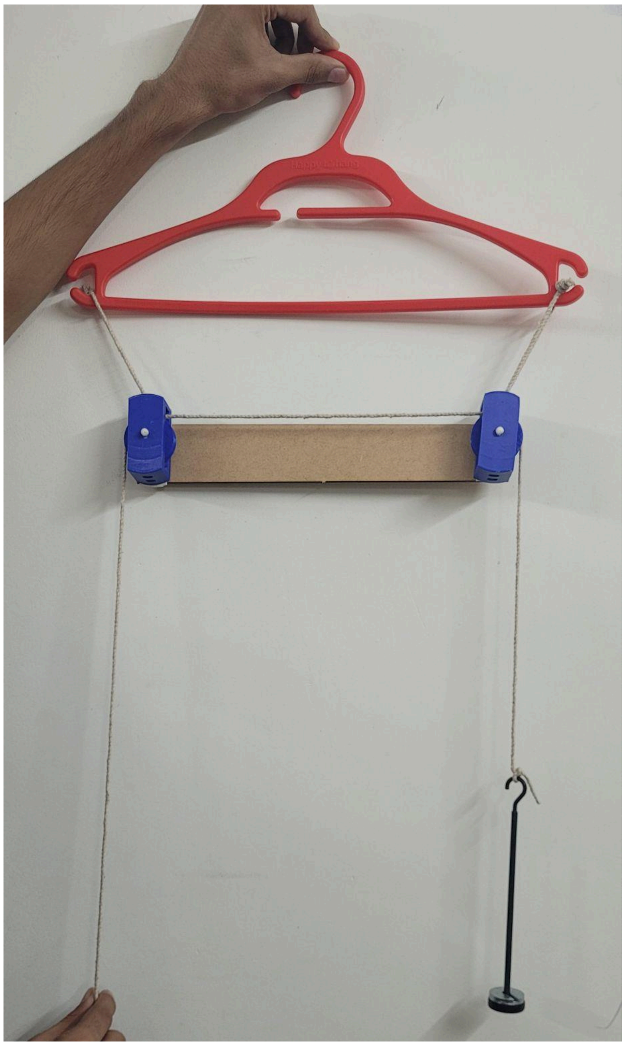


Abstract:
In this experiment, we designed an Atwood machine setup to show that Newton's second law works in an inertial reference frame, and not in non-inertial one. In the first part of the experiment, we will consider the Atwood machine within the lift as an inertial reference frame. In this scenario, the lift will be assumed to either be at rest or moving at a constant velocity concerning the ground. The occupants within the lift will not experience any acceleration. In the second part of the experiment, we will modify the lift's motion to introduce acceleration. This can be achieved by moving the lift either upwards or downwards. In this case, the lift's occupants, including the camera, will experience acceleration, making them part of a non-inertial reference frame. Through this experimental approach, we will effectively show how the concept of an inertial or non-inertial reference frame impacts the application of Newton's second law in the context of the observer, highlighting the differences in motion when the lift is stationary, moving with constant velocity, or undergoing acceleration.

Objective:
Our goal is to design an experimental setup that illustrates the application of Newton's second law works when all the measurements are done in inertial reference frames and fails in non-inertial frame of reference.

Educational Alignment and Practical Engagement:

Alignment with Learning Objectives:

- **Understanding Newton's Second Law:** The experiment aligns with the objective of teaching Newton's second law by providing a real-world application of the law. We can directly observe and measure the relationship between force, mass, and acceleration.

- **Reference Frames:** It helps us grasp the concept of reference frames. By comparing the Atwood machine's behavior in both inertial and non-inertial frames, they gain a deeper understanding of how the choice of reference frame affects the application of physical principles.

Bridging Theoretical and Practical:

- **Real-World Application:** The experiment bridges theoretical concepts with practical applications. It allows us to move beyond abstract equations and experience how physics principles work in real-life scenarios.

- **Experimental Design:** We are actively involved in designing and conducting the experiment, which not only reinforces theoretical knowledge but also helps them develop practical skills in experimental setup and data collection.

- **Data Analysis:** The camera recording provides practical data that we can analyze. This bridges the gap between theory and practice, showing us how experimental data supports theoretical concepts.

Preparation for Complexities:

- **Critical Thinking:** The experiment prepares us to think critically and adapt to varying scenarios. When the lift becomes non-inertial, we analyze how the pseudo-forces due to acceleration impact the Atwood machine's behavior.

- **Problem Solving:** We are exposed to potential challenges such as setting up the lift, adjusting variables, and dealing with technical issues. This experience fosters problem-solving skills and resilience in the face of complexities.

Application of Fundamental Principles:

- **Kinematics:** We have applied the concepts of velocity and acceleration to describe the motion of an object under the influence of forces.

- **Newton’s Second Law:** It states that the rate of change of the momentum of a body is directly proportional to the external force acting on the body. It’s basically a quantitative measurement of force.

$$\frac{d\vec{P}}{dt} = \vec{F}$$
$$\vec{F} = \frac{d(m\vec{V})}{dt} = m\frac{d(\vec{V})}{dt} = m\vec{a}$$
$$\vec{F} = m\vec{a}$$

- **Inertial Reference Frame:** A reference frame whose acceleration is zero, is called the inertial reference frame. More precisely, an inertial reference frame either doesn't move or moves with constant velocity with respect to an assumed reference frame.

- **Non-Inertial Reference Frame:** In contrast, a non-inertial reference frame exhibits non-zero acceleration and moves with respect to an inertial reference frame. A non-inertial reference frame moves with acceleration with respect to an inertial reference frame.

- **Atwood Machine:** To conduct our experiment, we will use an Atwood machine, which operates on the principle that the difference in masses of two objects determines the net force acting on each of them. Our setup will consist of an Atwood machine with two pulleys, which allows us to control and measure the forces acting on the masses and observe the behavior of Newton's second law in both inertial and non-inertial reference frames.

Materials used in the Experiment:

Various materials and components were utilized and carefully chosen to represent the experimental setup.

1. **3D Printing Materials:**
   We used PLA filament as the 3D printing material for printing the Atwood machine because PLA is known for its ease of use and design suitability.

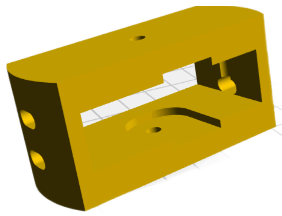
2. **MDF Board (Medium Density Fiberboard):**
   We used an MDF board to make the back-support of the experiment setup. We chose an MDF board because of its smooth surface, rigidity, etc.

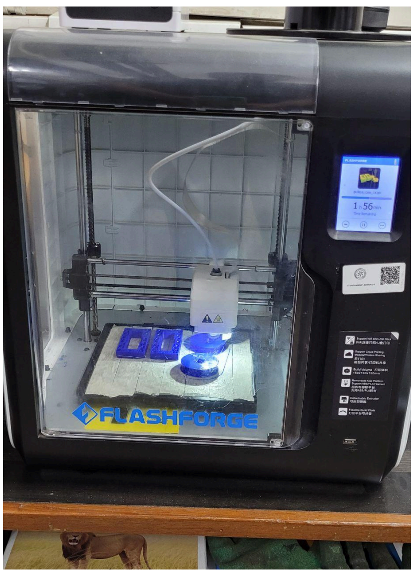
3. **Other materials:**
   We used hanger, weights, hooks, rope, etc in our experiment. Also, we performed our experiment in the lift.

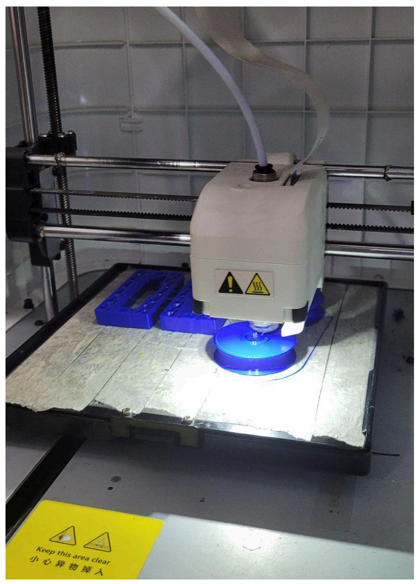
Fabrication Details:

The experiment employed a combination of various materials components and carefully created a function to create a functional and instructive setup.

1. **Design & 3D Printing:**
    - The design process involved the creation of detailed 3D models for the pully setup.
    - The 3D printing process utilized precise parameters to ensure accurate and high-quality printing. This included the Flash Print app's layer height, infill density, raft, and temperature settings.
    - Once the individual components were printed, they were carefully assembled to create the pulley model structure.







2. **MDF Board (Medium Density Fiberboard):** We used an MDF board to make the pulleys' support structure. We used the MDF board because of its smooth surface, rigidity, etc

Procedure:

1. Initially, we set up the Atwood machine by connecting two pulleys with strings and suspended this apparatus within the elevator, using a hanger. Subsequently, we attached weights to the strings on both sides.

2. We securely attach the pulleys to a sturdy MDF board to ensure they provided adequate support for the experiment.

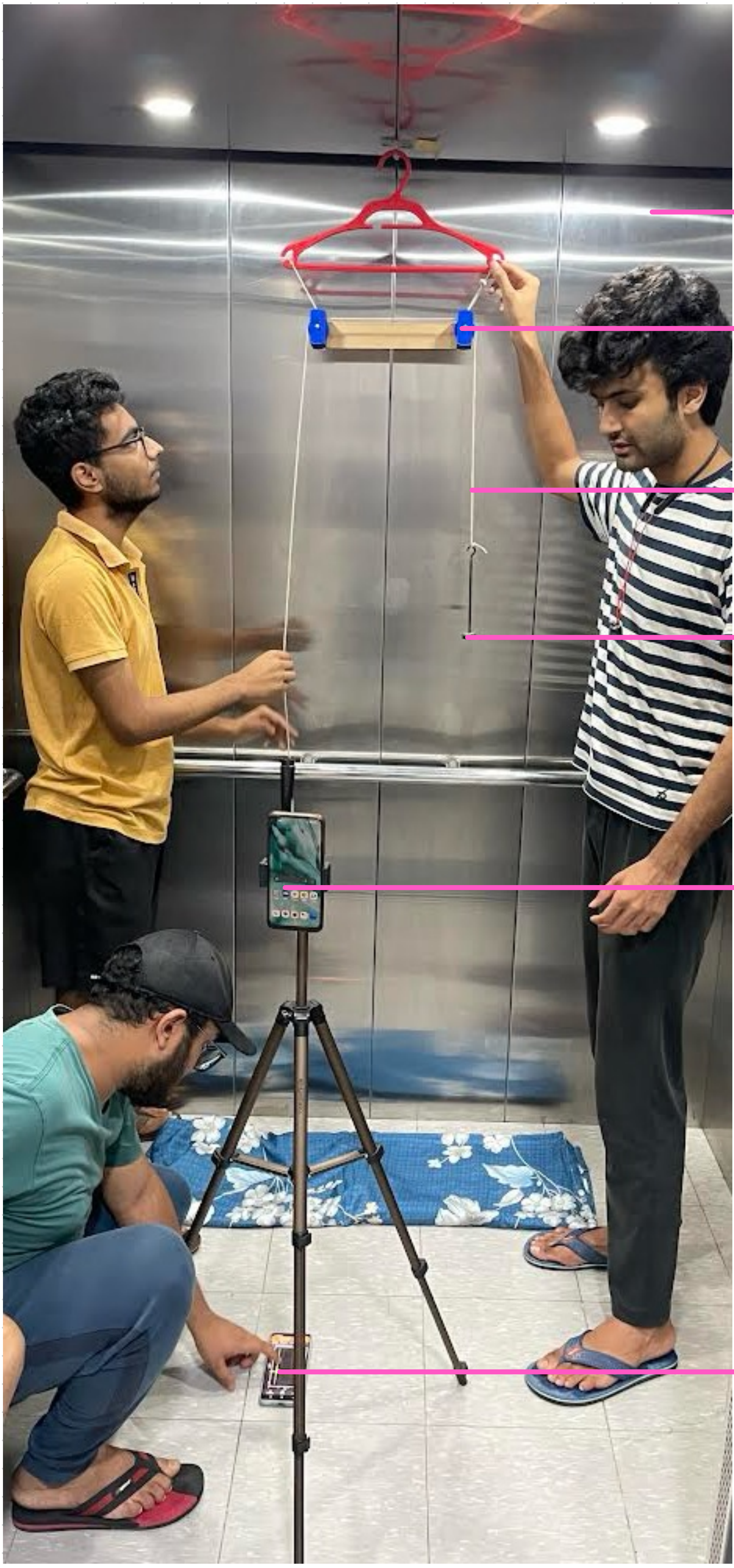
3. We commenced the data collection process by the camera while the lift remained stationary on the ground floor, utilizing the lift as an inertial reference frame.

4. Next, we initiated the lift's ascent from the ground floor to the 3rd floor. This transformation rendered the lift a non-inertial reference frame, introducing acceleration as a variable affecting the acceleration of the objects. To analyze the data, we calculated the force acting at a particular point at two instances Once witht the lift at rest and once with the lift in motion. We then compared this theoretical mass with the actual mass of the objects.

5. Now the important pictures that capture the experiment were extracted and their position vectors were calculated using Matlab image processing extension and velocity and acceleration vectors were calculated analytically.

6. All the information was then used to perform the required calculation. The calculations are discussed in the next to next section.

EXPERIMENTAL SETUP



LIFT

- Used for the frame of reference.

PULLEY

STRING

WEIGHTS

CAMERA (VIEWER)

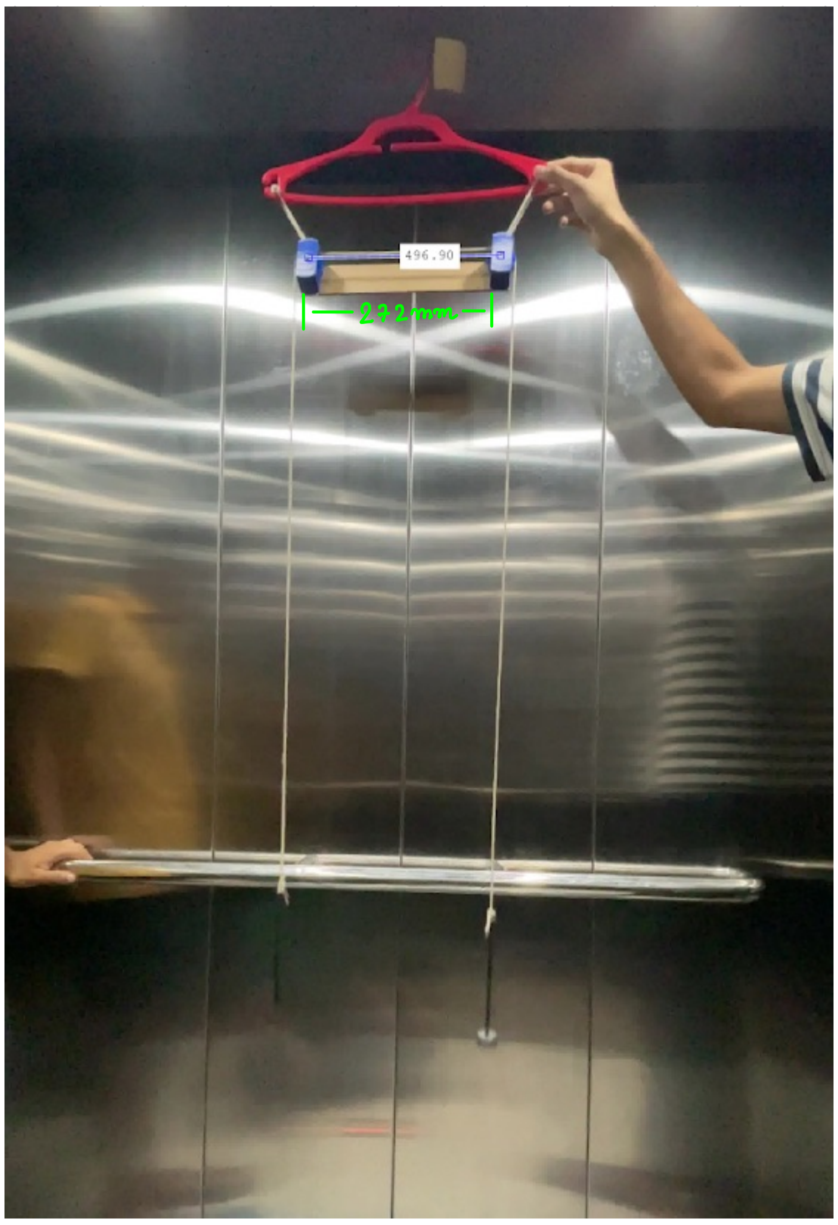
- When the lift is not moving the viewer is in inertial frame of reference.
- When the lift is moving (accelerating / decelerating) the viewer is in a non-inertial frame of reference.

PHONE

- We are using the phone accelorometer capabilities to measure the acceleration of the lift
- The phone is fixed with the floor of the lift.

CALCULATIONS

For measurements we are using the image Processing capabilities of MATLAB



MEASUREMENT TECHNIQUES

In Matlab the distances are calculated in pixels

Hence it is important to have a Scaling factor

In our case the scaling factor is

496.90 unit measurement on MATLAB is equivalent to 272 mm

$\therefore$ Scaling factor $= \frac{272}{496.90} \approx 0.5474$

Hence any distance calculation on MATLAB needs to be multiplied by this scaling factor

The videos are recorded in 60 FPS 4K Quality for better calculations

Here each frame represents $\frac{1}{60}$th of a second.

Now lets calculate the acceleration of the on the stand with weights on the right hand Side

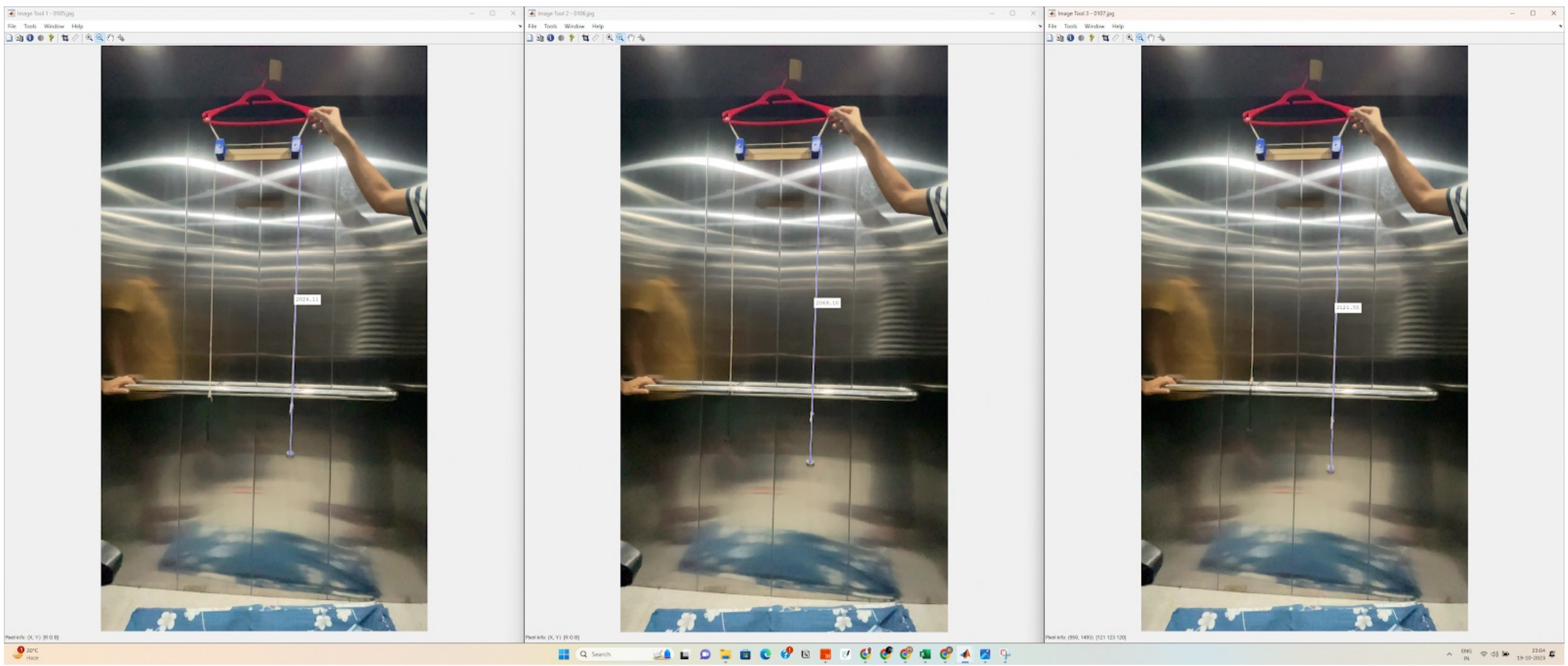
Now for the same reason lets analyze frames 105, 106, 107 to get the acceleration

WHEN LIFT IS AT REST ?

105th FRAME

106th FRAME

107th FRAME



Now the distances

2024.11 units

2068.10 units

2121.55 Units

After using scaling factors

1108 mm

1132.08 mm

1161.34 mm

Now the velocity between 105^{th} & 106^{th} Frame is

$$\frac{(1132.08 - 1108.00)\,mm}{1/60\ s}$$

$= 1444.8\ mm/s$

$= 144.48\ cm/s$

$= 1.4448\ m/s$

Now the velocity between 106^{th} & 107^{th} Frame is

$$\frac{(1161.34 - 1132.08)\,mm}{1/60\ s}$$

$= 1775.6\ mm/s$

$= 177.56\ cm/s$

$= 1.7786\ m/s$

Now the acceleration at the 106^{th} Frame

$$\frac{1775.6\ mm/s - 1444.8\ mm/s}{1/60}$$

$= 19848\ mm/s^2$

$= 1984.8\ cm/s^2$

$= 19.848\ m/s^2$

m = mass of holder + 2x mass of weights

$= 10g + 2\times10g$

$= 10g + 20g$

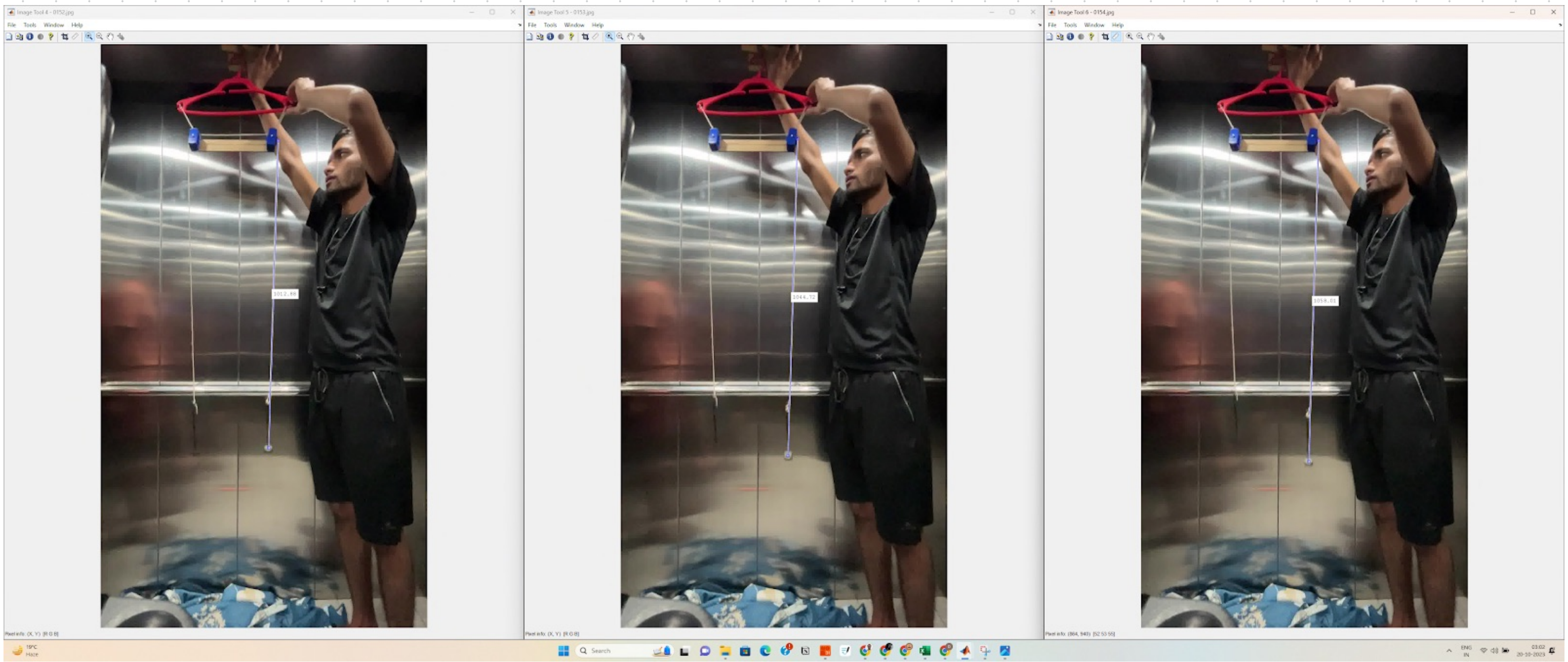
$= 30g$

Now $F = m\times a$ $\therefore$ At 1132.08 mm from the reference point the force we obtain is $0.03\ kg \times 19.848\ m/s^2$

$= 0.59544\ N$

WHEN LIFT IS ACCELERATING?

152^{nd} Frame | 153^{rd} Frame | 154^{th} Frame



The above were recorded in 4D compared to 4h. Hence the scaling factor 1.0948

1012.88 units | 1144.72 units | 1066.77 units

After using scaling factors

1108.90 mm | 1143.75 mm | 1167.89 mm

Now the Velocity between 152^{nd} and 153^{rd} Frame

$$\frac{1143.75 \text{ mm} - 1108.90 \text{ mm}}{1/60 \text{ s}}$$

$= 2091$ mm/s

$= 209.1$ cm/s

$= 2.091$ m/s

Similarly the Velocity between 153^{rd} and 154^{th} Frame

$$\frac{(1167.889 - 1143.75) \text{ mm}}{1/60 \text{ s}}$$

1448.98 mm/s

144.898 cm/s

1.44898 m/s

Now the acceleration at the 153^{rd} Frame

$$\frac{1.44898 - 2.091}{1/60}$$

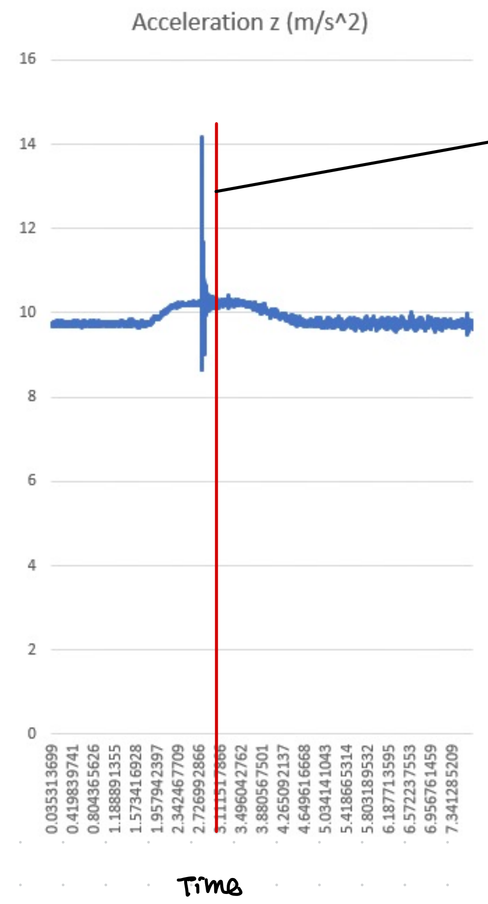
$= -38.5213$ m/s^2

m = mass of holder + 2 × mass of weights

= 10g + 2×10g

= 10g + 20g

= 30g



The value is quite similar with the nature of graph which suggest lift is decelerating.

• ACCELERATION OF THE LIFT

Now $F = m \times a$ ∴ At 1132.08 mm from the reference point the force we obtain is $0.03 \text{ kg} \times 38.5213 \text{ m/s}^2$

$= -1.155$ N.

Here we clearly see that for almost the same point the F=ma have different values when compared to when the inertial frame which was at rest.

Observations and Results :

In the previous section of calculation you can clearly see that we are trying to estimate the Force at the same reference point in both the cases once when the lift is at rest and once when the lift experiences some amount of acceleration or deceleration.

It can be clearly observed from the the image in the section When Lift is at (Rest 105^{th} Frame) and When Lift is Accelerating (152^{nd} Frame) the reference point is same approximately at 1108.90mm from the reference proint which is taken as the edge of the pulley from where the string makes the tangential contact with the pulley.

Now when the lift was at rest we observed that $F_i = m \times a_1 =$ 0.59544 Newtons
And when the lift was accelerating $F_n = m \times a_2 = -1.155$ Newtons.

Conclusion & Discussion :

Through the execution of this experiment, our primary objective has been successfully achieved. We set out to demonstrate the influence of reference frames on the application of Newton's second law, and the results provide clear evidence of the impact of reference frames on physical phenomena.

Ideally if Newton’s second law would also be applicable for non inertial frame we should have got the same value of force for both the cases when the lift was at rest and when it was accelerating. But this wasn’t the case.

In conclusion, our experiment effectively demonstrates that Newton's second law holds true in an inertial reference frame but deviates from expected behavior in non-inertial frames. This successful demonstration provides a concrete illustration of the fundamental concept that the choice of reference frame significantly affects the application of physical principles.

Learnings:

After completing the experiment, we acquired valuable insights and knowledge about real-world implementations and results. Here are the key takeaways from this experiment:

1. **Practical Applicability of Pseudo Forces:** Our implementation demonstrated the practical applicability of considering pseudo forces, such as those arising in non-inertial reference frames like the accelerating lift. This understanding is vital for predicting and explaining the behavior of physical systems in real-world situations.

2. **Discrepancy Between Theory and Reality:** We observed that real-life results sometimes deviated from theoretical predictions. This deviation was influenced by factors such as air resistance, friction, and other non-ideal conditions. This emphasizes the importance of accounting for such factors in practical physics experiments.

3. **Computational Tools and Software:** The experiment introduced us to various computational tools and software applications that were instrumental in data collection, analysis, and visualization.

What could have been done better?

There may be possible improvements in certain areas:

1. Improving the precision of measurements, such as using more accurate instruments for weight measurements or reducing parallax errors in data collection, could enhance the reliability of the results.

2. Conducting multiple trials of the experiment and calculating averages could provide more robust and reliable results, reducing the influence of random errors.

3. Choosing pulleys with lower friction (made with metal, instead of making them with 3D manufacturing) or specifying the surface friction coefficient and

incorporating it into calculations would lead to more accurate modeling of the Atwood machine's behavior.

4. Opting for an elevator with less lateral movement or a reference frame that minimizes additional accelerations could help reduce the complexity introduced by lateral motion and further isolate the impact of acceleration on the experiment.

5. Exploring more advanced technology or sensors for data collection, such as accelerometers or higher-speed cameras, could provide more detailed and precise data.

6. Replacing the jute thread with a smoother and less abrasive rope can significantly reduce friction in the Atwood machine setup. A smoother rope would minimize the impact of friction and allow for more precise measurements.

References:

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[2] Testbook's Team, “Atwood Machine: Learn Definition, Principle and Applications,” (Updated on September 15, 2023), https://testbook.com/physics/atwood-machine

[3] "Phyphox," Version 1.1.12, Mobile Application Software. Available: https://phyphox.org/ . Accessed: Oct. 19, 2023.

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