Impact of Elevator Car Motion on Weight Scale Readings

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Abstract:

The effects of the elevator car on readings in a weight scale were measured by university students, each of them measured their respective weights on the scales and compared them in six different zones (based on moving down, moving up, being stationary, or accelerating in any direction). It was hypothesized that the normal force should increase when the elevator is accelerating upward, and decrease when accelerating downwards, and remain as the normal weight when the elevator car is stationary or moving at constant speed. Free-body diagrams were used to provide visuals for the equations. Only one trial was performed for the purposes of this experiment. The hypothesis was proven to be correct as determined with the results of the lab experiment as well as the parameters substituted in each respective force equation for each elevator zone.

Introduction:

Experiments have been conducted to show the changes in an object's weight when in an elevator car. In one such experiment, students from the University of Virginia rode an elevator up and down while standing on a weight scale [2]. Scale readings at rest were recorded and the mass of each student was calculated using Newton's Second Law, $F = ma$, using the known parameters. Then, the students begin by going up from the second floor to the third floor and then back down. The purpose of this lab experiment is to observe the change in the normal force of the elevator while the elevator is accelerating and use Newton's 2nd law to calculate the acceleration of the elevator based on that change, and based on this law we hypothesize that the weight shown on the scale will increase when the elevator is accelerating upward, decrease when accelerating downward, and read the normal weight of a person when the elevator is at constant velocity [1].

Materials and Methods:

Materials:

- Weight Scale
- Elevator Car
- Human being used for trial experiment

Newton's 2nd law, $F = ma$, relates force, mass, and acceleration. A scale and an elevator is used to study this relationship. Scales do not actually measure weight, scales measure the normal force, that is, the force of the scale pushing up on the object. Knowing this, the scale can be used to determine the normal force while at rest and while the elevator is in motion. A free-body diagram will be used to represent the forces acting on the person in the elevator both while the person is in motion and when the person is at rest. Then, Newton's 2nd law will be used to determine the acceleration of the elevator. After recording the student's normal weight, there are a total of 7 weight measurements that should be taken in the elevator car. One when the elevator is moving downwards with increasing speed (accelerating downward), when the elevator is moving down at constant speed, when the elevator is moving up at constant speed, when the elevator is moving down and slowing down, when the elevator is moving up with increasing speed, and moving up while slowing down.

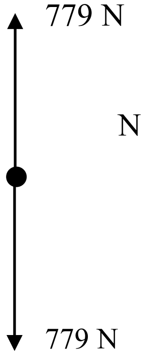
Each free-body diagram should be drawn the same regarding direction, however, for instances with acceleration that does not equal 0, the magnitude, or the weight shown on the scale, will change. As shown in the pictures attached, as the elevator accelerates or decelerates, the weight (newtons) will change. If the acceleration is positive, the scale will show a greater weight than the actual weight of the person, and if the acceleration is negative, the scale will show a smaller weight.

Data Table 1

Scale Reading at Rest (lbs)	175lb
Weight in Newtons (1 lb = 4.45 N)	779 N
Mass in kg	79.4kg

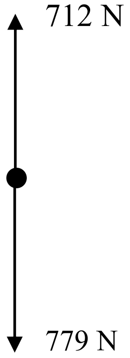
Free Body Diagrams:

Stationary – Normal Weight



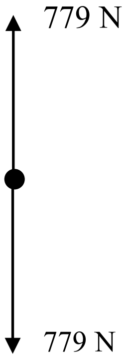
No movement (0 acceleration)

Zone 1: Moving Down Speeding Up



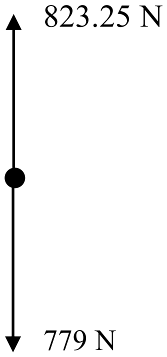
Normal Force is Smaller Than
the Force of Gravity

Zone 2: Moving Down Constant Speed



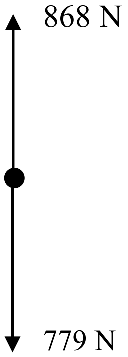
Constant Speed, 0 acceleration, and 0 acceleration means no net force.

Zone 3: Moving Down Slowing Down



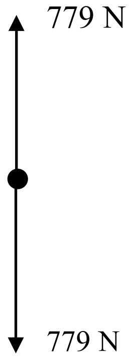
Acceleration is positive, because slowing down in the negative direction means a net acceleration upward.

Zone 4: Moving Up Speeding Up



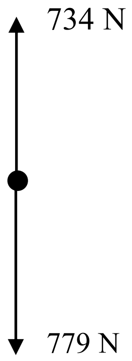
Accelerating upwards, normal force exceeds force of gravity

Zone 5: Moving Up Constant Speed



Constant Speed, 0 acceleration, and 0 acceleration means no net force.

Zone 6: Moving Up Slowing Down



Acceleration is negative because positive direction’s velocity is decreasing.

Data Table 2

Zone	Description	Sign of Acceleration	Scale Reading
1	Moving down, speeding up.	Negative	160lb
2	Moving down, constant speed.	0	175lb
3	Moving down, slowing down.	Positive	185lb
4	Moving up, speeding up.	Positive	195lb
5	Moving up, constant speed.	0	175lb
6	Moving up, slowing down.	Negative	165lb

Discussion:

In the first zone, the elevator goes from rest to going down. As it is accelerating downward, the object's weight is recorded to be less because the required normal force required is less than it usually is at rest or moving at a constant velocity. Since the normal force is less, the object accelerates downward. When the elevator begins to accelerate downwards, the scale reads a lower number because acceleration is inversely proportional to the mass of the object. The greater the mass, the less inclined an object will be in changing its motion. Therefore, the mass of the object prevents it from moving downward for a short period of time until the acceleration becomes large enough to change its motion.

In the second and fifth zones, both the elevator and the object are moving at constant velocity (albeit in different directions). Therefore, there’s no acceleration. The reading of the scale will show the object’s normal weight. In accordance with Newton’s first law of motion, the object continues to move at a constant velocity, with no outside forces acting on it.

In the third zone, the elevator goes down before slowing to a stop. As it accelerates downwards, the scale will record a greater weight because of the increase in normal force. The object experiences a change in velocity because of the downward force. This is like what is seen in a rollercoaster when you are at the very bottom of the rollercoaster. You seem heavier after accelerating downwards all the way.

In the fourth zone, the elevator goes from rest to going up. As it accelerates upward, however, the object’s weight is greater than normal due to the greater normal force, which allows the object to accelerate upward in a positive direction. In this case, the normal force (the support force) is greater than the force of gravity. In short, during the small interval of time it takes for the acceleration to overcome gravity, the object stays in place before finally accelerating upwards.

In the sixth zone, the elevator goes up before slowing to a stop. Acceleration due to gravity is negative so it will subtract in the equation, which means that you will feel lighter. However, your body doesn’t want to slow down due to inertia and because objects tend to remain at a constant velocity, so you feel lighter when you reach the top.

The six zone descriptions matched my hypothesis exactly with the free-body diagrams shown as depictions of this; simply put, the normal force decreases when the car is accelerating upward and decreases when the car is accelerating downward. When the velocity of the car is constant, the acceleration is 0 and there is no net force acting on the car, which means there will be no weight change. The scale will simply read as one’s normal weight because the normal force in this case is the same as when one is standing on the ground. There were certain limitations to this experiment, however. As there was one video and demonstration, I could only reproduce the experiment based on that demonstration only. If a person were to replicate the experiment again in real life, similar results would be expected, but nothing is for certain. Another limitation in this experiment is the delay in finding the scale readings; the scale readings could have been lower or higher depending on the time it took for the university students to react to the changes in their surroundings.

Conclusion:

The mechanics behind a particular object or person and the elevator car is purely based on the changes in normal force. The gravitational force will always be a constant downward vector equal to the product of the mass of the object and its acceleration (a vector quantity). However, when the elevator car is moving with a constant acceleration, the scale reading can be greater or smaller depending on if the car is moving up or down. When the elevator goes up and down at a constant speed, however, this implies that there is no acceleration, and the normal force is unaffected; the scale reading is the usual normal weight. Because there is no accepted value and there is only one trial, there is no error calculation in this exercise.

References

[1] “Force and motion - City University of New York,” *CUNY Physics*. [Online]. Available: https://physics.qc.cuny.edu/uploads/27/Wolfson%20EUP/M04_WOLF3724_03_SE_C04.pdf. [Accessed: 15-Feb-2023].

[2] *Weight Changes in an Elevator - U.Va. Physics 109*. 2008.