Newton's Laws I

Name:

PES 1150 Prelab Questions

Lab Station: 003

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• By Newton's 3rd Law, a train pulls backward on its engine exactly as hard as the engine pulls forward on the train. Since Newton's 3rd Law is correct, the force of the engine on the train should be equal and opposite to the force of the train on the engine. Therefore, the train shouldn't go anywhere. Carefully explain why this analysis is wrong.

Newton's 3rd Law states mathematically:

$$\vec{F}_{1,2} = -\vec{F}_{2,1}$$
$$m_1 \vec{a}_{1,2} = -m_2 \vec{a}_{2,1}$$

There are three points here which allow the train to move in its entirety, that are quite easily overlooked. These are:

- 1. Typically the engine weighs (mass x acceleration due to gravity) significantly more than the trailing carts
- There is friction between the wheels of the engine and the tracks (and the
- <u>coefficient of static friction on metals is high, but kinetic friction is low)</u>
- 3. There is compound inertia occurring effectively, increasing the mass of the pulling side while decreasing the mass of the being pulled side.
- 4. Newton's 3^{rd} law only considers an instantaneous isolated non-accelerating system with no jerk (time rate of change of acceleration = 0 m/s^3)

Notice that typically it is difficult for the train to get started (and usually there's a jolt effect); however, as more and more carts begin to move, the train's acceleration significantly increases.

• You are driving down the highway and a bug splatters on your windshield. Which is greater: the force of the bug on the windshield, or the force of the windshield on the bug? Explain your answer.

The force of the bug on the windshield and the force of the windshield on the bug are the same. Again, returning to Newton's 3rd Law: $\underbrace{\vec{F}_{1,2} = -\vec{F}_{2,1}}_{m_1\vec{a}_{1,2}} = -m_2\vec{a}_{2,1}$ The problem arises in that the mass of the car (windshield including) is much greater than the mass of the bug, hence the deceleration of the car versus the deceleration of the bug is the proportion of their relative masses. (In fact from the bug's perspective quite high). Let's use some hypothetical numbers to see the effects. $\underbrace{Mass_{car} = 5000 \text{ kg}}_{Mass_{bug}} = 0.002 \text{ kg}}_{Deceleration_{car}} = 0.1 \text{ m/s}^2} = -(0.002 \text{ kg})\vec{a}_{2,1}}$

$$\vec{a}_{2,1} = 250,000 \frac{m}{s^2}$$

 $\bar{a}_{\scriptscriptstyle 2,1}\approx 25{,}500\,g's$

(25.5 thousand times the acceleration due to gravity. No wonder it splats. Humans can survive only an acceleration of about 75 g's.)

• If you hold a rubber band between your right and left hands and pull with your left hand, does your right hand apply a force to the rubber band? What direction is that force compared to the force applied by the left hand?

This is how Physical Therapy works. When you pull with your left hand, Newton's 3^{rd} law says that the left side of the rubber band will apply an equal and opposite

force. This in turn (again by Newton's 3rd law) will apply an equal and opposite force on the right side of the rubber band. This in turn (again by Newton's 3rd law) will apply an equal and opposite force on the right hand.



Figure 1: Example of Newton's 3rd Law of Static Forces across an Exercise Band

In physical therapy (and by body builders) this is usually used for triceps and chest muscle strengthening to create symmetrical muscle strength. Typically, after a trauma one side of a person's body maintains strength while the traumatic side atrophies. Using Newton's 3rd law, you can use the strength of your maintained side to improve the strength of the trauma side. The main difference is we didn't show all the muscle interactions in the figure above on the human (see below for this illustration). There's actually static torques and forces set up in her arms and across her chest (as we will see during the BioPhysics lab we will be doing later in the semester) depending upon the tension of the rubber band exercise equipment.

The following figure shows the complete set of forces, torques, and tensions associated with the exercise (for use in physical therapy). Notice that the forces are in 3D although shown via the 2D image (the motion in and out of the page is not explicitly shown). Depending upon the location of an injury, this exercise can work the wrists (via force 1,2 or force 2,1), the forearms (via force A), the elbows (via torque A), the triceps (via force B), the shoulders [deltoids] (via torque B), or the chest (via the tension across the chest). Hence, this is why almost all upper body injuries use this technique for rehabilitation.



• If the Earth pulls on you exactly as hard as you pull on the Earth (because of Newton's 3rd Law), why doesn't the Earth appear to move when you jump up in the air?

This is exactly the same as the bug question. The force of the human on the Earth and the force of the Earth on the human are the same. Once again, returning to Newton's 3^{rd} Law:

$$\vec{F}_{1,2} = -\vec{F}_{2,1}$$
$$m_1\vec{a}_{1,2} = -m_2\vec{a}_{2,1}$$

The problem arises in that the mass of the earth is much, much greater than the mass of the human (you), hence the deceleration of the earth versus the deceleration of the human is the proportion of their relative masses. (In fact from the Earth's perspective quite low).

Let's use some hypothetical numbers to see the effects. $\frac{Mass_{earth} = 5.9737 \times 10^{24} \text{ kg}}{Mass_{human} = 75.0 \text{ kg}}$ Deceleration_{human} = -9.81m/s²

$$(75.0 kg) \left(-9.81 \frac{m}{s^2}\right) = -(5.9737 \times 10^{24} kg) \bar{a}_{2,1}$$
$$\bar{a}_{2,1} = 1.2316 \times 10^{-22} \frac{m}{s^2}$$

(So, basically the number is so small that effectively it doesn't acceleration [hence doesn't move off course]. If you want to get statistical, you could say that statistically speaking someone on the other side of the earth will jump at the same time you do – cause a cancellation effect of that small, but measurable value.)

Now, if the Earth smashed into you (i.e. you messed up the masses or accelerations of the relative participants) ... it would be the same problem as the bug and the windshield ... you would face an untimely death. So For that reason, it's imperative to keep straight which mass is coupled with which acceleration when doing these problems.

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