My Skydiving Mishaps: A Quick Lesson in Physics

by

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S-1-C: Can explain personal interactions with the physical environment using scientific principles

There is a familiar saying in life that you learn most from your mistakes. However, there are certain times in life when this method of learning is not exactly your best option, like when you're about to jump out of a plane. The series of events that follow this simple jump are pure physics at their finest, from gravity and terminal velocity to aerodynamics and surface area. When done correctly, skydiving can be a fun fluid process, but make a mistake along the way down, and you quickly understand the importance of the laws of physics.

I learned this particular physics lessons a few years ago when my friends gave me a skydiving gift certificate for my birthday. When I arrived at my jump site, the staff met us at the door and swiftly guided us through some quick training. After the obligatory signing of waivers and contracts, the instructional period began. As any typical young invincible twenty-something would do, I signed the waivers and marginally paid attention as the instructors explained the five simple commands for a successful jump:

1. When preparing to exit the plane, turn towards the open door with your thumbs tucked under the straps of your backpack and your elbows back close to your side and put your right foot on the step outside the plane.

2. When jumping out of the plane, jump facing outwards, nose first, head back, thumbs remain tucked in the backpack straps with your elbows back.

3. Hold this position, with your head back and thumbs and elbows tucked in, until your instructor jumping tandem with you taps your shoulder, then release your thumbs from the pack and spread your limbs with your head forward and chin up. Hold this position for your minute long free fall.

4. When the parachute opens, sit square in your harness and steer with the straps when they are passed to you.

5. When landing, pull your legs up in front of you and coast into the ground.

Before entering the plane, I went through a few dry runs on the ground to learn exactly how to move my body to correctly execute these instructions. In physics terms, this proved to be a relatively simple task. Just as when the actual jump takes place, the main force acting upon my body in these dry runs was gravity. The Earth has a natural existing gravitational pull that acts on all bodies. Newton's Laws of Motion tells us that the force created by gravity is an acceleration constant, where the acceleration force is calculated by the distance of the object from the earth's surface divided by the time it takes to fall that distance. The equation for the force of gravity is expressed as

$g = 9.8 \text{ m/s}^2$

Where g equals gravity, m equals meters and s equals seconds (Zimmerman Jones). When we are standing on earth, our acceleration downward is continual

(because we are standing on the ground and cannot physically go any further). We experience no actual acceleration, because we are zero meters from the Earth's surface, so the m value in the gravity equation equals zero. When we increase an object's distance from the Earth's surface, the m value increases accordingly and the object accelerates when returning to the Earth's surface. It's the gravitational force that allows objects on Earth's surface to remain on Earth's surface without floating up. While rehearsing the movements for skydiving when gravity is constant, I was allowed to learn the movements without any other forces working against my body.

However, the thrill of skydiving comes when you change the constant involved in gravity and experience acceleration. As you increase the distance between yourself and the Earth's surface, you change the acceleration constant in gravity. Because the distance between you and the Earth's surface is greater when the plane reaches higher altitudes (the m constant in the gravity equation) your acceleration potential increases. However, this acceleration potential remains a potential, and I don't immediately accelerate downwards because of Newton's Second Law of Motion. This law states, "The acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass" (Beichner and Serway, 117). Because as the plane climbs, the normal force of the plane is acting against the normal force of the gravity against the skydiver, and equilibrium is created (Lenaker).

$$F \text{ skydiver}$$

$$F \text{ plane} = F \text{ skydiver}$$

Where F equals the force of the object. And according to Newton's law, "An object will only accelerate if there is a net or unbalanced force acting upon it" (Henderson). This law can also be expressed as the equation:

$$a = F_{net} / m$$

Where a equals acceleration, Fnet is the measure of net force acting on the object and m is the mass of the object (Henderson). Since there is equilibrium between the force of gravity on the skydiver and the force of the plane, there is no net or unbalanced force acting on the skydiver, and therefore no acceleration occurs, and the skydiver remains in the plane.

One of the phrases repeated during our instructional by several of the experts was that when the door to the plane opens, everything changes. They were right. This was the moment I took over with the instructions I'd been given, and I was in control. So I walked to the door, and began my checklist of directions. One, tuck my thumbs under the straps of my backpack. Check. Second, put my right foot on the step outside the plane. Nope. I skipped all the rest of the steps; I just, tucked, rolled, and fell out of the plane. It clearly became apparent that the reason they give said instructions was because the laws of physics will immediately take over and a series of predictable events will ensue.

One of the main reasons the instructions included keeping your foot on the step of the plane was to gain leverage and steady yourself to jump away from the plane. The minute I tucked and rolled out of the plane, the normal force of the plane was no longer acting on me, equilibrium was lost, and the forces became unbalanced. These unbalanced forces produced a net force that caused my

immediate acceleration downwards. What the instructors neglected to mention was that if you miss the first instruction and move your leg off the step, there is a very likely chance that your leg will smack into that very step, as it is in the way of your immediate direction down. And that is indeed what happened to me, two miles above the Earth's surface. The impact ripped the jumpsuit I was wearing right behind the knee, and it began to split towards the zipper down my chest.

Since I had failed at the first direction, the second was doomed to fail from the beginning. Because I fell rather than jumping and caught the step on the way down, my direction was not outwards, but rather straight down leading with the top of my head. In an ideal simple situation, such as a vacuum tube, using Newton's Second Law of a=Fnet/m, we can simply calculate acceleration in terms of Fnet divided by the mass of the object. However, during skydiving there is another counter force to gravity, wind or air resistance. This air resistance creates a friction force that immediately acts on the skydiver's mass. To avoid further incidents with the plane, I followed my body's initial response to tuck my chin towards my chest, rather than keep it up as instructed. When I pulled my chin in, with my thumbs still under my arm straps and elbows in, the surface area of my body decreased, and my body became more aerodynamic. This aerodynamic position lessened the friction or air resistance called drag force and caused an increase in my velocity (Henderson). The combination of hitting the plane, my initial downward direction, and the tucked position of my head caused my tandem jumper and I to immediately begin barreling in a somersaulting motion towards earth at an accelerating rate.

During a typical jump, this would be the freefall stage, where the expert tandem jumper assumes control of the mechanisms, such as the release of the pilot chute, and maintains the free fall time and altitude. Once the pilot chute, or initial stabilizing chute, is deployed, free fall commences. This is when the tandem jumper taps out the novice jumper to release their thumbs and spread their limbs out. Once the head is tilted back, the body remains horizontal and the extended limbs create a larger surface area that acts as a friction drag force. Without this air resistance or friction drag force, the body will continue to accelerate until it collides with Earth (Henderson). In the case of my jump, since we were somersaulting rather than arrow diving, the instructor's cue to release my arms never came and subsequent release of the pilot chute became impossible.

However, since I had never been skydiving before, and didn't exactly know that the somersaulting sensation was wrong, I went ahead and proceeded with the next instruction, and took it upon myself to release my body position, and follow the image of flying I had in my head – Superman. Once I put my chin back, and the spinning stopped, I began to experience the freefall portion of my dive, just as it had been described to me. While gravity was the force pulling me downwards, air resistance was the friction force acting against gravity, slowing down the acceleration. When air resistance creates a force that is equal to the acceleration of gravity, the skydiver cannot accelerate or go any faster, as illustrated by the diagram below. The speed at which the forces balance and the skydiver is traveling their fastest is called terminal velocity (Henderson).
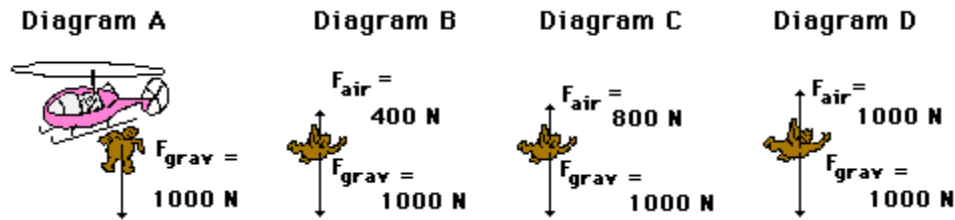
Fig 1. Paul Hewitt, <u>Newton's Second Law: Air Resistance</u>. (Physics Classroom. 2009)

http://ffden-2.phys.uaf.edu/211_fall2002.web.dir/DaneLenakerSkydiving/drag.htm.

Fgrav is the force of gravity, Fair is the force of air resistance and N is Newton, or measure of force. Newton's Second Law describes terminal velocity in terms of the mass and surface area of the object. When I opened my tucked body position, expanding my surface area, I changed my terminal velocity, slowing down my acceleration and ultimate traveling speed. The wind inflated every part of my face and turned my skin to putty. My eye goggles were not properly fit and the rip continued to tear my suit, causing it to inflate and flap along with one of my eyelids at the same rate we were traveling downward. My limbs became impossible to move downward, only laterally and my hearing and my voice were lost in the wind. The view was unreal as every familiar object grew in size as I soared down.

When the parachute was finally pulled, the upward jolt was intense. All the extreme sensations of the freefall were abruptly brought to a halt. With the pulling of the parachute, there was a dramatic increase in cross sectional surface area, and thus a dramatic increase in the amount of air resistance and terminal velocity. This rapid change in surface area causes a shift in the net force from the equilibrium of terminal velocity to the upwards force of air resistance, causing

us to rise up (Henderson). With this powerful shift in acceleration, I felt a sudden intense pain run up the back of my thigh from where I hit the step of the plane. With the recovery of my hearing came the concerned ramblings of my tandem jumper. "You hit the plane. Oh my God, you hit the plane. Are you O.K?" I reached a new terminal velocity that matched the increase in the surface area of the parachute, and drifted down to Earth at a much slower, safer rate.

And as I sat in the harness, and caught my breath, the magnitude of my decisions quickly caught up with me. The slow drift back to land offered lots of time for me to reflect on the poor choices I had made to bring about this experience. Lucky as I was, the entire situation was entirely my fault. I grabbed the steering toggles and guided us back to our landing zone. But as we drifted towards solid ground, the scenery took on an entirely new beauty. I breathed in the whole sight, and with a new calmness, I recalled the final instruction: I lifted my legs and landed.

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