Physics of a Snowboard Carved Turn

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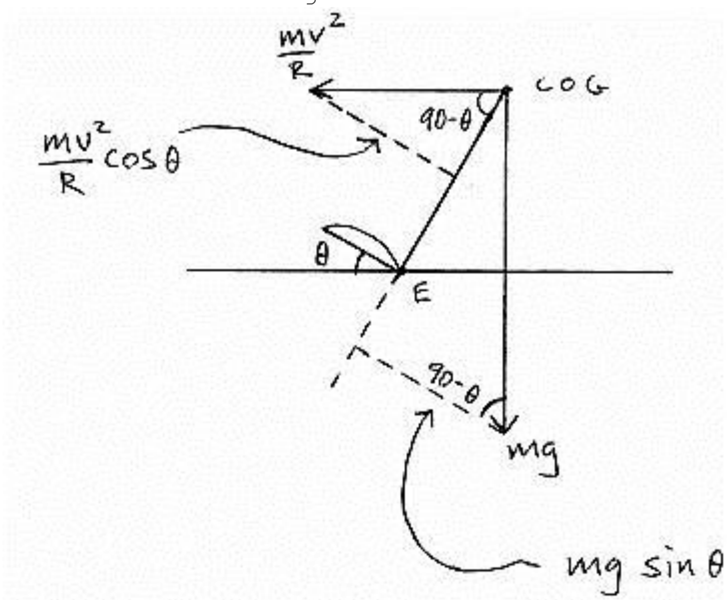
The snowboard is a wonderful tool that serves many purposes. We use them to have fun, to blow off steam, to exercise, to enjoy the outdoors, and to share good times with friends. However, as we use them, our subconscious learns valuable lessons in Physics. With a little trigonometry, we can realize a few key things that happen as we carve, that we can then consciously contemplate on the hill. Appreciating and understanding the physics at hand, we can become better carvers.

Have you ever taken a snowboarding lesson where the instructor says "keep your body over the board… this puts more weight on the edge"? While keeping your body over your board is good advice, the benefit is not that you somehow generate more weight on the edge. If while considering your instructor's sermon you thought to yourself "I can't put any more or less weight on the edge, I only weigh so much!" for the most part, you'd be right.

The real benefits to assuming a poised racer-type body position are balance and angulation. As we tilt our snowboard up on an angle, the shape of our snowboard carves a circular path in the snow. As we travel around this path, we feel a centrifugal force that seems to pull us towards the outside of the carve. To balance this force, we lean in towards the center of the carve. This is just like trying to walk while carrying a heavy suitcase in one hand. We have to lean away from the suitcase in order to balance. While we carve a turn, our centrifugal force is the suitcase. (Physics purists will insist that there is no such thing as centrifugal force and that it is only proper to speak of centripetal force acting towards the center of the circle. Though this is true in an absolute frame of reference, it is perfectly acceptable to discuss centrifugal force in a body-centered inertial frame of reference.)

You feel this every time you snowboard, you knew that already. But consider this chain of logic. Centrifugal force is determined by our speed and the radius of the turn. Our centrifugal force determines how much we need to lean in. Our lean angle helps determine our edge angle. Our edge angle and the sidecut of our board determine the radius of the turn. Sounds like a circular argument, right?

Consider this diagram:



- cog = center of gravity
- E = point of edge contact
- m = body mass
- θ = edge angle
- V = velocity (speed)
- R = turn radius

Omitting the effect of angulation for the moment, we tilt the board up and lean by angle θ in order to balance the centrifugal force mV2/R. The equation for this balance looks like this:

$$\frac{mV^2}{R} \cdot \cos\theta = mg \cdot \sin\theta$$

We shall ignore the effect of hill slope angle for the purposes of this discussion, as the analysis becomes much more complicated. For the complete description of the equation for a carved turn accounting for hill slope angle and rider position along the arc, make a pilgrimage to the library and pray that they have a copy of John Howe's book Skiing Mechanics. This representation of the balance of forces applies to any object travelling in a circular sense, so we can use it as a close approximation and a good illustration.

Before we continue, let's define a few terms. Inclination is the PSIA term for the lean angle of our center of gravity. Angulation is the PSIA term for creating angles in the body. If you stand on your board like a pole and simply lean into a turn, you are turning with no angulation, only inclination. When we bring angulation into the picture, some interesting things happen. By creating angles with our ankles, knees, waist and shoulders, it is possible to increase actual edge angle with respect to our angle of inclination. But the end result may surprise you.

To solve the equation for all of the above variables, we shall assume that our rider is making a purely inclinated turn, whereby the board remains perpendicular to the line between E and COG. In this case, edge angle and angle of inclination are one and the same. We can then approximate the turn radius our sidecut will carve when we lean in to the turn as:

$R = C \cdot \cos\theta$

where C is the sidecut radius of the board, and

. $0° \le \theta \le 90°$

By substituting this equation for R into the above equation, we can write:

$$\frac{m \cdot V^2}{C \cdot \cos\theta} \cdot \cos\theta = mg \cdot \sin\theta$$

which reduces to:

$$\frac{V^2}{C \cdot g} = \sin\theta$$

Remembering that sin2 + cos2 = 1, we can write

$\cos^2\theta = 1 - \frac{V^4}{C^2 \cdot g^2}$ or $\cos\theta = \sqrt{1 - \frac{V^4}{C^2 \cdot g^2}}$

Using this in our equation for R, we find:

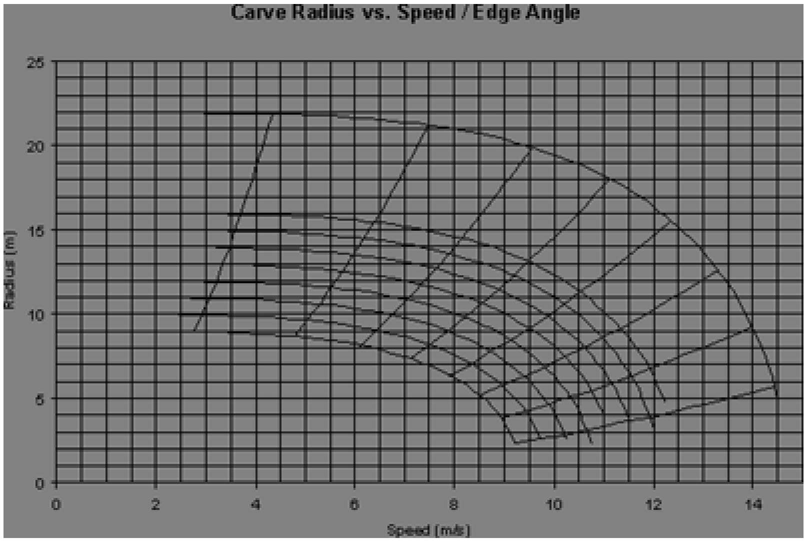
$$R = C \cdot \cos\theta$$

$$R = C \cdot \sqrt{1 - \frac{V^4}{C^2 \cdot g^2}}$$

Multiply the C through, and the final equation relating turn radius to speed and sidecut radius becomes:

$$R = \sqrt{C^2 - \frac{V^4}{g^2}}$$

It is clear that a given speed results in only one real carve radius where the sidecut is dictating the path, without angulation. We can calculate values of R versus V for given sidecut radii in a spreadsheet and plot the results:



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The downward curving lines represent our carve radius decreasing as speed increases. For reference, 10m/s = 22.5mph. Each curve is plotted for a different sidecut radius. The bottom curve results from a 9m sidecut radius, similar to many freestyle boards about 160cm long.

The top curve represents a 22m sidecut radius, similar to many of today's semi-shaped skis. The curves are incremented by 1 meter, with a gap between 16m and 22m. The straight lines that cross the radius curves represent lines of constant natural edge angle; "natural edge angle" meaning the angle that must be used without angulation. A dead weight could carve a snowboard balanced at the natural edge angle for a given speed, on a smooth surface. The left-most line displays a natural edge angle of 5° and the right-most line represents a 75° natural edge angle. These lines are incremented by 10°.

Example: using a board with a 12-meter sidecut radius at a speed of about 9.8m/s, we can carve a 7-meter radius turn using a 55° natural edge angle. If we tried to lean over any further, we would simply fall to the inside of the turn. If we didn't lean in enough, we would slide the board along a broader turn.

Admittedly, the decreasing radius with increasing speed seems counter-intuitive at first glance. Obviously, we can go careening down the hill at break-neck speeds making very broad, barely leaned-over turns. But in this sense, we are not truly carving the sidecut; we are forcing it to take a path other than the one its shape would rather make. Think about when you are carving down a gentle slope at relatively low speed. You can only lean over so much. Tearing down a steeper slope at high speed, we can lean over all we want. The more we can lean, the tighter radius we can carve.

Also, we can pump our turns with our knees and make sharper carves than these equations would permit. But a pumped carve is short-lived, as the pumping effect only lasts for a moment. Pumping temporarily magnifies force on the edge. Pumping a carve is almost always followed by a change of edges, as in slalom carving or slalom racing. If we apply additional force with a pumping motion, we can alter carve radius – briefly. But it's a trade-off. Pumping can benefit you in situations where you need to make a quick turn, but it can hurt in others where margin for error is slim, as the exaggerated up and down motion could upset your balance.

Back to the instructor telling you that one body position somehow puts more force on the edge than another. This is simply untrue. A person weighing a certain amount travelling at a certain speed around a certain radius only generates one certain amount of force on the edge. The force on the edge is the combination of our centrifugal force and our weight, if we are carving a consistent, sustained, non-pumped carve.

Perhaps the instructor tells you that assuming the racer-like position puts more body mass close to the edge. Now this is true. But it is important to realize that this does not generate more force on the edge, rather, it enhances balance. Notice that the distance between E and COG plays no part in the above equations. Therefore it is possible to carve a turn using either a low, properly angulated body position or an extended, laid-out, purely inclinated body position. This is why "eurocarves" are possible. However at high speeds on steeps and ice, eurocarving would require impossibly super-human balance

Having our center of gravity close to our point of support improves balance in all situations. It is easier to walk on a short pair of stilts than the two-story rigs you see at the circus. It is easier to ride your bicycle no-handed sitting in your seat than standing up on the pedals. The racer-like position, with deeply bent knees, upright upper body and shoulders level to the hill minimizes the distance between E and COG and therefore improves our ability to maintain balance while carving high speed turns on the steeps.

But what is the use of this information? It comes in very handy when selecting a snowboard for a particular use. Say you were looking to purchase a new carving board and you narrowed your selections down to either Prior or Burton. Prior's WCR175 has a sidecut radius of 11.5m; Burton's Factory Prime 173 has a sidecut radius of 13.31m. What this tells you is that the Prior will reach a particular turn radius at a slower speed and lower edge angle than the Burton. Also, at a given speed, the Prior will be carving a tighter turn. This may be a good or a bad thing depending on what you want to do. If you spend most of your time riding the narrower trails of eastern North America, the Prior would be the better choice. If you ride wide open terrain where you can arc huge high speed turns at your leisure, the Burton might be a better choice.

If you're a racer and you prefer the round-carves/stay-high technique, the Burton would carve a given radius at higher speed. If you race using the point-straight-at-the-gate-and-make-a-quick-turn-at-the-last-second technique, the Prior would make a quicker carve at a given speed.

Or, let's say you've been riding something like Burton's FP164 and you're considering something longer. If you like the size and shape of the carves you make on the FP164, but you feel you need more edge hold, you would want to shop for something with more length but similar sidecut radius. Noting that the FP164 has a sidecut radius of 11.79m, you would be wise to select the WCR175. It will carve turns of similar radius, but alas, there's no such thing as a free lunch. You'll have to exchange the lighter weight and maneuverability of the 164 for the superior edge hold and stability of the 175.

But what about angulation? Remember, angulation serves to adjust actual edge angle with respect to inclination angle, to a limit. With a purely inclinated turn, our edge angle and inclination angle are the same. Using angulation, our edge angle and inclination angle can be different.

Let's suppose we have a snowboarder using a board with a 12m sidecut radius. From the equations, we can determine that when this snowboarder makes a purely inclinated carve at 9m/s, he will be able to carve a turn with an 8.7m radius. This will occur at an angle of inclination of 43.5°. If he tries to lean in any further without angulating, he will simply fall to the inside of the turn. But what if he does use angulation? We must write new equations to determine what happens. The balance of weight vs. centrifugal force is:

$$\frac{m \cdot V^2}{R} \cdot \cos\theta = mg \cdot \sin\theta$$

which reduces to:

$$\frac{V^2}{g \cdot R} = \tan\theta$$

But with angulation, we have a new expression for R:

$$R = C \cdot \cos(\theta + \delta)$$

We show the extra angle δ supplied by angulation as being added to the angle of inclination. The sum of θ + δ is the total edge angle of the board.

When our snowboarder was only using inclination, traveling at 9m/s, his maximum edge angle was 43.5°. Using angulation, we can get around this apparent limit. Let's now suppose that the snowboarder uses angulation to dictate a 50° edge angle. The balance of forces becomes:

$$\frac{\left(9\frac{m}{s}\right)^2}{9.81\frac{m}{s^2} \cdot 12m \cdot \cos(50°)} = \tan\theta$$

Therefore, the angle of inclination must be = 46.9°

Since edge angle is q + d, the snowboarder is using 3.1° of angulation. This allows a carve radius of 7.7m, at the speed of 9m/s, where before he was only able to muster an 8.7m radius without angulation.

It is interesting to note that angulation allows us to increase inclination as well. Think of it this way. Increasing edge angle reduces turn radius. Reducing turn radius increases centrifugal force, at a given speed. The increase in centrifugal force requires our angle of inclination to increase.

Another curious effect of angulation is that as speed increases, the difference between the edge angle and the inclination angle gets smaller and smaller. At a speed of 10m/s, a 12m sidecut radius would produce a 6.3m radius turn, without using any angulation. The inclination angle and the edge angle would both have to be 58.3°, and no greater. Using angulation to increase edge angle to 65°, we find that the new angle of inclination is 63.5°. The angle supplied by angulation must be 1.5°. Evidence of this is shown in this picture of a racer, displaying excellent technique:

He is obviously angulated, but as he is moving at high speed, his inclination angle and edge angle are very close. If we were to draw a line from his center of gravity to the top of his board, it would be almost perpendicular to the top of his board. Without angulation, the line from his center of gravity would be exactly perpendicular to the top of his board. Had he not used any angulation, he wouldn't have been able to lean in as much. By using angulation, he carves a tighter turn, and is in better position for the next gate. He also gains stability by keeping his center of gravity closer to his point of support.

Why bother with all the physics and trig? You certainly aren't required to get so theoretical about it because our bodies can feel when we're balancing the forces properly. To have an understanding of some of the physics of carving could provoke you to consider aspects of your riding that you might not have otherwise. You might even consider it fun to ponder all this while carving, and to know exactly what is going on. These toys we strap to our feet provoke our brains to work probably twice as hard as normal, computing thousands of these physics calculations every second we spend hurtling down a snow-covered slope. Yet this is the stuff that recharges our batteries, fuels our spirit, makes us feel alive. Physics is what is at the heart of it all, and to know it is to know the heart of snowboarding.

Reference:
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