How an Inline Skate Turns

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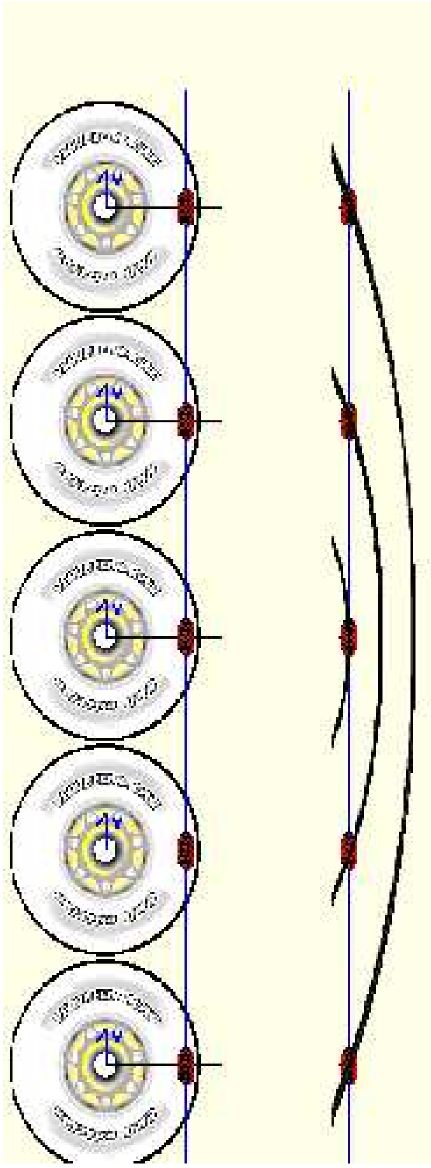
Note Added 6-24-00-- See also Turning: Part II

1. The Turning Path Of An Inline Skate



First I consider how a 5-wheel skate travels in "a circle" and then consider the basic turning process itself. The figure on the right shows five inline wheels leaning way left (exaggerated) with red-black contact patches where the wheels flatten against the floor. When the skate travels straight ahead along the blue line the contact patches are nicely in line. So if the skate were to travel a curved path either the contact patches must move out of line or the wheels must travel on different curves. It would seem to take a lot of energy to deform the wheels so that the contact patches move way out of line (unless you have very soft wheels) so I think the case of cornering for a speedskater follows the figure to the right.

The front wheel will be 1 and the rear wheel will be 5. So skating in a fairly sharp circle (10 foot diameter, 5 foot radius) the curves which pass through the middle wheel (3) and the curve which passes through 1 and 5 will be offset left-right by 0.3 inches or just over the size of the axle hole in the center of a bearing. So the curves are much straighter than they appear on my figure. If you slide there will be 5 curves instead of 3 as each wheel gets its own path. When you complete the turn the wheel paths will merge back to one if you move straight ahead. I am not aware of any real data on wheel paths but this seems most reasonable.

A 2-wheel skate will have only one wheel-trajectory curve if you use the most efficient turn so it really can travel in a true circle. A 3-wheel skate and a 4-wheel skate will have only two curves. A 6-wheel skate will have three curves like the 5-wheel. We assumed here that all the wheels on the skate are the same size and shape.

2. How Does An Inline Wheel Turn?

Now that we have seen how the skate fits on a curved path it is time to explain how the wheels themselves can roll off a straight path. I am not concerned here with the hockey-slide type of turn or the type where all but one wheel is off the ground as they are inefficient or lack sufficient control for racing. To explain how the wheel turns we first need to know

more about how they grip.

2a. Background on Wheel Grip

You can make these ideas on grip much clearer by demonstrating them for yourself. Locate a fairly new wheel which is soft. New means that it has a curved profile and a smooth surface. If the wheel is worn it will be difficult to observe the contact patches. If the wheel is hard it will be difficult to apply enough force with your hands to produce the contact patches. Put bearings in the wheel and slide a bolt through it and tighten a nut to hold the wheel. You should be able to hold onto the bolt and easily roll the wheel. Now find a piece of glass like an open window or glass table top where you have simultaneous access to both sides of the glass. Roll the wheel on one side of the glass and observe it from the other side. You should be able to see the contact patch where the wheel flattens against the glass. Get familiar with where the patch moves as you lean the wheel on edge. The wheel rolls ahead very easily. Now try to push or pull it in the direction of the bolt. If your wheels are like mine they have a pretty strong grip against sliding sideways. As you lay the wheel on edge (say 45 degrees) the sliding grip stays fairly strong. Now put the wheel straight up again and rotate the bolt in a circle parallel to the glass surface. It rotates fairly easily. Put the wheel on edge (45 degrees) and again the rotational grip is much weaker than the sliding grip.

Now get a pen and mark a small arrow on the bottom of the wheel (small enough to fit inside the contact patch if you were standing straight up on your skates). Point the arrow parallel to the bolt. Roll the wheel straight ahead and the arrow should maintain its direction as it rolls through the contact patch. This is how a wheel ought to behave. Right?

Ok, now mark an arrow farther on the side so it will fit into the contact patch when you place the wheel on edge at a 30-45 degree angle. Now roll the wheel straight ahead while it is on edge at the angle which will allow the arrow to contact the glass as it rolls. If you press the wheel against the glass lightly the arrow rotates as it passes through the contact patch. If you press hard the arrow stays at the angle it had when it entered the contact patch and then rotates quickly after it exits the contact patch. I conclude that if the wheel on edge is gripping rotationally, a torsional stress is built up on the surface of the wheel even as it rolls straight ahead!

This torsional stress starts as the arrow enters the contact patch and builds up to a maximum as it exits the contact patch. The level of torsional stress which can be built up can be controlled by the pressure you apply to the wheel. That is, the skater can determine when the rotational grip fails by selectively applying foot pressure. Because the sliding grip is so much stronger than the rotational grip the skater can probably modulate the rotational grip without destroying the

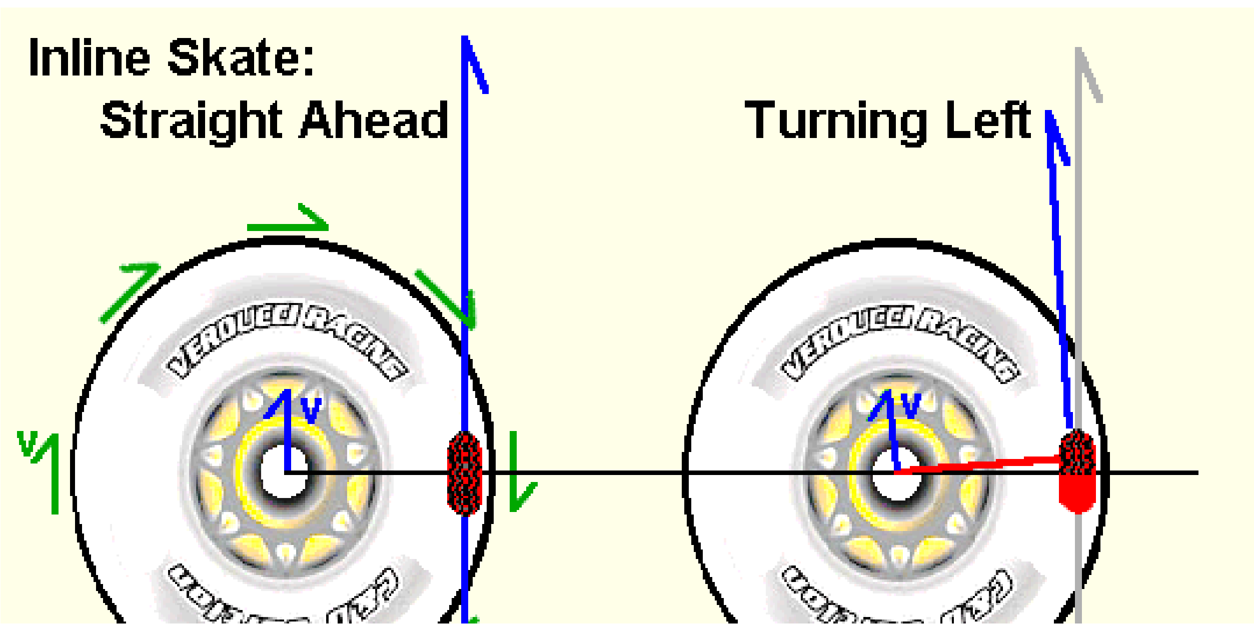
sliding grip. Although it is possible that if you really push the turns, applying a lot of force, that when the rotational grip fails the torsional waves sent out from the point of failure may weaken the sliding grip locally. In this case both the rotational and sliding grip would be lost at the rear of the contact patch and would appear to move forward, toward the leading edge of the contact patch where the torsional stress is lowest.

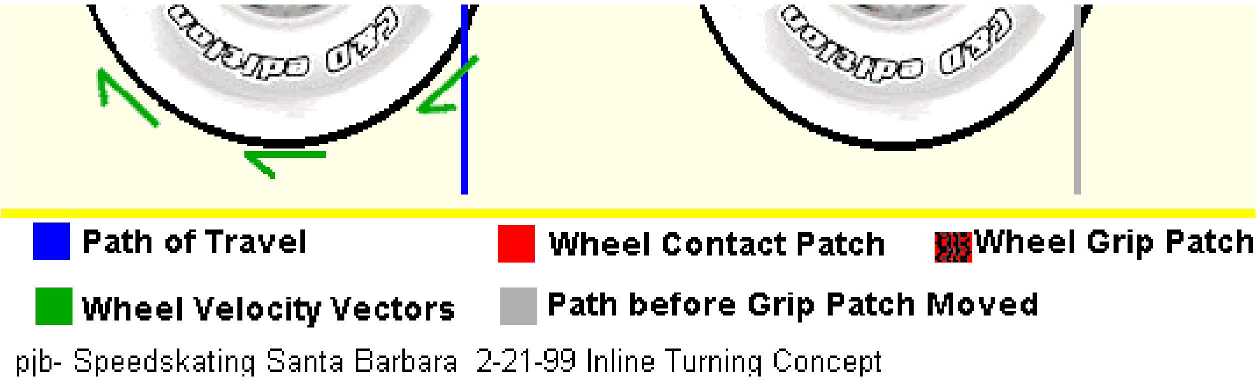
2b. The Turning Process

The left side of the figure below shows the wheel (and skate) moving straight ahead. The right side shows the proposed change during turning.

Left: The wheel is viewed from above looking down at the floor. The wheel is leaning way left (exaggerated). The wheel and skates move straight ahead along the blue line and the blue vector at the wheel axis shows the forward velocity there. The wheel makes contact with the floor at the red contact patch. The rotational grip patch is shown as black treadmarks. Note that the wheel as a whole moves forward at the speed v and every point on the periphery of the wheel (actually here a circle through the contact patch with center at the axle) moves with velocity v relative to the axle rotating around it. So long as the grip patch remains centered on the horizontal black line (connecting the axles on the left and right) the wheel and frame move straight ahead. Here the rotational component of velocity points directly behind the skater (down on the figure) but if you move the grip patch up or down just a little off the axle line there is a net horizontal velocity to the right or left.

The right side of the figure below shows the grip patch moved up a little or rotated forward through a small angle marked by the red line connecting the axle center with the grip patch center. Now the net velocity seen by the contact patch has a slight rightward rotational velocity which moves the wheel a little to the left.





3. Comments

It is this forward motion of the rotational grip (loss of the grip on the back portion of the contact patch where the torsional stress is largest) which allows the wheel to use the sideways motion of the wheel on edge to turn. Not surprisingly the turn is initiated by leaning to one side which builds up a torsional stress in the wheel's contact patch. When the rotational grip fails toward the trailing edge of the contact patch (through judicious choice of wheel compound, surface, speed ... or by judicious application of foot pressure) the grip moves forward and the skate turns.

There are a lot of complications which I will only point out briefly -- the contact patch cannot be formed or removed instantaneously. So when you move fast enough the contact patch length is not the same as you see at very low speeds. For car tires this effect is related to traction waves which distort the tire surface. For cars there is also a torsional wave but it is treated as separate from the traction wave because car tires do not lean on edge very far. For inline skate wheels on edge these waves are linked so at high speed the contact patch would be tied to torsional-traction-waves in an even more complex manner than car tire theory.

With the above understanding of turning it is not clear that the five-wheel skate is at any disadvantage over the 2-wheel skate for turning. The rolling-resistance and turning-resistance will be different for both but which is lowest needs more study. The two-wheel skate still has the advantage that larger diameter wheels can be used with their lower rolling-resistance. Would the losses be still lower for a hybrid skate with 2 large wheels in front-back and two or three regular wheels in between?

4. Acknowledgments

I appreciate helpful communications with Duncan Browne of the Inline Skating Newsgroup and from Dean Jackson of the Inline Racing Newsgroup. I found the series on *The Physics of Racing*--car racing-- by Brian Beckman to be helpful, especially *Part 10: Grip Angle*-- available on at least three servers on the internet.

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