Comparing Traditional, New School, and Coordinates Style Skiing

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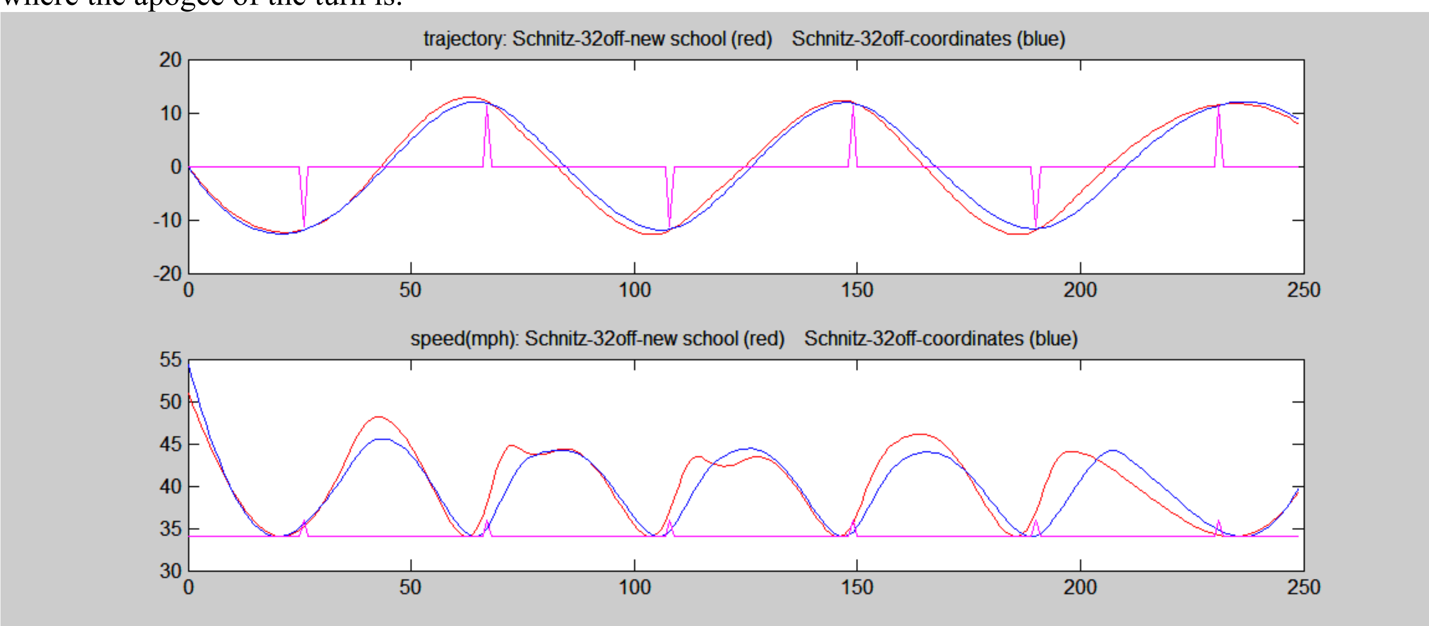
For the analysis I chose to focus on the skiing of four well known proponents of the three different styles – Andy Mapple and Chris Parrish for Traditional style, Chris Rossi for New School or the 'efficient' style, as Rossi likes to call it, and Steve Schnitzer for the Coordinates style. All four of these skiers ski well, and I had video of them skiing, filmed from the center of the boat. Video for the first three skiers came from Bill Holbert filming the Men's Preliminary Round of the 2002 US Open. Schnitz's ski passes and Chris Parrish's 41 off pass came from clips on Schnitz's web site.

Before going any further, I need to set the record straight on something. Coordinates is the style Steve defined and switched to in 2004. He defines it as a low speed technique, skiing with hips forward, and skiing toward a point about 5 meters before the next buoy. Coordinates is not the style Jim Michaels skied, according to Michaels and Steve. A lot of people assume it was, because Steve coined the approach and term at the same time he was analyzing and touting Michael's skiing. But if you read what Steve wrote carefully, you'll see Schnitz said Michaels does not ski Coordinates style. So the word Coordinates has a bad reputation – but in this article you'll come to see why I'd like to revive the term.

In diagram below, the top plot is the skier's trajectory, or path, through the course. The gate is on the left, at a position of 0 meters, and the end of the course is at 259 meters. The magenta spikes represent the balls 11.5 meters vertically above or below the centerline. Ball 1 is at 27 meters in the horizontal direction, ball 2 at 68 meters, and so forth to ball 6. The bottom plot is the skier's speed in mph, corresponding to his position in the course, and is lined up directly underneath the plot of the skier trajectory. The magenta line on the bottom of the speed plot spikes up a little at each buoy to show where the buoy is located. As you can see, the speed peaks at the wake crossing, and approaches the boat speed just before or just after the buoy, depending on where the apogee of the turn is.

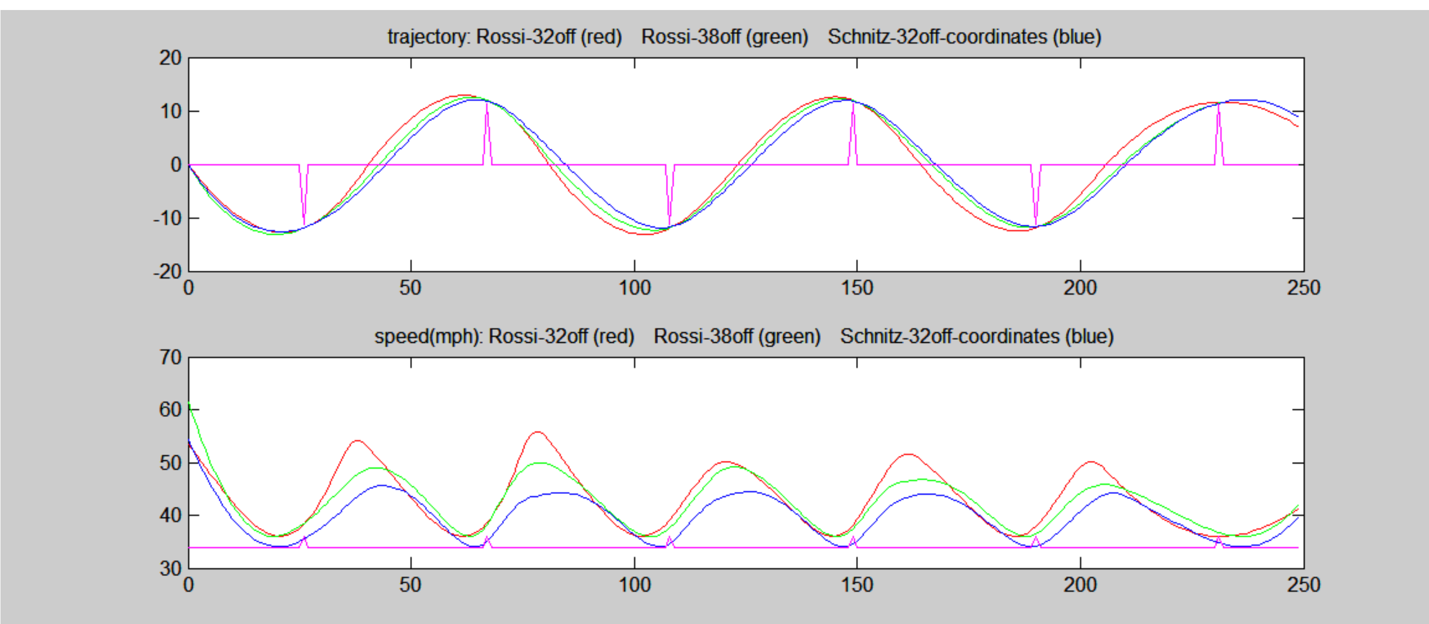


The two trajectories are both of Steve Schnitzer skiing at 32 off. The red path is taken from a video Steve has on his web site, skiing in pre-Coordinates style. From what Steve said about this pass a couple of years ago, he was using a one-handed gate and other New School techniques of skiers like Chris Rossi, Marcus Brown, Terry Winter, and Jamie Beauchesne. Looking at the red curve, Steve comes out of the gate and has a pretty nice line throughout the pass. At each ball, he is getting a little wider and earlier, and coming a little closer to backsiding the ball. You'll notice the point he crosses the centerline is moving up course as well – beginning at about 16 meters downcourse from ball 1 to about 15 meters on balls 4 and 5. Now there are conflicting reports on what the goal of New School style is, but backsiding the ball, pulling hard to cross the wake early to maximize the amount of time available for the preturn, and being way early and wide to the next ball is something I've heard many times from New School advocates. And Steve does a good job of doing just that in this pass. However, while the trajectory looks fairly smooth and consistent from ball to ball, the speed chart tells an interesting story. The max speed varies a lot at each wake crossing, indicating inconsistency. The 'flat' spots in the speed curve after balls 2 and 3 indicate a problem, and looking closely at the video it appears Steve 'broke' slightly from the ideal compressed position, i.e., the shoulders moved forward out of line with the hips and feet, so there was a center of mass problem. The analysis also shows the reason for the break: these turns were on a slightly tighter radius than the others, causing the hit from the boat to occur about a quarter second earlier than on the other turns, and it appears Steve was not quite ready for it. After those two balls, Steve corrected his anticipation of the pull, increased the turn radius a little, got back into form, and ran the rest of the pass according to New School style.

Now, compare the blue curve for the Coordinates style, measured from another video from Steve's website. The trajectory (blue curve) resembles a sine wave more closely. Notice Steve is still early and wide. The speed plot also has that nice sine wave shape, and is much more consistent from ball to ball, with no big peaks or flat spots. The wake crossings are about 18 meters downcourse from each ball, compared to 20.5 meters for the halfway point. His path from ball to ball is still S shaped, but you can see that basically he's skiing to an imaginary point in front of the next ball, as he suggests for the Coordinates approach. This was a very clean pass with no mistakes, and it's easy to see why Steve feels so much more comfortable with this style. One other thing worth noting is that from a mathematics point of view, the sine shaped paths in blue are a lot more 'efficient' than the paths in red – and that translates to easier passes with less effort, just as Steve claims.

Schnitz's wake crossing angle in his New School pass was as high as 45 degrees coming off ball 1, and as low as 38 degrees coming off ball 3. In his Coordinates pass, his angle was more consistent, and he needed less angle, at 40-42 degrees, yet he skied better – he skied a more efficient path.

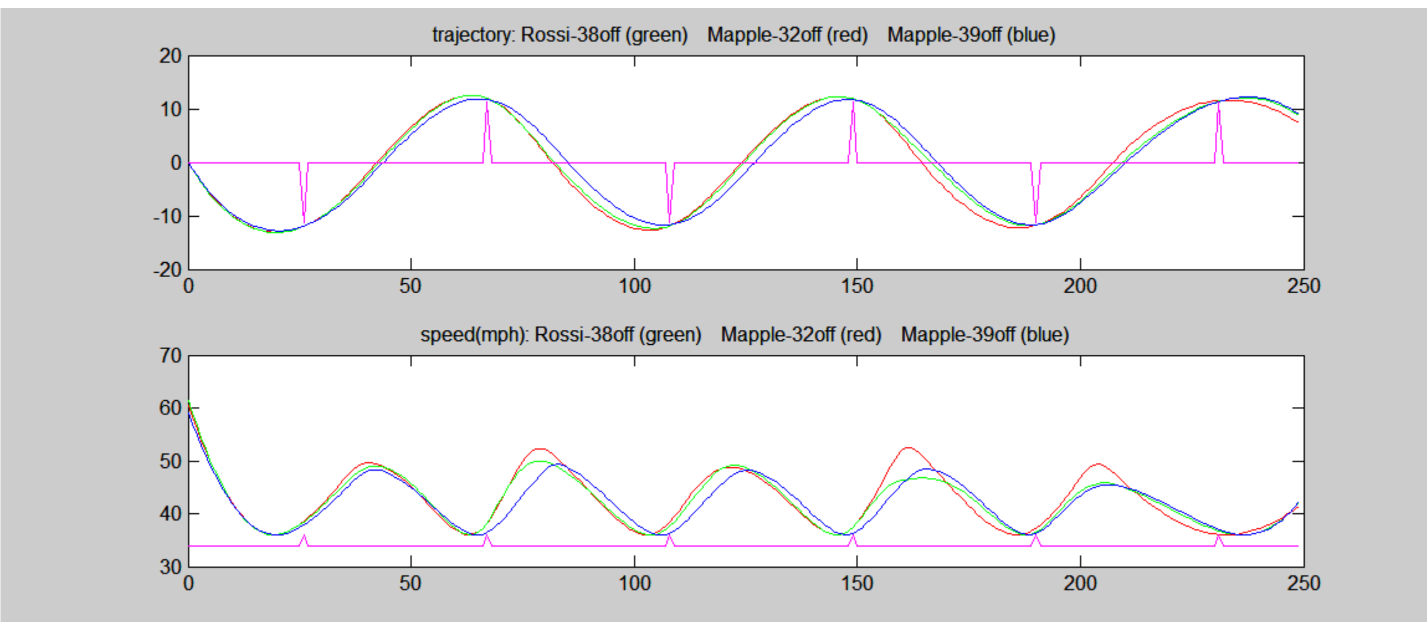
The New School style skiers say they target efficiency as a goal. Schnitz's New School pass was not the best example, so we should look at someone who is more proficient in that style – Chris Rossi is regarded by many as a leader in that style. (I would loved to have analyzed Jamie and Marcus as well, but I did not have any suitable video of them skiing – one of these days I'll look at them.) Chris's passes are shown in the next plots, and I'll keep Steve's Coordinates style pass on the graph for comparison.



Rossi's 32 off path is very wide and early. He's crossing the centerline on average about 14 meters past the buoy, well upcourse. After ball 2 he crosses 13 meters downcourse with 50 degrees of angle! His 38 pass is not as wide or early – it's about halfway between his 32 pass and Steve's Coordinates pass. At 38 off he's crossing the centerline 1-3 meters later with only 40-44 degrees of angle. Since he's skiing a more direct line between balls his maximum speed is *slower*. I claim Chris's 38 off pass is actually more efficient than his 32 pass, even though his 32 pass looks more like the New School style that is supposed to be efficient.

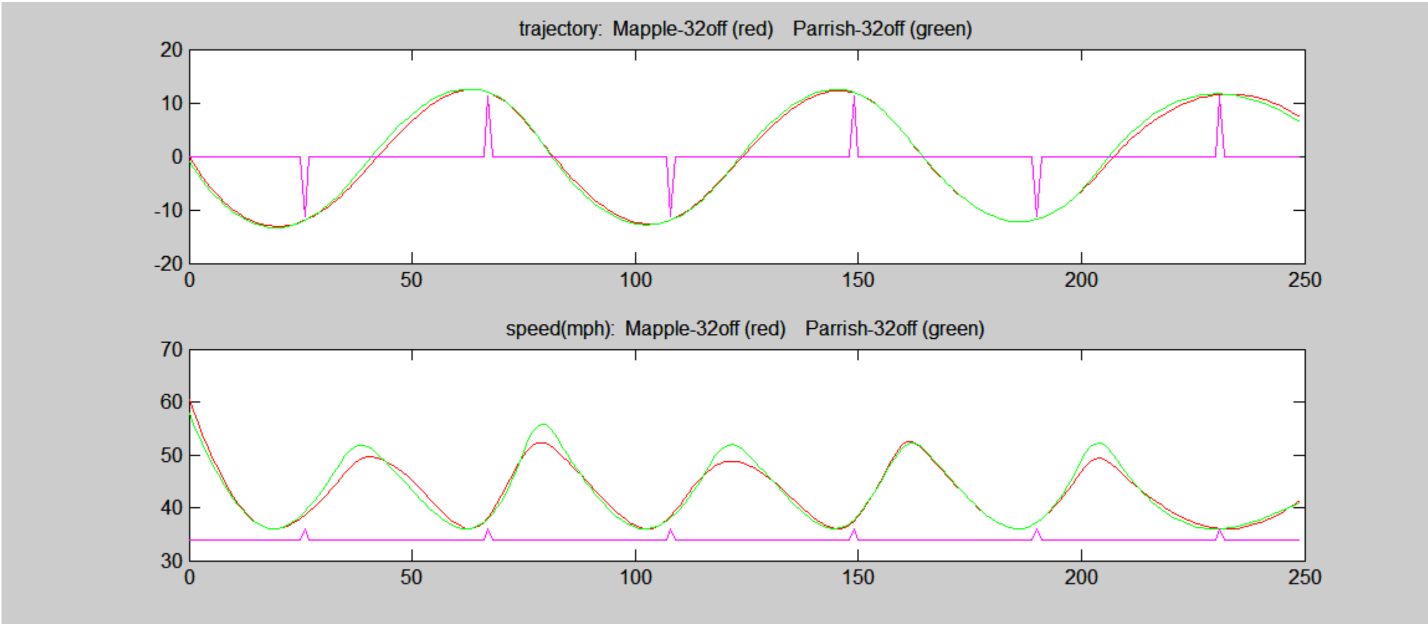
So just what is an efficient ski path? In practical terms, an efficient path is one that gets you through the course with less expenditure of energy. Chris Rossi's 32 off path looks a sine wave with a lot of 3^{rd} harmonic distortion. A 3^{rd} harmonic has a frequency three times higher. As a very rough analogy, try pedaling a bicycle three times faster – it takes a lot more energy. (If you added more 3^{rd} harmonic, and some 5^{th} and 7^{th} harmonics as well, you'd start to see the path becoming square – I've read some chat board threads by New School proponents touting a 'square wave' as the ideal way to ski and always be early.) As Chris goes from 32 to 38 off, it gets much harder to be as wide and early with a short rope, so he's forced to take a more natural path through the course – one with less distortion and more like the ideal sine wave. It's still not as efficient as Steve's 32 Coordinates pass, but that's the direction it's heading. More on this later.

Now let's compare Rossi's skiing to Andy Mapple's passes at 32 and 39 off. Andy epitomizes the Traditional Style, of course.

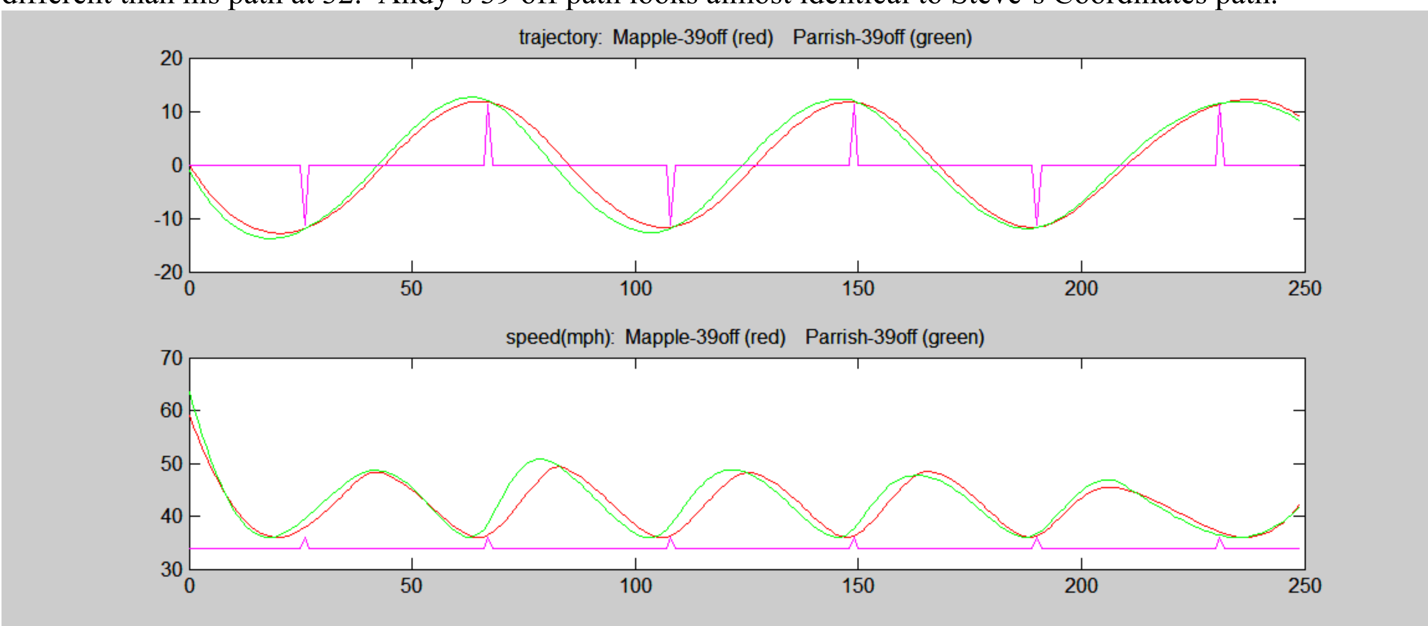


Notice that Mapple's 32 off path looks very similar to Rossi's 38 off path. In other words, Mapple is choosing to ski a more efficient path, and not trying to backside the ball or cross extremely early. At 39 off, Mapple's path is even more efficient. On average, he's crossing the centerline about 18 meters downcourse with 42 degrees of angle, which is less angle and further downcourse than his 32 off pass. So Andy is getting more efficient at shorter lines too.

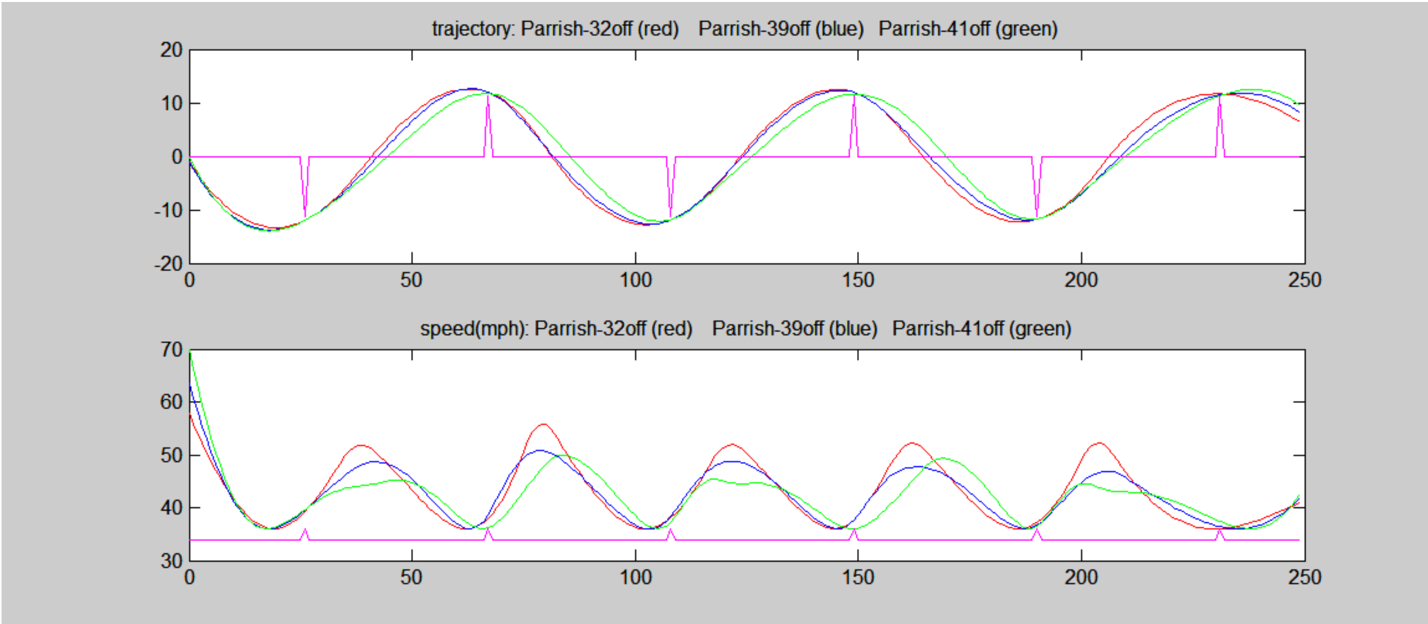
Next, lets compare Mapple and Parrish head to head at 32 off. At 32 off their paths look very close. Chris is just a little earlier, crossing the centerline as much as 1 meter earlier, with slightly more angle – 46 versus 44 degrees average. Consequently, Chris's max speed is a little higher. Both paths look like sine waves, so there is less 3^{rd} harmonic than Rossi's 32 pass. They are almost as wide and early as Rossi was, but the curves are smoother – they're skiing early by shifting the sine wave up course, rather than by trying to backside the ball and cross the wake as early as possible – which was what Rossi was doing at 32 off.



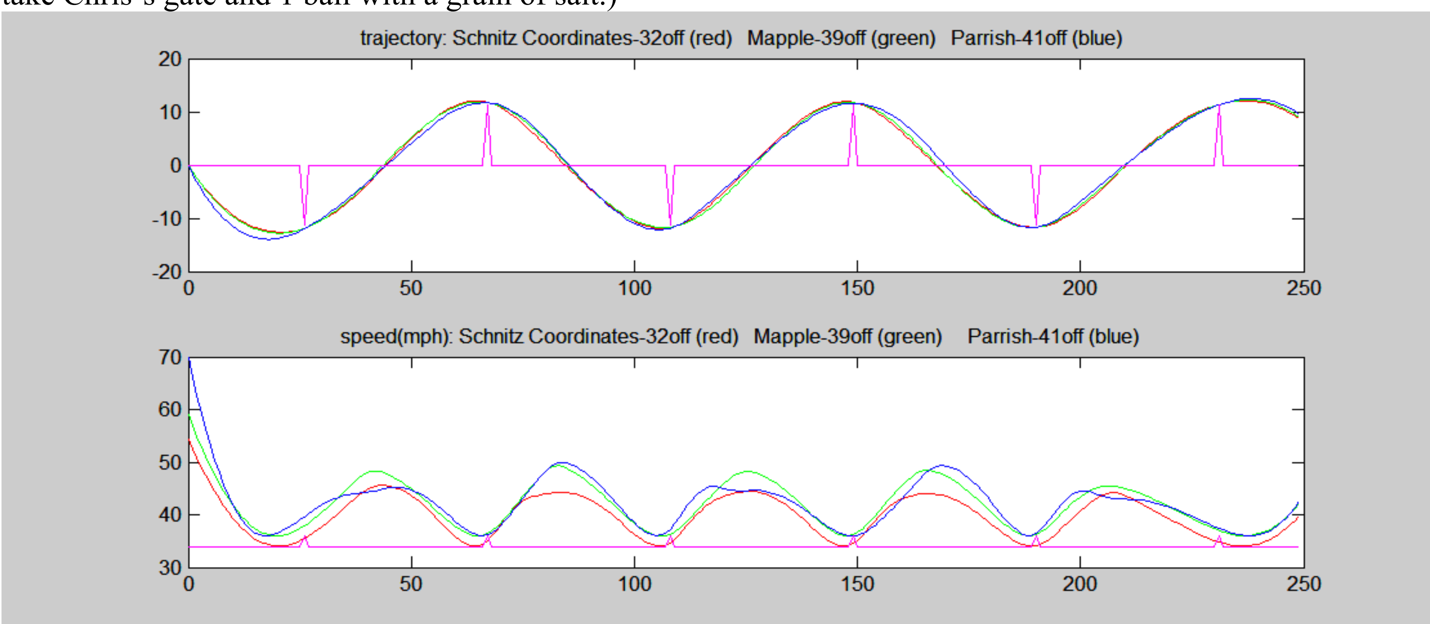
At 39 off, both skiers still take a very efficient line, while Chris is wider and earlier, with a path at 39 not much different than his path at 32. Andy's 39 off path looks almost identical to Steve's Coordinates path.



Finally, here is a comparison of Chris's 32, 39, and 41 off passes. Keep in mind that the first two passes are almost 4 years old, so Chris may have made some changes since then to become the world record holder. His 41 off pass, run last August, sure looks nice. Notice how similar his 32 and 39 off passes are. That's pretty consistent. He's able to maintain that very wide and early path, even at 39 off. That takes a lot of strength! But at 41 off, Chris finally reverts to a more efficient path. One problem with the 41 off video is someone's head is in the way for a second before & after Chris reaches ball 1, so I was forced to do a little guessing on some points. That may be the explanation for the flat spot on the speed curve coming off ball 1. So take his gate speed and 1 ball path with a grain of salt.



The next plot shows Steve's 32 off Coordinates pass alongside Andy's 39 off pass and Chris's 41 off pass. They are pretty close! They all look like sine waves centered around the buoys. There is very little distortion in any path. All three have average wake crossings about 18 meters downcourse with 40-42 degree angle. (Again, take Chris's gate and 1 ball with a grain of salt.)



It takes a lot of energy to ski a sine wave, but it takes a lot more to ski a distorted path with higher harmonics. I know, I know – it's fun to ski that New School path - it feels so nice to be early and backside the ball … and with a long enough line, all of us can ski that way. But as the line gets shorter, we all reach a point where we lack the strength to continue to ski like that. Rather than ski one path and rhythm at long line and another at short line, would we be better off to learn one style for all lengths? From an engineering point of view, the more efficiently we ski, the more buoys we'll get. Would we learn faster, and develop the habits that would help at shortline if we skied our longer passes in the same style? Any change is hard to make, but I suppose that makes more sense than continually trying to ski short the way we ski long.

I'm sure this article has raised some other controversial issues in your mind too, as it did mine, so let me address some of those.

1. From my measurements, I can calculate the angle of the skier at any point in the course. I talked about angles that ranged from 40 to 50 degrees for these four skiers. I know some of you are thinking, "I get more angle than that", or "there is an overhead photo of Andy crossing the wake at an angle of 57 degrees on Schnitz's Ski Tips section of his web site, so claiming an angle of only 40-45 degrees for Andy has to be wrong!" Actually, the angle measured in that photo is the angle of Andy's ski to the centerline. What is not measured is the angle of Andy's 'path'. The exact path is hard to see precisely, but it appears from the spray off the ski his path angle is roughly 15 degrees less than the angle of his ski, or close to what I calculate from the videos. This makes sense: since we're tied to the boat inexorably pulling us downcourse, we have to set our ski at a steeper angle than we actually ski to get across the wake fast. It's why our ski throws up such a wall of water during the cut – we're pushing the ski thru the water at a pretty steep angle. This might explain why we feel our crosscourse angle is much steeper than it actually is. (One more comment on the plots: the horizontal scale is compressed relative to the vertical scale, so the angle on the plots looks larger than it is.) This raises another interesting issue on whether pulling harder makes us go faster. Since the wake crossing angle tends to decrease as the line shortens, I conclude that getting more angle as the line shortens shouldn't be the goal, even though we do have to angle our ski more than the path we actually ski. Since the speed is also decreasing as the line shortens, I conclude that pulling harder against the boat should not be the goal either. Striving either for too much angle or too much pull may increase speed excessively, and it appears these pros do not rely on higher speed or angle to run the shorter passes. I'm not saying you can't ski with more speed and still make the shorter passes, but from my observations and experience, skiing faster is less efficient, gives us less time to react to errors, and leads to a more inconsistent buoy count.
2. Many skiers have a tendency to pull too hard to the gate at their shortest pass. I remember an article a couple years ago in WaterSki magazine. They used a radar gun to measure the skier speed at some point between the gate and ball 1. The speeds were all under 50mph until the pro skiers got to their hardest two passes at 39 and 41, and then the speed would creep up about 3mph and 5mph respectively. The article made it sound like increasing your speed at these line lengths was the desired thing to do. I wonder – pulling harder is probably the natural thing to do when you're feeling stressed by your shortest pass, but is it the right thing to do? At their shortest passes, Chris, Andy, and Chris were crossing the wake about 23 meters upcourse of the next ball. The gate is 27 meters upcourse of ball 1. Doesn't that suggest we could take the gate a little slower? Some guys I ski with at Laku in Windsor, Colorado, figured this out long ago – whenever I was having trouble with my short passes, Randy Hocking and Bill Brooks would tell me to 'back off the gate!' – it always helped. By slowing down a little, I got a quicker edge change, which was far more beneficial to my preturn than the speed. If you can get a lot of speed, and still make a fast edge change, it shouldn't hurt you – you can always just ski wide – but for many skiers like myself I think a little less gate speed helps.
3. My plots start at the gate, but I have looked at what happens before the gate, examining both the one-handed and the conventional gate. I don't see a clear performance advantage of one or the other, but personally I've come to think the one-handed gate is easier to become proficient at. My reasons are that the one-handed gate trajectory is closer to the sine wave I'd like to follow, and it's more like the 2-4 turns I've already mastered. The most important thing I noticed from my gate analysis is the gate is not located at the optimum point for an efficient path, so the ideal sine wave has to be stretched between the gate and 1 ball. The gate is 27 meters from ball 1. If the gate were located where our pro skiers cross thru on shortline, the gate should be about 23 meters from ball 1. This has interesting implications:
    a. If you are skiing New School style and longer line, where you backside the ball (say the virtual 'ball 0' in this case) and cross the wake way early, a wake crossing 27 meters upcourse of ball 1 keeps you right on the same rhythm you'd like throughout the course. When you get to shorter lines and crossing the wake way early becomes harder, you'll need a different rhythm through the gate than anywhere else in the course. In the Traditional or Coordinates style, the gate is

never a good match for the rhythm you'll establish after ball 1. This is a good argument for getting rid of the gate and replacing it with a ball 0, as I've heard suggested.

b. Don't worry if your trajectory through the gate is not crowding the right hand gate ball. I've seen a lot of skiers conclude they've blown it & give up when they don't clip the right hand gate ball. A trajectory passing close to the left hand ball is actually closer to the optimum. Don't worry about how close you are to the right hand ball, worry about your angle and control your speed, and get a fast edge change.

4. Doesn't it seem strange that these skiers had lower speeds at their shorter line lengths? It sure seems to me that the world is moving faster as the line shortens – but I trust measurements over perceptions. In fact there is good reason to distrust our perceptions of speed and time. Our eyes and brain don't handle very well the huge inrush of information that comes with higher speed and unfamiliar territory. Research has shown that when we're in those situations our peripheral vision goes haywire. When that happens, our balance is impaired, and visual information that is normally processed by the vestibular system that controls our balance then rushes straight to the brain, triggering our reflexes in an out-of-control fashion. This problem is always the worst at our shortest path. I recall when I was first trying to run the course at 15 off – it felt just as fast and out of control then as my shortest pass does now. Over time, one's brain begins to sort out which signals from our senses to ignore, and which to process. So with training, we develop the neural pathways to make sense of what we're experiencing, and to control our body to achieve our goal. At that point, skiing the course no longer felt fast and time seemed to slow down. Then at 22 off the world was once again fast and unpredictable. It took almost twice as long to master 22 off than 15 off, and every pass since then has taken longer to master, because the change is more dramatic each time the rope is shortened. As far as our actual speed is concerned: If you follow an efficient line, it should not seem strange that your speed at 32 off will be higher than your speed at 39 off – your momentum swinging on a longer rope naturally results in a more S shaped path, and allows more distortion than you can get with a short rope. If you ski a longer distance in the same amount of time, you're going faster. Of course, if you take an inefficient path – say you backside the ball and hook the turn, you'll accelerate like a rocket once the boat eats up your slack line, and you will create a lot of speed. On the passes I miss, I am usually doing something like that and consequently skiing too fast, making matters worse as I try to compensate for bad form. Also, our perception of speed is not just limited to feeling that we're going fast – it can also tell us we're going slow. One objection I hear from almost every skier is that my plots show the skier is never going slower than the boat. They have the perception they are going a lot slower than the boat as they round the buoy. To this objection, I ask them: When you watch from the boat a shortline skier approaching the buoy, are they gaining on the boat or falling behind? They say 'gaining'. How can you be going slower than the boat and gaining on it? Typically, a shortline skier continues to gain on the boat till they've passed the buoy and start the turn. That they are actually going at an angle into and out of the buoy makes an even stronger argument that they can't be going slower than the boat. The same is true at long lines – it's just harder to observe because the skier is not perpendicular to the boat where it is easy to compare their speed. Time seems to quicken in the cut as we accelerate, and to lengthen in the preturn as we decelerate – but actually it just keeps marching on at the same rate. Part of the reason we have difficulty making correct decisions about improving our skiing is that our perceptions are so often at odds with reality.

5. Coordinates is not really different from Traditional in its aim – it just introduces a different focus or goal to get you there. The Coordinates path at any line length is almost identical to the Traditional path at short line. That says a lot for Coordinates! New School, at least some interpretations of it, have you skiing a very different line. At longer line lengths, any of these styles seem to work. However, as the line shortens, the path you need to stay on is narrow and you have to ski efficiently to run it consistently, and the practitioners of all three styles converge to this efficient path. Paraphrasing Jamie Beauchesne, at 43 off the path you need to stay on is about as wide as a garden hose! From what I've seen, the best trajectory and speed are going to resemble sine waves. At long line, where it's easier to be wide, the whole sine wave is shifted upcourse a little, and at shortline, as width decreases, the sine wave is shifted a bit downcourse with an apogee right at the ball.

6. The question that really intrigues me is this: why does a shorter rope make skiing a pass so much more difficult? The answer I always hear is that you have to go so much faster – but I think I've disproved that idea. Another common answer is this: with the rope nearly perpendicular to the boat, the boat has tremendous leverage and forces you to accelerate rapidly, and it takes a lot of strength and skill to ride it out. I agree with that statement if you've come around the ball with too much speed, or if you have slack, or if you try to turn immediately after the ball – when the rope tightens up you are going to get hit huge! But looking at the paths of the skiers in this article, I don't see that happening. The key to a successful pass is not setting yourself up for that to happen. So exactly how do the pros avoid that hit? They do it by avoiding a sharp turn that would eat up their line, ski back toward the wake gradually on an efficient path, and delay the big pull from the boat until they are nearly half way back to the wake. The only path that allows that to happen is to ride the efficient sine wave path! Another way to verify what I just said is to ask what acceleration does the skier experience throughout a pass. So I computed the acceleration for the skiers I've been analyzing. Schnitz's max acceleration was 3.4G's New School and 2.4G's Coordinates. Rossi's max was 4.01G's at 32, 3.0G's at 38. Parrish maxed at 4.03G's at 32, 3.11G's at 39, and 2.5G's at 41. Andy's max was 3.03G's at 32 and 2.4G's at 39. Once again, I was surprised – but after reflection it makes sense. At longer lines, and especially with New School goals, a high speed high distortion path is going to lead to high peak acceleration. As the line gets shorter, continuing to ski this style, the strength and reaction time of the skier on that kind of path are gradually exceeded. So the skier does what is necessary to make the path and ends up skiing more efficiently. That keeps the acceleration, and therefore force, within the limits the skier can handle. So, summarizing: why is shortline skiing so much more difficult? There are really two answers:
    a. We make it more difficult when we try to ski the same way at shortline as we do at long line. In our fear of being late, we tend to come into the ball too fast, turn too sharply, and consequently get hit hard by the boat when we're still too wide of the boat. That exerts a tremendous load on us, and usually we don't handle it too well. Paradoxically, we can be much earlier to the next ball if we delay the pull from the boat by turning on a larger radius around the ball, so that when the boat hits us we are behind the boat. Then the boats pull aids us instead of clobbering us, and we can be early to the next ball without excessive speed.
    b. I'll paraphrase Jamie B. again: at 43 off the path you need to stay on is about as wide as a garden hose! At 41, the path is a little wider. At 39 wider still, and so on.

So the key to shortline is staying on an efficient path – *I'll call it riding the WAVE*. If you stay on that path, and do the fundamentals well, you'll make the pass. The fundamentals are: as you pull to the gate keep your mass centered over your feet, keep you arms close to your body in the pull, limit your pull & ski in the direction that allows you to get a quick edge change, keep the handle close to the body, counter rotate & reach to keep wide & set up the turn, be patient in a gradual turn until you hook up *behind* the boat, and repeat five more times.

I'm not sure it's possible for everyone to run 39 off, however. First of all, doing all the fundamentals I just mentioned is not trivial, but more importantly, going back to how fast and completely the brain rewires itself: we are not all equal. Some people may not be able to rewire as fully as others. Some people that have the capacity to rewire may ski so seldom that the progress in one practice does not carry forward fully to the next practice. But I have one big hope: if we could stop trying to ski the next path the way we skied the last one, maybe the learning curve wouldn't be so long!

Whenever we try to use brute force and take a shortcut, we lose, or at best win inconsistently. I'm not saying strength does not help – it does – that's probably why the best men can ski shorter than the best women, it's just that skill and efficiency matter more, and that's why many women ski better than stronger men.

One other comment on the acceleration: if a skier weighs 200 pounds and experiences peak acceleration of 4G's, that means the force against the ski (in the turn) or against the boat (in the cut) would be 4 times 200 or 800 pounds! And the force against the boat could go even higher, because this doesn't include the viscous drag on the ski through the water that the skier has to contend with. The forces in waterskiing are pretty high! No wonder we get such muscle aches when we start out at the first of the season.

When I finished analyzing these skiers, I realized something important: I had watched these videos many times before I analyzed them. There was really nothing I could pinpoint and say, that's why this person gets more buoys than that person. The differences I tended to focus on were not really big factors in making one skier more successful than another; they were just the differences I could see. The things that actually made a big difference were not things I could easily see, but they could be measured. As an example of what I mean: I had focused too much on 'style', such as compressed vs. upright body position, how much ski was in the water, etc. Those things all matter, but they were not as fundamental as I assumed. I hadn't noticed Steve's turn radius was shorter – it was a relatively small amount. And even if I'd noticed the slight break, I'd probably have attributed it to something that made sense from the perspective of style, not physics. Even looking at the trajectory plot didn't really alert me to any problems, but seeing those 'flat' spots in the speed plot showed something was wrong. The math pointed to a simple cause and effect. That was encouraging: the model, although simple, was good enough to point out fundamental issues that either helped or hurt the skier.

Until I did this analysis at the end of September 2005, I was running my longer passes backsiding the balls. Then at my shortest pass, 35 off, trying again to backside the ball, I'd get slack and end up taking a big hit from the boat that pulled me off my edge. I notice similar problems for other skiers on their short pass, whether that was 28 or 39 off. The Traditional advice for this problem seems sound: be patient, ski back to your handle, don't pull before you've finished the turn. Realize, as the line shortens, you can't be as wide and early as you could at longer lines. After doing this analysis, and proving to myself all the Traditional advice was sound, I stopped trying to backside the ball and be so early. In the week I had prior to the end of the season, I went from a PB of 2 at 35 off, where I'd been stuck for two months, to 4.5 at 35 off – that put a smile on my face! (update May 2006: now I'm just trying to shed the weight I gained over the winter and get back into shape!)

Now – back to the $64 question – which style is best? Andy and many others were skiing great before New School and Coordinates appeared on the horizon, so the Traditional style obviously has a lot going for it. The problem I sense with Traditional is that I've never heard a really detailed description of what it is. It's the default – if it's not New School or Coordinates, it must be Traditional. It's hard to criticize something that is never really clearly stated, but which has some world-class practioners. New School has made some important contributions with things like the one handed gate and emphasizing the importance of keeping your center of mass leading your motion – although that concept needs to be explained more clearly, I believe. The problem I have with New School is that there is so much said about it – some of it contradictory. We've already seen some of the advice leads in the wrong direction and doesn't work at short lines. Coordinates is simple and concise, but I see a problem with it too: although it puts you on an efficient path at longer lines, if at shortline you come round one buoy and immediately head toward the imaginary point before the next buoy, you're going to start pulling too soon and it's not going to work. So the point of this article was to find out what works and doesn't about these styles or techniques for skiing. What we need is a correct theory and approach to skiing – it doesn't exist now, as far as I can determine, but it should be our goal to find it. In the future, we should insist on analysis at least as rigorous as this to help us decide what works and what does not.

How the Skier's Path is Measured

I used inexpensive commercial video capture/editing software from Pinnacle Systems to step through the video of the ski pass frame by frame. Any similar software is sufficient. First I record the time and position of the skier crossing the gate line. Then, at and after each buoy, I record the time and position of three other points.

They are: First, when the skier is at the buoy. Second, a fraction of a second later when the buoy, skier, and boat pylon all line up. Third, when the skier crosses the centerline. At those three points you know exactly where the skier is in space and time - with one caveat: at the second point the line must be tight to know the skier's position - if there is slack, the skier will be somewhat closer to the boat. This is rarely a problem, however, because point 2 also comes just slightly after most skiers have initiated their hard pull and the line is under tension.

Then, I calculate the most efficient path that goes through the measured points – so in that respect I'm giving the skier the benefit of the doubt, and may miss some mistakes the skier makes – particularly in the preturn, where there are no measurements. Still, the preturn path should be fairly accurate, as long as the skier changes edges quickly after the 2nd wake. Here is my reasoning: if the skier continues to cut past the 2nd wake, he'll be exerting a force to change their speed and position, which my measurements will not account for. If the edge change occurs quickly, which is easy to verify from the video, then the skier's position and speed to the next buoy can be accurately calculated based on knowing the speed at the 2nd wake and knowing that the skier is holding on to a rope of fixed length. Another error inherent in this simple approach is that I don't account fully for differences in skier height & reach, and body angle around the buoy. I admit this will distort the result somewhat.

For you engineers and techies, what I'm doing is 'sampling' the skier's path. The Nyquist-Shannon Sampling Theorem says: to sample the signal (path) with no loss of information, you must sample the signal at a rate higher than twice the highest frequency in the signal. So to sample a sine wave accurately, you only need two samples per cycle or period. To sample a sine wave with 3rd harmonic distortion present, you need 6 samples per cycle. In the course, one cycle is represented by the path from ball 1 to ball 3, or ball 2 to ball 4, etc. So I am sampling 6 points per cycle, which allows me to capture the result of the 3rd harmonic present in some less efficient paths. By the way, this sampling theorem is at the foundation of all the wonderful digital electronics we have so much fun playing with – it may seem arcane but it is very useful!

Another drawback of this my approach can be illustrated by another example: Say the skier starts his pull while he's not centered over his ski, loses angle as a result, but then quickly corrects his position and ends up with good form before getting to the centerline. Since only points 2 and 3 are measured, my analysis will average the effect of the mistake between two points, so the skier may actually cross the wake with somewhat better or worse angle than my analysis calculates. This is the case of the flat spots on Schnitz's pre-Coordinates pass - he did correct his body position very quickly, so his actual speed and position would be slightly different than the plots show, but the mistake did not go unnoticed. (From the sampling perspective, a deviation like this would introduce even higher harmonics, so sampling 6 times per cycle is no longer adequate to capture the information.)

BUT: The question should not be whether this analysis is a perfect description of reality - it is not. The important question is whether this analysis is a useful description of reality! Does it help point out weak spots? Does it have the ability to settle arguments over what a ski-style does or does not do? Does it point out what changes when the rope is shortened? Can it help a skier focus on the things that matter? I think the answer is yes to all questions.

Finally: If someone wanted a more accurate analysis, would it be hard to do? No – you could easily add more sampling points – just put some black tape on the boat hull at a few specific angles relative to the pylon, so you could line the rope up on those points to make measurements from the video. You could measure as many points as you wanted to, both in the cut and the preturn. You could account for a skier's height, and measure the lean angle as he approaches the buoy. I've learned there are people planning to use relative GPS measurements to make accurate record's of the skiers position (accurate to less than an inch) in time and on the course, coordinated with signals from the perfect pass timing system – that sounds really great, and it would eliminate some of the errors my simple analysis can introduce. This raises interesting questions: will it be best to put the GPS receiver on the skier, to record the position of the center of mass, or should it be placed on the ski, to record the path of the skier? Or will you need two GPS receivers to know both measurements so you can avoid having to estimate skier reach, lean angle, and lower body compression? I've also learned that some people have been measuring the load the skier exerts on the pylon. This would be useful in separating the force coming from the skier's mass & acceleration (which I calculate) from the drag on the ski moving through the water (which I cannot calculate). This could help us separate the skier's path angle from his ski angle, and give us clues about when and where we should increase or decrease our load on the line.

All these potential refinements make the analysis much more complex, but it will probably add insights for how the skier can improve. Because it can get very complex in a hurry (for example: should we put two GPS transceivers on the ski, so we can measure the angle of the ski relative to the path we're moving?) I've preferred to keep it simple. As Einstein advised, "simplify as much as possible, but no further." Until the more complex analysis has been made, however, we won't know how far we can simplify without losing information – so I look forward to, and would be glad to help make a more sophisticated analysis.

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