Inline Grip, Friction And Skating Force

c. P. J. Baum

July, 1999

Inline skating as we know it would not be possible without friction because this force produces the wheel "Grip". If you have ever skated over a grease spot or water on a smooth floor you have an idea of the importance of friction and grip. Grip is essential for power production so your wheels can push against the ground. It is also essential for stopping and for turning. The better the grip, the more you can power forward and the better your chances of winning a race. This page shows how grip is a function of skate angle and, together with power and efficiency considerations, gives a basis for choosing your type of skating stroke.

Types of Friction:

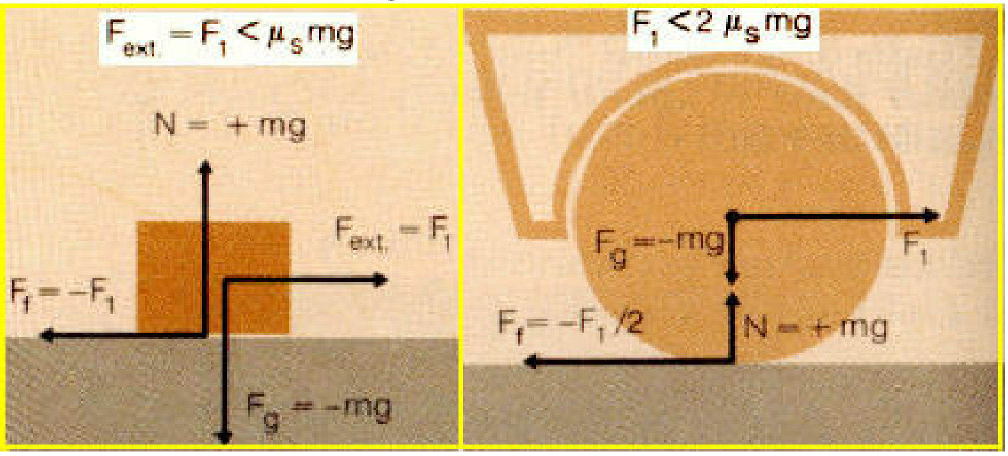
- **Static- An object at rest stays at rest until the applied force passes the static limit. Static friction is neither a power loss nor gain but does allow you to produce power when stroking.**
- **Sliding- An object with a force larger than the static limit slides producing heat and wear. Sliding friction always involves power loss but there could be enough grip left to produce some power also.**
- **Rolling- A wheel continues to roll under an applied force until the rolling limit is passed and then it slides. Pure rolling is neither a power loss nor gain but it allows you to do either while moving forward. A similar effect called "Rolling Resistance" is a loss due to wheel deformation or compression but is a loss internal to the wheel itself and not due to a drag with the surface below.**
- **Turning- I called this the rotational grip and it involves a torsional stress built up in the surface of a wheel which is rolling "On the edge". So far I have described it qualitatively in the way it "moves the contact patch forward of the axle" to allow turning. Nothing quantitative is known yet.**

Friction Considered for the Inline Skate

Here I will mainly be concerned with static and rolling friction. Sliding friction is useful as an emergency measure (the hockey slide) but it is a power loss and is not usually involved in racing. Sliding slows you down and burns up your wheels costing you both time and money. Turning friction is a part of closed-track skating but has not yet been quantified. I consider the turning friction (rotational grip) primarily as a means of modulating the static and rolling grip. So it is functionally very important but it is not clear that by itself it produces or loses power.

The figure below illustrates static and rolling friction. It is adapted from

Physics forScientists and Engineers **by Constantin and Lobkowicz, Saunders, 1975, Volume 1, Page 114.**



The left side is the case of static friction and the rolling case is on the right side. the object itself has mass "m" and is acted on by gravity's acceleration "g". Mu-sub-s is the static coefficient of friction which I will denote as "u_s". Later I will use "M" for the mass of the skate and the skater (actually about half the skater's mass when both skates support his weight).
The object remains static until the applied force exceeds the static limit which is u_s*m*g. In the case of the wheel, it rolls forward under applied force until the rolling limit is passed-- 2*u_s*m*g. Before that the contact patch at the bottom of the wheel is static when it is on the ground and after that limit the contact patch slides. So it is apparent that the skater can push forward twice as hard as he can sideways without sliding. I have added these two components of grip-friction vectorially to produce a polar plot of sliding and rolling grip on the next figure.

The Grip Ellipse

Grip And Slide Regions

The figure on the right shows the "Grip Ellipse" where the skater grips inside the ellipse (lighter blue) and slides outside the ellipse (yellowish). The sliding limit is the darker blue ellipse.
The black radial lines show *Angle2* which is the angle relative to the skate frame -- 0 degrees (up here) is straight ahead (relative to this skate only -- the skater moves in a different direction unless you are coasting), 90 degrees is sideways, and intermediate angles of 22.5, 45, and 67.5 degrees are also shown. The skate rolls in the 0 degree direction. The red circles and arcs are constant radius and have radii of 1.0, 1.5, and 2.0. The radial arcs are multiples of [Applied Force]/[u*M*g] where the large M*g refers to the

skater's weight. So in the direction of pure roll (0 degrees) the ellipse is at radius 2 while in the static sideways direction (90 degrees) the static limit of 1 applies. At intermediate angles the radius of the ellipse is between 1 and 2.

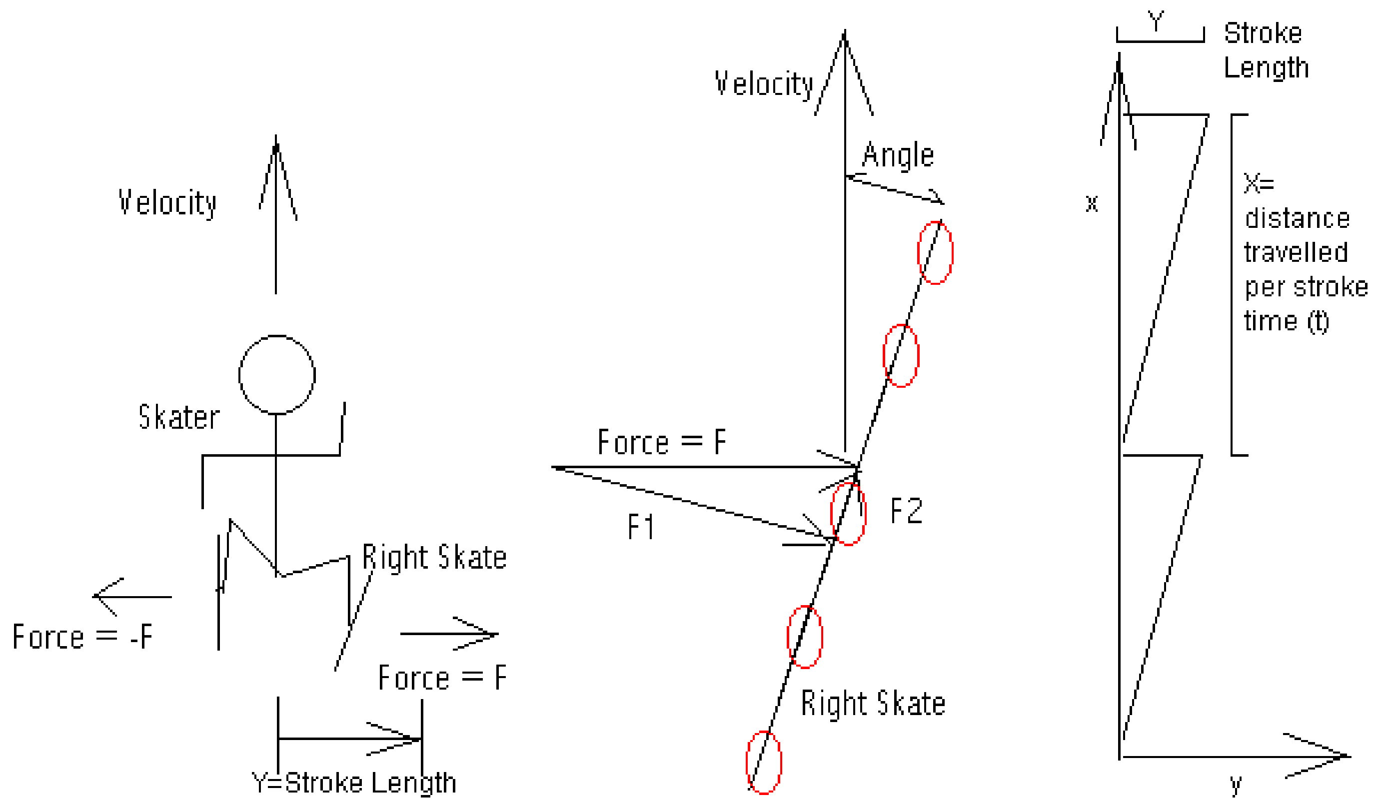
The *Grip Ellipse* follows from the coefficient of friction u which has equation:
u(Angle2) = u_s [4*cos(Angle2)*cos(Angle2) + sin(Angle2)*sin(Angle2)]1/2**

Skating Force Using the Grip Ellipse

The fundamental acceleration (a) for a skater is provided by force (F) via the relation a=F/M. The stroke rate together with stroke length define the duty cycle. Only that component of force which the skate allows to act in the forward direction is useful. Next I will look at the maximum skating force which would produce the highest acceleration. Later I look at a less forceful stroke which is more energy efficient and which would be more helpful in long duration races.

Maximum Skating Force With Constant Skate Angle

Now I will look at how the maximum skating force would be achieved. The figure below illustrates classic skating style and shows a stroke with constant blade angle. Here the parameter "Angle" is measured relative to the direction the skater is moving (not the direction an individual skate moves).



Now if we include the angle-dependent coefficient of friction, u(Angle2), and assume we stroke sideways so that

Angle + Angle2 = 90 degrees

we find for the forward force (Ff) component:

Ff = u_s*M*g*sin(Angle)*cos(Angle)*[1 + 3*sin(Angle)*sin(Angle)]1/2**

This produces a maximum forward force Ff~0.8*u_s*M*g at an Angle~50 degrees. The maximum acceleration is a = Ff/M ~ 0.8*u_s*g . The skater's acceleration is proportional to the gravitational acceleration (g) and increases with a larger static coefficient of friction (u_s) but is formally independent of his mass. The good news is that this acceleration can be realized on the start but the bad news is that it is not maintainable at higher speed. And why not?

To find the answer let's write the power in a form you may not recognize. It can be shown that the scalar power (P) in terms of vector Force (F) and vector velocity (v) is:

P = F.v or F = P/v

Consequently, since the skater is power-limited, the force which he is able to exert decreases linearly with velocity. And at fairly high speed it means that

sin(Angle)~1/v

so the Angle decreases rapidly with increasing speed and can drop down to 5 degrees or so. This produces a much smaller forward force than the maximum. Some have interpreted this weak forward force with some inefficiency of the skating process. In fact it simply follows from the skater's limited power output. If his power were unlimited he could still skate at the maximum force but at a greatly increased stroke rate.

Shortcomings of the Fixed-Angle Stroke

It has been noticed before that stroking sideways with a large force produces a small forward force at high speed. So skating has been referred to as an inefficient force converter (sideways to forward). But it seems not to have been noticed that the small forward force acts over a long distance (at high speed) whereas the sideways force acts over a small distance -- the stroke length. In fact, in the absence of various real drags like air etc., the forward energy (force times distance) exactly equals the sideways value. At first blush it seems like we have found the perfect

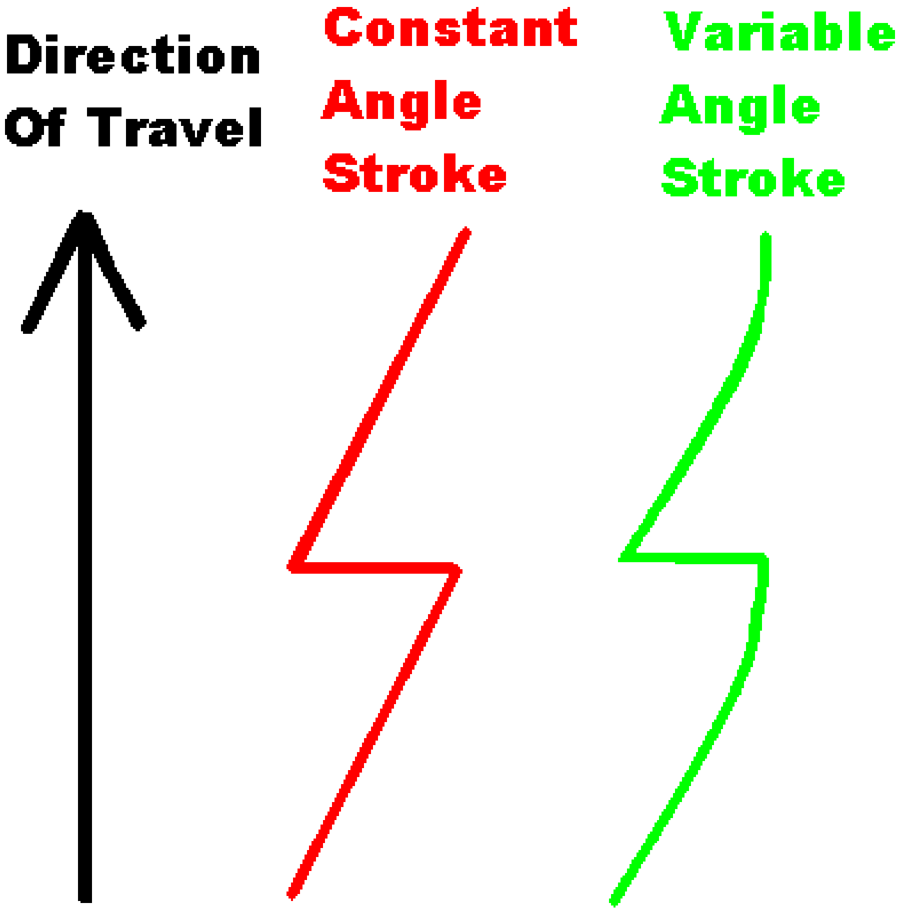
force converter. In fact, the sideways power does equal the forward power in the ideal case. However, I believe that the total power provided was the sideways power plus the forward power so that the constant angle stroke has actually acted as a power splitter which split the skater's power into two equal pieces -- only one of which is really useful. From another point of view, if you had really converted all your input power into forward motion the sideways motion of the leg and skate would stop at the end of the stroke. There would be no energy left in the sideways motion. The existence of "toe-flicking" etc. need not be the cause of skating inefficiency but may only be the symptom showing that the constant angle stroke is inefficient. In what follows I get away from constant angle skating to see if some of the power inefficiency can be remedied.

Large Skating Force With Higher Energy Efficiency For Variable Skate Angle

Because of the added complexities of this section, a fully quantitative presentation is not now available. However, the topic is of such importance that I think a qualitative discussion which points to elements of the answer will be useful. The maximum force (fixed blade angle) case suffers from the fact that accelerating the skate (and skater) forward also results in an acceleration (of the leg and skate) sideways. The sideways energy does not seem recoverable at constant blade angle and represents an energy loss to the skater. So a strategy to deal with this loss to achieve high power efficiency are presented next.

In order to minimize the residual sideways energy:
I think the constant angle stroke can be used over 70-80% of the stroke length. However, towards the end of the stroke the sideways energy must be channeled forward or the inefficiency remains. This can be accomplished by turning the skate forward toward the end of the stroke (not slid--turned). This would rely on the fact that as you lay the skate on edge it acts less like "a skate" with its power splitter properties and more like "a collection of wheels". The force equation used in the constant blade angle analysis earlier assumed that the skate acted like "a skate". That is, the wheel grip patches would be directly below the axles so there would only be a force division and not a production of torsional stresses and torques. A movement of the grip patches from below the axles would invalidate the force analysis used earlier. From my analysis of turning it became clear that when the skate turns on edge the grip patches move ahead of the axle so the properties of individual wheels become important and the velocity vector is turned. This would appear as a conversion of sideways energy to forward energy.

The figure below illustrates classic skating style as a constant angle stroke in red and as a variable angle stroke in green.



The difference mainly lies in the fact that the skater has turned the skate forward at the end of the stroke in green so that all the terminal motion of the skate and leg is now forward. The turn is accomplished by pushing preferentially harder with the heel than with the toe. Much the same is possible with the double-push.

Possible Role of Klapskates in Increasing Power Efficiency

It is claimed that Klapskates improve a skater's powering by lengthening his stroke as he can push a few inches farther with his toes. I am sure this is so but it may be only part of the story. If the stroke length were the main effect a skater with fixed skates could largely compensate by increasing the stroke rate a little til the power of the fixed skate matched the Klapskate. I think it is more significant that by pushing with the toes at the end of the stroke, the wheels are turned more forward as in the animation below. This would make a Klapskate a device for converting sideways power into forward power without having to learn the heel-powering technique which the great skaters already know. In this respect the Klapskate may be much more valuable to the not-so-great skaters who haven't learned to heel-power .

Click to go back to the *INDEX*