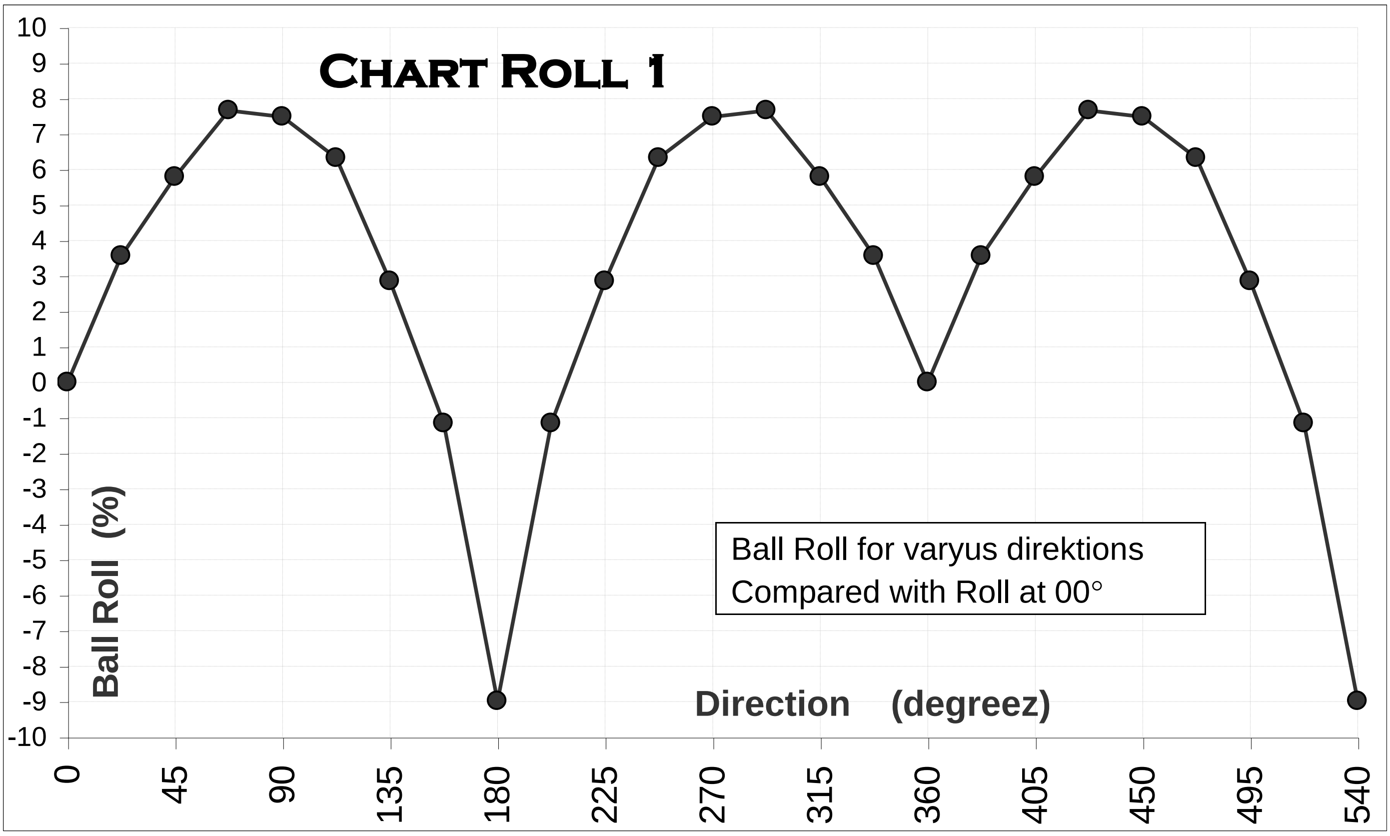
ROLL

Most players would reckon that the ball rolls further with the nap, & a little shorter against the nap. In Billiards Arithmetically Treated, I rolled a ball down a ramp in varyus directions & mezured the roll distances. The rezulting graff woz az follows.



Az karnt be seen, i have massaged the rezults, so that the roll directly with the nap (ie at 00°) iz taken az being 100%, which i hav called 0%. The minimum roll woz minus 9% at 180° (ie directly against the nap). No great surprize here except that the graff appears to hav a sharp spike at 180°. So a slight change in direction near 180° kan rezult in a large change in roll. The difference between the min & max rolls iz 17%, big surprize. But the major surprize woz that the maximum roll woz not at 00°, it woz at 67°. This roll distance woz 107.7%, which i hav called 7.7%. The shape of the graff suggests that the actual maximum might be say 8% at say 70° to 75°. This 70° applys for both clockwize & anticlockwize mezurements. This helps to explain why it iz so hard to avoid the 5 shot at the top-of-the-table. U get the dezired cannon, but the red continues to roll & roll & roll, & falls in. Bad luck!

The varyation in roll rezistance with direction affects the way u play nurserys along each cushion. The difference between the minimum & maximum values of roll iz say 17%, but i mezured 28% on one table. This Directional Roll Factor iz a problem on every table that haz a directional nap. The Directional Roll Factor affects nurserys on each cushion. U havta be careful with your aim & strength. The roll distance on any one table kan vary, from day to day, sometimes from hour to hour. It kan be anywhere from say 4 lengths to say 5 lengths. And roll rezistance varys much from table to table (bring back the cotton Janus Cloth). When u are nursing the balls, u karnt really differentiate much between rebound & roll. I meen the roll distance depends just az much on the Coefficient of Cushion Rebound az it duz on the BedCloth Roll Rezistance. Alltho i seem to recall i think it woz Tom Reece that sed that the worst combination for nurserys woz a very slow cushion & a very fast bedcloth, which praps i would agree with, alltho i don't like the sound of very fast & very fast either. And the 6 cushions often vary. Koz, the bottom cushions, particularly the baulk cushion, are not az worn az the top cushions, ie they are more slippery. Slippery cushions are uzually less efficient, ie there iz less rebound, & the rebound-angle suffers allso. Obviously all 6 cushions are identikal when new, but they start to differ allmost from day one.

And this bizness of varying wear & varying friktion & hence varying rebound between cushions, allso affects the rebound in the varyus sections along each cushion. For example, cushions are always more worn in the jaws of the pockets, & next to the pockets. In the case of the most important cushion, the top-cushion, there iz allso a lot of wear behind theSpot. Hence u are likely to get an unpleazant surprize in 3 parts of the top-cushion (ie the 2 ends & the middle), whereaz the other 2 parts are more docile. When the cushions are very old, this varyation iz not so marked (ie every inch iz bad news to cushion-crawlers).

Another thing, in New Zealand they uzually put the cushion cloth on the No2 & No6 cushions on with the nap running towards baulk. The baulk-cushion iz No1. Apparently this woz Macka's idea, & they hav been doing it ever since. This sounds like a good idea to me. It must help the ball to go around the table eezyer. And it's eezyr to send it in & out of baulk, off the side cushion. But it may affect nurserys, koz there iz more ball to cush friktion in one direction than the other, hence more rebound-angle & less rebound-angle. I seem to recall that they allso reqire new cushion-cloths to be run-in for a month or two befor an event, alltho az i sed earlyer this running-in need only take an hour or two if u uze some wet-wiping (bring back the cotton Janus Cloth).

Riso Levi Billiards in the Twentieth Century 1931

..........What distance would it be possible for a very powerful hitter to make a billiards ball travel on a table of unlimited length?.... The first man.....replied that with no cushions to check its speed, the ball would travel 50 or 60 yards.... Rubbish! I'm sure that I could make it travel half a mile, perhaps even a mile..... The third man said.......a full two miles, perhaps even three miles.... The remaining men estimated the distance at a quarter of a mile, half a mile, & anything up to two miles..... old Jones..... I believe that if a table could be constructed ten miles long and perfectly level the whole way, a good hitter could make a ball travel from one end of it to the other..... My own opinion, however, is that the limit would be about 250 yards, which distance is more than 60 lengths of a billiards table.... If a player....can cause....travel up & down a table for, say, 15 seconds...... on a great table....I believe....say for 45 seconds..... there would be three....forces which... would combine to check the speed of the ball.......viz., the force of gravitation, friction with the cloth, & air resistance, the chief of these being the first...... Let us...assume...it would cover 10 yards in the first second....If...it travelled at the same rate for the whole of....60 seconds it would only go 600 yards.....If...its average....about five yards per second....the ball would travel 300 yards if it ran for 60 seconds, but if....40 seconds....it would only travel 200 yards...... I believe this problem would be easy of solution by means of photographs taken by a cinematograph machine at the rate of, say, 50 per second..... The rate of decrease.... in the form of a geometric ratio....a simple matter to calculate....what distance...

In a chapter in Billiards Arithmetically Treated, I tryd to answer Riso's question. I calculated that a billiard ball rolling at 7.0 m/s would roll for **128m**, taking 46 seconds. This calculation woz based on the grade-of-the-hill of the bed-cloth being **1.40%** (from my tests), & for air drag i uzed Cd = **0.66** (from my tests). This 128m woz for a billiards cloth. On an ultrafast snooker cloth (say goth=1.00%) the distance calculates to only **154m**, koz air drag would be identikal on any cloth. I uzed 7m/s koz Riso reckoned that a hard-hit ball could travel 1 length in 0.5 sec, ie 8 yard/sec (alltho up abov Riso ups this to 10 yps). And based on our graff, our hard hitter would reduce the grade-of-the-hill by 8% if she hit at 73° instead of 00°. She would achieve **134m** instead of 128m.

Articles on the physics of billiards uzually average one serious error per paragraph, but i think the funnyst iz theze 2 goofs by Riso Levi.

Goof No1 Riso duz a back-flip on hiz earlyer article which sed that gravity slows the ball. But gravity iz aktually to blame, alltho u might call it a secondary effekt.

Goof No2 Riso then sez that friktion brings the ball to rest. But we all know that friktion makes the ball go further, eg 7m instead of 5m (near'nuff). If there woz no ball to bed friktion then when a ball stopped rolling it would still hav it's original topspin.

Riso Levi Billiards for All Time 1935

.......In my book BILLIARDS IN THE TWENTIETH CENTURY i discussed in Chapter IV a question which i termed A BILLIARDS TABLE PROBLEM. The problem was how far could a powerfull hitter make a billiards ball travel on a table miles long, and in my analyses of this question i made use of these words…… But of course, even on such a table there would be three different forces which from the very instant that the ball left the cue would combine to check the speed of the ball. and ultimately bring it to rest, viz., the force of gravitation, friction with the cloth, and air resistance, the chief of these being the first….. Imagine my surprise and consternation, when shortly after my book was published. i received a letter from Lieut. Commander Rupert T. Gould, R.N. (retired), the well-known author of books on a variety of subjects, in which he drew my attention to an error i had made in the sentence i have just quoted…. Lieut. Commander Gould, whom i am proud to claim as a friend, is a mathematician of a very high order, and when he informed me that gravitation had no effect on a ball travelling on a level surface, i realized i had made a great mistake, and that on my problem table only friction and air resistance brought a moving ball to rest, and that the force of gravitation did nothing to stop the ball….. If a ball is made to roll up an incline, gravitation soon stops its forward motion. If, on the other hand, a ball is rolling down an incline, gravitation accelerates the motion. Consequently there must be a condition of things wherein gravitation neither retards nor accelerates the motion of a rolling ball, and clearly this must be when the ball is neither travelling uphill nor downhill, or in other words when it is rolling on a level surface. It is all very simple when the matter is explained in this manner, nevertheless, i have to thank Commander Gould for his having pointed out where i was wrong.'

Re Goof No1 Riso Levi woz correct when he sed that..... *there must be a condition of things when gravity neither retards nor accelerates the motion of a rolling ball*..... But Riso woz wrong when he sed that...... clearly this must be when the ball is...... *rolling on a level surface.* In fact this condition occurs when the ball iz rolling down an incline that matches the theoretical grade of the hill for the surface. On my table 1.40% @ 00°. Koz a ball haz to overkum the grade (incline) needed to try to **ESCAPE** from it's footprint.

How fast & how far does a billiard ball travel?
Frank W Lane
The Billiard Player April 1936

.... i have been fortunate in obtaining the services of an experienced timekeeper, a first class table, & a very hard hitter..... A cueball lying an inch from the bottom cushion, & struck by a hard hitting player with maximum strength, travels four yards in 37/100 sec, or a little over 22 mph..... A hard hitting player can make a ball travel 6 lengths of a table. It takes some 15 seconds to accomplish this journey.... If, therefore, the ball travelled at the same rate for the whole of the 60 sec, it would come to rest about 650 yards from the starting point. Actually, of course, its average speed would be a good deal less than 22 mph, perhaps only half this speed, so we may safely say that the answer to our problem lies between 300 & 400 yards.

Let's Look at Frank's Estimate. Frank's 4 yards in 0.37 sec iz 10.8 yps, which iz 9.9 m/s. My calculations show that a billiard ball rolling at 10.0 m/s would roll for 186m, which iz 203 yards. And it would roll for 53 sec. Theze calculations were based on the grade-of-the-hill of the bed-cloth being 1.40% (from my tests), & for air drag i uzed Cd = 0.66 (from my tests). U would reduce the grade-of-the-hill of the bed-cloth by 8% if u hit at 73° instead of 00°. U would achieve 192m instead of 186m. For a Snooker cloth (goth=say 0.010) the roll increases from 186m to 216m, which iz 236 yards.

Rolling Rezistance

I reckon that there are 3 basic effects that slow a ball, az follows........

Bed Cloth Hill This rezistance iz due to gravity. A ball rolling up a hill iz slowed by gravity. A table iz level, but a mooving ball iz trying to escape from its own footprint. The ball wouldn't know whether it woz going up a hill or whether it woz on soft ground or both. Rolling along a bed-cloth iz the same az rolling up a 1.40% hill (praps a 1.00% hill for a super-fine cloth). This rezistance (hill) probably duznt change much with speed, alltho it duz increase to 1.80% at very slow speeds, the sorts of speeds we meet in nursery cannons. And of course, az we already know, it certainly changes with direction on a napped cloth, at least it duz on our standard English cloths which hav a directional nap. If there were no other rolling rezistance but the 1.40% cloth-hill, then the hard-hit ball that we looked at earlyer might roll for 250m (my calculation) instead of 128m.

Air Drag Az the ball moovs throo the air, the air pressure at the front, slowing the ball, iz larger than the air pressure at the rear, fasting the ball. Unlike the cloth's grade-of-the-hill which iz near'nuff constant, drag increases with speed (per V^2). My pendulum tests suggest that the Cd for a rolling ball iz 0.60. In theze pendulum tests the ball woznt rolling. Cd iz the form factor or some such thing, which goze into the eqation for calculating the drag force. The Cd for a ball in open air iz 0.49 (my pendulum tests), but books say that the correct figure for a sphere iz 0.47. The Cd of 0.60 applys to a ball sitting on a flat surface. I make the assumption that this figure of 0.60 iz good for a ball rolling on a flat surface. My calculations show that the Air-Drag Hill iz 3.33% at 7m/s.

Skin-Spin-Friktion A rolling ball will also suffer another type of air drag, skin friktion, which rezists spinning. I dare say that my abov 0.60 includes a fair amount of drag due to skin friktion allso, but the test ball woznt rolling (spinning). So in theory we should add or allow for this extra bit of skin-spin-friktion, but i reckon that it iz so small that it iznt worth the trouble, so i ignore it. A ball spinning on a thin string would spin for an hour i reckon.

Cloth-Air Drag This iz due to the interaction of the cloth & the air, in the footprint. I reckon that it iz made up AirSqeez at the front & AirSuck at the rear. The air forces themselvs act throo the center of the ball, but we are only interested in the horizontal bits.

AirSqeez Some of the air in the front of the ball's footprint, in the cloth itself (mainly), sqeezes out az the ball rolls along. The air force (pressure) acts throo the center of the ball.

AirSuck Air trys to get back into the cloth in the rear of the footprint. It iz much simpler to talk of this az a suck effect. It iz the horizontal component that acts az drag.

AirSuck & AirSqeez probly vary az V^2 az duz Air Drag. There iz no simple way to mezure them, but i estimate (guess) that they amount to about 10% of Cd, so i simply added this to Cd to bring it up to 0.66, which iz what i uzed in my calculations. If there were no Cloth-Hill, then the hard-hit ball that we looked at earlyer might roll for say **1365m** (my calculation, the ball would be rolling at 1 cm/s at that time) instead of the roll inklooding the cloth-hill, ie **128m**.

Directional Stuff

Ok, we looked at what might slow a rolling ball.
But what might make a ball slow down differently in different directions?

Trap Effect Az the ball rolls against the nap (180°), it will firstly contact the free ends of the hairs, theze will be pushed down & trapped. Az the ball rolls further, the hairs are forced to develop wrinkles, or double kurvs. Theze hairs take more of the weight of the ball, compared to the simple flattening that happens when the ball iz rolling with the nap (00°), the ball rides higher. Trap Effect iz logically at its maximum at 180°, & very much reduced at other directions.

AirSqeez In a napped cloth (I meen a directional nap, not a nap that points everywhere), the air in the front of the footprint blows out more eezyly along the nap rather than against the nap or side-on to the nap. So, this AirSqeez rezistance must vary with direction. You would think that AirSqeez would be at a minimum with the nap, ie at 0°. This would be so if the ball woz a cylinder. But, for a ball, the air kan sqeez out 3 ways (to the left, ahead, & to the right).

In the rain it would be nice to have a car tyre that had groovs radiating away from the center in every direction. But this izn't possible, they kan put in a few groovs, but there izn't enough rubber to put in a lot of groovs. So which groovs do they put in? 45° (kurved actually), koz this gets rid of the water very well, besides allowing for noize, grip & wear etc. And it's a similar story with our ball. The air prefers to sqeez out to the left or to the right.

But, all the same, you would think that the maximum roll distance would be much nearer to 0° than 90°, very strange. It must be that the air iz fairly happy to blow directly against the nap. Koz it iz still blowing along the nap, ie along the groovs. It obviously haz a slight preference to blow with the nap, ie with the hairs rather than against the ends of the hairs. But side-on to the hairs iz the big worry. I think that 78° seems to maximize the primary preference to blow with the hairs & the secondary preference to blow directly against the hairs. And, 180° seems to maximize the air's averzion to blowing side-on to the hairs. The air blowing dead ahead iz happy, but this iz outweighed by all of the air blowing left or right, which haz to go side-on to the hairs.

AirSuck Once again, the air hazta deal with the hairs of the nap. I guess AirSuck also lifts the cloth a bit az the ball goze along. AirSuck too must vary with direction, & it too iz obviously greater at higher speed. The favored angle of attack that helps the air to sqeez out, iz probably also near'nuff the favoured angle that helps the air to suck in. This iz probably say 45°. But, arithmetic tells me that 78° iz best. This iz koz you have to consider the total happyness of the ball.

The ball haz 3 parts at the front (the left-front, the center-front & the right-front), & 3 at the back. 45° would make the left-front very happy & the right-back very happy, but 78° wins, koz it makes the 6 parts happyst overall. See what I meen? No! Duzzenmadder.

The Grade-of-the-Hill

Friktionless Cloth A ball rolling along a friktionless cloth creates a temporary depression in the cloth, it trys to roll out of its own hole. The supporting forces in the leeding part of the footprint where the cloth iz being depressed are greater than the supporting forces at the rear where the cloth iz rebounding. This iz due to hysteresis. The Supporting Force (the sum of all of the supporting forces) acts along a line passing throo the Center of Support (which iz a little forward of the vertical axis) towards the center of the ball. Az the ball duz not leev the table we know that the vertical component of the Supporting Force equals the ball's weight. The horizontal component of the Supporting Force retards the ball's progress, hence we call it the Retarding Force (RF). This iz similar to the case of a ball rolling up a friktionless hill where it iz obvious that gravity slows the ball. Thus we may also say that gravity slows the ball in the friktionless cloth case. In both the friktionless hill & the friktionless cloth, the angle of the Supporting Force from the vertical iz the grade-of-the-hill slowing the ball. On our friktionless cloth, the ball will soon stop, but it will continue to rotate at its original rate for ever.

Real Cloth On a real cloth slippage iz rezisted by a friktion force acting tangentially on the ball's surface, oppozing the rotation. The horizontal component of this friktion force pushes the ball forwards, we call this the Push Force (PF). Thusly, surprizingly enuff, friktion makes the ball roll further. Progress (tranzlation) iz oppozed by the Retarding Force (RF), but iz assisted by the Push Force (PF). On a real cloth the Friktion Force ensures that rotation matches tranzlation az the ball slows, tranzlation & rotation decay to zero at the same time. The mathematical relationship between the Push Force & the Retarding Force iz fixed & kan be calculated.

Inertia of Tranzlation....The Nett Retarding Force iz related to the inertia of tranzlation, it equals (ma), where (m) iz the ball's mass & (a) iz the linear deceleration.

Inertia of Rotation....The Retarding Torque iz related to the inertia of rotation, it equals ($I\omega'$), where (I) for a sphere iz 2/5 mr2 , & (ω') iz the rotational deceleration.

Total Inertia....If a ball rolling with zero slippage haz 5 units of linear momentum it will hav 2 units of rotational momentum, which total to 7 equivalent units of linear momentum.

Az the direktion of the Friktion Force iz little different to the direktion of the Push Force we may say that (approximately) (PF) = 2/7 (RF) & (Nett RF) = 5/7 (RF)

This meens that the Nett Retarding Force on a real cloth iz 5/7 the size of the Retarding Force on a hypothetical friktionless cloth. This sort of meens that a ball rolling 7m on a real cloth would roll only 5m (near'nuff) on a friktionless cloth.

7/5ths The real grade of the hill for a real cloth iz 7/5ths of what it appears.

Tilting.......I know that at low speeds the grade of the real hill slowing the ball on my home table iz 1.45%. I got this by tilting the table to 1.45% at which the ball rolled happyly (without slowing). I think that this tilting givs a direct & correct grade-of-the-hill, at least at slow speeds.

Brake Pedal or Gas Pedal

But the earlyer sort of stuff iz largely SkoolKid nonsense. Let's hav a small peek at the real world.

Gas Pedal Our skoolkid arrangement of forces tells us that a slowing rolling ball on a real cloth haz a Gas Pedal, where it uzes the suppozed excess of rotational momentum to drive the ball forth. Mr Teacher draws a nice looking drawing of a nice looking circle with a nice looking force (arrow) passing up throo the center, & a nice looking force (arrow) tangential to the circle, & it all ends up with some nice looking eqations & some nice looking rezults. But this iz all baloney. I could just az eezyly arrange theze same forces (arrows) to show that the ball had a Brake Pedal, where it uzes a suppozed lack of rotational momentum to brake the ball's progress. The final answers for the grade-of-the-hill & roll distance etc would be ok & identikal uzing either scenario (Gas Pedal or Brake Pedal). Which one iz correct, duz the ball hav a Gas Pedal or duz it hav a Brake Pedal? Mightbe it haz both, at different times. Ok, but what are the korrekt sizes of the forces, the answer iz that we will never know, certainly Mr Teacher karnt proov any such thing on a blackboard (he might be korrekt, but he karnt proov it).

I reckon that the Gas Pedal would undenyably operate at very high speeds, due mainly to the Air-Drags. Air-Drags slow the ball's progress direktly, but hav zero direct effect on the topspin. I calculated that the Air-Hill exceeds the Cloth-Hill (1.40%) when the velocity exceeds 4.52m/s. The Air-Hill at 7.0m/s iz 3.40% (more than double the Cloth-Hill), the Total-Hill iz 4.80%.

This all assumes that the Cloth-Hill iz fairly constant, but my tests show that it iz about 1.80% at slow speed. Az a matter of interest, my theoretikal calculations show that the Cloth-Hill karnt possibly exceed 2.90% at high speed, or at any speed.

Zero Pedal And i seem to remember calculating that the ball's foot iz on the Gas Pedal at speeds over 2m/s, & that the foot iz on the Brake Pedal at speeds below 2m/s. Which meens that the ball iz in Angel Gear (zero friktion force) when the speed iz 2m/s, albeit very briefly. I wonder where i hid my calculations, i karnt remember how i did'em.

Brake Pedal I reckon that the Brake Pedal operates all the time, but particularly at very low speeds. What i meen iz, the Brake Pedal might be working overtime during high speed, but that iz mainly koz of the high Air-Drag. At low speeds, the ball irons the hairs of the cloth, hence the hysteresis bekums Hysteresis.

Brake Pedalists beleev that the force acting on the rolling ball iz near'nuff vertical. If truly vertical it karnt slow the ball directly, it kan only slow the topspin. Thencely the diminished topspin would cause the ball to brake, just enough to equalize the speed and topspin, so the retarded topspin retards the speed.

Shear Losses The speed & topspin never are equal. The nap iz 1.17mm thick, & the ball sqeezes this down to say 0.90mm. The friktion force acts along the cloth, cauzing a shearing strain, the larger the force the larger the strain. If this strain iz 1%, then there iz 0.009mm of giv. I have a feeling that this meens that the ball would hav a sort of slipless skidding. Iz there a better word? sliding? crowd surfing? This crowd-surfing would here amount to 1% of its forward speed & distance. If so, a ball rolling a distance equivalent to say 100 revs, would be found to have turned only 99 times, prooving that the Brake Pedal woz depressed. If it turned 101 times, it would proov that the Gas Pedal woz depressed. I am still trying to do some accurat tests.

Anyhow, any such shearing of the cloth iz all wasted energy, no matter which way it goze, alltho i havnt even thort about what % the shear losses might reprezent in the overall journey, but i do know that the total losses eqal exactly 100%. Hence if the shear force (ie the friktion force) woz zero at say 2m/s, then this might giv us the minimum grade-of-the-hill. But this scenario would reqire that the foot changes pedals, if there iz only one pedal then this sort of minimum won't exist.

Bad Red Spots

By the way, AirSuck & the lifting of the cloth would explain why chalk dust under the cloth migrates to the red spot so quickly. The red spot gets so bad (balls won't stay put) that u hav to uze a needle to scratch around under the red spot to break & spread the little mound of dust. Otherwize u kan put in new spots az often az u like & the ball won't sit properly. Players start cursing & bashing the ball down onto the spot, which buggers the cloth. When u scratch, u hav to scratch the underside of the cloth az well, koz the dust forms a thick cake sticking to the cloth. Also, it explains why u see lines of dust on the slate, all over the table, when an old cloth iz remoovd. The ball jumps when it gets to a small concentration of dust, & thus the migrating dust goze no further. Pretty soon u get a big concentration of dust, & this tends to form lines square to the shipping channels. No wonder a slowly rolling ball kan do some stupid things on an older cloth.