Variation of Calibration Constant with Surface Texture:
Part 1 Literature Survey

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Introduction

In *MN* 75 p 36, I reported my discovery that the constant for a solid tyre was higher on a rough road surface than on a smooth one, in contrast to a pneumatic tyre whose constant was unchanged. On the basis of my experiment I cautioned against use of solid tyres for measurement despite the fact they exhibit less temperature variation than pneumatics. Before making that report I had sought advice from experts on both sides of the Atlantic and was told that it was known that surface roughness affected the calibration constant but there was no particular information about solid tyres.

In the two and half years since my original measurements, I have continued to investigate this problem in a desultory fashion and in a future article I shall report on my latest data. I was, however alerted by David Reik's letter in *MN* 85 p7 to work done by Bob Thurston and Bob Baumel in the mid 1980s.

Imagine my pleasure when Tom Ferguson decided to pass on his old copies of *MN* going back to issue 3 in 1983, and Pete Riegel was kind enough to lug them all the way to London for me. I have spent a mind numbing few evenings look ing through all 2000 or so pages for references to surface sensitivity, and trying not to be distracted by the many interesting topics which seem to wax and wane in the pages of *MN*. Here are my findings.

Summary of published data

MN 8 p9 reports results obtained by Bob Letson in 1976, and by Ken Loveless in 1983/4. Comparing a road 'pavement' with a variety of surfaces beside the road, firm dirt, pine needles, grass, sand, gravel, and swale, they generally obtained a smaller calibration constant on the off-road surfaces. In this era both measurers were almost certainly using pneumatic tyres.

In *MN* 10 p12 (May 1985), Bob Thurston mentioned the constant on a concrete calibration course was higher than on a nearby asphalt surfaced one. He suspected temperature and roughness variations.

In *MN* 12 p1, Bob Thurston reported that Marc Gladney had found the opposite to the original work by Letson and Loveless: 1% larger constant on gravel than on asphalt. Pete Riegel mentioned that start up wobble might affect the result from Marc's 200 foot gravel calibration course.

In *MN* 13 p 11 Gaby Duguay reported two riders again getting a smaller constant on a crushed 2 mm gravel than on an asphalt road surface as Letson and Loveless had done.

In *MN* 13 p12 Pete Riegel calculated the extra distance traveled by a rigid wheel rolling on a rigid corrugated surface. For corrugations of 3 inch pitch he calculated that the constant would increase by 0.02%, but reported that he had not seen any difference on a road scarified for repaving. This was the first published attempt to explain the results theoretically.

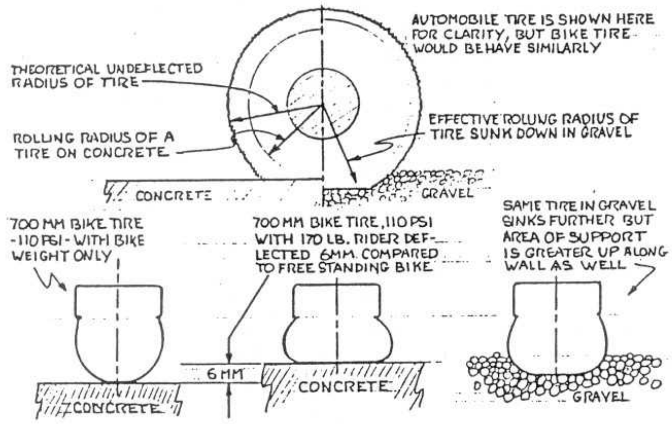
In *MN* 14 p 9, Bob Baumel suggested one might get a smaller constant on gravel if the front wheel slips on gravel. The idea of slipping is an important concept that must be carefully considered. Baumel reported an experiment in which he mounted a second counter on the rear wheel and compared asphalt and well-tended slightly wet grass. His counts using pneumatic tyres were:

Surface	FRONT	BACK
Paved	1303.5, 1303.5	1306.5, 1305.5
Grass	1295.5, 1296.5	1314, 1313

He explained the difference between the front and back by the saying the front is driven by the road so slipping gives less rotation whereas the back drives the bike so slipping gives more rotation. This is the second theorteical explanation.

Bob also gave a preliminary report of the discovery of a difference between rough and smooth calibration courses on paved roads. The rough course gave 4 to 5 more counts/km. He concluded, "...(this) should definitely serve as a note of caution. We are still pretty far from fully understanding all the sources of error in our measuring procedures!"

In *MN* 14 p 12, Allan Phillips, attempting to explain Duguay's results, gave described a theoretical model which would produce a smaller count on a soft surface where the tyre would sink in gaining support over a greater width, and thus reducing the deflection and so increasing the rolling radius. Allan calculated the necessary change in rolling radius to explain Duguay's results, about 0.5 mm. He gave the following diagrams in which you can see how he explains his idea of the tyre pushed into a soft, yielding surface is supported by a wider contact patch so the same upward force can be obtained with a smaller deformation of the tyre. Allan was dealing with a very yielding, non-road surface. This is the third attempt at a theoretical explanation, and the first time we see the involvement of the geometry of the contact patch.



MN 15 p19 p29 carried a major article by Bob Baumel in which he gave a detailed analysis of the calibration constants obtained on two calibration courses having different surface roughness. Bob and his wife measured with several different pneumatic tyres and also with a tyre having an Eliminator plastic insert instead of an inner tube. With a pneumatic at the normal pressure of 100 psi, the rough surface consistently gave a larger constant by about 0.05%. In this work Bob considered and eliminated a large number of possible causes of the variation. We can therefore have high confidence that the result is a consequence of the observed difference in road surface roughness. Since Bob's data and his analysis was probably a major influence on the US measurement community's views it is worth reproducing a summary table here.

Average Counts/kilometer				Tyre/conditions	Date
Old Rough Course		New Smooth	Diff		1985
W to E	E to W	Average			
9345.4	9343.24	9339.25	5.07	Pneu. normal pressure	10 Aug
9283.53	9283.19	9282.25	1.11	Pneu. low pressure	17 Aug
9458.02	9456.06	9452.62	4.42	Eliminator	17 Aug
9369.65	9365.94	9363.38	4.41	Pneu. normal pressure l	8 Aug
9360.52	9360.44	9356.12	4.36	Pneu. low pressure	18 Aug
9357.9	9354.56	9352.62	3.61	Pneu., mud on new course	24 Aug
9337.55	9335.91	9334.44	2.29	Pneu., mud on new course	24 Aug
9327.9	9326.69	9324.25	3.04	Pneu., mud almost gone	1 Sept
9342.9	9340.81	9337.75	4.11	Pneu. normal pressure	12 Oct
9364.15	9362.69	9359.58	1.04	Pneu. low pressure	20 Oct
9463.27	9460.94	9457.25	4.86	Eliminator	20 Oct

Counts obtained in Bob Baumel's experiment

In *MN* 17 p18, which carried Bob Baumel's report on measurement of a cinder track in Tulsa, it was noted that a rider's wheel might have been slipping on the track surface causing it to make fewer revolutions than on a road: i.e. a smaller constant on cinders.

In *MN* 18 p7, Pete Riegel described how in measuring the Rio Marathon with Gabriel Monteiro, whereas Gabriel rode a very accurate line in the gutter on bends, Pete deliberately rode 1m from the curb on long sweeping bends to find a smoother road surface hoping that he would get a smaller count as had been shown in Bob Baumel's experiments with the aim of getting a lower overall count than Gabriel. This strategy worked since Pete measured 34008m compared to Gabriel's 34019m.

In *MN* 18 p23, Pete Riegel described a 'tiny experiment' designed to test Bob Baumel's findings. Outside his house he rode twice in the gutter and twice on the smooth road. The rough gutter gave 10.5 counts more in 6350, i.e. 0.17%.

In *MN* 21 p3, Pete Riegel gave the following condition for on-site short calibration courses, "The calibration course should have a surface that is similar to the race course, A calibration course that is actually part of the race course itself is hard to beat."

In *MN* 22 p 3, Bob Thurston's report of the IAAF measurement seminar, Seoul 1986, takes issue with a report by Bob Letson that pneumatics achieve an accuracy of 1/1000 and solids 1/2000, arguing that pneumatics can do better than 1/1000 given appropriate calibration and "as for solids, 1/2000 may be a good ballpark figure, but with the wrong conditions, in particular measuring a rough-surface course from a smooth calibration course, solids can bomb out. More on this in another report." I have not been able to find a later report from Bob and I am disappointed not to be able to examine the experimental data on which Bob based his conclusions. Bob's statement that solids are worse than pneumatics pre-dated my independent discovery by 8 years.

At this point the measurement community in the US seems to have almost put the issue aside. They had established a validation procedure in case of record times and only a small proportion of courses were failing validation. *MN* contributors discussed issues of seemingly more practical consequence I found only 4 references in the next 10 years.

In *MN* 32 p26, Wayne Nicoll writes, "I find a rougher surface yields more counts on a calibration course than a smooth surface. Try calibrating on a pavement, then do it again in the grass, dirt or rougher pavement beside the roadway. It is probably due to more wobble or more bounce where the wheel turns while off the ground. If that holds true then to have a safe course you would want your calibration surface to be rougher than the course surface."

In *MN* 55 p45, Tom Knight obtained a constant 0.029% higher on the concrete gutter compared to the asphalt road surface. He highlighted that "..for really important validations we may have to consider such effects if a course is right on the edge of passing or failing."

In *MN* 56 p24, Bob Baumel in summarising cycling errors made the following perceptive summary, "It is very common to obtain relative consistency between multiple rides in the range 1/5000 to 1/3000.... It is true that the relative consistency is not the same as accuracy, as you can be extremely consistent about riding a path that differs significantly from the SPR. But among skilled, experienced riders, the relative consistency is probably a good indication of the accuracy (although I have to admit that variations in road surface increase the error somewhat)."

Recently in *MN* 82 p20, John De Haye reports experiments comparing a pneumatic tyre on a 'street' bike with a knobbly pneumatic on a mountain bike. He compared a road surface with a parallel grass soccer field and found that the constant was about 0.5% lower on the grass. There was little difference between the street bike and the mountain bike. This result qualatively agrees with that of Letson and Loveless for off road surfaces.

It is also interesting to note what the IAAF Booklet, "The Measurement of Road Race Courses" ed. Disley and Riegel, says on page 18,

"If different calibration courses are used, the calibration value may be slightly affected by the difference in road surface texture."

"Differences in road surface texture are unavoidable and are an inherent source of measurement error. Do not worry about them. It is wise to avoid very rough surfaces, whenever possible."

So, we have been warned! This now brings us up my own recently published work which I will describe in the following section. However, I will first make an observation about the above data. The type of tyre was not normally mentioned in the reports. I have identified it whenever it has been mentioned. I think it likely that most of the data refer to pneumatic tyres since solid tyres only started to be introduced in the mid 1980's. It would be worthwhile if any reader can give more detailed information about the tyres used in these early experiments.

Comparison of Solid tyre and Pneumatic by Mike Sandford

In ***MN*** 75 p 36, I reported discovering that my new solid tyre (a GreenTyre) increased its constant by an average of 0.045% on the slightly rough surface near the edge of my Long Tow calibration course compared with the track further from the edge worn smooth by the passage of vehicles. By contrast my pneumatic tyre (a Michelin World Tour) averaged about 0.9 counts or 0.12% larger. At the time I did not consider this small difference to be significant so I reported that the pneumatic was unchanged with surface. I now know this to be not quite true, a small increase on smooth surfaces is typical of this type of touring tyre.

The explanation I gave for the difference between the solid and the pneumatic was that with the solid the small stone chippings fixed in the road surface embedded in the soft rubber since the resistant layer, the steel rim, was some distance away. The tyre effectively follows a longer course by following the contours of the road more closely. With a pneumatic, however,the tension in the tyre casing resists sharp deflection around each protroding stone and the tyre effectively rides over the peaks of the rough surface. This is the fourth theoretical explanation for variations

At the time I thought I had uncovered an unknown problem with solid tyres. The historical review above shows that I in fact made an independent rediscovery of the sensitivity of tyres to surface texture which had already been reported in the pages of ***MN***. However, it seems that since 1986 interest in the topic had evaporated, until I started experimenting in 1995.

My next set of experiments was to lay out 4 new calibration courses in Abingdon and compare a wide range of tyres on the different surfaces including the two Long Tow surfaces. Some preliminary results from this were published in Certified Accurate, ***CA*** 1 p 8. and these results are shown here in the Table 1 reproduced from ***CA.*** In this table Copenhagen Drive has been used as the calibration reference. A figure of + 100 indicates using the tyre calibrated on Copenhagen Drive that the particular course would be found to be long by 100 cm in 1 km, exactly the amount of the SCPF. The table is ordered with the smoother course surfaces at the top and the rougher surfaces towards the bottom.

Table 1. Fractional error in cm per km in measuring on various surfaces using a bicycle calibrated on Copenhagen Drive. (Preliminary - Jan 97)

Course	Surface	Length m	SOLID Greentyre on front	SOLID Sure-trak on front	Eliminator on front	Pneumatic Continental on back	Pneumatic MWT on back	Pneumatic VR on front	Pneumatic fat VR on front
Copenhagen Drive (Cycle Path)	Very smooth painted white line on smooth tarmac with holes of 2-3 mm	650.603	Calibration Reference	Calibration Reference	Calibration Reference	Calibration Reference	Calibration Reference	Calibration Reference	Calibration Reference
Abingdon Airfield SW Taxiway	Tarmac on concrete base. 1 to 4 mm stones rolled smooth with depressions of upto 1 mm	499.702	+7	+18	+ 27		+ 4	+ 28	-31
Long Tow 1.1 m from edge	worn fairly smooth by traffic over 5 years	695.254	- 21	- 29	+ 53	+ 26	+ 20	+ 29	-10
Barton Lane (typical of many main roads in Abingdon)	20-30mm stones, rolled to a flat surface but with shallow holes between the stones	299.957	- 65	-58	+139		+ 66	+ 7	-10
Long Tow 0.4 m from edge	partly worn 5-15 mm stones protruding	695.254	- 80	- 79	+100	+ 50	+51	+ 27	15
Audlett Drive	sharp tarcoated 10mm stones, unworn half a year after resurfacing	199.930	-207	- 195	+ 176		+133	+ 13	-240
Tilsey Park Track: lane 8 outer white line	Synthetic: 1-2 mm bonded rubber pieces	459.281		- 59			- 38	- 63	

Figures in bold show where at least 3 separate measurements have been done under good conditions. For these, my measurement scatter (standard deviation of the mean) is typically 10 cm or better. For the other data only one or two measurements have been done and sometimes conditions have been poor, frost or rain, so the uncertainty in my data may be up to 20 - 30 cm. The results have been corrected for temperature using the measured coefficients given in table 2. The temperature changes were small, normally less than 1 C. For a 1 C change and the Vee Rubber tyre (temp. coeff. 140 ppm) the correction to the fractional error is only 14 cm.

The most striking discovery was the large range, twice the SCPF, for the two solids. By contrast the Vee Rubber Touring Pneumatic was almost independent of surface. On the basis of this I concluded that pneumatic tyres should be recommended for normal measurement practice, but temperature changes must be recorded and the constant of the day should be derived from the largest constant or by a sound alternative method (*based on the temperatures and the thermal expansion coefficient*).

The results were described as preliminary because I intended to add more measurements and refine my data analysis. In fact I have done neither of these things since I have since worked on different aspects of this subject and on other subjects. So they are preliminary in the sense that they are not exhaustive. On the other hand I think they need to be more widely known and understood before I publish my most recent results in the second part of this article.

One possible source of experimental error was the calibration of the different steel tapes which had been used to establish the calibration course lengths. Typical accuracies quoted by manufacturers are 1 in 10,000, so if one course was measured with a long tape and another with a short tape a relative error of up to 20 cm in 1 km could be introduced. I still have to check this, by remeasuring all the courses with the same tape. However, a 20 cm error would be too small to affect my main conclusion.

In *CA* 3 p 5, I briefly mentioned the results by 6 expert measurers using the two Long Tow surfaces to measure a 4.5km course. These experts used a variety of tyres and obtained results spanning a range from 4529.1 m to 4534.5 m, more than the SCPF. This clearly demonstrated the practical importance of minimising surface texture variations between the calibration and the race course and of choosing a tyre with minimum sensitivity to surface texture. I have since obtained additional results and all the data will be presented in detail in part 2.

Conclusions

Large variations of calibration constant with surface texture are an established fact. Different tyres respond in different ways. This variation may account for a considerable part of the variation seen in some group rides. It could also seriously affect the results of a validation, if identical tyres and calibration course surfaces are not used for the layout and validation.

Four theoretical explanations have been given for the variations:

1. Longer contours covered by a rigid tyre on a rough, rigid surface.
2. Slipping of the tyre in contact with the surface.
3. Change of deformation of the contact patch due to support over a larger area.
4. The tension in the casing of a pneumatic tyre resists deflection by small irregularities, in contrast to a solid which follows the contours more closely.

I intend to examine these explanations more closely in the light of my new data which I will report in part 2 of this article. For the moment I shall refrain from commenting on the practical implications for measurement.

To: Peter Riegel
Fr: Robert Letson, 2870 Amulet St., San Diego, CA 92123-3137
Da: 29 April 1998
Re: Puzzle for MN

San Diego plans to host the equivalent of the New York City Marathon in June (RnR Marathon), and I was asked (regarding a temporary bridge that is being built especially for the race)

"How many runners can be in this event without causing delays on a bridge 12 feet wide at 38.1 km?"

ASSUMPTIONS:

a. Distribution of runners is same as '97 NYCM (30,000 runners).
b. Minimum space for each runner is 2.5 feet wide, 5 feet long.
c. Pedestrian bridge is at 38,100 meters.
d. Race length is 42,195 meters.
e. Speed of runners is constant.
f. Delays up to 3 seconds are allowed.
g. The peak 3-seconds flow in the '97 NYCM is:
    3:56:21 15 finishers
    3:56:22 4 finishers
    3:56:23 4 finishers

PUZZLE
Rock 'n Roll Marathon