The Temperature Sensitivity of Pneumatic Tyres

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Introduction

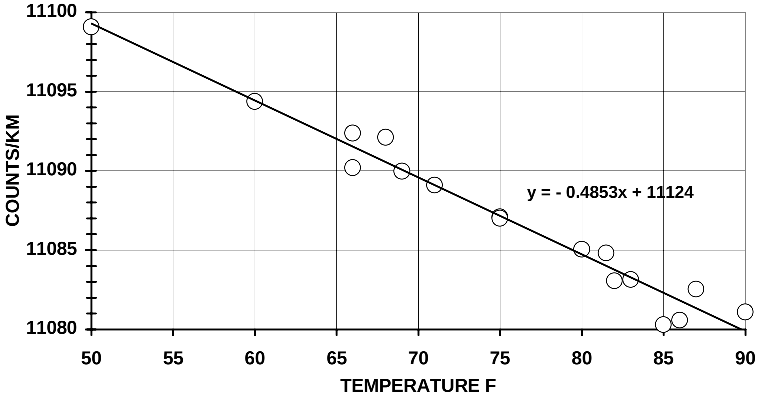
Solid tyres have the disadvantage that their calibration constant varies strongly with surface roughness, so measurers need to consider using pneumatic tyres. Pneumatic tyres are the norm for bicycles and they give a smoother, and some find, more stable ride. However, their calibration constant changes with temperature much more than for the very best solid tyres. We have measured the temperature coefficient of the calibration constant for 12 pneumatic tyres in order to characterise their variability and find the best tyres to recommend for measuring.

Experimental Method

The full details of the method are given in the technical appendix, but it can be simply summarised. At least two times a day for a series of about five days, we rode our bikes along a calibration course and recorded the temperature. The times of the rides were chosen so that there were significant temperature changes, nearly always more than 5 C and sometimes more than 10 C. These large temperature changes match what happens when measuring under unfavourable weather conditions.

We also investigated the deflation of the tyre by setting the pressure before the first ride and not adjusting or measuring it at all until after the end of the measurement series several days later.

FIG. 1. PR's SPECIALIZED TURBO A at 123 psi,
DEFLATION CORRECTED



Temperature Coefficient

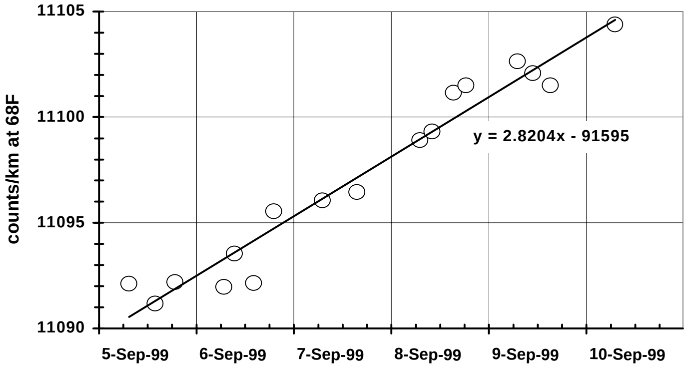
To illustrate the calculation of the temperature coefficient for one of the data series, we show in Fig. 1 a plot of the different values of calibration constant against the temperature. In order to allow for the deflation of the tyre, which over 5 days in this case amounts to a change of 13 counts/km, the values have been corrected for the amount of deflation that occurs each day. This deflation has been derived as described in the following section.

The data fit a straight line very closely. The greatest distance of any point from the line is about 2 counts/km. So by measuring the temperature, and if necessary correcting for deflation, we can predict the calibration constant to within 2 counts/km. The temperature coefficient is given directly from the slope of the line, in this case - 0.486 counts/km/F. When comparing different tyres it may be more useful to convert this to the parts per million (ppm) change, i.e. (- 0.486/11090)*1,000,000*(9/5) = - 79 ppm/C, where 11090 is the counts/km at 20C.

Deflation

To find out how the deflation affects the calibration constant we have to remove the effects of the temperature changes. This is done by adjusting the calibration constant to the value it would have been at some fixed temperature. I have chosen 68 F, so for measurements when the temperature is not 68 F, we just need to add or subtract the temperature difference times the temperature coefficient times the calibration constant. The resulting plot in Fig. 2

FIG. 2. DEFLATION of PR's SPECIALIZED TURBO A:
Calibration Constant Corrected to 68F (123 - 103 psi)



shows that over 5 days the tyre's calibration constant increased steadily by 2.82 count/km each day.

Does Tyre Pressure Really Matter?

It has always been measurement practice to pump tyres up hard, certainly fully up to the maximum recommended pressure marked on the tyre wall. The origin of this is lost in the mists of time. Nowadays many people rationalise it by suggesting that the tyre will perform less well if under inflated. In particular the suggestion is often made that it will exhibit a higher temperature coefficient and thus be more susceptible to temperature changes.

We have been able to test this using the data for two tyres at a range of pressures. The table of results on the right shows there is very little change of temperature coefficient when the pressure changes by a factor of two. So, it is not possible to justify a recommendation for high pressure on the grounds of obtaining a low temperature coefficient. It is not clear why else the recommendation is made. That low pressure causes more temperature variation seems to be another measurement myth.

Tyre	Pressure, psi	Temp Coeff, ppm/C
MS's Vee Rubber 27 x 1.25 Max. Recommended Pressure 80 psi	~ 110	- 144
	105	- 140
	100 to ~75	- 128
	~ 90	- 144
	~ 63	- 144
	123 to 106	- 79
	59 to 53	- 75

RIDER - TYRE	Nominal Diameter inches	Calibration Const change cts/km/10F for 10,000 cts/km	Temp Coeff ppm/C
HJ - Michelin World Tour	1.125	- 4.0	- 72
PR - Specialized Turbo A	1.25	- 4.4	-79
ETMcB - Continental Goliath	1.6	- 5.9	- 107
MS- Michelin Tracer	1	- 6.4	- 116
MS - Michelin World Tour	1.25	- 6.4	- 116
MS - Continental Super Sport	1.125	- 7.7	- 139
MS - Vee Rubber	1.25	- 7.8	- 140
MS - Vee Rubber	1.9	- 8.3	- 158
RG - Shrinka Golden Boy	1.125	- 9.1	- 164
PR - Kenda	2.125	-9.4	-169
JG – Avocet Cross	1.5	-10.8	-195
RG - Rocktrax	2	-11.6	-208
Bob Thurston (MN 91, p22)	1.125	- 4.6	- 83
Pittsburgh men's 2000 OT Validation, pre & post cals only			
BC - Vittoria	0.9	- 9.9	- 179
PH - Performance	1.46	- 10.0	- 180
DD - Specialized Team	2.0	- 10.2	- 183
JG – Avocet Cross	1.46	- 13.7	- 246

The Best Tyres for Measurement

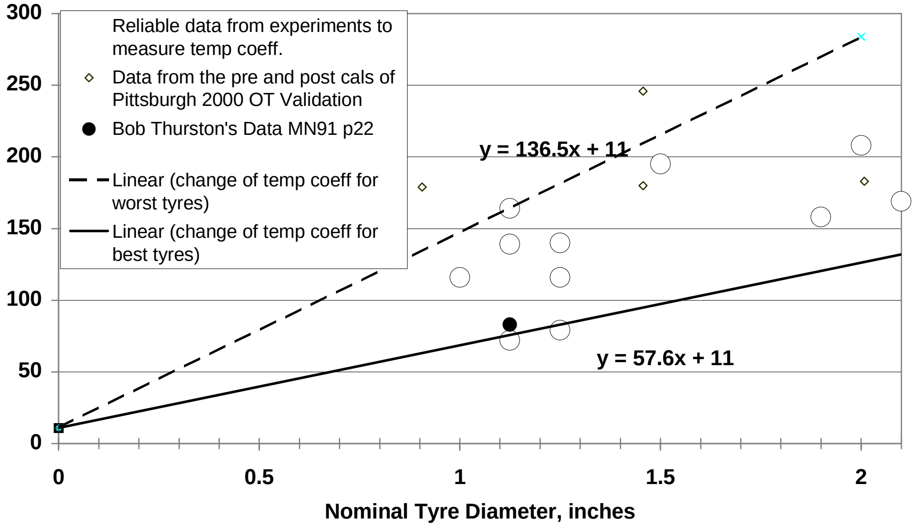
The table on the left summarises all the data from different tyres, and these are plotted in Fig.3 against the width of the tyre. The straight lines show how the temperature coefficient would vary if it was proportional solely to tyre width. The scatter of points between the two lines with slopes differing by a factor of 2.4 could mean that not only does the temperature coefficient depend on tyre width as expected, but there is also another source of variation present. This could be variations in the composition of the tyre casing. The 'best' tyres, ie those with the lowest temperature coefficient for their diameter, are those close to the lower line. These are HJ's Michelin World Tour, BT's unknown tyre, PR's Specialized Turbo A, and one of the fatter tyres, ETMcB's Continental Goliath.

Conclusion

In Fig. 3 the temperature coefficients of 13 pneumatic tyres for which we have good measurements are compared. Skinny tyres do tend to be a bit less sensitive to temperature changes than fat mountain bike tyres. Data from other measurers would help build up a fuller picture.

The temperature coefficient multiplied by the temperature change could be used to calculate corrections to the calibration constant, which could occasionally be

Fig. 3. Variation of Temperature Coefficient with Tyre Size



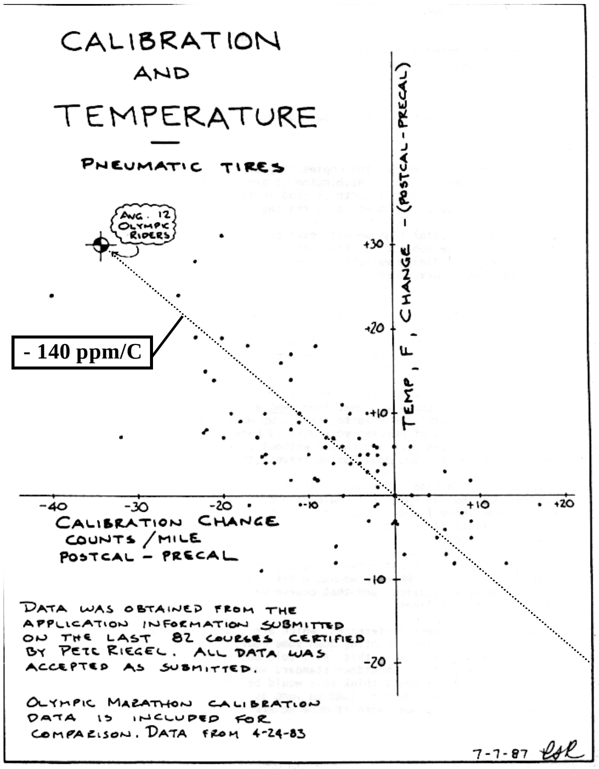
useful to measurers experiencing large calibration constant changes.

Technical Appendix by M.C.W.Sandford

Our main objective has been to summarise this work within two pages, in a form that can be quickly understood by the busy measurer. The purpose of this appendix is to present greater detail and to cover aspects omitted from the summary pages. Firstly, in the historical survey the new results are related to what was previously known. Secondly, full details of the experimental method are given, which will enable others to see exactly how the experimental data was acquired and afford them the opportunity to duplicate the experiments on their own tyres. Thirdly, I address deflation and an opposing effect, creep. Fourthly, I make some remarks on a phenomenon I call hysteresis. Fifthly, I give examples of using the temperature coefficient to correct measurement data. Sixthly, I summarise implications of the technical appendix. Finally, the calibration ride data are tabulated, which enables anyone to check the analysis behind the graphs presented. If required, additional information covering calibrations not on the table, weather conditions, tyre pressures, etc. are available either from the individual riders or from MS.

1. *Historical Survey*

In MN 8, p3 March 1984, PR gave the results of the calibration rides of 12 pneumatic tyres used at the Los Angeles Olympic Marathon measurement the result was 139 ppm/C with 1 standard deviation of 29. The other major source of information is two articles in MN 74, p12-16, March 1995. The first is in Spanish by Rolando Czerwiak (RC), Professor of Thermodynamics at Buenos Aires University and a leading Argentinean measurer, who presented a theoretical calculation of the temperature coefficient of a pneumatic tyre. In the second article, PR presented a different model, and compared the results from both models with experimental data which had been collected from calibrations in 82 measurement reports, and which PR had previously published in MN 25, p11, Sept 1987.



DATA WAS OBTAINED FROM THE APPLICATION INFORMATION SUBMITTED ON THE LAST 82 COURSES CERTIFIED BY PETE RIEGEL. ALL DATA WAS ACCEPTED AS SUBMITTED.

OLYMPIC MARATHON CALIBRATION DATA IS INCLUDED FOR COMPARISON. DATA FROM 4-24-83

7-7-87

In summary, RC's model gave a temperature coefficient of - 117 ppm/C for a very thin tyre with a tube diameter of 2.4 cm. PR's model gave - 15 ppm/C. The experimental data given (see figure below) agreed more much closely with RC's result.

Working through RC's mathematics without fully translating the Spanish text, I deduced that RC's model was based on the expansion of the air in the tyre on the assumption that the pressure remains constant as the temperature changes and the tyre casing stretches or contracts. This simplifying assumption might be approximately true for a tyre which was stretched to many times its uninflated size. However, for an average tyre, inflated to less than twice its uninflated size, this assumption will not be true. An increase of the air pressure is required to expand the tyre by increasing the amount by which the casing is stretched.

A further problem arises with RC's model in that the variables which it contains are only tyre's circumference and cross-section. It can therefore provide no explanation for the discovery reported in this article that tyres with the same circumference and cross-section exhibit variations of temperature coefficient by up to a factor of 2.4.

PR's model was based on an inelastic tyre which would maintain a constant volume. PR calculated the rise in pressure as the temperature increased, and then deduced the reduction in size of the contact patch which would be required to support the weight on the front wheel. Geometrical considerations were then used to calculate the variation of the axle to ground distance. This approach gave an unrealistically small temperature coefficient, because the stretching of the tyre casing with increasing pressure was ignored.

The contrast between these two approaches is interesting. I suspect the truth lies somewhere between these extremes in a model which also incorporates the variation with temperature of the elasticity of the tyre wall.

The plot reproduced above is interesting because it shows the limitations of collecting data from measurement reports, as compared with data produced in the well defined experiments such as those we have carried out. The tyre dimensions are rarely recorded on measurement reports so data from many different tyres are mixed together. Measurement reports give no information about how the temperatures were measured. In fact quite a number of measurers probably rely on rather crude temperature estimates. There can be no correction for deflation. An individual point is obtained from each report and there is no way of demonstrating that a measurer is producing consistent results by plotting a graph of the type shown in Fig 1. While the coefficient for the average of the 12 Olympic Marathon rides was - 139 ppm/C (on the assumption of an average constant of 15000 counts/mile), which is within the range reported in our experiments, the scatter of the other points on the graph is very much greater than we have observed. For the reasons noted above it would be unwise to expect that this scatter is a true reflection of the scatter of the underlying temperature coefficient of different tyres.

It was these limitations of using data from measurement reports that prompted me in 1996 to undertake a careful series of calibrations using methods which have evolved into that described below in Section 2. The first set of my data were published in an article in MN 80, p5, Nov 1996. The data in that article were analysed by essentially the same method as used here. That article concluded with the words,

"With precise temperature plots such as Fig. 2, I hope to investigate the performance of different pneumatic tyres under different conditions in my search for the perfect pneumatic tyre with a low temperature coefficient."

It has taken exactly three years to realise that ambition and it has only been possible by combining the efforts of a team of experienced measurers.

2. *Experimental Method*

This is a refined version of the call for data which was issued in MNF #0377 by PR. It identifies the key experimental steps. Pete said, "We are hoping for data from a wide variety of tires. The job is not hard. It takes 5 days. Here's what we want."

Preliminary: These data need only be recorded once, before you begin:

- Record all the data from the tire side wall – tire manufacturer, model, size, recommended pressure, etc.
- Pump up the tire to the pressure at which you customarily use it. Record it. Don't pump the tire again until the series of rides is done.
- Measure the width of the tire, from side wall to side wall. Record it.

Daily Data:

- Go out in the morning when it's cool and do at least two good calibration rides of at least 3000 to 4000 counts. If you know the distance, great. If you don't, just make sure the ride is on the same course each time. Try to estimate at least to the nearest 1/2 count.
- Go out again later in the day when the temperature has risen, and do a couple more rides. If you manage to get 3 or 4 points at various temperatures in one day this may give slightly useful extra data.
- Record the temperature in the shade when you do the calibrations, and the time of day. Be sure the bike has reached temperature equilibrium, and has not just emerged from the garage. Temperature measured on the verge out of sun is just OK - provided the day when you are going to do the experiment will have a big temperature change say 10C or more. Better is a thermometer waved in the air in the shade to measure air temperature. Better still is a digital aquarium thermometer mounted on the bike with the probe taped near the wheel and shielded from the sky (and sun) but NOT the wind with some aluminum cooking foil. (MS believes air temperature = tyre temperature when you are riding at 10 mph)

- After 5 days you will have at least ten rides done. Send PR the data, and he will summarize it and forward it to MS for final analysis.
- If you can, record the tire pressure when you are done.
- If you are not sure whether what you have in mind is OK, email PR or MS. Please help. This data can help us understand the tool we use.

3. *Deflation and Creep*

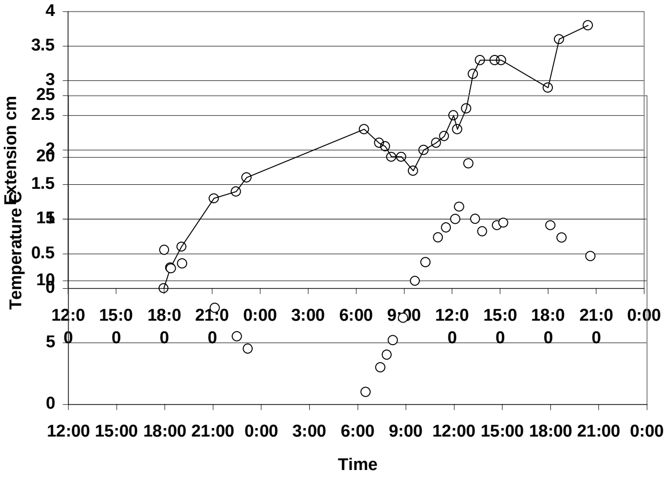
For the majority of the tyres tested here, if we compare calibrations taken at a constant temperature, or if we correct the data for temperature changes, then we find that tyres deflate at a constant rate. This was shown in Fig. 1, which shows that the data can be fitted by a straight line and we can determine from the slope of the line the rate of the deflation in counts per day. The deflation shows up as an increase in the calibration constant of between 0.9 and 4.2 cts/km each day. The variation from tyre to tyre doubtless depends on the permeability of the inner tube. The data are summarised in this table.

Rider - Tyre	Diameter inches	Deflation cts/km/day
MS - Vee Rubber	1.9	-1.6
RG - Shrinka Golden Boy	1.125	- 0.3
MS - Vee Rubber	1.25	- 0.8 to +0.9
MS - Michelin World Tour	1.25	+ 1.3
RG - Rocktrax	2	+ 1.3
JG – Avocet Cross	1.5	+ 1.9
HJ - Michelin World Tour	1.125	+ 2.0
ETMcB - Continental Goliath	1.6	+ 2.0
MS- Michelin Tracer	1	+ 1.6 to + 2.2
PR - Kenda	2.125	- 7 to +3.1
PR - Specialized Turbo A	1.25	+ 2.8 to + 4.2
MS - Continental Super Sport	1.125	Not measured

A few tyres show a decrease in constant over several days. These tyres appear not to be deflating but actually increasing in diameter. I first reported this in MN 80, p5, Nov 1996 for my 1.25 inch Vee Rubber. I looked carefully for the same effect in the Michelin Tracer which I tested in 1997, but did not see it. I found some indication of creep in the very short series of data on my 1.9 inch Vee Rubber, but with only 5 measurements the confidence is these data was not very high.

At the time of the 1996 observation I had convinced myself that the effect was real by the following experiment. I took a discarded tyre, cut off the wire reinforced bead, and cut and straightened out the loop of the tyre. I firmly clamped one end of the 2 m length of casing to a ladder leaning against a wall. At the lower end I clamped a weight of about 50 pounds. I recorded the distance between the weight and the ground. In the plots below I show the increase in extension that occurred after the weight was initially applied, and also the temperature which varied by 20 C of the 27 hour duration of the experiment, which ended when the tyre had stretched about 4 cm and the weight came into contact with the ground. Had I anticipated that the creeping would be so large (over 2% of the unstretched casing length), I might have started the experiment with more ground clearance.

Fig.4 Stretching of 2m of tyre casing under 50 lbs load

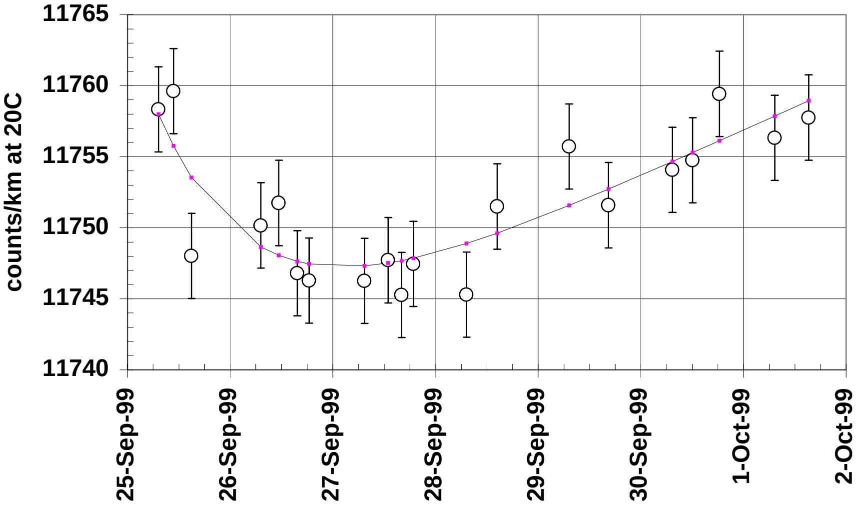


Overall, the tyre casing showed an increase in length with time. The overall trend suggests this might have continued for several days before the tyre stabilised. This of course was qualitatively consistent with what I had just observed on the Vee Rubber tyre, and thus confirmed the reality of the phenomenon which I had observed in my calibration data.

One intriguing detail which I noted was that between 6 am and 9 am on the second day as the temperature rose from 1 C to 6 C, the tyre casing contracted by about 5 mm. At first sight one would have thought that the observed creep and normal expansion of the tyre with increasing temperature would have reinforced one another during this period to give a clear increase of length with time. The unexpected contraction is evidence that there are more complex processes present in the polymer composite which forms a tyre casing. Reference to text books on material properties confirmed the complexities of polymers, summed up by the statement that the coefficient of elasticity, Young's Modulus, varies with temperature and time.

It is very interesting now to find the creep phenomenon in two further tyres. RG's Shrinka Golden Boy gave a very slight decrease in constant amounting to 3 cts/km over the 5 days after he pumped the tyre up hard to 78 psi. In the case of PR's Kenda, the effect was very marked, the tyre initially appearing to inflate by 7 cts/km in one day. Since Pete obtained a good series of data it can be analysed in detail.

Fig. 5 PR's Kenda: Cal Constant Corrected to 20C



Pete's first inclination was to disregard his first few points. However, I noticed that the points followed the general trend seen twice before in my Vee Rubber tyre: an initial expansion for a few days followed by a steady deflation. I therefore constructed a correction which comprised two parts. For the deflation I chose a linear function with time, which I have found fits all tyres. The only variable parameter in this is the slope. A value of 3.3 cts/km/day fitted the best. For the initial creep I chose an exponential decay. This has two parameters, an initial amplitude, 20 cts/km in this case, and an 'e-folding time' of 1 day. The 'e-folding time' of 1 day means that every day the creep correction is reduced by 1/2.7. In order to produce the curve show in Fig. 5, the two corrections are applied to the value of the calibration constant which I estimate the tyre would have had on 25 Sept had creep not been present, ie 11738 cts/km. The curve fits the data fit very well. The error bars show an estimate of the standard deviation of each point, ± 3 cts/km. This error corresponds to a temperature error of 2 C. So part of the scatter could easily have been due to unavoidable errors in measuring the tyre temperature.

It is clear that tyres differ in their propensity to creep after inflation. In fact, we have more examples of tyres where creep has not been detected than where we have seen it. This is yet another example of the variation in properties of the polymer matrix used to construct tyre casings. I expect that the magnitude of the creep will also depend on how much the tyre has been stretched by pumping up at the start of the series. Creep could be avoided by making only small changes to the pressure, or by leaving the tyre for a few days to stabilise.

It is interesting to speculate whether creep could explain some of the anomalous effects which are occasionally seen in calibrations for measurement. For example when I inspected the results of the 7 riders of validating the women's marathon trial for the 2000 Olympics, I noticed quite high values for the temperature coefficients of the tyres. I can most easily quote my MNF #0353 posting on 14 August 1999.

The pre cal temperature was 80F. The post cal temp was 88F. Ed Prytherch said, "The recorded temperatures probably understate the change in tire temp .... since they are shade temperatures. The pre calibration ride was in the dark, but the post measurement cal had hazy sun for the validation....." I have calculated temperature coefficients for the tyres using an 8F change and ignoring a possible few F extra increase in the sun. In my experience the temperature of a tyre being ridden at 10 mph in bright sun is within 4 F of the shade temperature because the temperature of the tyre is dominated by the temperature of the air rushing past rather than that of the road contacted in one small area or the direct sunlight.

The temperature coefficients can be compared with ordinary touring and racing pneumatic tyres, 23 mm to 32 mm width, which I have measured to have coefficients in the range of -80 to -150 ppm per degree C. Thus Amy's knobbly mountain bike tyre has about 2.7 times the coefficient of any tyre I have seen, including one fat knobbly mountain bike tyre which I once tested and was somewhat surprised to find that its temperature coefficient was in the same range as thinner pneumatics. Simple reasoning would suggest that the coefficient should be roughly proportional to the thickness of the tyre. But I suspect that the composition and structure of the tyre casing also plays an important part in determining the expansion coefficient. Please can anyone who regularly uses a fat tyre report their calibration coefficients with measured temperatures, for about 5 occasions when there has been a reasonable temperature change say at least 5F, so that I can calculate more examples of coefficients for this type of tyre.

Despite the inclusion of two novices, I do not have any doubt about the riding performance of this measuring team. I am sure it was their tyres which were behaving strangely. For example looking at the 5 km splits measured by Amy, these varied steadily during the marathon. Initially she was measuring about 2 m per 5 km more than Ed and Danny's layout, but by the end it had steadily decreased to about 3.5m per 5 km less. By contrast the other riders in the validation showed small irregular changes and which averaged 4m per 5 km more than Ed and Danny and had no overall trend throughout the 42 km. The 4 m per 5 km more than Ed and Danny arises primarily from use of the average constant for the validation.

It does seem that Amy's tyre was the odd one out, expanding steadily by an unusually large amount. Was it a make of tyre with an unusually high temperature coefficient, or were more obscure processes at work such as the relaxation of the tyre casing after being pumped up to a very high pressure? Unfortunately such questions are difficult to answer for a borrowed tyre.

We can now construct a scenario which would explain the apparently high value of the temperature coefficient of Amy’s tyre. The actual change of calibration constant of Amy’s tyre during the 4¼ hours between the pre and post calibration was 11927 to 11906 i.e. 21 cts/km. Now, if the creep of Amy’s tyre was, say, twice as large as that of Pete’s Kenda then I calculate the constant would decrease 6.2 cts/km. Such a very large creep would thus reduce the calculated temperature coefficient to -290 ppm/C. Now, allowing for temperature errors, which might change the observed 8F difference to 12 F, then the temperature coefficient comes down to -193 ppm/C which is within the range of the tyres we have measured in Fig 3. We can not of course prove this scenario is correct without additional data or measurements, but this example is useful in that it illustrates how very large changes of calibration constant can happen.

4. *Hysteresis*

By hysteresis I mean that the tyre does not follow exactly the linear temperature coefficient during the day. In my data in section 7 there are examples of days when the tyre expands following the expected coefficient early in the morning when the temperature is rising fast, but later in the day when the temperature increases only slowly the tyre continues to expand much less than would be expected. I have found examples of days when this effect would cause an error of 30% in the value of the correction one would be applying for the temperature change. This effect is small but may limit the ultimate accuracy of any temperature correction method which ignores it. Unfortunately, to investigate it requires a lot more data than we have acquired so it may not be an issue worth pursuing. I mention it here in case anyone with more than 3 calibrations in one day is ever confused by the data.

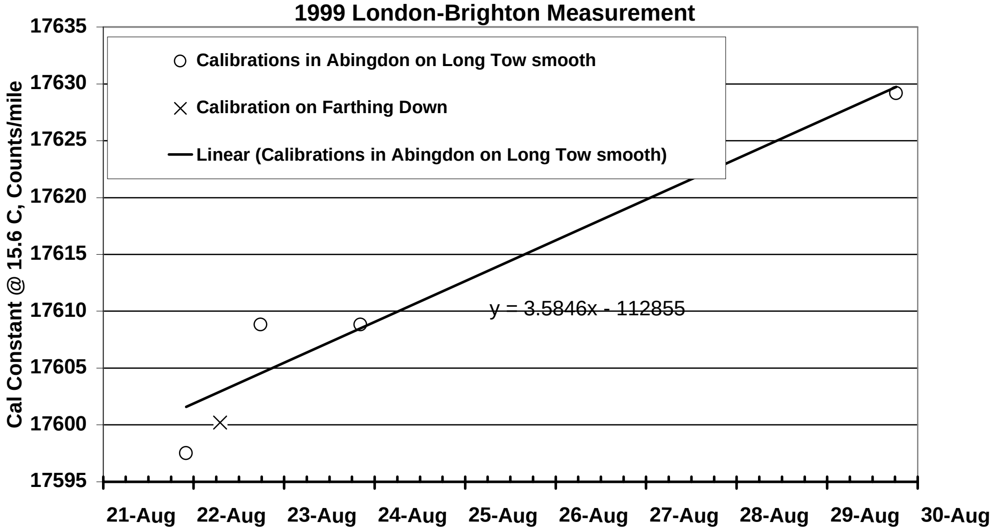
RIDER	*Description of Tyre*	*Temp Coeff ppm/C*
Kathy	*medium width road*	*-159*
Janice	*medium width road*	*-160*
Carol M	*medium width road*	*-185*
Holly	*70 psi road*	*-238*
Karen	*medium width road*	*-291*
Carol K	*knobbly mountain bike*	*-310*
Amy	*knobbly mountain bike*	*-409*

5. *Temperature Corrections for Course Measurements*

I shall now outline how I used my knowledge of my temperature coefficient in a recent measurement which I performed of the 54 mile 198 yard London to Brighton route for the 1999 race.

For various logistical reasons, I performed my calibrations on my home calibration course on Long Tow in Abingdon, but these were necessarily separated in time by 20 hours. I started my ride in line with Big Ben on Westminster Bridge at 05:00. Outside London at 15 miles I had laid down a 300 m calibration course on Farthing Down, one of the very few possible locations en route. I also had a very short calibration course at the finish in Brighton. However, when we arrived at 12.30 I had no time for a reacalibration, if I was going to take advantage of a lift back from the race director, so in view of the modest temperature change I decided to recalibrate in Abingdon. The data obtained are in the table on the right.

Fig. 6 Calibration of Michelin World Tour for the 1999 London-Brighton Measurement



Using my measured temperature coefficient for the tyre of -120 ppm/C, I corrected all the calibration data to a convenient temperature, 15.6 C. They are plotted in Fig. 6. Ignoring for the moment the Farthing Down data point, I fitted a straight line and its slope 3.6 cts/mile/day gives rate of deflation. Reading from the straight line, at the time of the Farthing Down calibration, the constant based on Long Tow data was 17603, just 3 cts/mile more than actually measured on Farthing Down, good agreement although one should bear in mind that the surface roughness may have been slightly different.

When reducing the ride data, I calculated the corrected constant for each 5 mile stretch using the average temperature, and I made the small correction for deflation. The correction to the total distance was just 20 yards because on this occasion the day was mostly cloudy and the extreme temperature range experienced was only 8 C. It could have been a different matter under other weather conditions. Indeed, it would have been foolhardy to plan this single ride measurement of over 7 hours duration without the knowledge of my tyre's characteristics and the plan to carry out this correction method.

Constant of the Day	Distance
Largest of pre and post cal ('Standard Method')	54m 178y
Average of pre and post cal ('Allowed by IAAF/AIMS')	54m 183y
From detailed temperature and deflation corrections	54m 198y

6. *Implications for Measurers*

This technical appendix has been long and detailed. Measurers need not wade through all the details unless they wish to copy my methods. You can obviously get good results by intelligently following the well established methods. However, my experience has been that often when a group of riders take the same measurement, the difference between the results is sometimes surprisingly large. This work is aimed at understanding, and perhaps also reducing or correcting, such differences for pneumatic tyres.

Date/Time	Temp C	Cts/mile	Cal Course
21/8 22:00	13.0	17602.8	Long Tow
22/8 07:00	12.6	17607.0	Farthing Dn
22/8 17:47	18.6	17601.1	Long Tow
23/8 20:15	17.6	17608.8	Long Tow
29/8 18:20	21.7	17629.2	Long Tow

1. Measure the temperature coefficient of your tyre. Try a

different tyre if the coefficient is large (over about 140 ppm/C.)

2. Look out for evidence of creep: your tyre expanding at constant temperature for a few days after you have pumped it up. If you are very unlucky and happen to have large creep, greater than 10 cts/km/day, then you should let your tyre settle for a day or two after inflating it, or possibly try another tyre.
3. If you get very large temperature changes during a measurement you can still recover a good result, but you need to measure the temperature at each split en route. You will need your tyre's temperature coefficient and possibly the rate of deflation. The calculations would be tiresome and prone to error if done by hand, but if you can master a spreadsheet they are trivial.
4. The temperature correction method should be considered for use by experienced measurers when validating another measurer's work. It should always give a more accurate result than use of the average constant and may occasionally avoid falsely failing a marginal course due to adverse temperature changes.

7. *Data from the calibration rides*

DATE	TIME	C	CTS/KM
MS -Michelin World Tour 1.25inches			
5-May-96	6:36	3.7	10921.3
5-May-96	18:43	10.9	10914.1
6-May-96	6:41	0.8	10923.9
6-May-96	14:10	15.7	10909.7
12-May-96	7:27	6.4	10927.5
12-May-96	16:07	14.6	10918.3
29-May-96	5:57	13.4	10938.1
15-Jun-96	12:53	22.1	10952.6
16-Jun-96	6:33	11.7	10971.1
16-Jun-96	16:24	27.9	10946.9
23-Jun-96	8:40	15.4	10969.9
23-Jun-96	16:03	21.4	10967.0
20-Jul-96	7:05	15.3	11011.1
20-Jul-96	10:42	24.1	10996.3
20-Jul-96	14:54	29.8	10990.7
21-Jul-96	6:22	13.1	11012.7
21-Jul-96	8:53	21.3	11004.6
21-Jul-96	13:09	29	10993.3
21-Jul-96	16:11	31.5	10992.9
MS -Vee Rubber 1.25 inches			
20-Apr-96	10:42	16.4	11009.3
20-Apr-96	12:10	16.9	11011.8
24-Apr-96	7:52	12.5	11013.2
24-Apr-96	8:22	14	11010.7
24-Apr-96	13:50	21.7	10995.7
24-Apr-96	19:36	16.7	11004.8
24-Apr-96	20:15	14.9	11012.0
26-Apr-96	17:20	21.4	10998.2
26-Apr-96	20:39	14.1	11009.4
27-Apr-96	6:20	4.8	11021.3
27-Apr-96	9:50	13.3	11007.5
27-Apr-96	11:57	17.1	11001.8
27-Apr-96	16:05	19	11001.2
27-Apr-96	20:36	14.6	11010.7
28-Apr-96	10:21	12.5	11007.0
28-Apr-96	16:40	14.2	11007.4
28-Apr-96	17:22	13	11010.6
4-May-96	7:00	2.2	11028.6
4-May-96	12:15	10.2	11016.6
5-May-96	7:05	4.1	11026.9
6-May-96	7:08	2.1	11029.0
6-May-96	13:53	13.9	11012.7
12-May-96	15:38	13.4	11019.1
29-May-96	6:30	13.6	11032.3
29-May-96	14:47	18.2	11029.5
29-May-96	15:05	18.4	10996.3
29-May-96	15:18	18.4	10996.1
29-May-96	19:46	15.5	11001.6
30-May-96	5:41	13	11003.5
30-May-96	17:14	25.2	10984.0
30-May-96	21:42	19.1	10997.0
31-May-96	5:47	12.4	11003.6
31-May-96	17:25	16.2	10999.3
1-Jun-96	6:03	9.2	11009.5
1-Jun-96	19:08	15.1	10998.8
2-Jun-96	15:26	19.4	10991.9
5-Jun-96	19:22	25.3	10991.0
7-Jun-96	18:20	26.9	10988.7
8-Jun-96	6:55	13.4	11008.8
8-Jun-96	19:03	21.5	10997.1
15-Jun-96	12:19	21.7	11000.0
16-Jun-96	7:03	13.3	11017.5
16-Jun-96	15:51	27.1	10993.8
20-21 July: 7 further sets,			

DATE	TIME	C	CTS/KM
MS - Michelin Tracer 1 inch			
7-Jun-97	15:12	22.3	11293.1
7-Jun-97	15:28	21.6	11293.8
7-Jun-97	15:40	21	11294.4
7-Jun-97	16:52	22	11293.8
8-Jun-97	6:45	14.3	11303.1
8-Jun-97	7:49	15.9	11301.4
8-Jun-97	8:35	16.9	11300.1
8-Jun-97	13:40	19.9	11295.9
8-Jun-97	20:52	15.4	11301.9
11-Jun-97	17:21	23.3	11296.7
12-Jun-97	6:16	15	11308.2
12-Jun-97	17:14	20.7	11299.9
13-Jun-97	6:24	15	11308.2
13-Jun-97	17:09	19.9	11303.9
13-Jun-97	20:00	17.5	11308.5
14-Jun-97	6:22	12.2	11315.8
14-Jun-97	8:57	15	11308.5
14-Jun-97	10:45	16.6	11307.5
14-Jun-97	16:16	15.4	11311.4
15-Jun-97	12:05	16.7	11311.3
15-Jun-97	16:21	17.4	11311.2
21-Jun-97	6:33	12	11325.5
21-Jun-97	6:46	12.2	11325.4
21-Jun-97	12:57	15.4	11320.5
21-Jun-97	13:09	16.4	11319.2
21-Jun-97	13:20	17.1	11318.6
22-Jun-97	12:21	15.9	11323.0
22-Jun-97	14:15	17.7	11320.6
22-Jun-97	17:23	14.8	11329.0
23-Jun-97	21:12	14.1	11331.0
24-Jun-97	17:48	16.3	11327.8
4-Jul-97	17:59	18.6	11335.9
5-Jul-97	8:12	14.4	11342.3
5-Jul-97	12:54	20.4	11334.5
5-Jul-97	17:42	22.6	11334.3
6-Jul-97	8:09	15.6	11346.3
6-Jul-97	12:03	23.3	11332.7
6-Jul-97	14:58	23.6	11334.4
12-Jul-97	7:25	14.3	11360.2
12-Jul-97	9:20	18.4	11353.3
12-Jul-97	15:08	24.1	11347.7
12-Jul-97	22:25	17.7	11360.8
13-Jul-97	7:50	16.5	11362.4
13-Jul-97	13:46	24.3	11347.7
19-Jul-97	14:36	25.1	11360.1
19-Jul-97	15:23	25.2	11252.3
19-Jul-97	15:34	25.4	11252.0
19-Jul-97	21:35	18.4	11264.4
20-Jul-97	6:33	11.1	11272.9
20-Jul-97	7:41	14.5	11268.2
20-Jul-97	9:18	19.4	11259.8
20-Jul-97	11:18	23.2	11255.0
20-Jul-97	13:42	24.4	11254.8
20-Jul-97	15:43	25.6	11254.7
20-Jul-97	19:12	23.9	11260.0
20-Jul-97	21:44	18.2	11268.0
26-Jul-97	7:43	15	11278.8
26-Jul-97	19:10	20.8	11273.0
27-Jul-97	7:14	14.8	11281.2
27-Jul-97	9:25	17.6	11276.4
27-Jul-97	12:37	22.2	11267.2
27-Jul-97	14:55	24.4	11267.8
27-Jul-97	20:03	21.5	11276.2
27Jul to 30 Aug: 44 further sets			

DATE	TIME	C	CTS/KM
PR Kenda 2.125 inches			
25-Sep-99	7:12	9.4	11779.3
25-Sep-99	10:43	20.0	11759.6
25-Sep-99	14:58	26.7	11734.8
26-Sep-99	7:11	11.1	11767.8
26-Sep-99	11:22	25.6	11740.7
26-Sep-99	15:41	31.1	11724.8
26-Sep-99	18:27	27.8	11730.9
27-Sep-99	7:25	16.7	11752.9
27-Sep-99	12:58	22.8	11742.2
27-Sep-99	16:06	24.4	11736.5
27-Sep-99	18:49	23.9	11739.7
28-Sep-99	7:15	16.7	11751.9
28-Sep-99	14:23	28.3	11735.0
29-Sep-99	7:11	20.6	11754.5
29-Sep-99	16:26	13.9	11763.7
30-Sep-99	7:21	7.2	11779.5
30-Sep-99	12:06	17.2	11760.3
30-Sep-99	18:21	18.3	11762.7
1-Oct-99	7:18	5.6	11785.1
1-Oct-99	15:13	24.4	11748.9
RG - Rocktrax 2.0 inches *			
*In counts, = approx 12000 cts/km			
28-Sep-99	7:57	12.3	3917.0
28-Sep-99	14:55	15.8	3912.0
28-Sep-99	18:15	14.1	3914.8
29-Sep-99	8:12	14.0	3915.6
29-Sep-99	13:21	16.8	3914.6
29-Sep-99	15:55	18.3	3911.8
29-Sep-99	19:06	15.2	3915.0
30-Sep-99	8:12	12.67	3916.7
30-Sep-99	15:28	15.5	3913.3
1-Oct-99	7:46	10.5	3918.7
1-Oct-99	15:36	14.33	3917.3
RG -Shrinka Golden Boy 1.125 inches*			
*In counts, = approx 9000 cts/km			
7-Sep-99	18:28	19.8	3189.8
7-Sep-99	19:55	16.4	3191.7
8-Sep-99	7:15	12.1	3193.0
8-Sep-99	10:47	23.7	3187.1
8-Sep-99	14:12	23.7	3187.5
8-Sep-99	18:59	20.9	3189.3
9-Sep-99	6:55	13.0	3193.5
9-Sep-99	10:27	20.0	3188.8
9-Sep-99	15:28	21.7	3188.4
9-Sep-99	19:31	13.6	3192.5
10-Sep-99	16:38	19.8	3189.6
ETM -Continental Goliath 1.6 inches			
12-Sep-99	6:55	25.56	9997.1
12-Sep-99	14:55	37.22	9986.3
13-Sep-99	5:25	25	10000.0
13-Sep-99	13:20	33.33	9989.8
14-Sep-99	7:15	23.89	10002.5
14-Sep-99	13:15	33.89	9994.5
15-Sep-99	5:55	23.89	10005.3
15-Sep-99	15:10	34.44	9992.9
16-Sep-99	5:20	22.78	10008.2
16-Sep-99	21:35	27.22	10005.2
MS -Vee Rubber 1.9 inches			
27-Jul-96	10:18	20.0	11629.9
27-Jul-96	12:17	22.6	11622.8
28-Jul-96	6:12	15.0	11637.6
28-Jul-96	10:55	21.5	11624.8
18-Aug-96	07:38	19.8	11612.5
18-Aug-96	13:52	32.8	11591.0

DATE	TIME	C	CTS/KM
PR 123psi Spec. Turbo A 1.25 inches			
5-Sep-99	7:24	20	11092.1
5-Sep-99	13:51	28.3	11083.9
5-Sep-99	18:45	26.7	11086.4
6-Sep-99	6:45	18.9	11092.9
6-Sep-99	9:20	23.9	11090.1
6-Sep-99	14:05	29.4	11083.9
6-Sep-99	19:02	27.5	11089.0
7-Sep-99	7:00	20.6	11095.6
7-Sep-99	15:30	27.8	11089.7
8-Sep-99	7:00	15.6	11102.8
8-Sep-99	9:58	21.7	11097.9
8-Sep-99	15:15	32.2	11090.5
8-Sep-99	18:21	30.6	11092.3
9-Sep-99	7:00	18.9	11103.6
9-Sep-99	10:47	23.9	11098.7
9-Sep-99	15:08	30	11092.8
10-Sep-99	7:02	10	11113.1
PR 59psi Spec. Turbo A 1.25 inches			
10-Sep-99	8:57	15.6	11170.1
10-Sep-99	12:09	22.2	11163.4
10-Sep-99	15:20	25.0	11160.6
11-Sep-99	7:01	9.4	11181.0
11-Sep-99	14:13	28.9	11163.1
11-Sep-99	18:06	28.9	11168.5
12-Sep-99	7:10	15.6	11179.1
12-Sep-99	10:07	22.8	11172.3
12-Sep-99	15:54	32.2	11164.5
13-Sep-99	7:05	20.0	11180.8
13-Sep-99	14:38	23.3	11177.2
14-Sep-99	7:33	10.0	11190.0
14-Sep-99	11:05	21.1	11179.6
14-Sep-99	15:24	25.6	11180.3
14-Sep-99	19:01	20.6	11186.5
15-Sep-99	7:03	8.3	11195.2
HJ -Michelin World Tour 1.125 inches			
7-Sep-99	9:42	20.5	9374.0
7-Sep-99	11:42	22.5	9372.6
8-Sep-99	6:42	14.5	9381.8
8-Sep-99	7:55	16.5	9378.7
8-Sep-99	9:37	18	9378.0
8-Sep-99	11:18	21	9375.9
9-Sep-99	6:43	13	9389.4
9-Sep-99	7:32	13	9388.6
9-Sep-99	9:44	17.5	9380.8
9-Sep-99	13:19	21	9378.2
10-Sep-99	6:44	12	9383.3
10-Sep-99	7:35	13	9386.5
10-Sep-99	9:15	16	9383.3
10-Sep-99	11:48	21	9380.0
10-Sep-99	13:31	23	9379.4