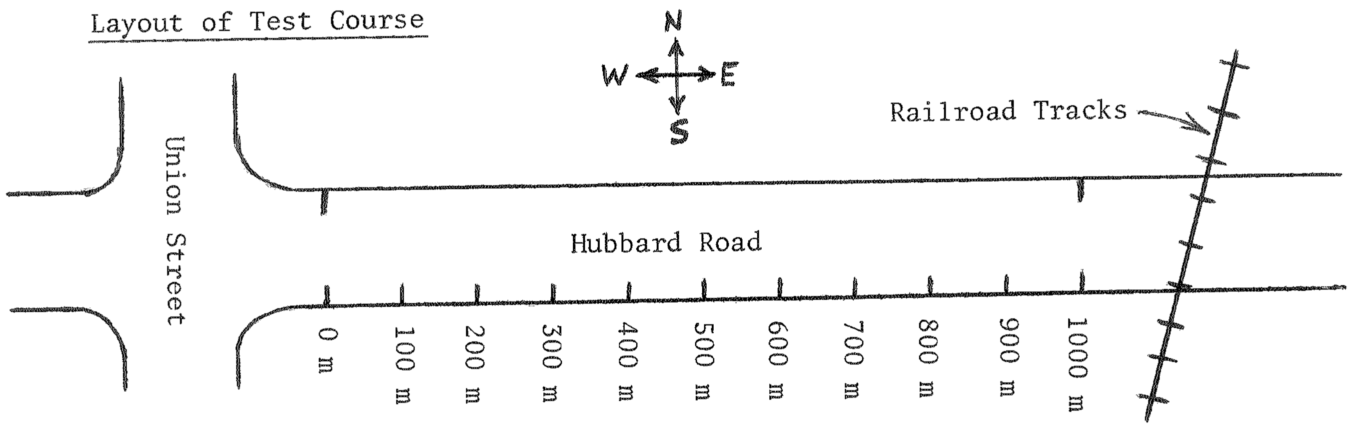
April 1983

An Experiment to Test SHORT CALIBRATION COURSES

by Bob Baumel
Oklahoma Certification Chairman

Considering the recent interest in the possibility of allowing shorter calibration courses for the Calibrated Bicycle Method, thereby permitting measurers to set up short on-site calibration courses and to avoid the errors due to transporting the bike long distances between the calibration course and the race course, and considering also a similar experiment performed by Bob Letson, I have done the following experiment to test the effectiveness of short calibration courses:

Layout of Test Course



The Hubbard Road calibration course in Ponca City, Oklahoma consists of two parallel 1 km courses, on the northern and southern edges of the road. This allows 1 km calibration rides to be performed in either the eastbound or westbound direction, riding legally on the right side of the road with traffic in either direction. (Note: it would not be safe to ride facing traffic on this road). The kilometer on the southern edge of the road is subdivided into 100 meter intervals as shown in the diagram above.

This course was laid out with a 50 meter steel surveyor's tape on March 6, 1983, at a temperature of 15°C under overcast skies. We used a tape tension of 45 newtons (10 pounds-force), and we applied a temperature correction of 5.8 mm to each 100 m interval, or 5.8 cm for the full kilometer (lengthening the course by these amounts). We then marked all the endpoints and 100 m points with PK nails and paint.

The course was checked with a Hewlett Packard 3810B electronic distance meter on April 2, 1983. We found the course on the southern edge of the road to be 1000.04 meters in length, while the course on the northern edge was 1000.02 m. We also checked each of the 100 m intervals on the southern edge. These were all in a range from 99.998 m to 100.011 m.

This course is on the same site as my previous Ponca City calibration course which I have used to certify a number of race courses in Ponca City and environs. However, we had recently lost the old markings due to repaving of the road. Nevertheless, we were able to re-locate the old course (to within a few centimeters) using reference positions on the side of the road. On this basis, it appears that the new course is about 2 or 3 centimeters longer than the old course.

short cal course write-up
April '83

Experimental Procedure

I performed the bike riding during a period of slightly over 2 hours on the afternoon of April 3, 1983. I made 10 passes of the course, from west to east, in order to obtain 4 rides at each of the following distances:

100 m, 200 m, 300 m, 400 m, 500 m, 1000 m.

For example, on my first pass of the course, I made intermediate stops at the 100 m, 300 m and 600 m marks, thereby obtaining rides at the four distances: 100 m, 200 m, 300 m and 400 m. I rode these same 4 distances on my 4th, 5th and 9th passes of the course, but on those later passes, I permuted the order of the distances, thereby using different 100 m sections of the course for each distance.

I did not use Bob Letson's technique of "freezing the wheel" (which would have been impossible since my 4 rides at any given distance were not performed consecutively). Instead, I always reset the counter to a multiple of 1000 counts before starting the bike. For example, at the 100 m mark on my first pass of the course, I obtained a reading of 257939. I then reset the counter to 258000 before proceeding to the 300 m mark. All counter readings were taken after the wheel had been advancing forward, so as to take the "play" out of the counter (and similar care was taken when resetting the counter). I always tried to sight vertically downward through the wheel axle to the desired point (i.e. PK nail) in the road. And I read the counter to as small a fraction of a count as possible (often to 1/4 of a count).

My 4 rides at each distance were distributed over the duration of the experiment, so as to eliminate any systematic tire-heat effect. As previously indicated, I did combination 100 m - 200 m - 300 m - 400 m rides on my 1st, 4th, 5th and 9th passes of the course. I did 500 m rides on my 3rd and 7th passes. And I did non-stop 1000 m rides on my 2nd, 6th, 8th and 10th passes.

In between my 10 eastbound passes of the course, I did 9 westbound return rides (of 1 km each) on the northern edge of the road. Although I did record my counter readings from the 9 return rides, I have not included that data in my analysis. The northern and southern courses differed most notably in wind direction (which was from the east), and grade (the eastern end of the course is 4.7 m higher than the western end). There may also be some perceptual differences to alter a rider's style on the 2 courses. If I were going to measure a race course, then I would definitely take an average of both eastbound and westbound calibration rides. But in the present experiment, my sole object was to compare calibration courses of different lengths; therefore, I used only eastbound rides.

DATA - CALIBRATION EXPERIMENT - Bob Baumel

April 3, 1983
12°C Sunny
2:55 PM
wind from East

1st pass

0 - 257000
100 - 257939 → 258000
300 - 259879½ → 260000
600 - 262817 → 263000
1000 - 266756

Return
267000
276 387½

2nd pass

0 - 276 000
1000 - 285 387

Return: 285 000
294 387¾

3rd pass

0 - 294 000
500 - 298 693⅓
→ 299 000
1000 - 303693

return 304 000
313 387½

4th pass

0 - 313 000
400 - 316 754⅓
→ 317 000
700 - 319816
→ 320 000

4th pass (continued)
900 - 321877
→ 322 000
1000 - 322 939

return 323 000
332 386¾

5th pass:

0 - 332 000
300 - 334 815½
→ 335 000
400 - 335936*
→ 336 000
800 - 339 754½
→ 340 000
1000 - 341 878

return 342 000
351 387

6th pass 0 - 351 000
1000 - 360 384¾

return:
360 000
369 386

7th pass

0 - 369 000
500 - 373 693
→ 374 000
1000 - 378 694

return
379 000
388 386¾

8th pass 0 - 388 000
1000 - 397 385

return
397 000
406 387¼

9th pass

0 - 406 000
200 - 407877½
→ 408000
600 - 411755½
~~[illegible]~~ → 412 000
700 - 412 938½
→ 413 000
1000 - 415816

return 416 000
425 386¾

10th pass

0 - 425 000
1000 - 434 387½

5:06 PM
12½°C

* - MOST LIKELY MISCOPIED FROM COUNTER. CORRECT READING WAS PROBABLY 335939

short cal course write-up
April '83

SUMMARY OF DATA

Distance	No. of Counts & which Pass of Course				Avg. Count
100 m	939 1st	939 4th	936* 5th	938½ 9th	938.833 (9388.33/km)
200 m	1879½ 1st	1877 4th	1878 5th	1877½ 9th	1878 (9390/km)
300 m	2817 1st	2816 4th	2815½ 5th	2816 9th	2816.125 (9387.08/km)
400 m	3756 1st	3754⅓ 4th	3754½ 5th	3755½ 9th	3755.083 (9387.71/km)
500 m	4693⅓ (3rd)	4693 (3rd)	4693 (7th)	4694 (7th)	4693.333 (9386.67/km)
1000 m	9387 2nd	9384¾ 6th	9385 8th	9387½ 10th	9386.06

Return Rides: 9 rides of 1000 m each on the opposite edge of road (with wind at back, while all the above rides were done heading into wind). Counts:

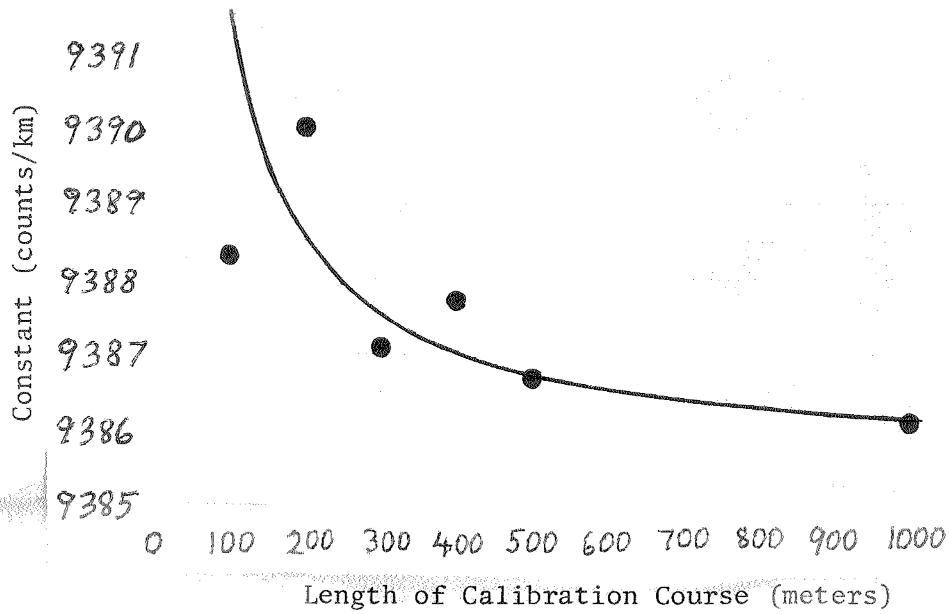
9387½, 9387¾, 9387½, 9386¾, 9387, 9386,
9386¾, 9387¼, 9386¾   Average = 9387.03

* This 936 count reading obtained on the interval from the 300 m to 400 m mark, during my 5th pass of the course, has not been included in the average. I distinctly recall being conscious during the experiment that each 100 m ride gave 939 counts, except for the final ride which gave 938½ counts. I was therefore quite surprised to later look at my data sheet and discover this freak count of 936. Chances are, I simply mis-copied a "9" as a "6". Note that our EDM check of each 100 m segment of the course thoroughly rules out any possibility that this particular 100 m interval might have been short by 30 cm!

short cal course write-up
April '83

Mathematical Analyses

The following graph shows the "Constant" I obtained at each calibration course length:



The smooth curve on the graph is a plot of the "Calibration-Wobble Equation" which I first presented in my letter to Ted Corbitt of March 5, 1983; namely:

$$C = C_{\infty} \left(1 + \frac{W}{L}\right) \qquad (1)$$

where: C = "Constant" obtained by riding over calibration course of a given length.
L = Length of Calibration Course.
C_{∞} = Limiting value of "Constant" for an infinitely long calibration course.
W = "Wobble distance" = extra distance covered due to wobbles in starting and stopping bike.

The numerical values used for the parameters C_{∞} and W were:

$$C_{\infty} = 9385.54 \text{ counts/km}$$
$$W = 6.36 \text{ cm} \qquad (2)$$

These values were obtained from my data as follows:
I started by analyzing the relation between the parameters

N = average number of counts for a given calibration course length,
and L = Length of calibration course.

A least squares straight line fit of N versus L yields the regression equation:

$$N = 9385.54\, L + 0.597 \qquad (3)$$

where, in this equation, the length L is in kilometers.

Interpretation: In "steady-state" riding, I was recording 9385.54 counts/km, but in each ride, I also obtained an additional 0.597 counts (independent of course length) which was probably due to wobbles in starting and/or stopping the bike.

To calculate a "Constant" (C) from the calibration rides at a given distance, the average number of counts (N) must be divided by the course length (L). Equation (3) thus predicts that:

$$C = \frac{N}{L} = 9385.54 + \frac{0.597}{L} . \quad (4)$$

Comparison of equation (4) with the theoretical form of the Calibration-Wobble equation (1) readily yields the numerical values shown in equation (2).

> Note: Considering that the theoretical Calibration-Wobble equation (1) predicts C to be a linear function of 1/L, it is tempting to try analyzing the data by fitting a straight line to a plot of C versus 1/L. That was, in fact, the <u>first</u> method I tried, but found unsatisfactory, as it places too much weight on the data from the shortest calibration distances, where the data displays the most "scatter." By contrast, the regression analysis of N versus L seems to put about the right statistical weight on each data point.

In the graph at the top of page 5, the data points cluster about the smooth curve, but are increasingly scattered at the shorter calibration course distances. Please note that there is another type of "scatter" which is not apparent on the graph. Recall that each plotted point on the graph represents an average of 4 rides (or 3 rides at the 100 m distance where I had to discard a bad data point). The following table shows the range of counts obtained for each course length, <u>before</u> computing the averages plotted on the graph:

Length of Calibration Course	Range of Counts	Corresponding Range of "Constant" (counts/km)
100 m	938½ to 939	9385 to 9390
200 m	1877 to 1879½	9385 to 9397.5
300 m	2815½ to 2817	9385 to 9390
400 m	3754⅓ to 3756	9385.83 to 9390
500 m	4693 to 4694	9386 to 9388
1000 m	9384¾ to 9387½	9384.75 to 9387.5

Discussion

Every one of my short calibration courses (100 m to 500 m) yielded a larger constant than the full-sized 1 kilometer course. Thus it would have been legitimate to use the constant derived from any of my short calibration courses in measuring a race course, since the resulting race course would come out longer than by using the constant from the legal 1 km calibration course.

As an example, if I were to use my constant from the 200 m course (where I obtained the largest constant) to lay out a 10 km race course, then the resulting race course would be about 4 meters longer than if I used my constant from the 1 km calibration course.

There would seem to be little doubt that perfectly acceptable measurements can be made with calibration courses considerably shorter than those now allowed. But before we can actually start using shorter calibration courses, we must answer a few questions:

Question 1: What is the minimum acceptable length for a calibration course?

Question 2: How many times must the calibration course be ridden?

Question 3: What measures need be taken to ensure adequate counter resolution?

Comments on Question 1

The present experiment seems to suggest that courses as short as 100 m might be acceptable. In my letter to Ted Corbitt of 5 March 1983, I argued for a 300 meter minimum (i.e., the metric near-equivalent of Peter Riegel's suggestion of 1000 ft = 304.8 m). My argument in that letter was based on counter resolution. But that may not be the proper criterion. In fact, since race course length tends to increase as the calibration course is made shorter, the proper criterion for choosing a minimum length calibration course might simply to pick a maximum value for how long a race course can be!

One possibility might be to say that the race course is too long when the lengthening due to the use of a short baseline exceeds the 0.1% "safety factor" that we now routinely add on to race courses. For example, if a cyclist has a wobble distance (W) of 20 cm (which is 3 times my own wobble distance as determined by this experiment), then a race course lengthening of 0.1% would be attained by using a calibration course of 200 meters or less. Thus, we might set the minimum at 200 m. Or perhaps we should be more conservative, and set the minimum at 250 m or 300 m (which would take us back to my earlier recommendation). The 250 m figure is natural from a metric point of view (exactly 1/4 of the old IAAF figure of 1 km). But 300 m has the advantage of being an integer multiple of all standard metric tape lengths, and the English near-equivalent of 1000 ft would be natural for those Americans who still measure in English units.

Another argument for a 300 m minimum comes from consideration of validation re-measurements. Just as short calibration courses tend to result in laying out longer race courses, the use of short baselines in validation re-measurements would tend to increase the chances of finding race courses short! Thus, to be fair to race directors, we should not allow extremely short calibration courses for validation re-measurements. Assuming that such re-measurements will always be performed by skilled cylists (with wobble distances comparable to mine and Bob Letson's), then a 300 m minimum will mean that the increased tendency to find race courses short will be no more than 2 meters in 10 km -- which is, I hope, acceptable. As a matter of general principle, I think the shortest allowable calibration course for the initial certification of a race course should be the same as for a validation re-measurement.

Comments on Questions 2 and 3 (General remarks)

Bob Letson has proposed answers to both these questions. For question 2, he suggests riding a total distance of at least 1600 meters (on each calibration occasion). And for question 3, he suggests that this sequence of rides be unbroken and that the measurer "freeze the wheel" between rides.

It should be noted that I did not follow either of Letson's recommendations; yet I think I obtained adequate accuracy!

To discuss these questions in more detail, we look again at the graph on page 5. Three general trends are visible in the data:

(i) On the average, the data points follow the smooth curve of the "Calibration Wobble" equation, which explains the increase of "constant" with decreased calibration distance, due to wobbles in starting and/or stopping the bike.

(ii) However, the data points are somewhat scattered about this smooth curve, and the amount of scatter increases as the calibration distance is decreased.

(iii) Of the two effects listed above, the second is dominated by the first. Thus, in spite of the scatter in the data, the constants derived from all the "short" calibration courses were larger than the constant obtained on the regulation length 1 km course.

Bob Letson's procedures are no doubt quite effective in reducing the scatter of the data (trend number ii). In fact, Letson's data falls on a smoother curve than my own, showing very clearly the increase of constant with decreasing calibration distance (trend number i). It is possible, however, that Letson did more than necessary in reducing the scatter of his data.

The crucial observation is trend number (iii) -- that the scatter of the data is dominated by the Calibration-Wobble effect. This is what makes short calibration courses legitimate -- by assuring us that race courses measured with a short baseline will be no shorter than race courses measured with a full-size calibration course.

From this point of view, it is not necessary to go to heroic lengths to reduce random fluctuations and counter resolution errors; it is sufficient merely that the scatter due to these effects be smaller than the Calibration-Wobble effect.

Specific remarks on Question 2: My data seems to indicate that 4 calibration rides (even at the shortest distances) are enough for trend (iii) to hold. It is conceivable, however, that a less skilled cyclist would need more rides in order to obtain the same data quality. Therefore, I would recommend 6 rides (on each calibration occasion) for calibration courses shorter than 500 meters. For courses longer than 500 m, we should continue using 4 rides.

Note 1: The required number of rides on each calibration occasion should be an even number since calibration courses are normally ridden back and forth, and an even number of rides provides an equal sampling of both directions. This principle prevents me from, let's say, recommending 5 rides.

Note 2: I think that post-measurement re-calibration rides are just as important as pre-measurement calibration rides. Therefore, the number of re-calibrations should match the number of pre-calibrations.

Note 3: If a 300 m minimum course length is adopted, then my recommendation of 6 rides agrees with Bob Letson's (i.e., 6 rides of 300 m are needed in order to exceed 1 mile of riding). If the minimum is set at 200 m, then I still recommend 6 rides, while Letson proposes 8 rides. For long calibration courses of 800 meters and up, Letson would have us reduce the number to 2 rides, but I don't think this provides enough redundancy, and urge that we retain the present 4 ride minimum for such courses.

Specific remarks on Question 3: As for counter resolution, our basic principle (that the Calibration-Wobble effect must dominate the scatter of the data) implies only that any errors due to counter resolution must be suitably smaller than the cyclist's wobble distance (W). My wobble distance of 6.36 cm translates to about 0.6 counts (and Bob Letson has a similar wobble distance based on analysis of his experiment. Chances are that a less skilled cyclist would have a larger wobble distance). Now if the counter is carefully reset to a whole number at the beginning of each calibration ride, and is then carefully read to the nearest half-count at the end of each ride, then the resolution error should be within ± 1/4 count, which is sufficiently small compared to the wobble distance of 0.6 counts.

Bob Letson's "wheel freezing" technique probably achieves better counter resolution, although I'm not entirely convinced, as Letson's method is still subject to two types of error: parallax errors (i.e., lining up the wheel axle with the point on the ground), and accidental slippage of the wheel while turning the bike around. (Of course, parallax error affects my method and Letson's method equally). It should be noted that Letson used a rather artificial technique in his experiment -- doing 220 yard rides in sets of 8, on a 1 mile course marked in eigths, without resetting the counter at intermediate points. That technique totally eliminated all errors due to counter resolution at the intermediate points, but in that respect was not representative of an actual measuring situation. After all, a real measurer using a 220 yd calibration course would have only one such course -- rather than 8 of them laid end to end! Thus, it would be necessary to turn the bike around after each ride (thus incurring some counter resolution error).

Both Bob Letson's technique (freezing the wheel), and my own technique (using the counter in a more standard manner, but with considerable care), provide adequate accuracy to permit use of short calibration courses. However, it is clear that short calibration courses do require more care in using the counter than many measurers now exercise. Thus, proper use of the counter must be emphasized in any instructions that we issue for using short calibration courses.

Letson's wheel freezing method does have one (probably rather minor) drawback from a psychological point of view. The requirement of an unbroken string of calibration rides creates an ever-present possibility that some minor mishap (such as swerving to avoid a car, or some slippage of the wheel while turning the bike around) will invalidate all the preceding rides, forcing the measurer to start the sequence all over again. Thus, there is something to be said for an approach that allows the measurer to start out fresh on each individual calibration ride.

Perhaps the ultimate improvement in counter resolution would be obtained by a spoke-counting technique, as was used with the old Veeder Root 5-star counter (except that in this case, small fractions of a spoke are estimated). I have used this technique in previous short course calibration experiments (as described in my letter to Ted Corbitt 5 March 1983), but did not use it in the present experiment.

The spoke-counting approach does totally eliminate parallax error and counter backlash. Unfortunately, it complicates the arithmetic, and requires more time and effort to actually do the spoke counting (as compared with just reading a counter). Furthermore, I fear that many measurers would systematically get their counts wrong by 1/2 spoke (i.e., they'd use the valve stem as a reference position when starting the ride, but would then fail to account for the fact that the valve stem is located halfway between spoke positions). Thus, I don't recommend spoke-counting as a practical method.

Other assorted Comments

My wobble distance of 6.36 cm, as estimated by this experiment, is not an isolated value. In my letter to Ted Corbitt of 5 March 1983, I estimated Bob Letson's wobble distance at 7.4 cm on the basis of his experiment. Also in that letter, I analyzed two of my own earlier (far less systematic) experiments, and obtained values of 4.0 cm and 7.5 cm for my wobble distance.

In the present experiment, my 9 westbound 1 km return rides were not included in the data analysis. Those return rides averaged about 1 count/km higher than my 4 "official" eastbound 1 km rides. The direction of this difference is consistent with earlier observations I've made, considering that I was riding with the wind and slightly downhill during the westbound return rides. When a cyclist rides downhill, or with the wind at his back, then more of his weight is concentrated over the front wheel (i.e., measuring wheel). This decreases the wheel circumference, thereby increasing the number of counts for a given distance. This trend probably holds until the wind speed gets so strong as to seriously impede the cyclist's progress when heading into the wind.

The table on page 6 verifies an effect previously found by Peter Riegel in his analysis of Bob Letson's experiment (see Riegel's measurement newsletter of 25 Dec 1982). If we look at the minimum count obtained for each calibration distance, then the resulting constants are nearly independent of course length (and we see no evidence of the Calibration-Wobble effect!). However, I'm sure that using the minimum count would, in general, result in laying out short race courses. Thus we should continue using the average count. In this case, the Calibration-Wobble effect re-asserts itself, and assures us that race courses measured with short baselines will be at least as long as race courses measured in accordance with current rules.

Along with the use of short calibration courses, I would suggest that all measuring tapes used for laying out calibration courses be at least 25 meters in length (i.e., I would not allow 15 meter or 50 ft tapes). Then if a 300 meter calibration course is short or long by one tape length, the error would be a whopping 8 or 10 % (for a 25 or 30 meter tape), which is long enough that it could not long remain undetected! In particular, if the measurer somehow avoids discovering the mistake himself, then the certifier will immediately notice that the measurer's "constant" is weird!

Bob Letson mistakenly assumed the constant to be a logarithmic function of calibration course length; i.e., he claimed his constant increases by a fixed amount (1.5 counts/mile, or 0.93 counts/km) every time the calibration distance is halved. But the correct theoretical relation is the Calibration-Wobble equation, whose graph is a hyperbola. This equation predicts that my constant increases by 0.6 counts/km when the distance is halved from 1000 m to 500 m. But halving the distance from 500 m to 250 m causes my constant to jump by 1.2 counts/km!

(see Appendix – page 12)

Summary of Recommendations

1. Measurers should be allowed to use shorter calibration courses than are now allowed. Decreasing the length of the baseline tends to slightly increase the "constant" obtained by a cyclist, and thereby increases the length of measured race courses.

2. 300 meters would be a nice value for the minimum acceptable course length. It's short enough that it might provide some benefit in helping prevent short race courses. But it's long enough that it won't unfairly increase the chance of finding race courses short when doing validation re-measurements.

3. Do 6 rides (on each calibration occasion) if the calibration course is shorter than 500 meters. Do 4 rides (on each occasion) for courses of 500 m and up. In either case, the number of post-measurement re-calibrations should match the pre-measurement calibrations.

4. Bob Letson's wheel freezing method is a nice way of insuring adequate counter resolution, but is not necessary. It's enough to carefully reset the counter (to a whole number) before each ride, and then carefully read the counter (to the nearest half-count) after each ride. But we will have to be much more vigilant in ensuring that measurers are sufficiently careful in using the counter.

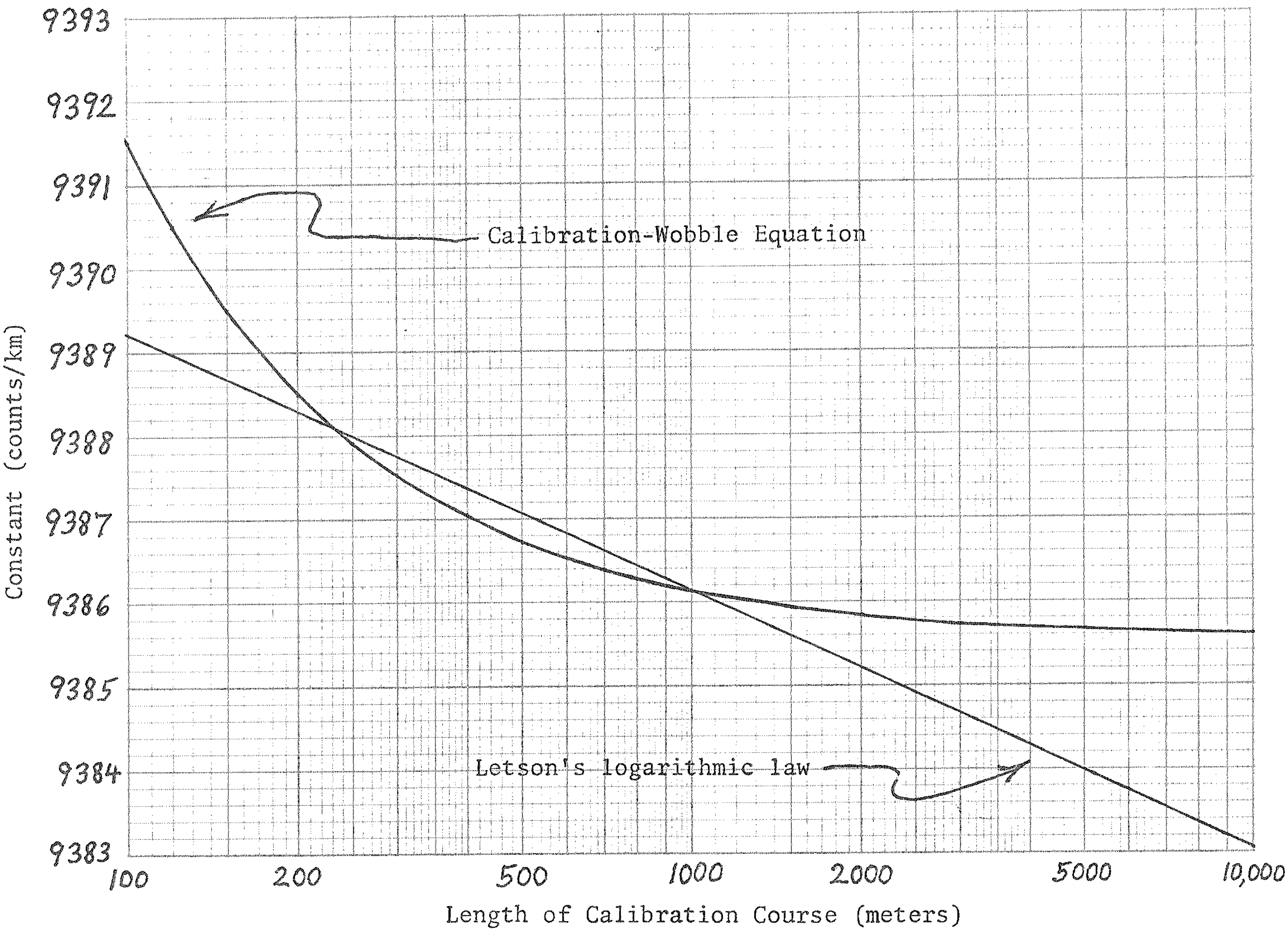
Bob Baumel

April 16, 1983

copies to: Ted Corbitt
Peter Riegel
Bob Letson
Ken Young

Appendix

Comparison of CALIBRATION-WOBBLE EQUATION versus LETSON'S LOGARITHMIC ASSUMPTION



Bob Letson's logarithmic assumption shows up as a straight line when plotted on semilog paper as above, while my "Calibration-Wobble" equation is still a curved line. The slope of Letson's line is determined by his statement that his constant increases by 1.5 counts/mile (or 0.932 counts/km) every time the baseline length is halved. However, I have shifted Letson's line vertically so that the two curves intersect for a calibration course length of 1 km.

The 2 curves are actually in excellent agreement over the range of course lengths covered by Letson's experiment (200 m to 1600 m), but they deviate significantly for longer or shorter courses. The most notable difference occurs at very long calibration courses, where the Calibration-Wobble equation correctly predicts that the constant levels off to an asymptotic value C_{∞} (which is only very slightly less than the constant obtained on a 1 km calibration course). But Letson's assumption predicts that the constant decreases without bound as the calibration course length is increased!