(A)

Boston Athletic Association

131 CLARENDON STREET, BOSTON, MASSACHUSETTS 02116
(617) 236-1652 Fax (617) 236-4505

The Marathon Performance

by Leonard F. Luchner

Regardless of any program or method of analysis to evaluate a marathon course, the runner must still traverse the required distance of 42.2 kilometers plus a corrective addition of 42.2 meters.

A current basis of analysis, by the Baumel mathematical model, is based on an article by R. Margaria, P. Ceretelli, P. Aghemo, and G. Sassi (Margaria et al), published in 1963, supported by the Italian Research Council, titled "Energy Cost of Running". The results, as noted, indicate that calorimetric measurements on athletes, running at different speeds and at various grades of slope, -20% to +15%, were found to be linearly related to speed and, that within these limits, the net calories, per kilogram of weight per kilometer, seem to be independent of speed and related only to the incline.

The article further states that the performance levels shown on the charts extend only to maximum aerobic metabolism, corresponding to a speed of 20km. per hour (5.55 meters per second) running on the level. (Energy wise, this value relates to approximately 20 kilocalories per kilogram of body weight per hour of effort; or as applied by Baumel, 3.86 Joules per kilogram meter, Joules being the metric equivalent energy work unit related to calories.)

This relationship between slope and energy, forms the basis of analysis by Baumel. He establishes relationships beween energy output and slope (both positive and negative), at total distances calculating the sum and proportionately evaluating it to the energy value at zero slope. The method is simplified by adopting average slopes for total rise and drop related to total distance. The differential is then evaluated as positive or negative and stated as an effective lengthening or shortening of the standard course length.

In relation to Boston, the method indicated an effective shortage equivalent to 1 minute 30 seconds.

Mr. Baumel further states that, from Margaria et al data, "although runners obviously consume energy at a faster rate when running faster, the energy consumed per meter is essentially constant, regardless of running speed" and, "naturally the energy cost per meter does depend on the degree of uphill and downhill incline".

Recent studies culminating in an article published in 1989, presented by Francois Peronnet and Guy Thibault of the Department of Physical Education at the University of Montreal, entitled "Mathematical Analysis of Running Performance and World Running Records", notes an important adjunct to energy output by relating aerobic to anaerobic performance at various distances, concluding, that as the race distance increases, anaerobic performance proportionately decreases to where, at the marathon distance, it becomes negligible (three tenths of one percent).

Note the following chart:

Distance/Meters	Percent Anaerobic	Percent MAP*
100	92.4	31.2
200	85.9	50.4
400	69.9	77.8
800	43.0	96.9
1500	23.9	99.9
3000	12.0	99.7
5000	6.3	96.5
10,000	2.5	92.3
21,100	0.9	87.7
42,195	0.3	83.5

* % of Maximal Aerobic Power (average power sustained over the total time of the event).

The above Table represents a level of achievement concurrent with maximum effort by today's elite athletes. Thus, it can be concluded that, for the marathon distance, the runner must limit performance to maximum aerobic output offset slightly by a decrease in total potential of approximately 16.5%.

M'ssrs Peronnet and Thibault make note of an interesting observation in their article. "It has long been recognized that performance in long distance events depends not only on the runners maximum oxygen uptake and running efficiency but also on the ability to utilize a large percentage of maximum oxygen uptake over a long period of time." "All runners have different levels of performance, depending upon their physiology. Although there is wide inter-individual variation in endurance capability, marathoners as a whole have a 85.3 percent ventilatory threshold of maximum aerobic power."

Professional medical consultation supports the above statement as follows:

The "Margaria et al" model of an athlete expending similar quantity of energy, no matter what the speed (as long as the pace is aerobic) with grade causing an increased or decreased energy use as the runner runs uphill or downhill, is a good one. However, it assumes that the athlete's physiological condition is unchanging during the time of measurement. For short distance racing, this is essentially true. However, for marathon racing it is most certainly not true.

A marathoner at 26.2 miles is a vastly different creature than at 2 miles or 12 miles. Dehydration has increased the heart rate required to maintain a given cardiac output, thereby increasing cardiac stress at any given work rate. Decreasing available carbohydrate fuel supplies in the working muscles require more energy provision from fat, and this alters the optimally maintainable pace. The beginnings of accumulating metabolic acidosis not only decrease the optimum rate of fuel metabolism but also adversely affect the kinds of length/tension relationships in skeletal muscle fibers required to maintain normal flexibility. Thus stride length decreases but stride frequency tends not to change. All of these factors tend to increase the amount of energy required to maintain a given pace or cause a decrease in pace for any given effort level.

Under these conditions, running uphill becomes even more difficult, and running downhill is not nearly as energy conserving. This is often reported subjectively by runners at

Boston who comment that the uphills come at a particularly nasty time in the race (as these physiological changes are becoming noticeable) and that even though the final several miles are noticeably downhill it is often difficult, or not possible at all, to pick up the pace. This suggests that under conditions of considerable physiological fatigue, the theoretical beneficial effects of downhill running in pace quickening and energy savings are not able to be incorporated successfully into a faster finish time.

The Baumel model is based on a quadratic equation, graphically representing the published data of Margaria et al, relating energy rate to slope in a parabolic form. Through mathematical derivation, the model presents a method by which road racing courses can be designated effectively short or long, by analysing the effect of drop and rise, in meters, to the measured length. For simplification, the occurrence of hills along the course route are assumed as "gentle" and cancel out. The original conclusion that Boston is 90 seconds "short" was based on such an analysis. Unfortunately, with full credit to Mr. Baumel, further analysis concluded that "hills do not cancel out" and should be included in determining the "effective length". Thus the original analysis loses credence.

Another approach, based again on Margaria et al data, relates to an energy balance. Average slope values, positive and negative, applicable to the total length of each, are used to obtain the equivalent energy rates from the same graphical representation, noted above. These rates, when multiplied by the total respective lengths of drop and rise and compared to the energy rate at zero slope for the same length of course, determine the effective length.

The graphical representation of the energy curve does not make any distinction between aerobic and anaerobic performance with respect to slope. By neglecting the physiological limits of anaerobic performance over the full distance, this method also loses credence as being an acceptable model.

Peronnet and Thibault, in their article, stress the progressive reduction, even in aerobic power, that can be sustained as running distances increase beyond 3000 meters, stating that "the major limitation of hyperbolic models is the assumption that maximal aerobic power (MAP) can be sustained for an infinite period of time. Such models are unable to provide accurate descriptions of running performance beyond 10,000 meters." The Baumel model commits the identical error by not recognizing a variation in the constancy of performance as the race distance increases.

Analyses based on "effective" length do not indicate the effect of grade on pace. The occurrence of oxygen debt, within the runner, increases the total elapsed performance time. Not only does a marathon course require energy output limited to aerobic performance, but gains and losses are to be measured and compared by the elapsed time for the total distance.

Because of the high degree of publicity related to the Boston course, it is necessary to analyze the Boston course based on the individual existing conditions and not averages. Slope variations exist between zero and 6 percent.

For the marathon, with its emphasis upon aerobic metabolism for energy production, even downhill running has very specific limits, although the maximum maintainable pace downhill at a given slope is relatively faster than that on level terrain. When running uphill the limitations to speed are, of course, more severe. The power output is proportionately greater (1.75 times - Baumel), hence the slower pace. The decreased energy needs for running downhill by a given amount do not cancel the energy need for running an equivalent grade uphill. Equal plus & minus slopes on hills do not cancel out.

The parameters of the Boston course, when both rise and drop are analyzed within aerobic limits, and its relation to pace, the time calculated to complete the distance, compared with a flat course, is evaluated at plus 50 seconds. The negative slopes show a gain of 51 seconds and the positive slopes a loss of 101 seconds. This does not include any additional reduction in the fractional utilization of aerobic power with increased running time.

A basis of comparison can also be established with reference to the Rotterdam course, which is perfectly flat, and has a best performance mark of 2hrs 6min 50sec. Interestingly, the maximum aerobic pace for zero grade, developed experimentally by Margaria et al, establishes an aerobic time of 2hrs 6min 36 secs for a 42.2 kilometer distance without grades. Densimo, in 1988, establishing his mark, showed differentials not exceeding 10sec, plus or minus, for each 5 kilometer section. The first three 5000 meter sections were run at 15min 10secs each.

Compare this to Boston. De Castella, with his best Boston performance, ran the first equivalent 5 kilometer segment at 14min 45secs, and 15min 14secs for 2nd and 15:16 for the 3rd segment. These sections contain the most significant drops along the course (86 meters, net). Half time for de Castella was 1:03:38 compared to Densimo's at Rotterdam of 1:03:22.

Kilometers:	**0-5**	**5-10**	**10-15**	**15-20**	**20-25**	**25-30**	**30-35**	**35-40**
Densimo:	15:05	15:00	15:01	15:06	15:00	15:01	15:09	15:07
						Total Time: 2:06:50		
DeCastella:	14:55	15:14	15:16	14:58	15:07	15:04	15:31	15:14
						Total Time: 2:07:50		

The Boston course weather conditions in 1986 were not a factor. Also, the Rotterdam course had a scpf of one (1) meter, in contrast to the longer Boston course scpf of 42 meters.

Compare, also, Steve Jones' time in 1985 at Chicago (basically a flat course), for half time of 1:01:42 and finishing time of 2:07:13. This suggests increased speed beyond that which can be maintained aerobically, whether downhill or a flat course, will inhibit that runner in the later stages of the race from maintaining a similar pace. The explanation is simple, anaerobic inhibition of aerobic metabolism through its slowing effects on metabolic enzyme activity.

The comparative performances of Ikangaa at Boston and New York also bear this out. Ikangaa ran 1:02:01 at half-point in Boston (April, 1989) and 1:03:44 in New York (Nov.,1989). The early fast pace in Boston subsequently forced Ikangaa, in the later stages of the race, to a much slower pace with accompanying leg cramps, (see Don Kardong's article in Runners World, July, 1990), finishing Boston in 2:09:50. Leg cramps are a direct metabolic result of prolonged anaerobic performance. By running at a more even pace, he was able to win in New York at 2:08:01, another striking example of steady performances at aerobic levels. Jack Fultz, a former Boston Marathon winner, notes that, "Boston should be run at a pace equivalent to the total distance, thus conserving energy on the down hill sections for later use on the hills. "Even at the elite running level, it is possible for the marathon to be completed with the second half faster than the first, but only if that first half was completed aerobically." (1991 race.) No runner completing the first half of the marathon with anaerobic output of energy has completed the total distance with a time less than the world best, regardless of course profile. More typically, the second half is drastically slower than the first, and the athlete might not even be in contention for victory.

The conclusion from these analyses enforces the need that races of at least marathon length must be run at a uniform aerobic metabolic output. Downhill portions can be run faster than uphill segments, but anaerobic contributions, no matter where they occur in the race, will negatively influence overall performance.

With respect to the rule (185.5) itself: a constant slope of one tenth of one percent (1/10 of 1%), equally apportioned over the entire marathon distance, and based on maximum aerobic performance, would mathematically result in a benefit of 14 seconds compared to the effective distance shortage method (Baumel) of 4 x 42 meters (168 meters) equivalent, at an equal pace, to 31 seconds. The effective shortening of 4 meters per one meter of drop does not apply at the marathon distance.

Acceptance of the .1 of 1% rule would have to acknowledge a short course effect for any elevation differential between 10 and 42.2 meters. According to Baumel's hypothesis, this would mean a 2 to 20 second gain. Is it fair to allow a record on a course within the allowable elevation limit, based on the one tenth of one percent rule, alone? Regardless of any elevation differential, whether within 42.2 meters or more, the analysis of a course effective length is incomplete without the inclusion of hill effects. The rule should, in effect, disqualify every race with an elevation differential greater than 10 meters if there were no intermediate hills. Yet, any course so arranged, cannot practically have a hill legislated within its course limits. Marathons should be a distinct entity without restrictions. There is precedence for this type of action. Cross country courses have no elevation restrictions or, for that matter, have no fixed distance, allowing them to vary for each venue. There is no Cross Country World Record, only course records.

From the point of view of race records, consider the potential variation that occurs within the limits of the short course prevention factor (scpf). A difference between the standard marathon length and an additional 42.2 meters amounts to approximately 8 seconds at maximum aerobic pacing. Measurements, after best performances on a given course, have shown variations of 1 meter up to and exceeding the 42.2 meter allowance. Should the course performance have a footnote as to the scpf differential, or should the performance not be recognized if the scpf is less than 42.2 meters.

Thus far nothing has been said about point to point or loop configurations for the marathon. It has been advanced that point-to-point marathons have an advantage over "loop" courses due to wind effects.

At present, there is the 30 percent rule, that supposedly counteracts a wind aided performance. Various directional representations on course structure have been examined, and when considering that head winds may have a deterrent effect up to 4 times the advantage from a similarly equal tail wind, it is possible to concede a certain differential between start and finish. The ratio of 4 to 1 does vary with wind intensity, as well as the pace of the runner; in any event, it does not seem to relate to a 30% differential. Some would say, as an example, that because the London Marathon has a 23% differential, a 30% rule would be proper. But what about a course that has a 31% differential, or for that matter, a point to point course without a loop, such as the 1991 site of the national championship for the Masters marathon. (St. George, Utah). Shouldn't national championship courses have respect for the rules? On an international basis, the Barcelona Olympic Marathon will be point to point, with the possibility of a revision of the final hill section near the stadium, to maintain the elevation differential and construct an alternate route with a lesser grade. The need to avoid heavily polluted areas by use of a point-to-point course along the ocean quite appropriately overcame any other consideration. At present TAC has not even addressed the question of an air pollution time differential factor.

If there is one thing about wind, it is omni-directional, rarely occurring in direct alignment to a course orientation. Wind is a complex process involving the sun's heat, the earth's motion, and the oceans. Local topography, determined by land variations of valleys and hills, also affects wind.

Wind cannot aid a runner, unless it exceeds the running speed of the athlete, which for the elite men in long distance races is approximately 5.5 meters/second or its Imperial equivalent of 12.4 miles/hour. If we examine the maximum possible gain of wind on point-to-point course, vis a vis the 30% rule, the only section coming into analysis is the last 35% of the course. The 30% differential, together with a 35% section in either direction is within the concept of not being in contention. Any winds against the runner will certainly impede a performance.

Winds usually are not steady but normally vary in speed and direction. Prevailing winds may vary with course venue, but again, who can actually predict that they will be in line with the runner. Any orientation to the runner does not aid performance to the full effect of the wind velocity. Since wind is a force, it can be vectorized so that only that portion aligned with the runner would be effective. And above all, aerobic performance again would limit any advantage of direct, wind alignment. Another consideration is how wind affects the runner in combination with hills.

This brings up an interesting point. A wind of 2m/sec in line with a runner on a 100 meter course is considered as aiding the performance. But what about a wind at 45 or 30 degrees to the runner, from behind, with a magnitude of 5.0 meters/sec, which can aid the runner in line with the course in excess of 2 meter/sec velocity? Should there be consideration for adopting a series of gauges at various orientation to the track to record cross wind velocities? Mr. Baumel states, for a marathon distance, that a runner with a tail wind of 8 meters/sec or approximately 20 miles/hour, along the entire course, with a corresponding running speed of 5.43 m/sec (compared to 5.5 m/sec aerobic limitation) can complete the marathon in 2:09:28. This is hardly a best in world performance with 67 thousandths of that time as wind aided effect. Were the runner to proceed beyond the 5.43 m/sec. pace, the time would be less than 2hrs 6mins, but this assumes a flat course with anaerobic performance. This is not commensurate with the present level of elite runner capabilities.

Eventually, a marathon time of two hours and 6 minutes will be bettered. As in the past, athletes will improve and extend present aerobic performances. Some of you, and certainly your children, will witness a marathon run in approximately 2 hours. It will not be because of hills or down grades. When it does occur, the performance will take place at a venue similar to Rotterdam.

The 30% rule, as now decreed, is lost in the myriad of variations prevalent in all courses, which take on a polygonal form, subject to limiting city requirements of street grids and the need to fit the length of the course into an area compatible to the required open spaces necessary at both start and finish. Any resemblance to location within a 30% margin is purely coincidental. It certainly is not a considered differential for wind effect, which might apply to parallel legs, but still subject to whatever velocities of prevailing winds occur at each venue. As Mr. Riegel, Chairman of the TAC Technical Committee, recently stated, "What is the use of all this? Well, it allows a highly individualized object, a race course to be measured by various criteria. What is to be done with these observations is unclear. To date, the criteria we officially use to define race courses are drop and separation. These are easy to calculate, and not too puzzling. The more complicated criteria would probably have some usefulness, but the limiting factor is data. In order to calculate anything accurately beyond drop and separation we need to have all the data for a highly detailed course profile. Since this is labor intensive, we will probably never obtain very many of them, except when curious people produce them for some reason."

It is not possible to relate a marathon course performance characteristic to average down hill slopes without conceding the "complicated" effect of hills and distance.

We claim Rule 185.5 oversimplifies. Varying conditions between start and finish on a course of 42.2 kilometers, with compromised local aberrations in course orientation, and supporting, at best, an empirical separation of start and finish, does create complications.

It is improper to rate a marathon course performance characteristic without consideration of the "complicated" effect of hills and distance. Equally applicable are the physical conditions along the entire course, and the runners varying energy conversion rate, that does not remain constant at the marathon distance. It is comparatively expedient to develop data indicating the effect of distance on a runner's performance. It is highly complicated to develop a mathematical model that must include such a feature and have it based on elapsed time.

They are necessary parts of any rule, equally applicable to all venues and distance. Simply put, the marathon should be recognized in a manner similar to Cross Country. Course length and its measurement must remain a controlled feature. (Baseball parks, golf courses, and tennis court surfaces have variations and, though not measured in a time frame, are all sanctioned venues.)

On an international basis, the 5000 and 10,000 meter distances are excluded from the Rule, presumably because of conflict between road and track. There is, however, technical credence to the elimination of some 5000m and 10,000m road performances from record consideration. The 5 and 10 kilometer distance allows anywhere from 3 to 6% of anaerobic performance by the runner, so that elevation differential between start and finish could effectively create an artificial benefit to total performance. Not so for the marathon. The marathon, with its extreme international variations in venue, and historical background, should have its own exemption. Again, cross country courses already enjoy such a distinction. (Course records only.)

What is being suggested is that the marathon be allowed to uphold a niche in the running world for the continued commemoration of an event, inspired by history, and indoctrinated into the modern Olympics as such. The marathon is currently fixed at 42.2 kilometers (since 1908) which harks back to an event that was a point-to-point run over historic terrain with an elevation variation of more than 42.2 meters. It commemorates an individual who, as is told, unfortunately died at the completion of his task. Today the distance is annually completed by hundreds of thousands of individuals, each with recorded time, over a distance properly and correctly ascertained by a method of course measurement certified by all national and international federations. These take place at venues of national and international interest, without relation to wind, temperature, orientation or elevation profile. The features that make the event different should not be sanitized to the equivalent of an oval track event, but should be allowed, regardless of venue, to reflect local surroundings and history.

Aside from impractical physical and physiology conditions of control, the need to separate the marathon from an event of strict regulation is to maintain its historic character to the world. In so doing, it enhances its significance to all long distance runners. A runner is proud just to complete a marathon. The prizes accompanying marathons relate to the individual venue and its competitors. The awards and elapsed time also relate to the venue and not the Rules, as it should be.