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The physics of "everesting" on a bicycle

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Among cycling enthusiasts the word "everest" has also become a verb over the last few years. "To everest" means going up and down the same hill or mountain until the elevation of Mount Everest (8848 m) has been accumulated in the course of the repeated ascents. It has been suggested that considerable advantage can be obtained by having a strong tailwind on the climbs. We make a quantitative assessment and show that the effect of a tailwind is small. Using control coefficients, we furthermore assess how factors such as weight reduction, increased power output, and improved aerodynamics can enhance the performance.
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I. INTRODUCTION

"Everesting" is to ascend the elevation of Mount Everest (8848 m) on a bicycle in a minimal amount of time. There is, of course, no road leading to the summit of Mt. Everest, so that the "everesting" has to be performed in another geographical location, through smaller climbs cycled multiple times. A hill that, for instance, makes the cyclist ascend 100 m is to be covered 88.48 times. The 88 descents are to be included in the time that is ultimately recorded. The rules state that ascent and descent must be via the same road. Internet-connected GPS trackers help verify the claimed achievements. All of the rules are listed in Ref. 1.

The original "everester" was George Mallory, the grandson of the famous George Mallory who took part in legendary Mt. Everest expeditions in the 1920s.[2] Back in 1994, young Mallory was preparing for a mountaineering expedition to Mt. Everest and, in order to get into shape, he would spend his weekends bicycling multiple times up Mount Donna Buang near Melbourne, Australia. He published about his rides and gained a following.[3] Inspired by Mallory, the Australian cycling enthusiast Andy van Bergen formulated rules and organized a world-wide everesting event in 2014.[1] In this event, riders picked a close-to-home hill and used web-based technology to keep track of each other's progress. However, it was in 2020, as the lockdowns forced cyclists to ride in solitude and communicate through the internet, that everesting really came to the fore.[4]

For an ordinary cyclist in good shape, the effort will generally take more than 20 h. Pros and semi-pros are much faster. On July 6, 2020, three years after his retirement from professional bike racing, Alberto Contador completed the challenge in a record time of 7:27:20. Just a few weeks later, on July 30, the Irish cyclist Ronan McLaughlin completed the challenge in 7:04:41.[5] In March of 2021, McLaughlin used the same hill as for his 2020 record, Mamore Gap, County Donegal, Ireland, to considerably improve on his previous accomplishment and achieve 6:40:54.[6,7]

We will use McLaughlin's record as a gauge in this article. The road that McLaughlin used for both attempts is an 810 m segment that climbs 117 vertical meters.[6] Weather reports show that McLaughlin did his first record-breaking performance with negligible wind. However, the second time he broke the record, there was a 5.5 m/s (20 kph or 12 mph) tailwind on the ascent.[6] Of course, that same wind was a headwind on the descent. There has been qualitative speculation about the extent of the "help" that McLaughlin got from the wind. Below we will build a simple physical model to quantitatively account, not only for the effect of the wind, but also to systematically assess the effect of increased power output, weight reduction, the use of a steeper hill, and improved aerodynamics.

II. THEORY AND RESULTS

A. Basic formulae

On a flat smooth road and at speeds larger than 10 m/s (36 kph or 22 mph), more than 90% of a cyclist's energy generally goes into overcoming aerodynamic resistance.[8] Cycling speeds, the cyclist's size, and the air's viscosity are such that the air flow is turbulent. In such a high-Reynolds-number environment, the force due to air friction is quadratic in the speed v,

$$F_{\mathrm{fr}} = \beta v^2, \quad \text{where} \quad \beta = \frac{1}{2}\rho C_{\mathrm{d}} A. \tag{1}$$

Here, ρ is the air density, C_{d} is a dimensionless drag coefficient that depends on the shape of the moving object, and A is the frontal area of the cyclist and their bike. We take $A = 0.45\,\mathrm{m}^2$ and $C_{\mathrm{d}} = 0.65$.[9] For the air density we have $\rho = 1.2\,\mathrm{kg/m}^3$, which leads to $\beta = 0.18\,\mathrm{kg/m}$. The parameter β cannot be accurately known. It changes as the rider changes position on the bike and it may therefore actually vary in the course of the ride. Other factors in the calculations are similarly imprecise. In what follows, we will consistently use two significant digits.

Following Eq. (1), to maintain a speed v on a smooth flat road, the cyclist has to provide a power

$$P_{\mathrm{fr}} = \beta v^3. \tag{2}$$

With $\beta = 0.18\,\mathrm{kg/m}$, this tells us that it takes 250 W to maintain a speed of 11 m/s (40 kph or 25 mph).

On an everesting, a single lap of length L involves ascending and descending the same road. On the ascent, we have to include $F_{\mathrm{gr}} = mg\sin\alpha$ as the extra force due to gravity. Here, m is the combined mass of the cyclist and the bicycle, g is the acceleration of gravity (9.8 m/s^2), and α is the angle of inclination. We let v_{up} be the ascending speed. The cyclist then has to work against a total force

$$F = \beta v_{up}^2 + mg \sin \alpha. \tag{3}$$

If the cyclist delivers a power P, a cubic equation in v_{up} ensues,

$$\beta v_{up}^3 + mg(\sin \alpha) v_{up} - P = 0. \tag{4}$$

Although a general solution for a cubic equation such as Eq. (4) is readily available, in what follows we will numerically solve this equation.

The top athletes generally use steep hills ($\gtrsim 10\%$) for their everestings and do not pedal on the downhill parts.[10] When coasting down a constant slope, a terminal speed v_{term} is approached, at which the aerodynamic resistance equals the gravitational pull,

$$v_{term} = \sqrt{\frac{mg \sin \alpha}{\beta}}. \tag{5}$$

B. Going up and down a steep hill

As mentioned above, Ronan McLaughlin used a 810 m road segment with a vertical rise of 117 m, i.e., $\sin \alpha = 0.14$ and $\alpha = 8.3°$. The incline of a road is commonly expressed as a "rise over run" percentage, i.e., the tangent $\times 100\%$. However, for angles of about 8° and smaller, the tangent and the sine are equal to within 1%. For his second record-breaking ride, Ronan McLaughlin used a 5.5 kg bike.[7] For Ronan's mass, we take 68 kg.[11] We thus have $m = 74$ kg. Parameters associated with Ronan's record-breaking ride are listed in Table I. To come to a first estimate for the time needed to cover the uphill part of the ride, we neglect air resistance. The functional threshold power (the highest power output that can be maintained for one hour) of a semi-professional bicycle racer is about 5 W per kilogram of body weight.[12] Taking 335 W for Ronan's power output and using

$$v_{up} = \frac{P}{mg \sin \alpha}, \tag{6}$$

we find an ascending speed of $v_{up} = 3.2$ m/s (12 kph or 7.2 mph). At that speed, the power to overcome the air resistance in windless conditions, i.e., βv_{up}^3, amounts to 6.5 W or about 2% of 335 W. This is already an indication that winds of up to about 5 m/s do not affect ascending speeds significantly. A speed of 3.2 m/s implies that the 810 m ascent is covered in 250 s.

Going down a 14% incline, high coasting speeds are achieved and a good aerodynamic position is generally more effective than an attempt to pedal. In order to save weight, Ronan McLaughlin's bike was actually equipped only with the few sprocket wheels that were appropriate for the climb. Applying Eq. (5), we find a terminal downhill speed of $v_{term} = 24$ m/s (86 kph or 54 mph). This is in agreement with a report that states that Ronan achieved speeds of 86.5 kph during his first record breaking of October 2020.[5] At such a speed, it would take just 34 s to go down the 810 m hill.

However, the terminal speed is asymptotically approached. To find out how rapid this approach is, a differential equation for $v(t)$ has to be solved. The equation and its solution are presented in the Appendix. Figure 1 depicts the solution of the differential equation for the parameter values listed in Table I. The figure shows that it takes about 10 s to reach half the terminal speed. Ultimately, the time to complete the 810 m descent in windless conditions comes out to be 46 s (cf. Eq. (A4)).

So far, the rolling resistance has not been taken into account. Rolling resistance is due to the deformation of the tires and of the road surface as the cyclist is moving. It is proportional to the normal force and follows $F_{fr,rol} = \mu_r mg \cos \alpha$, where μ_r is the coefficient of rolling resistance. For a racing bike on an asphalt road, $\mu_r = 0.006$ is a good estimate.[13,14] For our model, such an estimate will lead to corrections on the ascending and descending times in the range of one to five percent.

Like the gravitational force, the rolling resistance force does not depend on the speed. On the ascent, the rolling resistance can be incorporated by adding $F_{fr,rol} = \mu_r mg \cos \alpha$ to the $F_{gr} = mg \sin \alpha$ that the cyclist works against. On the descent, the rolling resistance opposes the gravitational pull that propels the cyclist, which means that we need to subtract $F_{fr,rol}$ from the gravitational force F_{gr}. Eventually, the rolling resistance can be incorporated as two small corrections on the slope: $(\sin \alpha)_{up} = \sin \alpha + \mu_r \cos \alpha$ for the uphill and $(\sin \alpha)_{down} = \sin \alpha - \mu_r \cos \alpha$ for the downhill. Implementing these corrections, we find a 4% decrease of v_{up} (cf. Eq. (6)) and a 2% decrease of the terminal downhill speed, v_{term} (cf. Eq. (5)).

Table I. The model parameters used to quantitatively account for Ronan McLaughlin's record-breaking everesting ride of March 2021.

Model parameters			
Symbol	Description	Units	Value
m	Combined mass of rider and bike	kg	74
β	Coefficient of friction (cf. Eq. (1))	kg/m	0.18
$\sin \alpha$	The sine of the angle of inclination of the hill	⋯	0.14
$L/2$	Length of the ascent/descent	m	810
P	Estimated power generation on the climbs	W	335
μ_r	Coefficient of rolling resistance	⋯	0.006
$(\sin \alpha)_{up}$	$\sin \alpha$ with a rolling resistance correction for the uphill	⋯	0.150
$(\sin \alpha)_{down}$	$\sin \alpha$ with a rolling resistance correction for the downhill	⋯	0.138

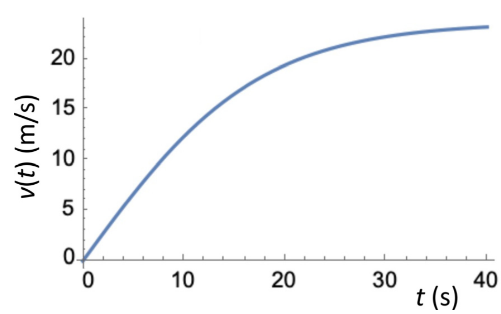

Fig. 1. The velocity $v(t)$ on the descent at zero wind speed ($v_w = 0$) follows $v(t) = v_{term} \tanh(v_{term} t / l_0)$, where $l_0 = m/\beta$ is a characteristic length. Parameter values are as in Table I. There is an asymptotic approach to the terminal speed $v_{term} = 24$ m/s. The rolling resistance is not included here, but it is small and does not noticeably alter the curve.

There are other small effects that are not incorporated in the model and it is not reasonable to expect the model to be 100% accurate. It is, for instance, likely that there are variations in the slope, i.e., α is not constant. Also β is likely to vary in the course of a lap as the rider takes on an aerodynamic tuck during the descent and does not do so on the ascent.

Another small complication occurs at the turnarounds at the top and bottom of the hill. The descent does not start at zero speed. At the top of the hill, the cyclist has to go down to a speed that is sufficiently low to make the 180° turn. Furthermore, for the first few seconds of the descent, the speed is so low that the cyclist can still add to the acceleration by pedaling. These two effects can reduce the rider's descending time by a few seconds. However, a few seconds are to be added again, when, toward the end of the descent, the cyclist has to brake and slow down to almost zero speed in order to turn and start ascending again. In the following, we will neglect these corrections and assume that the rider's velocity is zero at the beginning of each descent. The ascending speed, $v_{\rm up}$, is small and assumed to be constant during the entire duration of the ascent.

Let us note that the ascent lasts about five times as long as the descent. A 1% improvement on the ascent time will therefore be much more effective than a 1% improvement on the descent time.

C. Taking the wind into account

For his 2021 record, Ronan McLaughlin had a 5.5 m/s (20 kph or 12 mph) tailwind on the uphills. That wind speed is larger than the uphill speed of 3.2 m/s that we calculated in Sec. II B. Ronan thus received a push from the difference between his own speed $v_{\rm up}$ and the wind speed $v_{\rm w}$. It is straightforward to correct Eq. (3) and include the rolling resistance and the wind,

$$F = mg(\sin\alpha)_{\rm up} - \beta\,{\rm sgn}(v_{\rm w} - v_{\rm up})\,(v_{\rm w} - v_{\rm up})^2. \qquad (7)$$

Here, "sgn" denotes the sign function. For the power generation on the ascent, we have

$$P = mg(\sin\alpha)_{\rm up} v_{\rm up} - \beta\,{\rm sgn}(v_{\rm w} - v_{\rm up})\,(v_{\rm w} - v_{\rm up})^2 v_{\rm up}. \qquad (8)$$

This equation is again a cubic polynomial equation that we will solve numerically for $v_{\rm up}$. With $T_{\rm up} = L/(2v_{\rm up})$, we then obtain the time to complete the ascent.

Equation (5) gives the terminal speed of the descending cyclist relative to the air. In case of a headwind with a speed $v_{\rm w}$, the speed relative to the road will not converge to $v_{\rm term}$ but to $(v_{\rm term} - v_{\rm w})$. In the last paragraph of the Appendix, the headwind and the rolling resistance are taken into account and the differential equation for $v(t)$ is solved (cf. Eq. (A6)). The time $T_{\rm down}$ to complete the descent is then numerically derived as a function of the length $L/2$ of the descent (cf. Eq. (A7)).

All in all, for the time $T_{\rm tot}$ to complete one up-and-down lap, we have

$$T_{\rm tot} = T_{\rm up} + T_{\rm down}. \qquad (9)$$

For his record of March 2021, Ronan McLaughlin completed 76 laps in 6 h and 40 min, i.e., $T_{\rm tot} = 316$ s. Taking $v_{\rm w} = 5.5$ m/s and the values listed in Table I, the model developed here leads to $T_{\rm up} = 259$ and $T_{\rm down} = 56$ s, i.e., $T_{\rm tot} = 315$ s.

D. The effect of the wind on the everesting time

The aim of this section is to assess the effect of $v_{\rm w}$ on the lap time $T_{\rm tot}$. This will tell us to what extent the wind can help the everester. Figure 2(a) shows the uphill speed $v_{\rm up}$ as a function of the windspeed $v_{\rm w}$. If the windspeed equals the speed of the rider, the rider feels no wind. At that point, the $(v_{\rm w}, v_{\rm up})$ curve has an inflection point that is due to the quadratic term in $(v_{\rm w} - v_{\rm up})$ changing its sign (cf. Eq. (8)). An inflection point will also be present when we plot $T_{\rm up} = L/(2v_{\rm up})$ as a function of $v_{\rm w}$.

Figure 2(b) shows $T_{\rm tot}$ (cf. Eq. (9)) as a function of the wind speed, $v_{\rm w}$. Remarkably, the curve shows three extrema. How this happens can be understood upon inspection of Fig. 2(c). Figure 2(c) shows how the time $T_{\rm up}$ decreases as $v_{\rm w}$ is increased. However, near the inflection point, for $v_{\rm w}$ in the range of 2–4 m/s, $T_{\rm up}$ remains practically constant. The almost linear increase of $T_{\rm down}$ then leads to an increase of $T_{\rm tot}$. Only at about $v_{\rm w} = 6$ m/s does the decrease of $T_{\rm up}$ become dominant again. After $v_{\rm w} = 13$ m/s, the increase of $T_{\rm down}$ becomes faster than the decrease of $T_{\rm up}$ and a second minimum ensues. The three extrema persist when parameter values are taken that are slightly different from the ones in Table I.

For reasonable values of $v_{\rm w}$ (i.e., wind speeds of less than 15 m/s), $T_{\rm tot}$ varies by only 2% (Fig. 2(b)), which means that the decrease in $T_{\rm up}$ is almost canceled out by the increase in $T_{\rm down}$ (Fig. 2(c)).

E. Control coefficients

We saw in Sec. II C that a relative change in wind speed leads to a smaller relative change in $T_{\rm tot}$. In this section, we develop a quantitative formalism to assess the influence of the wind and of other parameters.

We let T be the full everesting time. Obviously, a relative change of the lap time $T_{\rm tot}$ leads to the same relative change of T. If λ is one of the model parameters, then the control coefficient C^T_λ is defined as the following ratio of the relative changes:[15,16]

$$C^T_\lambda = \frac{\Delta T/T}{\Delta\lambda/\lambda}. \qquad (10)$$

In numerical and experimental practice, C^T_λ is commonly taken as the percentage by which T changes if the parameter λ is changed by 1%. In case of a q% change of λ, T will change by (qC^T_λ)%, provided q is not too large and the involved functions are not "too wild." The control coefficient thus assesses the influence that λ has on the everesting time T and can be evaluated by numerically solving Eqs. (8) and (A7).

Taking $v_{\rm w} = 5.5$ m/s, we find $C^T_{v_{\rm w}} = 0.0051$. This quantifies the observation that we made in the context of Fig. 2: wind speed $v_{\rm w}$ does not affect much the total everesting time.

Still with $v_{\rm w} = 5.5$ m/s, we obtain $C^T_\beta = 0.067$ for the effect of β. The value of β changes as the rider changes position on the bike. On the downhill, a more aerodynamic position decreases β and decreases $T_{\rm down}$. But with a tailwind that exceeds $v_{\rm up}$, the smaller β leads to less help from the

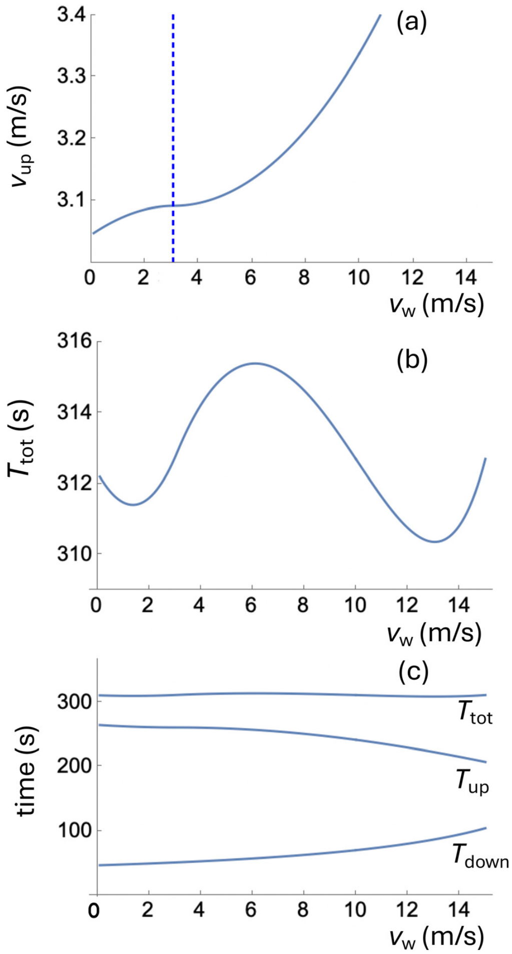

Fig. 2. (a) The uphill speed, v_{up}, as a function of the windspeed v_w (cf. Eq. (8)). The parameters are as in Table I. The vertical dashed line indicates the inflection point at $v_{up} = v_w$. (b) The total time, $T_{tot} = T_{up} + T_{down}$, to complete a lap as a function of the wind speed v_w. (c) The total time T_{tot}, the ascending time T_{up}, and the descending time T_{down} over the full range. Note that for increasing v_w, the decrease of T_{up} and the increase of T_{down} almost cancel out. The resulting variation of T_{tot} is less than 5 s, i.e., 2%.

wind on the uphill and a larger T_{up}. As with v_w, the downhill and uphill effects almost cancel out and lead to the very small control coefficient. It is hard to assess what happens with a β that is different on ascent and descent. Both the frontal area A and the drag coefficient C_d change when the cyclist changes position. The value of C_d, moreover, depends on whether the apparent wind is a headwind or a tailwind. However, given the small value of C^T_β, incorporation of the effect of position-change should not affect T too much if the difference between the uphill and downhill β is not too large.

Every biker and hiker is familiar with the fact that weight makes a climb harder. With $v_w = 5.5$ m/s, we find $C^T_m = 0.74$. That the control coefficient is smaller than unity makes sense after realizing that a larger m increases T_{up} but reduces T_{down}. If the everesting effort had only involved a steep climb and no aerodynamic effects, the control coefficient for the mass m would have been unity (cf. Eq. (6)).

Similar logic applies for the power P. The control coefficient C^T_P would be -1 if there were only a climb and if the wind were neglected. With our values, we find $C^T_P = -0.80$. This result is in agreement with the fact that there is power input for about 80% of the time.

An important issue for an everesting attempt is the inclination of the chosen hill.[4] Is there an optimal steepness? The height that is covered in one lap is $h = (1/2)L \sin\alpha$. The height h remains the same if L is decreased by the same small percentage that $\sin\alpha$ is increased by. For the above parameters, we find $C^T_L = 0.97$ and $C^T_{\sin\alpha} = 0.67$. That C^T_L is slightly smaller than unity makes sense upon realizing that T_{down} includes a characteristic length, l_0, that is associated with the asymptotic approach to $\tilde{v}_{term} - v_w$. This length is independent of L. It is also easy to understand that for a steeper slope and the same L, the uphill speed will be smaller and the downhill speed will larger. A positive $C^T_{\sin\alpha}$ ensues, because the uphill speed is held for a longer time. With a simultaneous 1% increase of $\sin\alpha$ and 1% decrease of L, we find $C^T_{\sin\alpha} - C^T_L = -0.30$. Several effects lead up to this final value. The first approximation, $v_{up} = P/(mg\sin\alpha)$, shows how a steeper hill leads to a smaller speed. Nevertheless, because of the smaller L, the time to reach height h will stay the same. Next, taking the wind speed v_w into account, the smaller v_{up} will make the rider feel a bigger push from the tailwind if $v_w > v_{up}$. This leads to a slightly smaller T_{up}. On the downhill, the increased steepness will have a much larger effect. Both the higher descending speed and the smaller L will lead to a T_{down} that is significantly smaller.

As was already noted, the best everesting times were all achieved on inclinations that are larger than 10%.[10] The analysis of the previous paragraph explains why better everesting times can indeed be achieved on steeper hills. A relative increase in the steepness of 1% reduces the time by about 0.3%. With this observation, it must be realized that when riding up hills that are steeper than about 15%, the mere force that has to be continuously applied to keep rolling and the lack of good balance at low speed become factors that can no longer be neglected. It appears that the top everesters have converged on an optimal steepness between 10% and 15%.

III. DISCUSSION

The reference by Knight[13] is titled "The Bicyclist's Paradox" and starts out with the following observation: "*If you cycle up a hill and then back down with no net change in elevation, it seems as if your slower uphill speed and faster downhill speed should offset each other. But they don't. Your average speed is less than it would have been had you cycled the same distance on a level road. Similarly, cycling into a headwind for half your trip and returning home with a tailwind yields an average speed less than you would have achieved on a windless day*." The lower average speed is due to the fact that the lower speed is held for a longer time. After these realizations, one may next be tempted to conjecture that wind and slope can offset each other. In our case, a strong tailwind would exactly cancel out the effect of the uphill slope and, after the turnaround, the now headwind cancels out the effect of the downhill slope. It would then next be possible to ride up and down the hill as if the road is level. But a short derivation involving formulae used in this article and neglecting the rolling resistance shows that such intuition is misguided. For $F_{gr} = mg\sin\alpha$ and $F_{fr} = \beta v_w^2$ to cancel, we need $v_w = \sqrt{mg\sin\alpha/\beta}$. With the parameter values in Table I, this implies $v_w = 24$ m/s (86 kph or 54 mph). Such a wind is considered a "severe gale." Going up the hill, Eq. (8) translates into $P_{up} = mg(\sin\alpha)v_{up} - \beta(v_w - v_{up})^2 v_{up}$. Writing out the quadratic term and using the fact that $mg\sin\alpha = \beta v_w^2$, we then find

$$P_{up} = \beta v_{up}^2(2v_w - v_{up}). \tag{11}$$

The equation for the descent, $P_{down} = -mg(\sin\alpha)v_{down} + \beta(v_w + v_{down})^2 v_{down}$, likewise leads to

$$P_{down} = \beta v_{down}^2(2v_w + v_{down}). \tag{12}$$

In Sec. II A, it was explained how on a flat surface in windless conditions we have $P = \beta v^3$ (cf. Eq. (2)) and that, with $\beta = 0.18$ kg/m, this leads to a manageable 250 W to maintain 11 m/s (40 kph or 25 mph). With Eqs. (11) and (12), we find that it takes unsustainable power generations of $P_{up} = 790$ and $P_{down} = 1270$ W to maintain 11 m/s on the ascent and descent, respectively.

It is easy to check that the cancelation of wind and incline could have worked in a low Reynolds number environment where the air friction is linear in the speed, i.e., $F_{fr} = \gamma v$ instead of Eq. (1). Ultimately it is the air friction's "quadraticness" in v that makes it fundamentally impossible to compensate for incline with wind and to get a significant wind advantage in an everesting effort.

In our analysis, we had the wind blow parallel to the direction of the road. But a wind from the side, i.e., a perpendicular component, actually also affects the speed of the cyclist.[17] Decompose the wind velocity into a parallel component, $v_{w,par}$, and a perpendicular component, $v_{w,perp}$. Let the cyclist ride with a speed v and let $v_{w,par}$ point in the same direction as the cyclist's motion. With Pythagoras we have for the absolute value of the aerodynamic force on the cyclist:

$$F_{fr} = \beta\left[(v - v_{w,par})^2 + v_{w,perp}^2\right]. \tag{13}$$

It is the component of this force that is parallel to the road that affects the riding cyclist. After some trigonometry and algebra, we derive

$$F_{fr,par} = \beta(v - v_{w,par})^2\sqrt{1 + \left(\frac{v_{w,perp}}{v - v_{w,par}}\right)^2}\,\mathrm{sgn}(v - v_{w,par}). \tag{14}$$

It is obvious from this formula that the absolute value of $F_{fr,par}$ increases with a stronger sidewind. The sign function tells us that the "extra push from the sidewind" works against the cyclist if the parallel component makes the riding cyclist feel a headwind. On the other hand, $v_{w,perp}$ assists if the parallel component makes the cyclist feel a tailwind. It is again the quadraticness of Eq. (1) that is behind this counterintuitive phenomenon.

That the control coefficient $C_{v_w}^T$ is almost zero is due to a cancellation: an ascent that is Δt faster is offset by a descent that lasts Δt longer (see Fig. 2(c)). However, there is an obvious advantage here for the cyclist as ascending requires a power P, while their legs are held still on the descents. Transferring Δt from the ascent to the descent means that a lap is completed in the same time, but with an energy input that is $P\Delta t$ smaller. With the $v_w = 5.5$ m/s of Ronan's record, ascents are eight seconds faster and descents are eight seconds slower as compared to $v_w = 0$.

For wind speeds that are more realistic than the severe gale considered in the first paragraph of this discussion, we found a control coefficient $C_{v_w}^T$ that is negligibly small and a T_{tot} that does not significantly vary with v_w (cf. Fig. 2(c)). The advantage presented in the previous paragraph is relatively small. All in all, changing the everesting rules to set limits on allowed wind speeds is not warranted by the physics.

In Sec. II B and in the Appendix, we saw that it takes time to accelerate to the terminal speed on the downhill. This adds about 12 s to the lap time. An obvious way to improve the everesting time would be to take a longer lap that covers a bigger elevation difference. With a hill that is twice as long as Mamore Gap and an ensuing 38 instead of 76 downhill accelerations, more than 7 min could in principle be gained. For Ronan McLaughlin's achievement at Mamore Gap, each 5-min lap consisted of a 4-minute climbing effort followed by, effectively, a 1-min rest. Because of the regular rests, the power output during the 4 min effort is probably higher than an output that could be sustained uninterruptedly. It is likely that there is an optimum time interval if one is to follow each effort with a rest that lasts about a quarter of the time of the effort. The optimum may, moreover, differ from one athlete to another. But these are physiological issues that we do not address. Suffice it to say that the aforementioned 12 s is the price one pays for a shorter lap.

The coverage of Ronan McLaughlin's two everestings makes mention of the "normalized power"[5] and the "weighted average power."[6] Bike computers can give these numbers as part of the ride data. We have not made these data part of the analysis as they are not simple averages over a ride with varying speed and power output. They are actually the result of algorithmic operations that purport to derive a sustainable power from an effort with a varying power.

Parameters that we found to have small control coefficients do not warrant serious consideration for an everesting attempt. What the control analysis ultimately tells us is that the most intuitive ways toward faster everesting times, i.e., reducing weight and increasing power, are indeed the most effective ways. There are no clever tricks to get around the necessary diet and exercise.

AUTHOR DECLARATIONS

Conflict of Interest

The author has no conflicts of interest to disclose.

APPENDIX: A TRANSCENDENTAL EQUATION FOR THE DOWNHILL TIME

The net force on the descending, non-pedaling cyclist is the difference between the force of gravity and the force due to air friction: $F_{net} = F_{gr} - F_{fr}$. Through Newton's Law, we thus find a differential equation,[18]

$$\dot{v} = g\sin\alpha - \frac{v^2}{l_0}, \tag{A1}$$

where the dot denotes differentiation w.r.t. time ($^\bullet \equiv d/dt$) and $l_0 = m/\beta$. The parameter l_0 is a characteristic length of the system. For the values in Table I, we have $l_0 = 408$ m. Setting $v(t=0) = 0$, the solution is readily found,

$$v(t) = v_{\mathrm{term}} \tanh\left(\frac{v_{\mathrm{term}} t}{l_0}\right). \tag{A2}$$

The prefactor v_{term} is the terminal speed that was calculated in Sec. II B (cf. Eq. (5)). Figure 1 shows $v(t)$ for the values given in Table I.

We integrate $v(t)$ to obtain the distance s_0 that is covered in a time t_0,

$$s_0 = \int_0^{t_0} v(t)\, dt = l_0 \ln\left[\cosh\left(\frac{v_{\mathrm{term}}}{l_0}\, t_0\right)\right]. \tag{A3}$$

From Eq. (A3) we readily find a formula for the time t_0 that it takes to descend a distance s_0,

$$t_0 = \frac{l_0}{v_{\mathrm{term}}} \cosh^{-1}\left(e^{s_0/l_0}\right). \tag{A4}$$

With a headwind v_{w}, the terminal speed is lower. Taking the rolling resistance into account (see main text), we now have

$$\dot{v} = g(\sin\alpha)_{\mathrm{down}} - \frac{(v + v_{\mathrm{w}})^2}{l_0}. \tag{A5}$$

After taking $v' = v + v_{\mathrm{w}}$, an equation like Eq. (A1) is obtained for v'. The initial condition, $v(t=0) = 0$, makes the solution now slightly more complicated,

$$v(t) = \tilde{v}_{\mathrm{term}} \tanh\left(\frac{\tilde{v}_{\mathrm{term}}}{l_0}(t + \tau)\right) - v_{\mathrm{w}},$$
$$\text{where} \quad \tau = \frac{l_0}{\tilde{v}_{\mathrm{term}}} \tanh^{-1}\left(\frac{v_{\mathrm{w}}}{\tilde{v}_{\mathrm{term}}}\right). \tag{A6}$$

Here $\tilde{v}_{\mathrm{term}}$ includes the rolling resistance correction, i.e., $\tilde{v}_{\mathrm{term}} = \sqrt{mg(\sin\alpha)_{\mathrm{down}}/\beta}$. Note that we now have $v(t \to \infty) = \tilde{v}_{\mathrm{term}} - v_{\mathrm{w}}$. Integration is once again possible and leads to a relation between the length of the descent $L/2$ and the descending time T_{down},

$$L/2 = l_0 \left[\ln\cosh\left(\frac{\tilde{v}_{\mathrm{term}}(T_{\mathrm{down}} + \tau)}{l_0}\right) - \ln\cosh\left(\frac{\tilde{v}_{\mathrm{term}}\tau}{l_0}\right)\right] - v_{\mathrm{w}} T_{\mathrm{down}}. \tag{A7}$$

Unlike Eq. (A4), this is a transcendental equation, i.e., an analytic expression for the descending time T_{down} cannot be obtained and one must resort to numerical methods for a solution. Equation (A7) is what we use in the main text to evaluate the actual everesting times.

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