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Translating Uphill Cycling into a Head-Wind and Vice Versa

Sjoerd Groeskamp [1]✉

Abstract

Forces acting upon a biker, can be expressed in terms of power (in Watts). Such forces are for example (but not limited to) air-drag, rolling friction and changes in potential energy (due to gravity, when riding up a hill). Here, the author will specifically compare power related to air drag, with that related to cycling up a hill. This allows the author to define the Incline-Equivalent Wind Velocity. The Incline-Equivalent Wind Velocity translates a slope of a mountain into a wind speed, such that overcoming both forces require the same power. The Incline-Equivalent Wind Velocity can therefore be interpreted as the velocity with which the wind has to push a rider such that the rider does not roll down a slope of a certain angle, and the net movement is zero. This can be used to recalculate mountain profiles into Incline-Equivalent Wind Velocity profiles and can express the effect of drafting in terms of a reduction in wind speed and incline, rather than power.

Keywords: cycling, power, air drag, uphill, head wind, drafting.

✉ sjoerdgroeskamp@gmail.com (S. Groeskamp)

[1] Columbia University

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Introduction

Many cyclist have battled against both hills and mountains, sometimes simultaneously. As a result, many have wondered how cycling up a hill compares to cycling against the wind. In addition, many cyclist live in areas without mountains, but subject to plenty of wind (such as the Netherlands). To understand the effort required to ride up a mountain (as for example in a Tour de France), it is more intuitive for such cyclists to express this effort into a head-wind. In this study, I will express the incline of a mountain as a head-wind velocity, such that riding up mountains can be compared to riding against a head-wind.

In case of cycling against the wind, generally air drag is the largest force that needs to be overcome in order to move forward. When cycling up a hill, when speeds are lower, gravity is the main force to overcome in order to move forward. Both types of forces can be expressed as a power (in Watts, where 1 W = 1 J s^{-1}). By comparing the power required to cycle against the wind, to the power required to cycle up a hill, a relationship between the two will be established.

Martin et al (1998) showed that almost 98% of the power and velocity during road cycling can effectively be predicted by a mathematical model. They also claimed that the missing 2% could be explained by friction in the drive chain. Therefore, using the same mathematical model as described by Martin et al (1998), it is possible to accurately relate cycling up a hill with cycling against a head-wind and define the `Incline-Equivalent' Wind Velocity.

This paper is organized as follows; first the mathematical model that is used (section 2) is described, after which the incline is expressed in terms of an Incline-Equivalent Wind Velocity (section 3 and 4). Once the Incline-Equivalent Wind Velocity is defined, this is used to translate mountain profiles into wind profiles (section 5) and express the effects of `drafting' in terms of a reduced incline (section 6). This study is finalized with some concluding remarks (section 7).

The Mathematical Model

Two expressions are required in order to relate uphill cycling with a head wind; 1) an expression for the required power to cycle up a hill P_{hill} (with no wind) and, 2) an expression for the power it takes to cycle against the wind P_{wind} (with no incline). First, the mathematical model as presented by Martin et al (1998) is described for the total power P_{total} required for cycling. Then the components related to uphill cycling P_{hill} or cycling against the wind P_{wind} are defined and equated, in order to obtain the incline equivalent wind velocity v_α. Here α stands for incline.

Total Power

Total power is given by (Martin et al 1998)

$$P_{\text{total}} = E_c^{-1}(P_{\text{AD}} + P_{\text{WR}} + P_{\text{WB}} + P_{\text{RR}} + P_{\text{PE}} + P_{\text{KE}}). \quad (1)$$

Here E_c^{-1}, is the chain efficiency, representing how efficient the power is transferred from the rider into forward motion after frictional losses in the chain drive. Throughout this study it is used that $E_c^{-1} = 0.98\%$ (Martin et al 1998). Below, the expression for the different components on the right-hand side of Eq. (1) are provided.

Air-drag Power
Air-drag Power P_{AD} is due to friction of the air moving relative to the position of the cyclist (Fox et al 1995)
.

$$P_{\mathrm{AD}} = \frac{1}{2}\rho C_{\mathrm{d}} A v_{\mathrm{a}}^2 v_{\mathrm{g}} \quad (2)$$

Here ρ is the density of air (kg m^{-3}), C_{d} is a unit less drag coefficient, A is the frontal area (m^2) of the rider and $v_{\mathrm{a}} = v_{\mathrm{g}} - v_{\mathrm{w}}$ is the net velocity (m s^{-1}) of the bike with respect to the air. Hence, v_{a} is made up of v_{g}, which is the forward velocity (m s^{-1}) of the bike relative to the ground, and v_{w}, which is the wind velocity (m s^{-1}) parallel to the direction in which the bike moves (same direction as v_{g}). This means that when $v_{\mathrm{w}} < 0$, it represents a headwind. As a result, v_{a} is the net velocity of the bike, with respect to the air. For example, if the wind is moving in the same direction as the bike, and has the same speed as the biker, such that $v_{\mathrm{g}} = v_{\mathrm{w}}$ then the air around the bike is moving with the same speed as the biker. As a result, there is no air-friction as $v_{\mathrm{a}} = 0$. However, if there is a headwind ($v_{\mathrm{w}} < 0$), then this will increase the net velocity of the bike with respect to the air.

Wheel Rotation Power
Wheel Rotation Power P_{WR} is due to friction of the spokes of wheels moving through the air

.

$$P_{\mathrm{WR}} = \frac{1}{2}\rho F_{\mathrm{w}} v_{\mathrm{a}}^2 v_{\mathrm{g}} \quad (3)$$

Here F_{w} is a factor (m^2) associated with wheel rotation that represents the incremental drag area of the spokes.

Rolling Resistance Power
Rolling Resistance Power P_{RR} of the tire moving over a surface. This factor depends on variables such as the roughness of the tire and the surface, the tire pressure and the weight of the rider and the bike. The characteristics of the tire and the surface are represented by a single non-dimensional rolling resistance coefficient C_{RR}, leaving

.

$$(P_{\mathrm{RR}} = C_{\mathrm{RR}} m g v_{\mathrm{g}} \cos(\tan^{-1}(\alpha)) \quad (4)$$

Here g, is the gravitational acceleration, and $m = m_{\mathrm{rider}} + m_{\mathrm{bike}}$ is the total mass of the rider (m_{rider}) and the bike (m_{bike}). Finally, $\alpha = \Delta H \Delta S^{-1}$ is the incline of the hill measured as the height difference (ΔH) over the horizontal distance (ΔS).

Wheel Baring Power
Wheel Baring Power P_{WB} is the loss of power due to frictional loss in the wheel bearing. I use the same expression as Martin et al (1998), who got their values from a study by Dahn et al (1991)

$$P_{\mathrm{WB}} = v_{\mathrm{g}}(b_1 + b_2 v_{\mathrm{g}}) \quad (5)$$

where $b_1 = 9.1\mathrm{x}10^{-2}$N, and $b_2 = 0.87\mathrm{x}10^{-2}$N s m^{-1}.

Potential Energy Power
Potential Energy Power P_{PE} is a result of cycling up or down a hill. When cycling down a hill, gravity does work for you. This work can be expressed as a change in potential energy and depends on the mass m and the incline α
.

$$P_{\mathrm{PE}} = m g v_{\mathrm{g}} \sin(\tan^{-1}(\alpha)) \quad (6)$$

Kinetic Energy Power
Potential Energy Power P_{KE} is the result of acceleration. When a cyclist changes speed (acceleration), this changes the kinetic energy of the rider (+ bike) and that related to the speed of rotation of the wheel. The change in kinetic energy over time Δt is given by
.

$$P_{\mathrm{KE}} = \frac{1}{2}(m + I r^{-2}) \frac{(v_{\mathrm{g}} + \Delta v_{\mathrm{g}})^2 - v_{\mathrm{g}}^2}{\Delta t} \quad (7)$$

Here r is the outside radius of the tire (m), I is the moment of inertia of the two wheels, and Δv_{g} is the increase in speed over time Δt, starting from v_{g}. Below, a brief look at the magnitude of the different components is presented.

Comparing the different powers
To compare the relative importance of the magnitude of the different Power-components that make up P_{total}, values as given in Table 1 are used for an amateur rider (in which, AC_{d} is combined into one number), and Table 2 for the other parameters.
In the appendix of Martin et al (1998), a value of $F_{\mathrm{w}} = 0.0044$ is used (about 2 orders of magnitude smaller than AC_{d}), without further explanation. Greenwell et al (1995) and Tew and Sayers (1999) however, suggest that F_{w} is between 2% and 25% of that of AC_{d}, depending on the type of wheel that is used. This would lead to values possibly up to $F_{\mathrm{w}} = 0.06$. Here a fixed value of $F_{\mathrm{w}} = 0.04$ (Table 2) is used, about an order of magnitude larger than that suggested by Martin et al (1998), and in the range of possible values for both amateurs and professionals. Finally, to calculate the kinetic energy an acceleration of 5 km h^{-1}, over 5 seconds (Table 2) is used.
From the results (Fig. 1), it is clear that the power required for Potential and Kinetic Energy and to overcome the Air Drag, are the dominant, specifically for larger velocities. Rolling friction, Wheel Bearing friction and wheel rotation play a minor role. As I will consider a cyclist at constant speeds ($P_{\mathrm{KE}} = 0$), the

Table 1. For different types of riders (1st column), different values for AC_d (2nd column) and the total mass (3rd column) are given. The AC_d values are mainly based on Wilson (2004). This results in different `drag' velocities (4th column).

Rider Type	AC_d (m^2)	$m_{bike} + m_{rider} = m$ (kg)	v_d (m s^{-1})
Commuter	0.65	20 + 80 = 100	50.2
Amateur	0.4	10 + 75 = 85	55.6
Prof Time Trial	0.28	7 + 70 = 77	71.0

Table 2. To provide a bulk estimate for comparison of the different components of P_{total} (Fig. 1), the above values (2nd column) for the different variables (1st column) are used. The source is provided in the 3rd column, where G95, M98 and T99 stand for Greenwell et al (1995), Martin et al (1998) and Tew and Sayers (1999), respectively.

Variable	Symbol	Value	Source
Density	ρ	1.20 kg m^{-3}	Dry air, T=20 °C, P=101.325 kPa
Gravity	g	9.81 m s^{-1}	
Drag Spokes	F_w	0.04 m^2	G95 & T99
Rolling Resistance	C_{RR}	0.0032	M98
Velocity Biker	v_g	25 km h^{-1}	
Velocity Head-Wind	v_w	-30 km h^{-1}	
Radius	r	0.660 m	Tire (2.5 cm) + Wheel (63.5 cm)
Moment of Inertia	I	0.14 kg m^2	M98
Incline	α	0.05 (5 %)	
Acceleration	$\Delta v_g/\Delta t$	0.278 m s^{-2}	5 km h^{-1} per 5 s

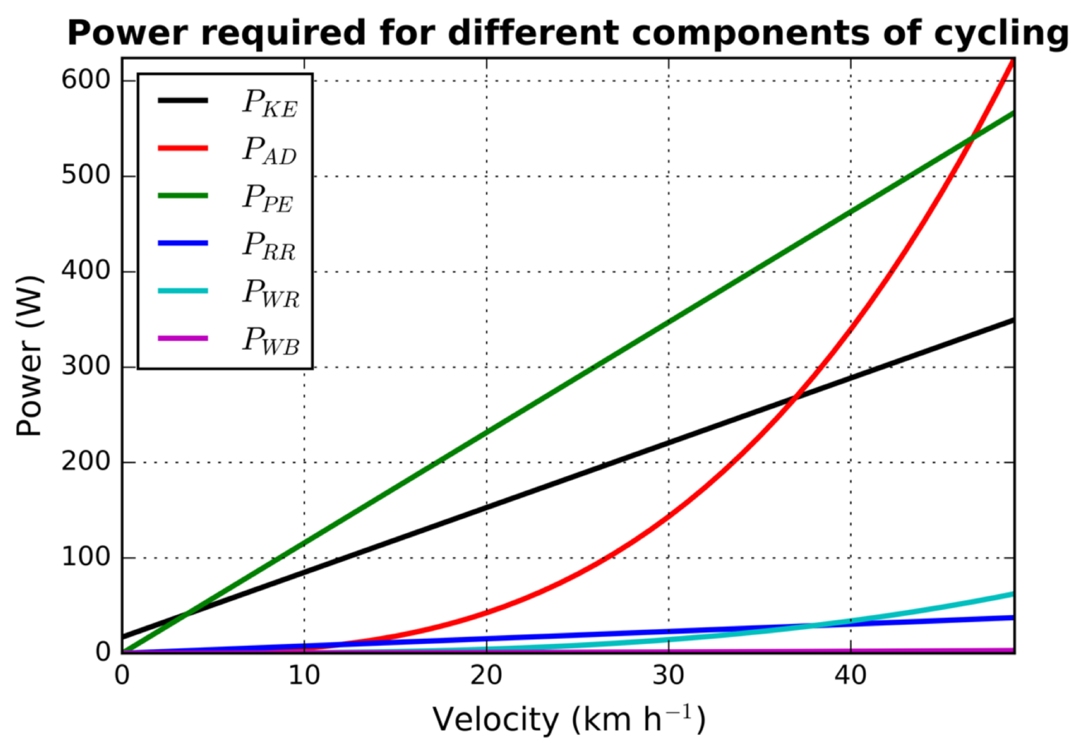

Figure 1. The components of P_{total}, given by the power required for Kinetic Energy P_{KE}, Air Drag P_{AD}, Potential Energy P_{PE}, Rolling Resistance P_{RR}, Wheel Rotation P_{WR}, and Wheel Baring P_{WB}.

dominant balance to convert uphill cycling into cycling against the wind, will be between the power related to the change in potential energy (P_{PE}) and that to overcome air drag (P_{AD}).

Translating uphill cycling into a headwind.

Here an expression that compares riding up a hill (without wind) to riding against the wind (on a flat surface) is derived. It is assumed that the rider has a constant speed such that $P_{\mathrm{KE}} = 0$ (black line in Fig. 1). Using Eq. (1), the expression for cycling against the wind ($v_{\mathrm{w}} \neq 0$), but on a flat surface ($\alpha = 0$), is given by:

$$P_{\mathrm{wind}} = v_{\mathrm{g}} E_{\mathrm{c}}^{-1} \left(\tfrac{1}{2}\rho(C_{\mathrm{d}}A + F_{\mathrm{w}})(v_{\mathrm{g}} - v_{\mathrm{w}})^2 + C_{\mathrm{RR}} mg + [b_1 + v_{\mathrm{g}} b_2]\right). \quad (8)$$

The power to cycle without wind ($v_{\mathrm{w}} = 0$), but up a hill ($\alpha \neq 0$) is given by:

$$P_{\mathrm{hill}} = v_{\mathrm{g}} E_{\mathrm{c}}^{-1} \left(\tfrac{1}{2}\rho(C_{\mathrm{d}}A + F_{\mathrm{w}})v_{\mathrm{g}}^2 + C_{\mathrm{RR}} mg \cos(\tan^{-1}(\alpha)) + [b_1 + v_{\mathrm{g}} b_2]\right) + mg \sin(\tan^{-1}(\alpha)) \quad (9)$$

To be able to compare the two, I equate them ($P_{\mathrm{hill}} = P_{\mathrm{wind}}$), leaving:

$$P_{\mathrm{wind}} - P_{\mathrm{hill}} = v_{\mathrm{g}} \frac{mg}{E_{\mathrm{c}} v_{\mathrm{d}}^2} \left((v_{\mathrm{g}} - v_{\mathrm{w}})^2 - v_{\mathrm{g}}^2 - v_{\mathrm{d}}^2 f(\alpha)\right) = 0 \quad (10)$$

To ease notation, it is used that $f(\alpha) = C_{\mathrm{RR}}(1 - \cos(\tan^{-1}(\alpha))) + \sin(\tan^{-1}(\alpha))$, and the `drag velocity' is defined as

$$v_{\mathrm{d}} = \frac{2mg}{\rho(C_{\mathrm{d}}A + F_{\mathrm{w}})} \quad (11)$$

Note that $v_{\mathrm{d}} \geq 0$ and depends on the coefficients related to different types of bikers. From Eq. (10), it shows that one solution is obtained when $v_{\mathrm{g}} = 0$. A more interesting solution is obtained when the part within the brackets is zero, leaving $v_{\mathrm{a}}^2 = (v_{\mathrm{g}} - v_{\mathrm{w}})^2 = v_{\mathrm{d}}^2 f(\alpha) + v_{\mathrm{g}}^2$. From which it can be worked out that $v_{\mathrm{w}}^2 - 2v_{\mathrm{g}}v_{\mathrm{w}} - v_{\mathrm{d}}^2 f(\alpha) = 0$. Using the Quadratic formula $x = \left(-b \pm \sqrt{b^2 - 4ac}\right)(2a)^{-1}$, with $x = v_{\mathrm{w}}$, $a = 1$, $b = -2v_{\mathrm{g}}$, and $c = -v_{\mathrm{d}}^2 f(\alpha)$, the following expression is obtained:

$$v_{\mathrm{w}} = v_{\mathrm{g}} \pm \sqrt{v_{\mathrm{g}}^2 + v_{\mathrm{d}}^2 f(\alpha)} \quad (12)$$

Eq. (12) provides an expression for the wind velocity v_{w} as a function of the ground velocity of the biker v_{g}, the drag velocity v_{d}, and the slope of the hill α.

The Incline-Equivalent Wind Velocity

Here I will define the `*Incline-Equivalent Wind Velocity*' v_α, which is defined as the velocity the wind must have, in order to push a biker up the hill, as fast as it rolls down the hill, such that it does not move and $v_{\mathrm{g}} = 0$. The Incline-Equivalent Wind Velocity is given by inserting $v_{\mathrm{g}} = 0$ into Eq. (12) leaving:

for $\alpha < 0.1$

$$v_\alpha = v_{\mathrm{d}}\sqrt{f(\alpha)} \approx v_{\mathrm{d}}\sqrt{\alpha}, \quad (13)$$

For the second (approximated) part, it is used that $\sin(\tan^{-1}(\alpha)) \approx \alpha$, and $\cos(\tan^{-1}(\alpha)) \approx 1$, for $\alpha < 0.1$. The Incline-Equivalent Wind Velocity v_α (Fig. 2) is the power a rider requires to provide in order to overcome a wind velocity that is exactly the same as the power a rider needs to overcome when riding up a hill with a certain incline α, assuming that in both cases the rider is in exact balance (no forward motion, i.e. $v_{\mathrm{g}} = 0$). For example, when a cyclist is rolling down a hill (without cycling) with incline α and has a headwind of v_α, then the rider is in an exact stand still as the gravity pulls as hard as the wind provides a drag.

Commuters have a larger total weight and are pulled down harder by gravity then a professional cyclist, while the professionals have very small $C_{\mathrm{d}}A$ coefficient compared to the commuter (Table 1). This means, the wind has less `grip' on the professional, then on the commuter. As a result, the wind must blow harder to keep a professional cyclist at zero velocity, then it needs to blow against a commuter.
As a result, for a given incline, a professional athlete must train against a higher wind then a commuter, in order to exert the same power. That is why the lower boundary of the yellow area (Fig. 2) represents the Incline-Equivalent Wind Velocity for a commuter, while the upper boundary is the Incline-Equivalent Wind Velocity for a time trail professional athlete.

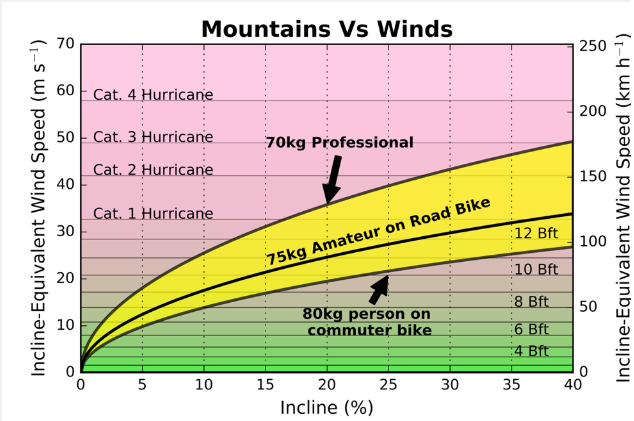

Figure 2. The Incline-Equivalent Wind Velocity $\mathbf{v}_\alpha$, as a function of the incline (100 *x* **α** in %). The yellow range provides the wind velocity that corresponds with the type of cyclist. The y-axis shows the wind speed in m s^{-1} (left) and km h^{-1} (right). The background color shading corresponds to the wind speed of the Beaufort Scale (1-12), which then changes into the Saffir-Simpson scale for Hurricanes (1-5).

A windy climb of the Mont Ventoux

Using Eq. (13), the profile of the incline of a mountain can be translated into the Incline-Equivalent Wind Velocity profile. There is no better example to take than the Mont Ventoux, or `windy mountain'. The Mont Ventoux is a famous mountain in France, often included

in big cycling races such as the Tour de France and the Critérium du Dauphiné. The Mont Ventoux has an average incline of about 7.3%, with some parts being much steeper (Figure 3).
Using Eq. (13), the Incline-Equivalent Wind Velocity profile of the uphill component of the Mont Ventoux is calculated (Fig. 4). As Climbing the Mont Ventoux is not done on time trial bikes, I have used the values for the amateur rider (Table 2). Cycling up the Mont Ventoux is equivalent to cycling against 30 to 65 km h^{-1} winds, averaging around 56 km h^{-1}.

For comparison, the fastest time recorded up Mont Ventoux is that by Iban Mayo, in the time trail of Stage 4 of the Critérium du Dauphiné in 2004 (Maloney 2004,). It took him just under 56 minutes from Bédoin to the top, on a calm day, leaving an average pace of 23.2 km h^{-1}. To mimic that ride, you need to ride against 56 km h^{-1} head-winds for an hour, with an average of 23.2 km h^{-1}.

Drafting as Incline

Drafting (or slip-streaming) is a technique in which two or more cyclists align in such a way that the lead objects slipstream is exploited, reducing the drag for the followers. Drafting can reduce the power required to cycle with the same speed, up to 40% for well-trained cyclist (Kyle 1979; Belloli et al 2016; Blocken et al 2013). Here this effect is recalculated in terms of a reduced `incline'.
First rewrite Eq. (12) such that it expresses v_w as a function of the power input of a rider P_{wind}, leaving:

$$v_w = v_g - v_d\sqrt{c_1 + c_2 P_{wind}} \qquad (14)$$

where $c_1 = -\left(P_{WB}P_g^{-1} + C_{RR}\right)$, and $c_2 = E_c P_g^{-1}$, and $P_g = mgv_g$. The front rider has ground velocity $v_g = v_g^{front}$, and cycles against a headwind of $v_w = v_w^{front}$ (Table 3). For the second rider, use that $v_g^{second} = v_g^{front}$ and because of the drafting effect, $P_{wind}^{second} = \varepsilon P_{wind}^{front}$. Here $\varepsilon < 1$, and represents the percentage of power that the second rider exerts, compared to the front rider, as a result of drafting. Using Eq. (14) this can be recalculated into a wind speed,

,

$$v_w^{second} = v_g - v_d\sqrt{c_1 + \varepsilon c_2 P_{wind}^{front}} \qquad (15)$$

where $v_w^{front} > v_w^{second}$. Now, both wind speeds can be recalculated as the Headwind-Equivalent Incline (α_{wind}), i.e. the reverse of the Incline-Equivalent Wind Velocity.

In order to do so, the Incline-Equivalent Wind Velocity v_α is rewritten as Headwind-Equivalent Incline α_{wind}, using both Eq. (13) and $f(\alpha) = C_{RR}(1 - \cos(\tan^{-1}(\alpha))) + \sin(\tan^{-1}(\alpha))$, leaving.

$$v_\alpha^2 = v_d^2\left(C_{RR} + \frac{\alpha - C_{RR}}{\sqrt{1+\alpha^2}}\right) \qquad (16)$$

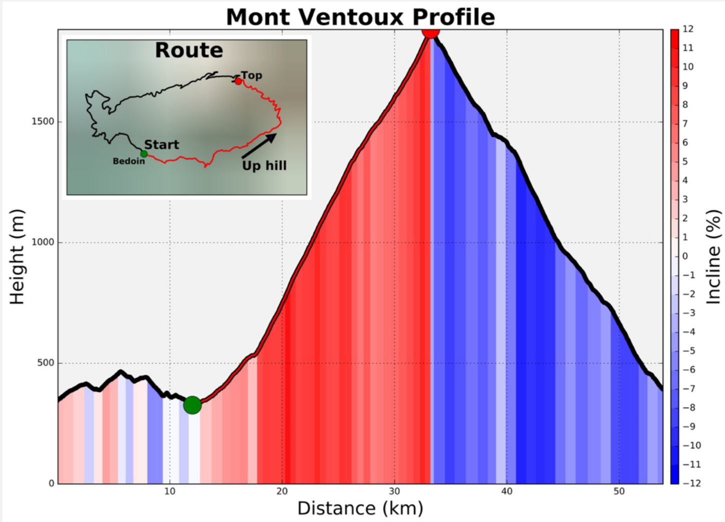

Figure 3. The Mont Ventoux. The inset (top left) provides a top-view of the route, with the uphill part colored in red. The start and end are indicated with a green and red dot, respectively, in both the inset and the profile. The x-axis shows the distance cycled, while the y-axis show the height. The different colors show the incline of the slope (%) for both the uphill (red) and downhill (blue) parts. In the remainder of this study, the focus is on the uphill part.

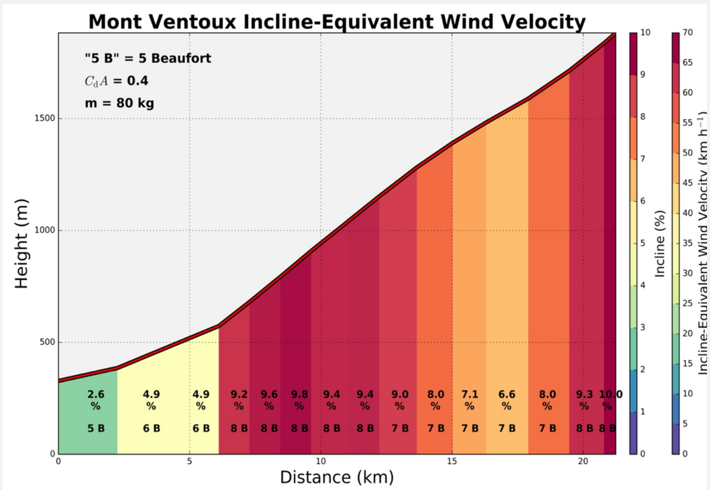

Figure 4. The climb of the Mont Ventoux, from Bédoin to the top. The climb is divided in a couple of section, for which the average gradient is shown in both color and numbers. The Incline-Equivalent Wind Velocity $\mathbf{v}_\alpha$ is shown in color in km h^{-1} and provided in `Beaufort' and m s^{-1} as text.

Here the relationships $\cos(\tan^{-1}(\alpha)) = \sqrt{1+\alpha^2}^{-1}$, and $\tan(\tan^{-1}(\alpha)) = \alpha$ are used. I now apply that $C_{RR}^2 = \ll 1$, to rewrite Eq. (16) into $0 = (1 - c_3^2)\alpha^2 - 2C_{RR}\alpha + C_{RR}^2 - c_3^2$, with

$$v_\alpha^2 = \frac{v_d^2}{v_\alpha^2} - C_{RR}. \qquad (17)$$

Using the Quadratic formula, with $x = \alpha$, $a = (1 - c_3^2)$, $b = -2C_{RR}$, and $c = C_{RR}^2 - c_3^2$, while taking the positive root I obtain:

$$\alpha_{\text{wind}} \approx \frac{v_\alpha^2}{v_\text{d}^2\sqrt{1-c_3^2}} = \frac{v_\alpha}{v_\text{d}\sqrt{\frac{v_\text{d}^4-v_\alpha^4}{v_\text{d}^2 v_\alpha^2}-2C_{RR}}} \approx \frac{v_\alpha^2}{\sqrt{v_\text{d}^4+v_\alpha^4}} \tag{18}$$

Here it is used that $2C_{RR} \ll (v_\text{d}^4 - v_\alpha^4)(v_\text{d}^2 v_\alpha^2)^{-1}$, for most situation. This means that, for a certain power input by the rider to cycle against the wind, I can calculate how this would compare to cycling up the hill. As the cyclist are drafting, they have the same ground velocity v_g, but a lower relative wind speed, and therefore a lower α_{wind}. Hence, the effect of drafting can be expressed as climbing up, with a reduced slope (Table 3). For the example provided, it shows that the front rider is cycling `up a hill' with slope $\alpha_{\text{wind}} = 4.5\%$, while the second and third rider provide an effort comparable to riding up a slope $\alpha_{\text{wind}} = 2.6\%$ and $\alpha_{\text{wind}} = 1.3\%$, respectively.

Conclusions

The main result of this study, is the derivation of the Incline-Equivalent Wind Velocity v_α (Eq. 13). This is the wind velocity a cyclist has to overcome on a flat road, to equal the power spend to cycle up a certain incline, without a headwind. To obtain this expression, I equated the power it takes to ride against the wind on a flat surface, and up an incline without any wind. The dominant balance is between that of the power related to changes in the rider's potential energy and overcoming aerodynamic drag. As a result, v_α, is a function of the incline α, and the drag velocity v_d, which depends on the drag coefficient, mass and frontal area of the rider and the bike.

Using the Incline-Equivalent Wind Velocity, the profile on the Mont Ventoux was calculate in terms of wind velocity, varying between 30 to 65 km h^{-1} winds, averaging around 56 km h^{-1} (7.3 % incline), for an amateur rider. Also, defined here is the Headwind-Equivalent Incline α_{wind} (opposite of v_α) and recalculated the effect of drafting on power input, as a decline in α_{wind}.

The power exerted by a rider is translated into forward motion through the inertial load on the crank. For the same power exerted by the rider the inertial load on the crank depends on many variables, including the rider's position with respect to the crank (Houtz and Fischer 1959; Wozniak Timmer (1991); Bertucci et al. 2005, 2012). This position, and therefore the forward motion of the rider, changes with incline. This effect is not included in this study and is left as future work. In addition, the change in position with respect to the crank between riding uphill or on an flat road, may also result in a different load on muscles and tendons. The study presented here is purely mathematics and does not take into account such biomechanics.

Using the results of this study for training purposes is possible within the limitation mentioned above. For example, one can now translate a training with a head-wind into a ride up a mountain. However, in order to also train the difference in the biomechanical load on muscles and tendons between riding uphill or on a flat road, one may have to alter the position of the rider on the bike, with respect to the crank.

A small anemometer on a bike would provide $v_\text{a} = v_\text{g} - v_\text{w}$, i.e. the net velocity of the bike with respect to the air. In combination with a speedometer providing v_g, this can be used to calculate v_w. The resulting v_w can be inserted into Eq. (18) to obtain α_{wind}. Hence, bikes equipped with both instruments have the ability to output v_g, v_w, and α_{wind}, which can be used as a training diagnostic.

Acknowledgement
None

Conflict of interest
The author notes that there is no conflict of interest.

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