Presentation by George Barnaby (george.barnaby@bristol.ac.uk), given at Science & Cycling Conference 2021 in Leuven, Belgium

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Science & Cycling

Mapping whole-event drive losses: the impact of race profile and rider input on transmission efficiency in cycling

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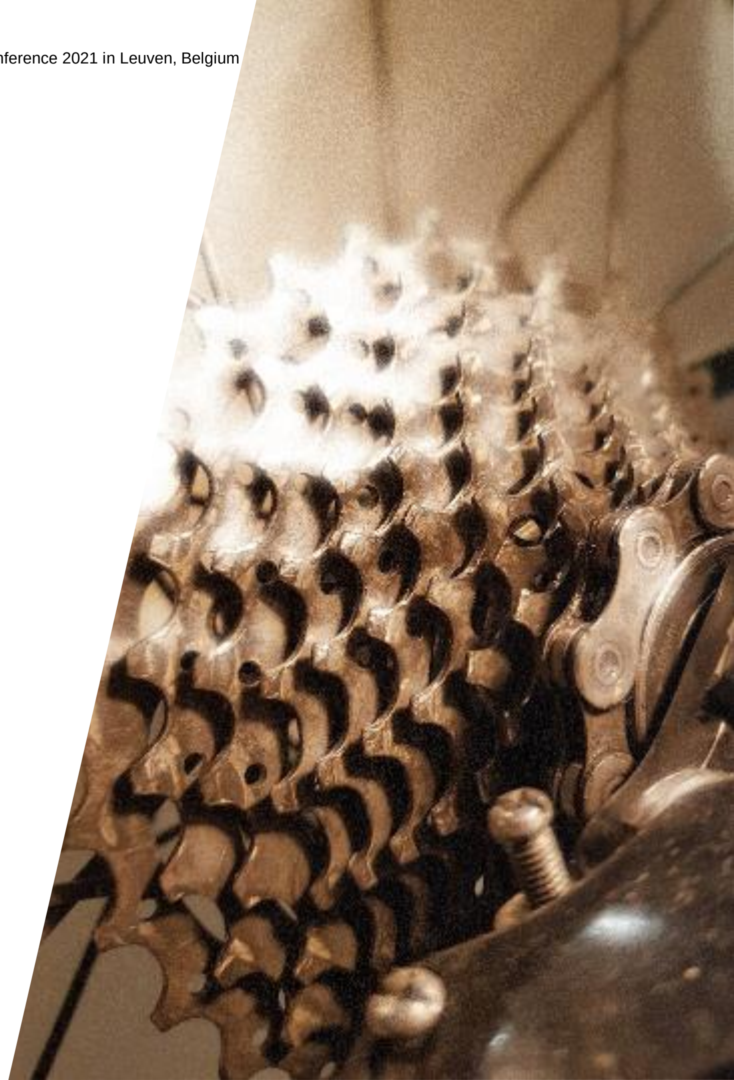
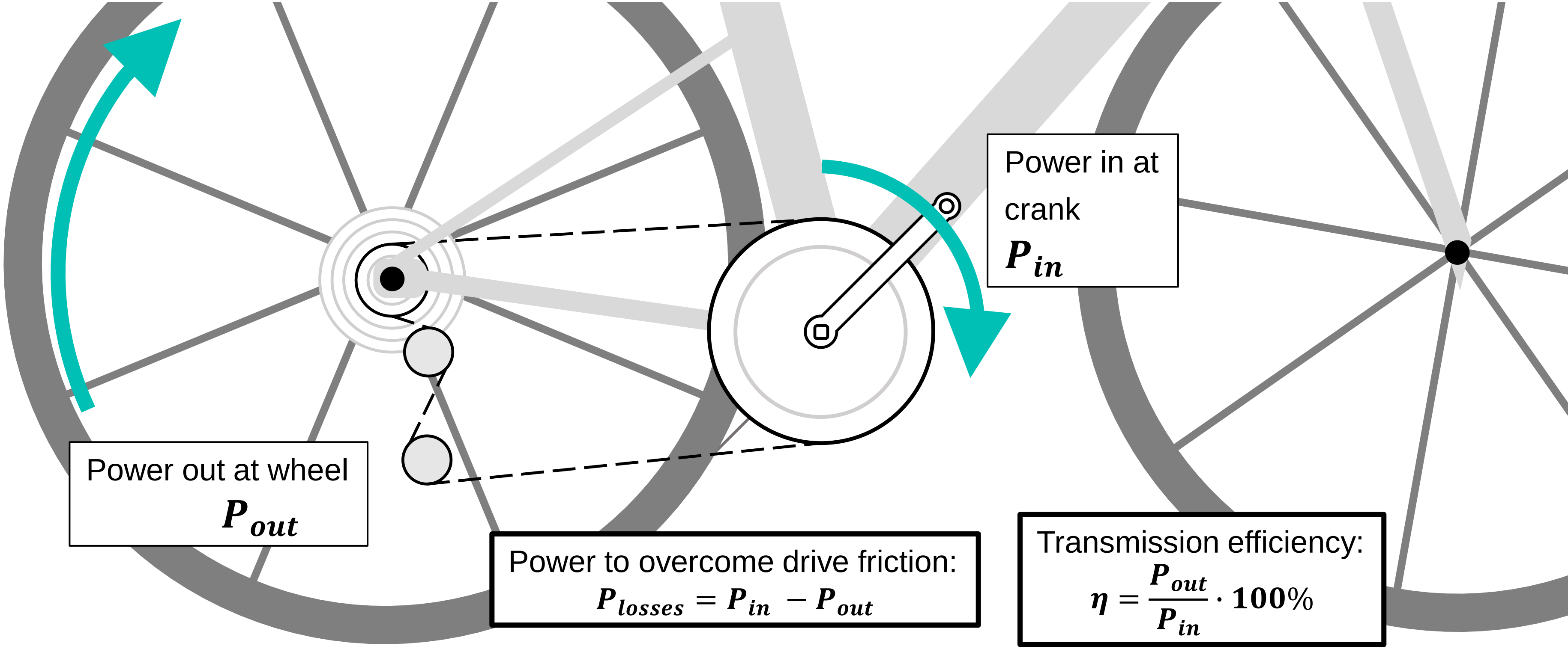
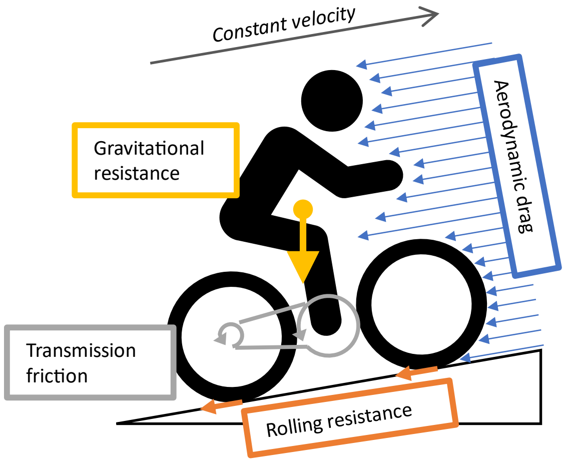
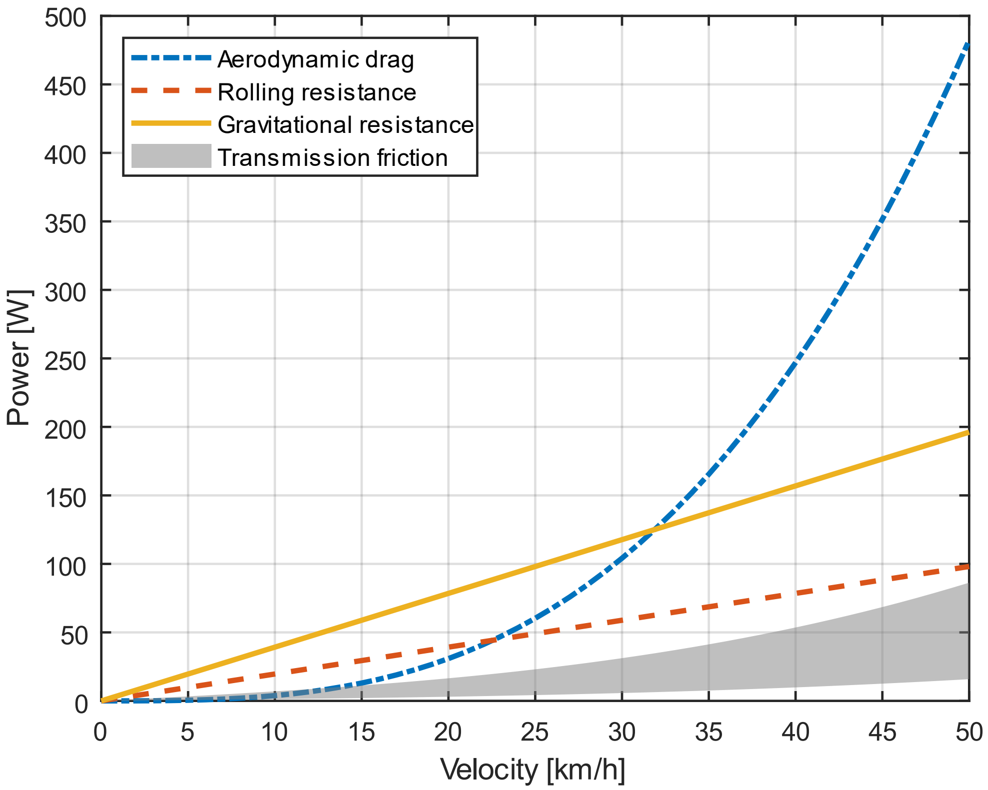


What is transmission efficiency?




Constant velocity
Gravitational resistance
Aerodynamic drag
Transmission friction
Rolling resistance


Aerodynamic drag
Rolling resistance
Gravitational resistance
Transmission friction
Power [W]
0
50
100
150
200
250
300
350
400
450
500
0
5
10
15
20
25
30
35
40
45
50
Velocity [km/h]

Transmission efficiency in power modelling

- η is commonly assumed to be **constant value** in literature [1]
  - From test data, or arbitrary estimated value
- Wide range of efficiencies are possible from the same chain [2]
  - **80.9% – 98.6%** measured
- Efficiency shown to vary with:
  - Input power
  - Rider cadence
  - Gear configuration

Each varies with race type, rider type and during events

- **How much do we expect efficiency to vary in elite cycling?**

[1] Martin, J. C., Milliken, D. L., Cobb, J. E., McFadden, K. L., & Coggan, A. R. (1998). *Validation of a mathematical model for road cycling power*. Journal of applied biomechanics, 14(3), 276-291.
[2] Spicer, J. B., Richardson, C. J., Ehrlich, M. J., Bernstein, J. R., Fukuda, M., & Terada, M. (2001). *Effects of frictional loss on bicycle chain drive efficiency*. J. Mech. Des., 123(4), 598-605.

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Modelling variable efficiency

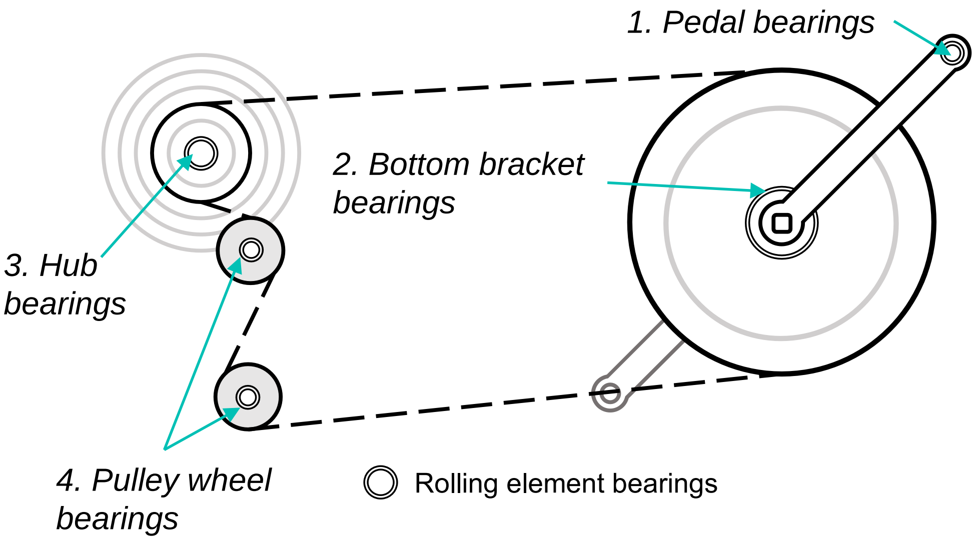
Identifying sources of friction in bicycle transmission and calculating efficiency for different loading scenarios

Rolling friction in bicycle transmission

1. Pedals rotate about spindle
2. Axle rotates in bottom bracket
3. Rear wheel rotates at hub
4. Pulley wheels rotate with chain

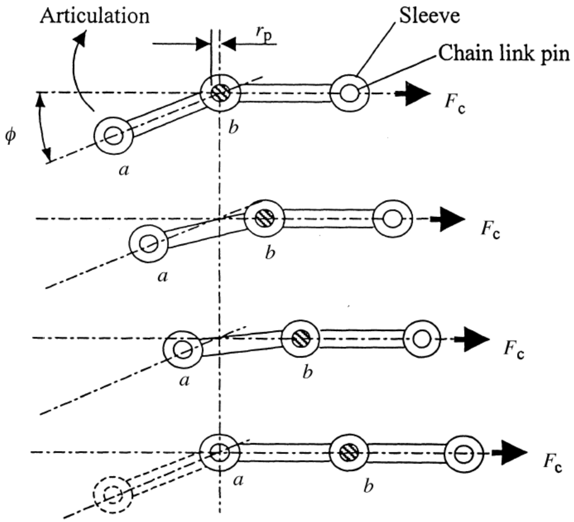
Rolling friction is small*

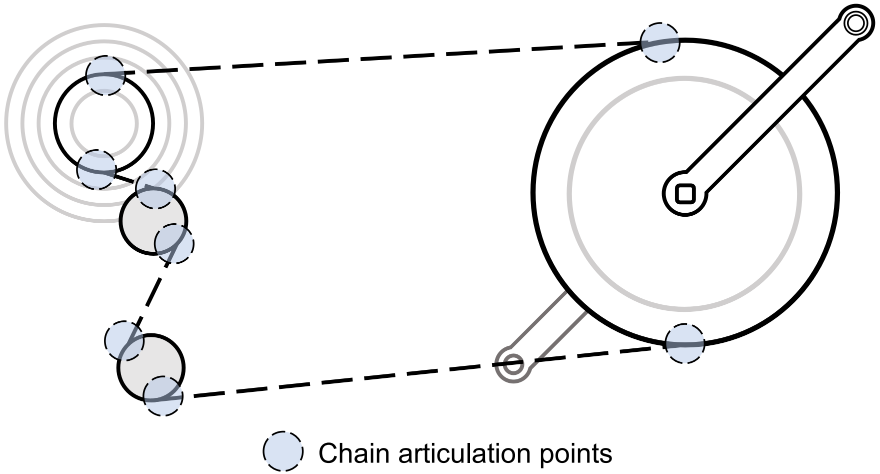
*Assuming high-quality rolling element bearings are used



Sliding friction in bicycle transmission

[3]

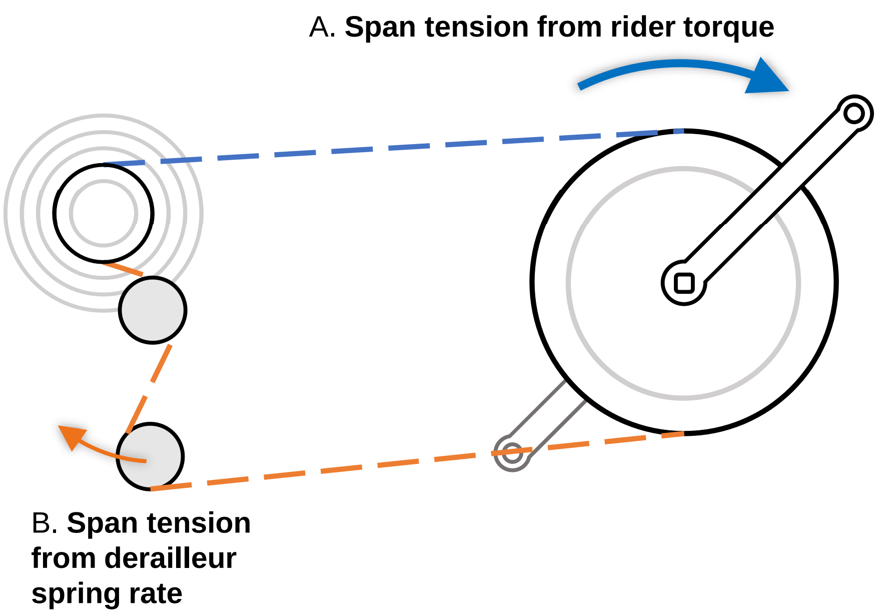




Sliding friction >> Rolling friction [4] [5]

[3] Burgess, S. C. (1998). *Improving cycling performance with large sprockets*. Sports Engineering, 1(2), 107-113.
[4] Lodge, C. J., & Burgess, S. C. (2001). *A model of the tension and transmission efficiency of a bush roller chain*. Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science, 216(4), 385-394.
[5] *The SKF model for calculating the frictional moment* (n.d.).

Contact forces from span tension



Friction depends on the **contact force** between articulating links, which comes from chain tension

Top and bottom chain spans are tensioned independently:

A. Top span (chainring-sprocket direct)

- Span tension from applied torque by rider
- **Torque-dependent friction** in articulating links

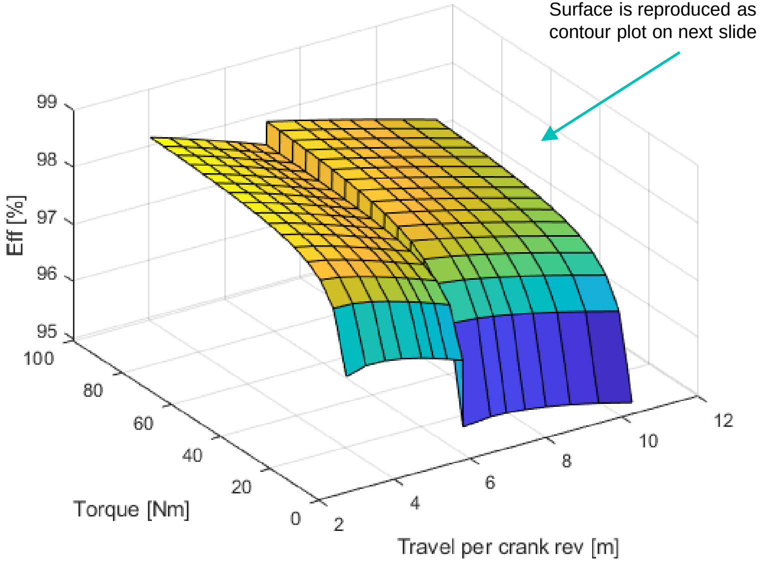
B. Bottom span (sprocket-chainring return via pulley wheels)

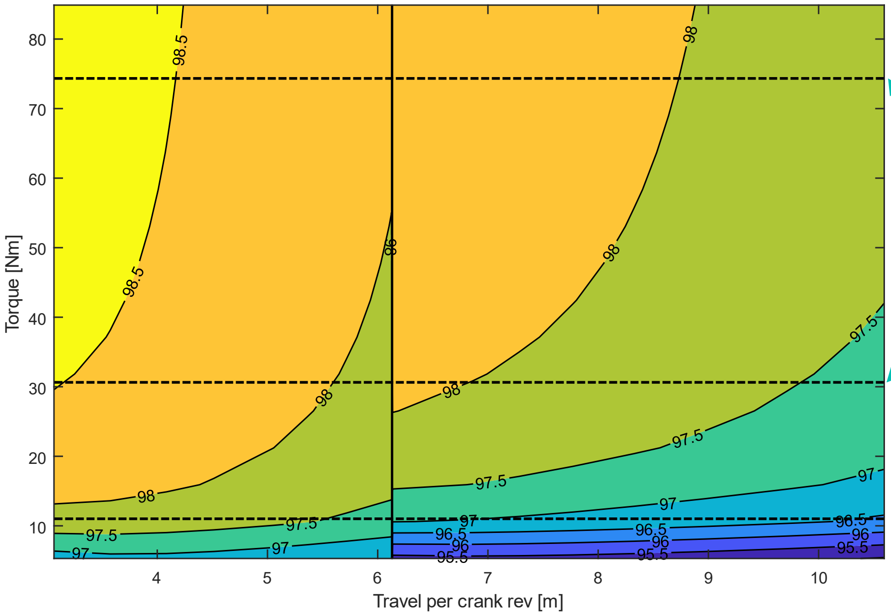
- Span tension from derailleur arm
- **Gear-dependent friction** in articulating links

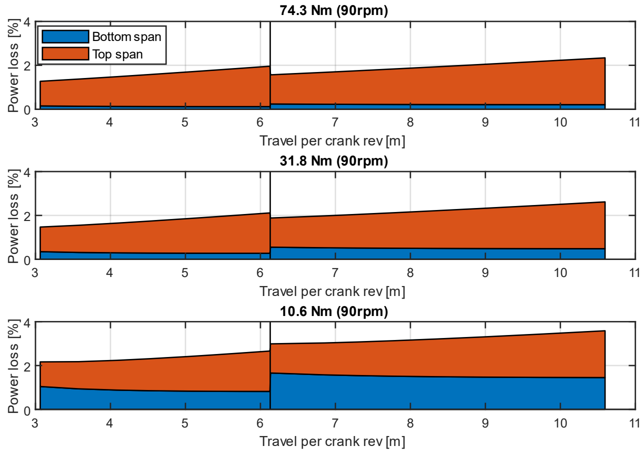
Variable efficiency with torque and gear

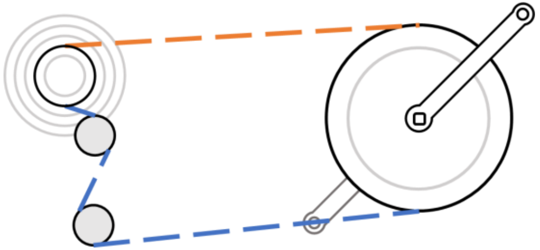
- Combining different loss mechanisms from different chain spans, transmission efficiency varies with changing parameters
- Transmission efficiency is illustrated for an example case across range of torque and gear
  - Torque equivalent to range 50 W – 800 W power at 90 RPM cadence
  - Gear based on 53t/39t chainrings, 11t-28t cassette sprockets (2x11)

Surface is reproduced as a contour plot on next slide









- As torque increases, losses in bottom-span become less significant.
- Torque-dependent losses dominate at high torque, hence the relative plateau in efficiency values.
- At low torque, bottom-span losses are significant and efficiency is significantly reduced.

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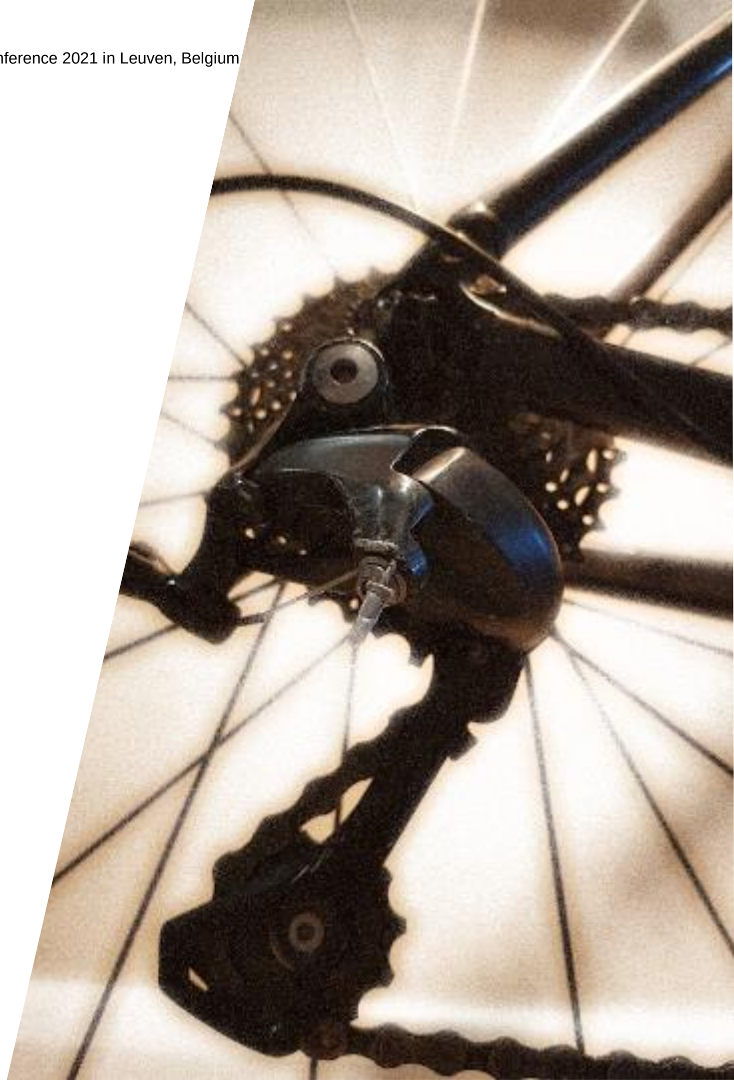
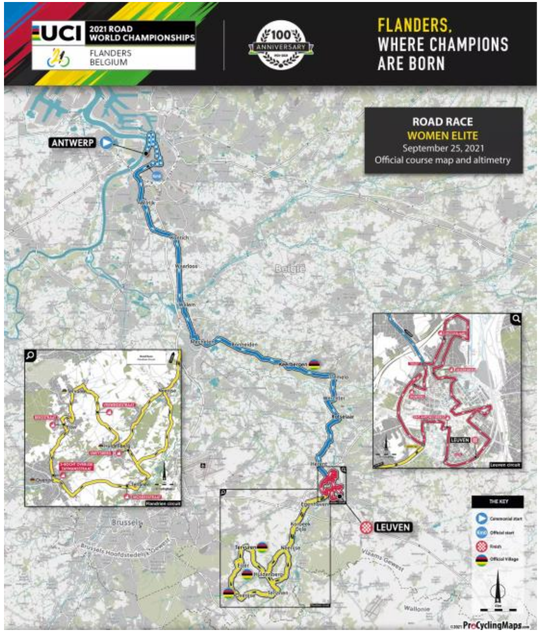
Variable efficiency during a bicycle race

Illustrating the changing efficiency during a bicycle race using a cycling power-model to predict gear selection and crank torque.



Case study: UCI 2021 Road World Champs



[6]

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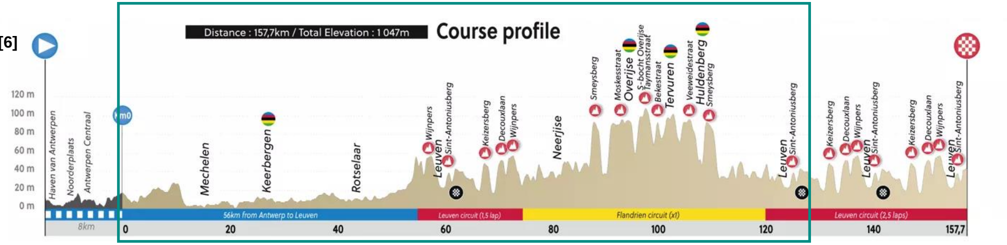

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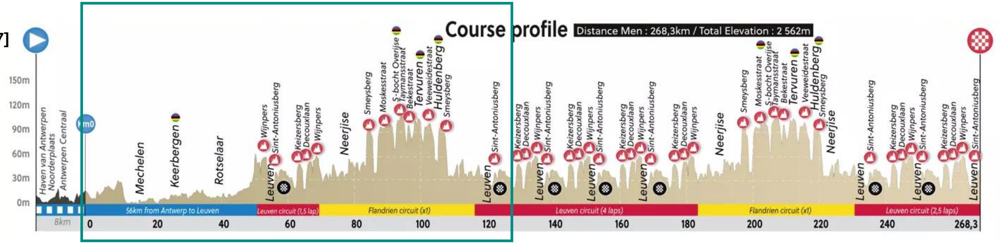

- A section of the UCI 2021 Road World Championships is selected for the case study

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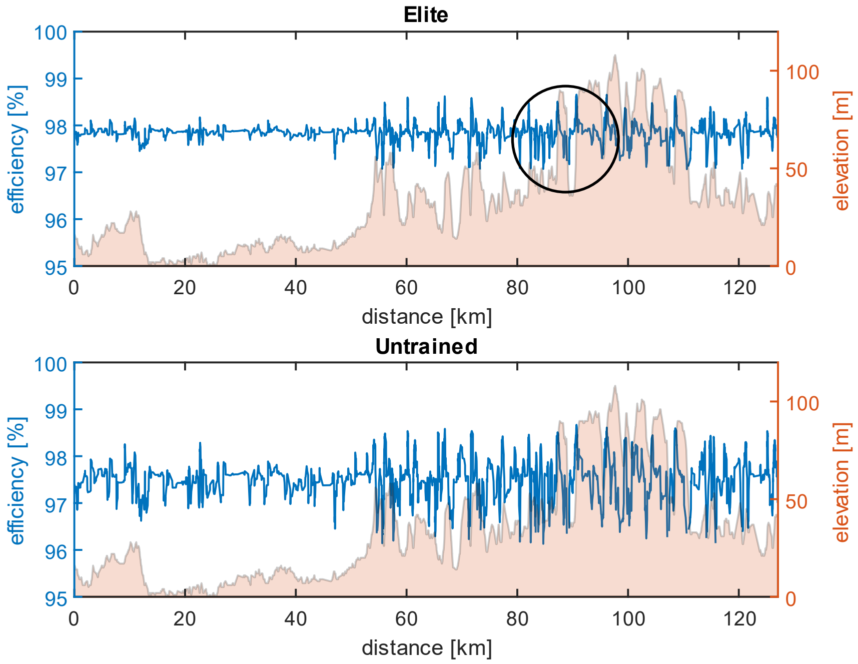
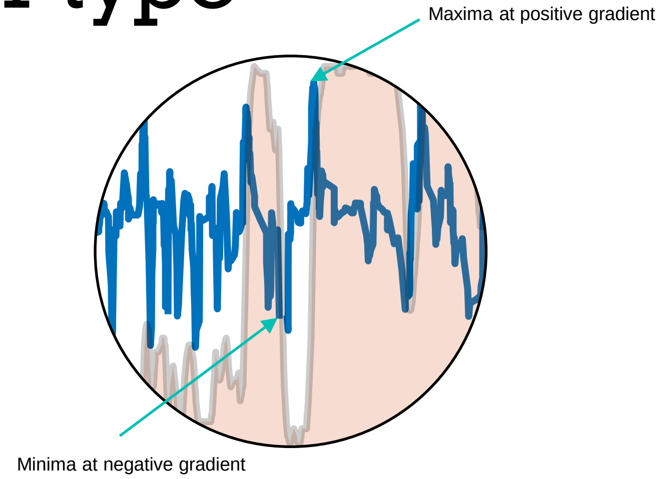
[6] UCI Website Women’s Elite road race. Retrieved from flanders2021.com/en/races/women-elite-road-race
[7] UCI Website Men’s Elite road race. Retrieved from flanders2021.com/en/races/men-elite-road-race

Efficiency variation by rider type



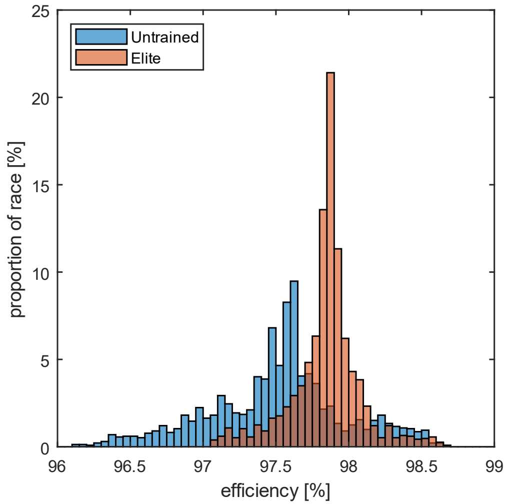


- Elite rider with higher power and higher, less variable cadence shows increased transmission efficiency and reduced efficiency variance

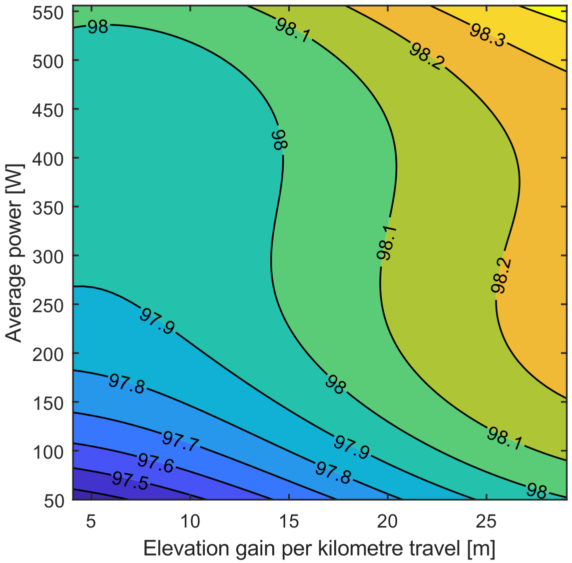
Elite:	Untrained
250W, 80-100 RPM	100W, 60-90 RPM
97.9% (s.d. 0.2)	97.5% (s.d. 0.5)

Efficiency variation in elite riders

- Variation is **relatively small** for elite riders, with a symmetrical distribution
- Using a **single value** of transmission efficiency across the entire race results in little error
- **Key factors** affecting this are:
  - **Elevation profile**
  - **Average power input**
- By extending analysis to a number of race-courses, general trends can be illustrated



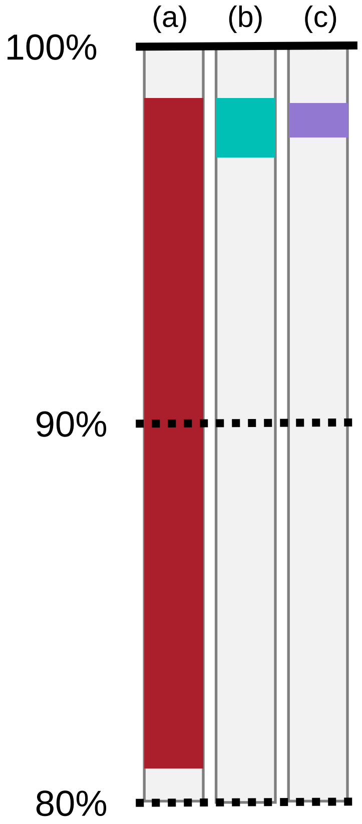
Variation of average efficiency in elite riders



- Average efficiency across a race as function of:
  - Average power input
  - Elevation/travel
- Modelled efficiency, averaged across entire race:
  - 97.5% - 98.4%
- Average efficiency increases with higher average power
- Average efficiency increases with greater elevation gain

Conclusions

- Range of transmission efficiency found in previous research is not realised in loading regimes typical to elite racing
  - (a) **80.9% - 98.6%** → (b) **97.1% - 98.7%**
- This is effectively described by an average efficiency across a race, provided:
  - Power is high with small variation
  - Cadence has small variation
- Range of average transmission efficiency is smaller still across example racecourses
  - (c) **97.5% - 98.4%**
- There are inherent variations in transmission efficiency between riders, course profiles and races which may be considered for more accurate estimates of transmission efficiency in future work



Practical applications

- Using contextually accurate transmission efficiency in modelled environments:
  - Predicting race outcomes based on rider/equipment performance parameters
  - Accurately simulating static trainer loads and performance for virtual bicycle races
  - Calibrating between crank and hub power measurements
- Particularly of note in ‘extreme’ race scenarios, where they may be more significant error in *not* accounting for load- and gear- dependent efficiency:
  - Hill climbing races (specific low gearing, higher rider power)
  - Time trial races (specific high gearing, higher rider power)
  - Endurance rides (range of gears, lower rider power)
- Extrapolating from narrow test measurements of transmission losses:
  - Where transmission is tested in narrow loading regimes or gearing, analysis such as that demonstrated here may be used in interpolation and/or extrapolation of data

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End of presentation.

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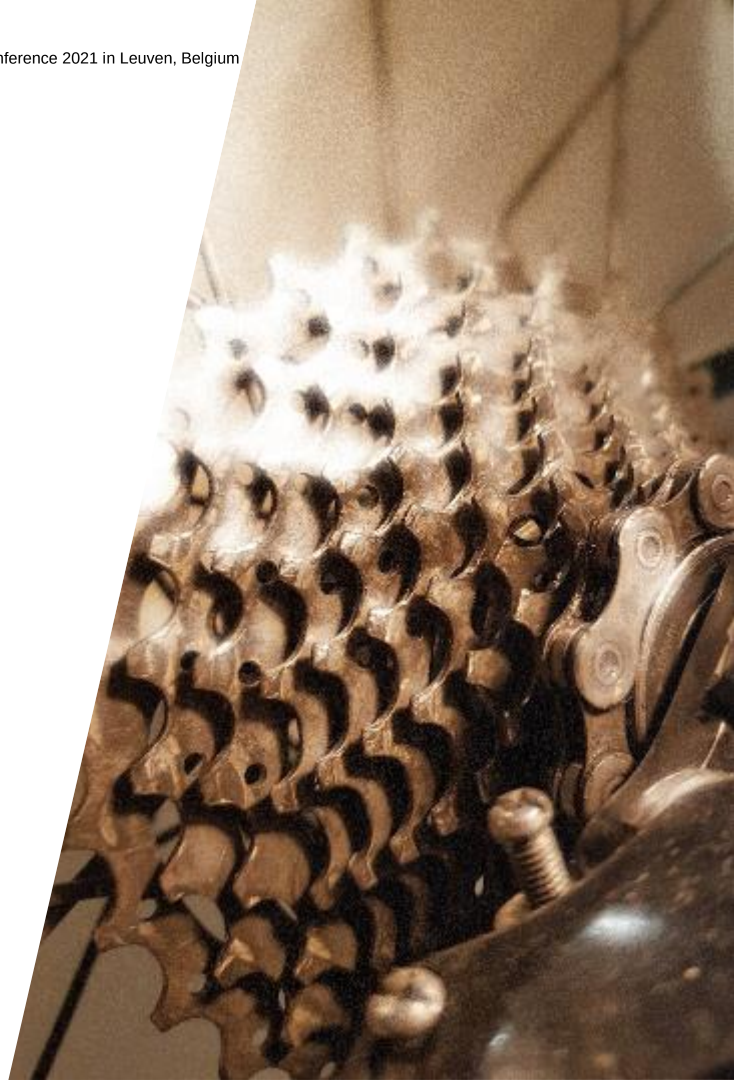

References

[1] Martin, J. C., Milliken, D. L., Cobb, J. E., McFadden, K. L., & Coggan, A. R. (1998). *Validation of a mathematical model for road cycling power*. Journal of applied biomechanics, 14(3), 276-291.

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[4] Lodge, C. J., & Burgess, S. C. (2001). A model of the tension and transmission efficiency of a bush roller chain. Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science, 216(4), 385-394.

[5] The SKF model for calculating the frictional moment (n.d.). Retrieved from skf.com/binaries/pub12/Images/0901d1968065e9e7-The-SKF-model-for-calculating-the-frictional-moment_tcm_12-362 299767.pdf

[6] UCI Website Women's Elite road race. Retrieved from flanders2021.com/en/races/women-elite-road-race

[7] UCI Website Men's Elite road race. Retrieved from flanders2021.com/en/races/men-elite-road-race

[8] Wells, M. S., & Marwood, S. (2016). Effects of power variation on cycle performance during simulated hilly time-trials. European journal of sport science, 16(8), 912-918.

Further references:

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Wilson, D. G., Papadopoulos, J., & Whitt, F. R. (2004). Bicycling science (3rd ed.). MIT press.

Wragge-Morley, R., Yon, J., Lock, R., Alexander, B., & Burgess, S. (2018). A novel pendulum test for measuring roller chain efficiency. Measurement Science and Technology, 29(7), 075008.