Modeling energy expenditure and recovery in cycling

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Outline

- Motivation
- Existing models in the literature
- Previous work
- Testing protocol
- Hypothesized model
- Preliminary results
- Path ahead

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Motivation

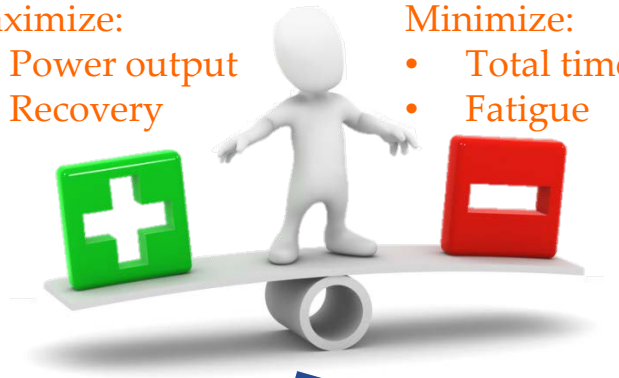
Train better

Avoid premature fatigue

Optimize performance

Maximize:
- Power output
- Recovery

Minimize:
- Total time
- Fatigue



Meet race goals

Optimal performance on race day

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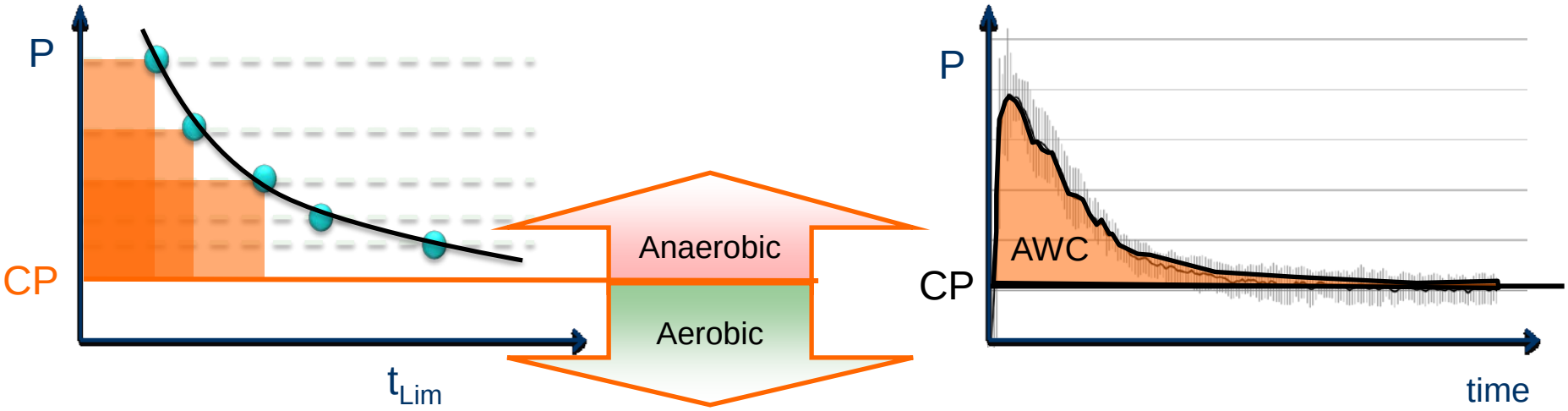
Model of Expenditure

- Critical Power (CP)
- Anaerobic Work Capacity (AWC)
- Monod and Scherrer[1] suggested a hyperbolic relationship

$$P = CP + \frac{AWC}{t_{lim}}$$

- 3 min all out test[2]



Time to exhaustion tests

3 minute all-out test

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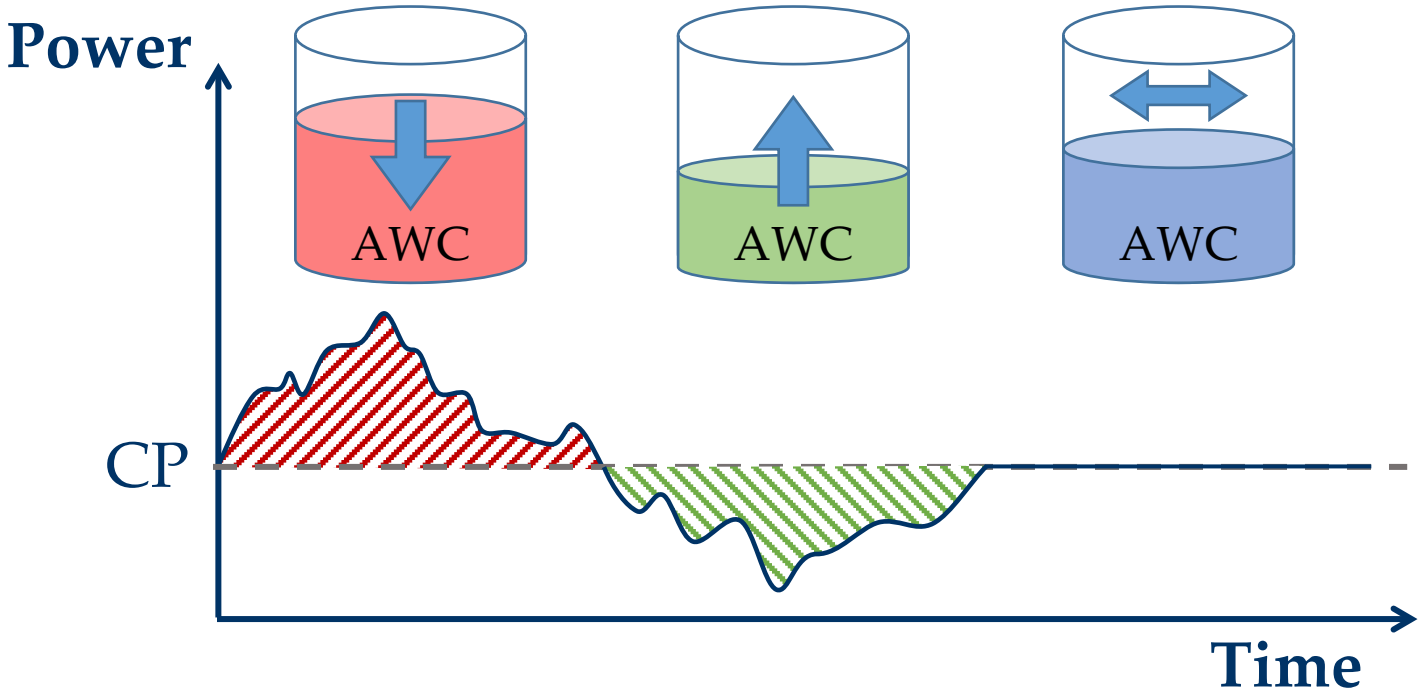
Expenditure and recovery related to CP



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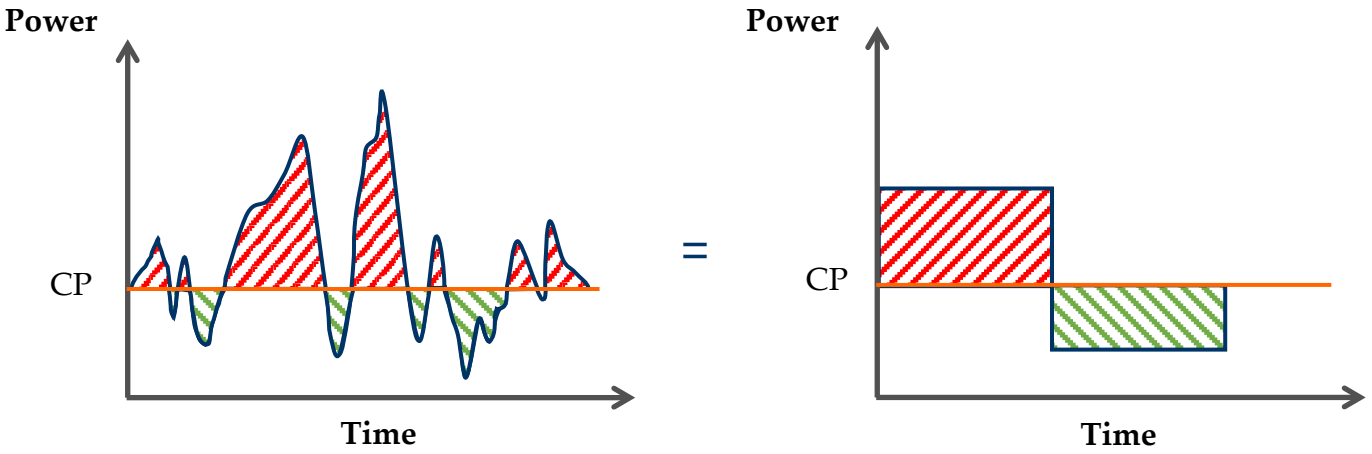
Modelling Recovery: Literature

- Ferguson and colleagues[3] suggested a "curvilinear" behavior

- Skiba and colleagues[4] proposed an exponential model

$$AWC_{bal} = AWC - \int_0^t (AWC_{exp}) \cdot e^{-\left(\frac{(t-u)}{\tau_{W'}}\right)} du$$

$$\tau_{W'} = 546e^{(-.01D_{CP})} + 316$$



All recovery intervals lumped as one

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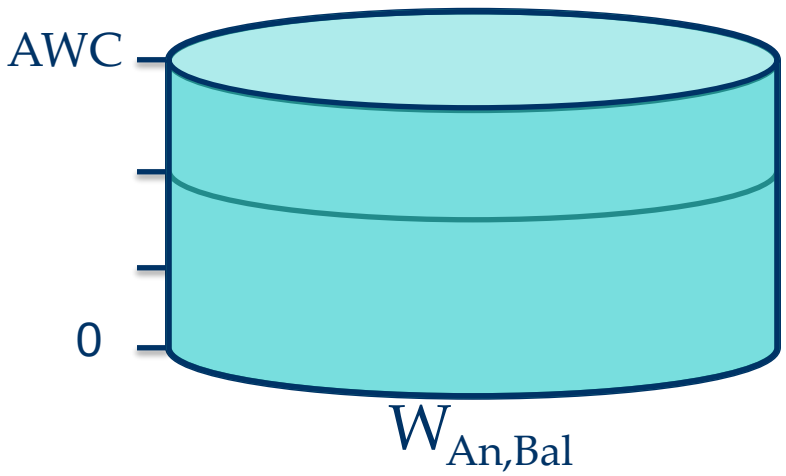
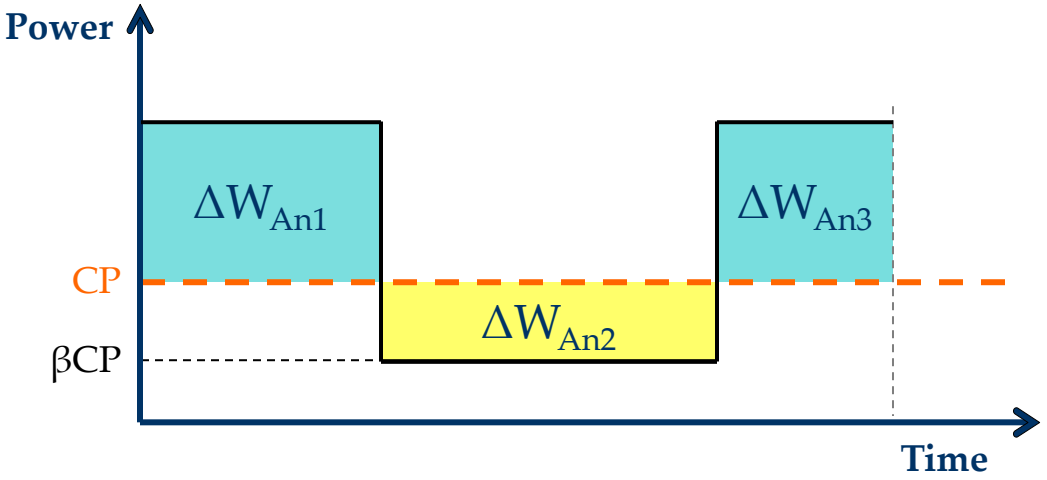
Modeling Recovery: Previous work

Bickford[5] looked at the ratio of the exertion and recovery intervals





$$\Delta W_{An} = CP \cdot (\beta - 1) \cdot \Phi \cdot \Delta t$$

$$\beta = \frac{P}{CP}$$

$$\Phi = \begin{cases} 1 & if\ \beta > 1 \\ 0 & if\ \beta = 1 \\ f(\beta, t) & if\ \beta < 1 \end{cases}$$

$$W_{An,Bal} = AWC - (\Delta W_{An_1} + \Delta W_{An3})$$

$$W_{An,Bal}\ \alpha\ \Delta W_{An_2} = CP \cdot (\beta_2 - 1) \cdot \Phi \cdot t_2$$

$$\Phi = \frac{AWC - (\Delta W_{An1} + \Delta W_{An3})}{CP \cdot (\beta_2 - 1) \cdot t_2}$$

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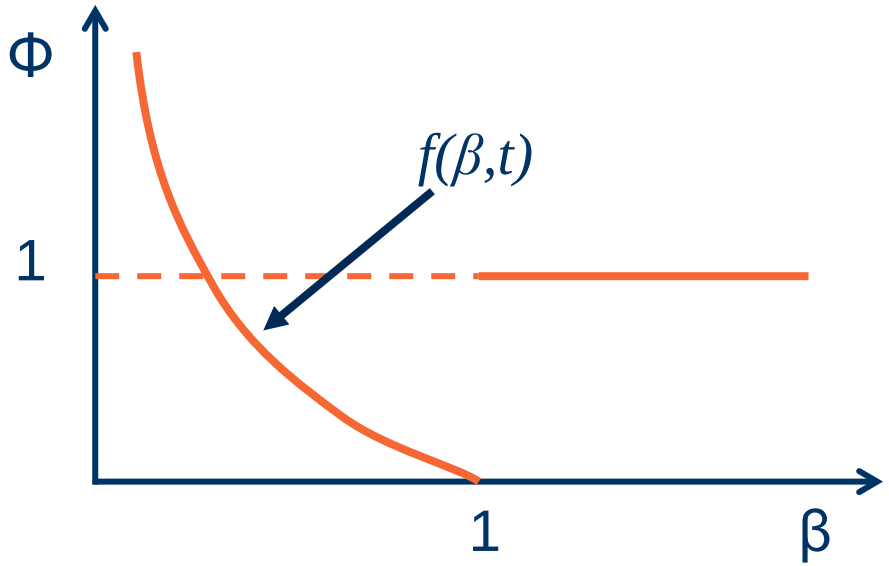
Revisiting Φ

$$\Delta W_{An} = CP(\beta - 1) \cdot \Phi \cdot \Delta t$$

$$\Phi = \begin{cases} 1 & if\ \beta > 1 \\ 0 & if\ \beta = 1 \\ f(\beta, t) & if\ \beta < 1 \end{cases}$$



$$\Phi = \frac{AWC - \left(\Delta W_{An1} + \Delta W_{An3}\right)}{CP\left(\beta_2 - 1\right) \cdot t_2}$$

$$as\ \beta \to 1, \Phi \to \infty$$

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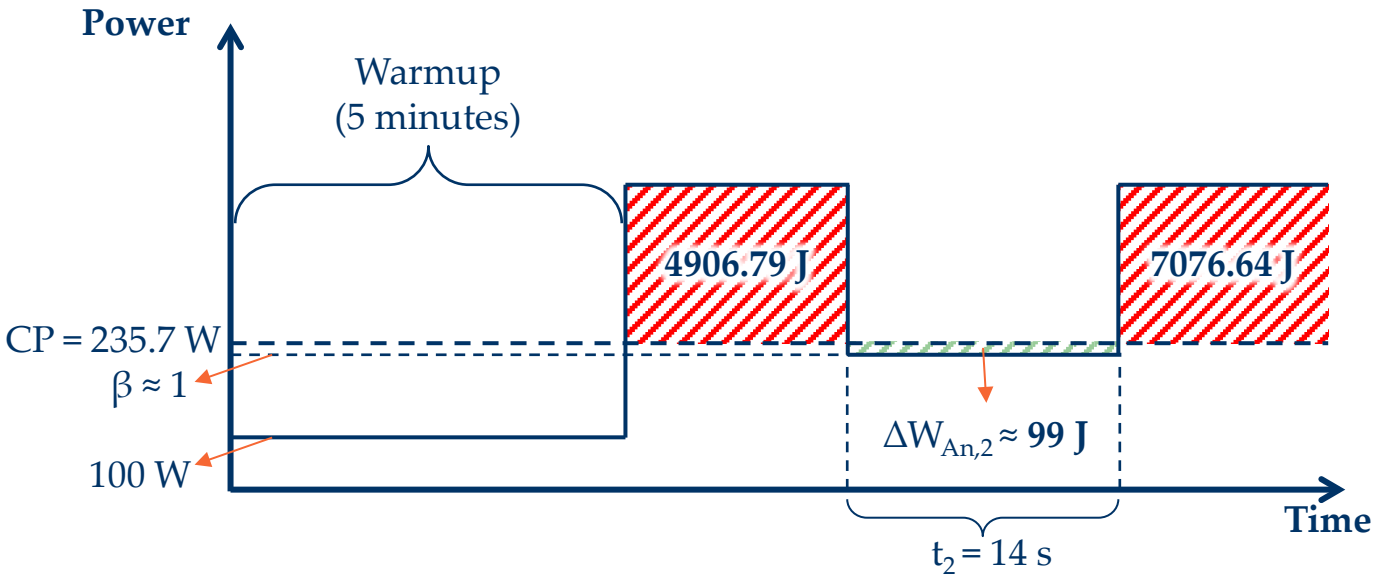
Illustration

Subject C4

- AWC = 10500 ± 1023 Joules
- CP = 236 ± 6.4 Watts
- β = 0.97, t_2 = 14 seconds



$$\Phi = \frac{10465.3 - (4906.79 + 7076.64)}{235.7(.97 - 1)\cdot 14} = 15.34$$

Should be ≈ 0!

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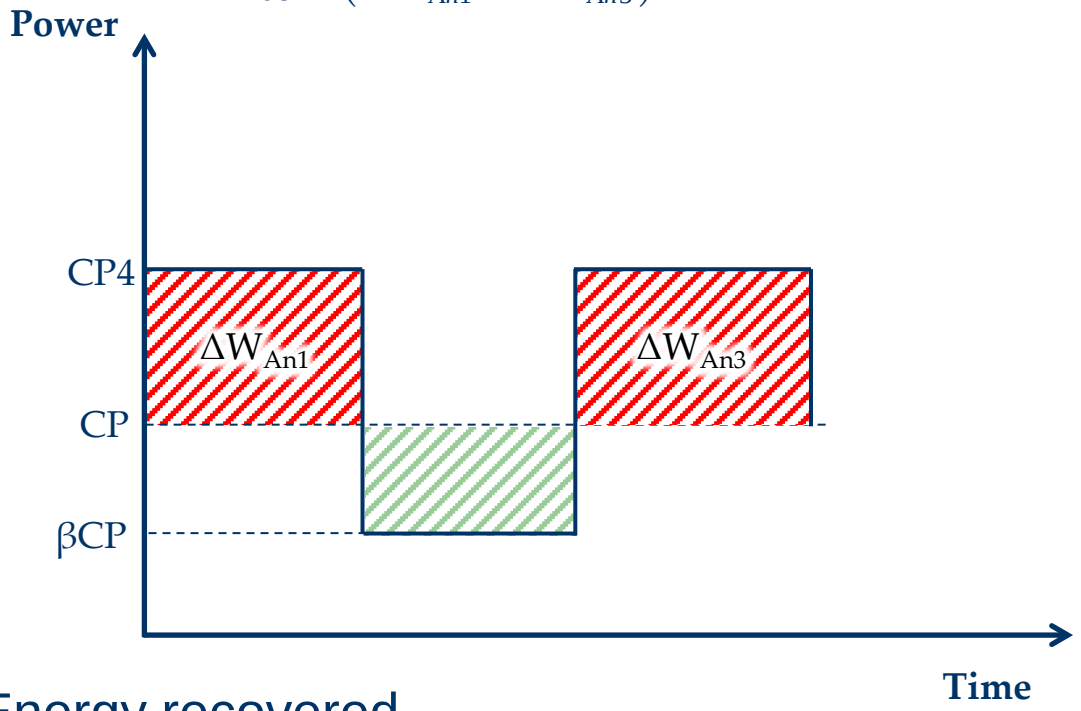
Energy recovered

- Energy recovered during recovery

$$E_{rec} = \left(\Delta W_{An1} + \Delta W_{An3}\right) - AWC$$

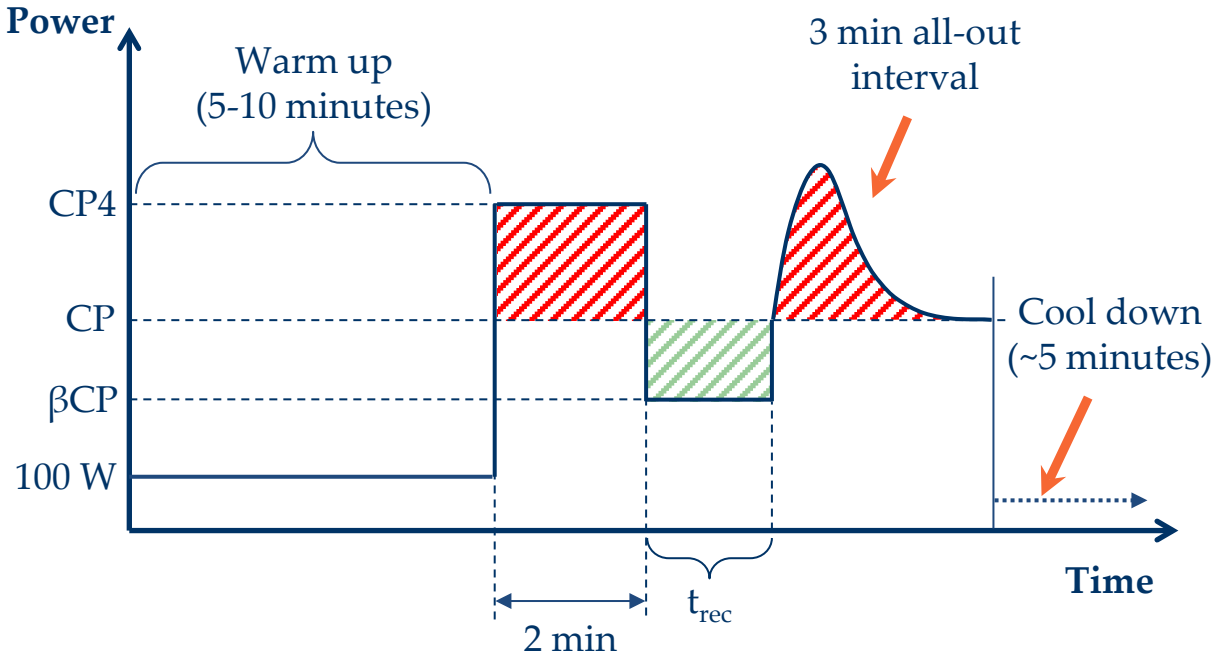


- Percentage Energy recovered

$$\%E_{rec} = \frac{E_{rec}}{AWC}$$

Testing protocol

- Step 1: VO_2 max ramp test
- Step 2: 3 min all out intensity test
- Step 3: Intermittent cycling protocol to determine recovery behavior of AWC (3 recovery powers and 3 recovery durations)



CP4- power at which a subject completely expends their AWC in 4 minutes

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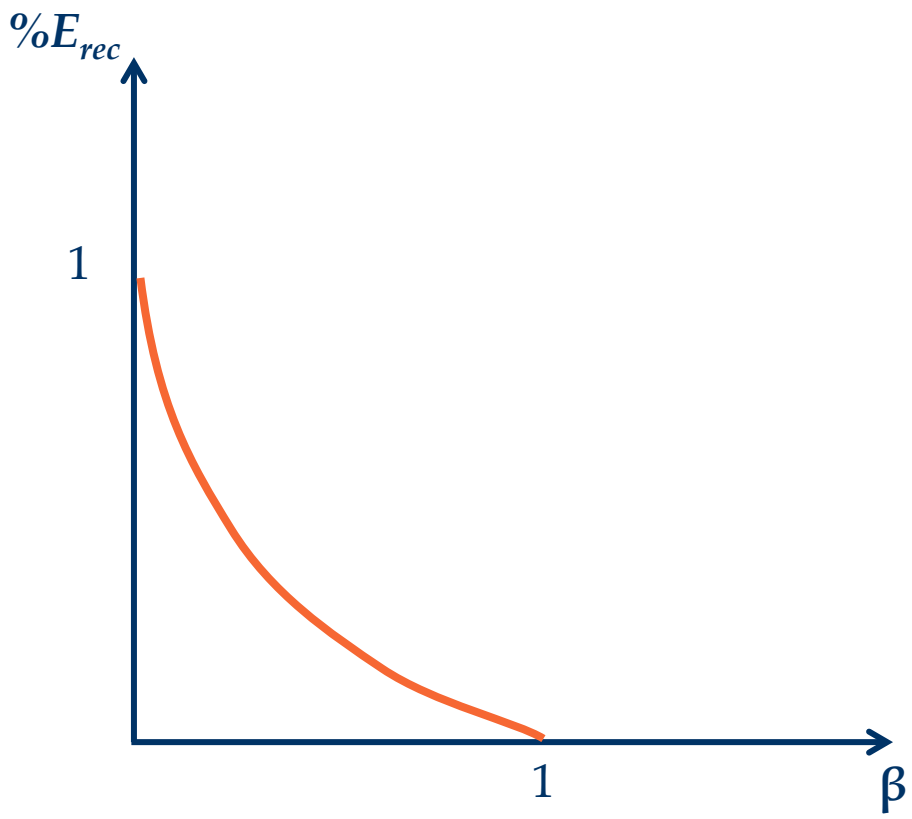
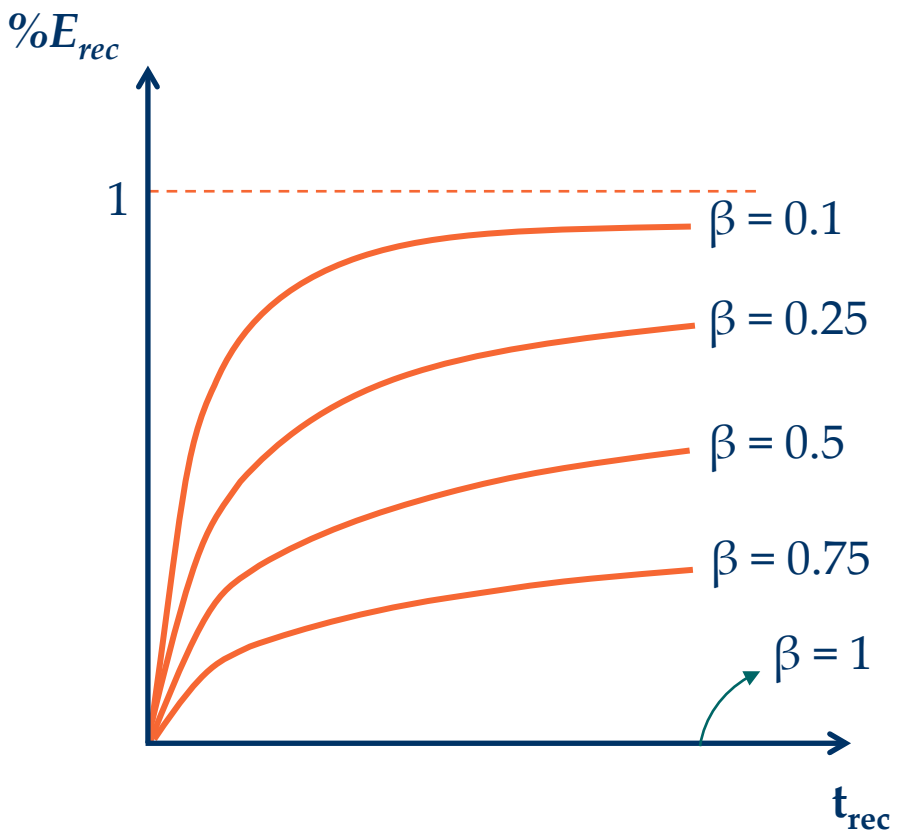
Energy recovered w.r.t AWC

Hypothesized behavior of E_{rec} versus β and t_{rec}





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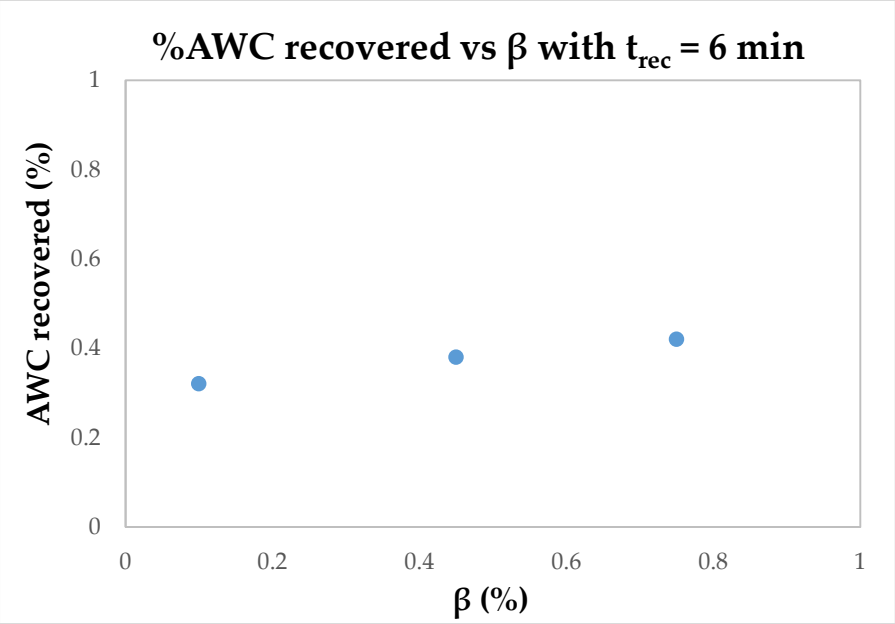
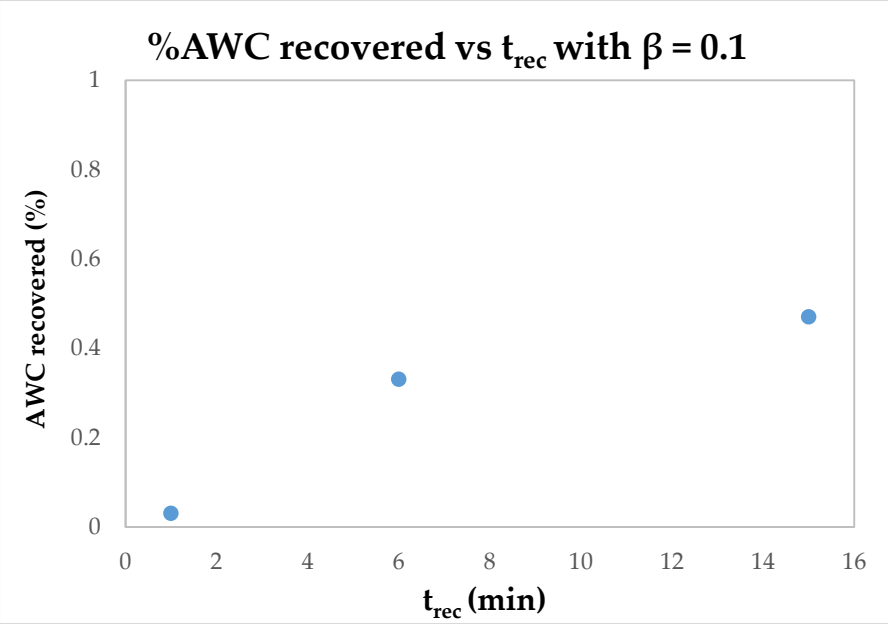
Preliminary results

Subject FP

- Age: ~21
- Gender: Male
- CP: ~200 W
- AWC: ~17600 J





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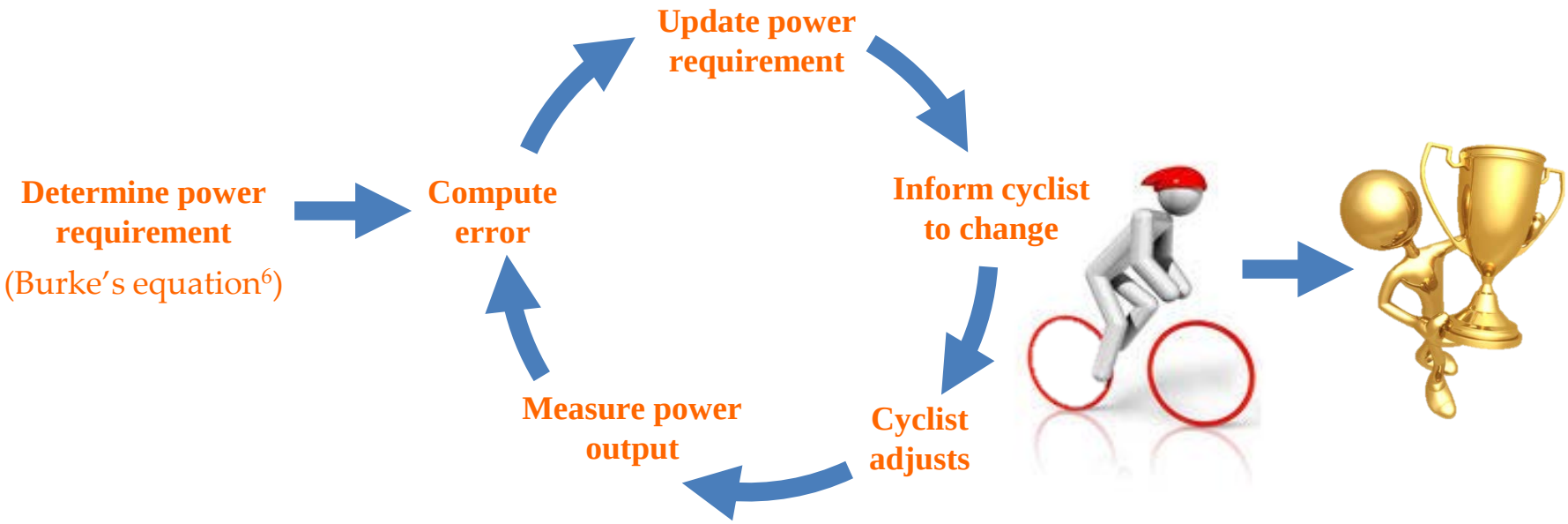
Path ahead

- Completion of testing (February-March 2018)
- Model of recovery (April 2018)
- Optimal control (Summer 2018)



- Real time testing and validation (Fall 2018)

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References

[1] Monod, H., and J. Scherrer. "The Work Capacity Of A Synergic Muscular Group." Ergonomics 8.3 (1965): 329-38.

[2] Vanhatalo, A. "Determination of critical power using a 3-min all-out cycling test." Medicine and science in sports and exercise 39.3 (2007): 548.

[3] Ferguson, C., Rossiter, H. B., Whipp, B. J., Cathcart, A. J., Murgatroyd, S. R., & Ward, S. A. (2010). Effect of recovery duration from prior exhaustive exercise on the parameters of the power-duration relationship. *Journal of applied physiology*, *108*(4), 866-874.

[4] Skiba PF, Chidnok W, Vanhatalo A, Jones AM (2012) Modeling the Expenditure and Reconstitution of Work Capacity above Critical Power. Med Sci Sports Exerc 44:1526–1532. doi: 10.1249/MSS.0b013e3182517a80

[5] Bickford, Phoebe, "Understanding the Expenditure and Recovery of Anaerobic Work Capacity Using Noninvasive Sensors" (2016). *All Theses*. 2488. http://tigerprints.clemson.edu/all_theses/2488

[6] Burke ER, Pruitt AL (2003) Body positioning for cycling. In: Burke ER (ed) High-Tech Cycl., 2nd ed. Human Kinetics, pp 69–92

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Thank you for your attention

Questions?

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