technische universiteit eindhoven

To design a human powered aircraft

Multi-body modelling of recumbent cycling: An optimisation of configuration and cadence

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Introduction

This study is part of the work done by 'Team Icarus' that is aiming to break the long distance record flying a Human Powered Aircraft. The aim of this study is to find an optimal recumbent position in combination with an optimal cadence using musculo-skeletal modelling and optimization algorithms. Two objectives will be compared with each other and will be experimentally validated:

- Minimising energy expenditure
- Minimising peak activitation of lower extremity muscles

Methods

- 2 male subjects were modelled and experimentally validated
- A recumbent cycling model was created in the multi-body software 'AnyBody', in which the lower extremity model was realistically represented by bones, joints and 35 Hill-type muscles *(figure 1).*
- By means of the min-max criterion, pedal forces, shortening speeds, muscle activities and forces were predicted at a specified movement and crank torque.

Figure 1 *Recumbent cycling, a model versus experimental set-up*

- For minimisation of energy expenditure a separate energy model based on Umberger [1] is combined with the recumbent model and implemented in Matlab.
- Saddle distance, saddle height and cadence were optimised using the Golden section method, while ankle offset and crank torsion phase were taken into account as secondary parameters
- The configurations following from the optimisation were validated by EMG, kinematics, oxygen consumption and pedal force measurements.

Results

- The energy model resulted in plausible efficiency results (0.23-0.24)
- Accuracy from model was not experimentally reached.
- Model predicts pedal forces and muscle activities well. (*figure 2)*
- Trends found in simulation not experimentally found. (*figure3)*
- The optimal value of cadence depends on the seat configuration and vice versa.
- Sensitivity to Distance > Cadence > Height

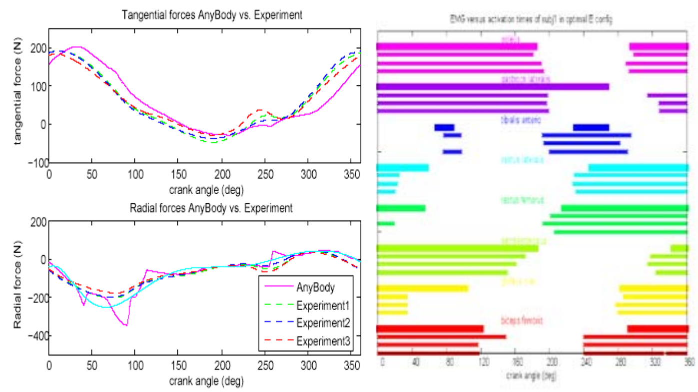

Figure 2 *left) predicted pedal forces (dashed) versus experimental pedal forces (solid). Right) predicted activation times (fat) versus experimental activation times (small) per muscle*

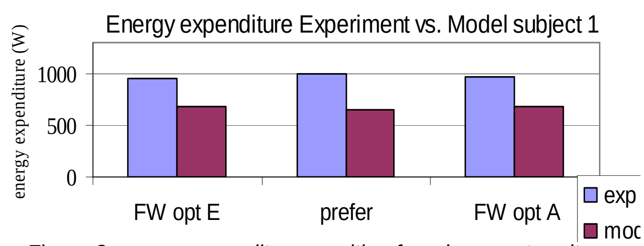

Figure 3 *energy expenditure resulting from lower extremity model versus experimental whole body expenditure*

Conclusions

- A robust recumbent model foundation was developed and a proper start is made for searching the optimal recumbent configuration in combination with cadence. Configuration and cadence were closely related.
- The recumbent model predicts muscle activation times and pedal forces well.
- Energy model is applicable to all AnyBody models and led to plausible efficiency values.
- Experimental validation of the chosen objectives was difficult.

Future Work

Future work is needed on both modelling and validation to improve reliability of the model. The optimisation can be expanded by more variables.

References:

1] *Umberger, et al: A model of Human muscle energy expenditure, Comput. Methods Biomech Biomed Engin 2003, 6 (2):515-525*

[2] *Jong, de: Multi-body modelling of recumbent cycling: An optimisation of configuration and cadence, internal report* , TU/e

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