Heat Transfer Numerical Simulations for Bicycle Disc Brakes

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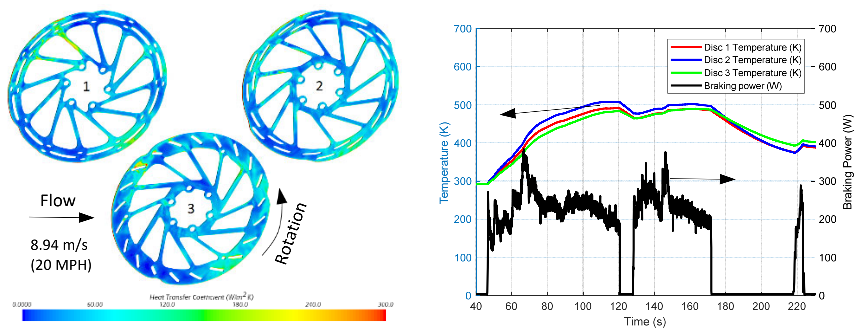
Prior brake temperature prediction efforts have established convective heat transfer coefficients from computational fluid dynamics (CFD) and dynamometer experiments, and found friction coefficients as functions of disc temperature and pad clamping force [1, 2]. A MATLAB transient numerical heat transfer model using friction data has shown reasonable agreement with experimentally measure disc temperatures for downhill trials [2]. However, the model requires convective heat transfer coefficients for the disc, coefficients which were previously obtained via simplified steady CFD simulations that modeled only the outer disc brake pad track. Prior CFD models did not include the radial metallic spokes connecting the disc to the hub, nor design features such as slots/holes in the brake track surface.

This work is important because it extends the previous efforts to determine disc heat transfer coefficients, and specifically includes additional modeling of the radial disc metallic spokes and brake track slots/holes using transient CFD simulations. Three commercial 160 mm diameter bicycle brake discs are modeled completely in CFD, including all the geometrical design features such as holes, slots, corner radii, and the disc to hub radial spokes. Turbulent simulations are performed in STAR-CCM+, a commercial CFD code [3], and include rotating reference frames and transient (typically 0.001s) time stepping to capture the rotation, forward speed, and the dynamic nature of heat transfer from the discs.

The geometry and example instantaneous convection contours for each disc are shown in Figure 1(a), and corresponding convective numeric data is tabulated in Table 1. Although experimental convection validations are not available yet for these slotted discs, prior experimental data for solid discs [1, 2] show this CFD methodology to be accurate. To determine in use temperature predictions for a downhill braking event, the CFD convective data is used with a node based MATLAB transient temperature prediction model, to predict the relative temperature histories for the three discs. The braking power history is the same as in prior work [2], obtained from a downhill test. Figure 1(b) plots the chosen brake input power and resulting temperature histories. Design 3 shows the lowest overall predicted transient temperatures due to its specific geometry, convection, and mass properties; sometimes over 30K lower temperature than design 2, for example.



(a) (b)

Fig. 1: (a) Instantaneous CFD convective coefficient distribution for the three designs labeled 1, 2, and 3, (b) Performance comparison from a transient MATLAB heat transfer simulation using a brake input power history from a representative downhill test (right axis), with the predicted temperature histories (left axis) for the three designs.

Table 1: Heat transfer data (averaged over two rotations) for the three different brake disc designs, with disc temperatures set to 100K above ambient temperature.

Surface	**Disc 1**	**Disc 2**	**Disc 3**
Heat transfer, disc surfaces (W)	*91.95*	*93.08*	*95.06*
Heat transfer, spoke surfaces (W)	*49.97*	*50.07*	*48.21*
Heat transfer, TOTAL (W)	141.92	143.15	143.27
Convective area, TOTAL (m^{-2})	0.021615	0.021765	0.025189
Convective coeff., TOTAL ($W{\cdot}m^{-2}{\cdot}K^{-1}$)	65.66	65.77	56.88

This work shows that CFD can be used to predict convective heat transfer coefficients for rotating brake discs, which when coupled to a transient heat transfer model can predict disc temperatures during braking events. Temperature predictions can help riders and teams to choose between different brake discs in order to avoid excessive temperatures while also minimizing weight.

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3. Simcenter STAR-CCM+. Available online: https://www.plm.automation.siemens.com/global/en/products/simcenter/STAR-CCM.html (accessed on 1 September 2021).

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