Reduction of heat-fluxes during re-entry using magnetic fields

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In wind-tunnel experiments a heat flux reduction was observed by applying magnetic fields. The underlying mechanism is still unexplained. One possible reason is the indirect effect of magnetic fields on the total heat flux. The application of magnetic fields influences the flux of electrons and ions, and through charge-exchange collisions also the dominant contribution of neutrals in the heat flux.

To reduce heat fluxes during re-entry one idea is to use magnetic fields that shield the spacecraft from the flux[1]. In 2002 the European Space Agency started an investigation on heat-flux mitigations by externally applied magnetic fields in partially-ionised argon-flows [2]. In these test experiments due to large differences between plasma density (~10^{17} m^{-3}) and neutral density (~10^{21} m^{-3}), most of the heat-flux is carried by neutrals. Therefore, it is not directly expected that it can be reduced by magnetic fields.

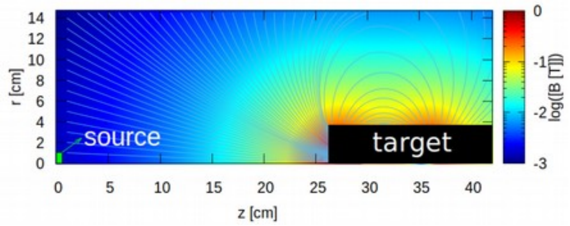

Figure 1: Magnetic field and simulation domain.

To study such scenarios the Particle-in-Cell method with Monte-Carlo collisions [3,4] was used. The simulation reproduces the heat flux reduction qualitatively. The magnetic field leads to a change in electron and ion density by affecting the trajectories of the charged particles through the Lorentz force. Magnetic field lines in the dipole-like field converge to the centre of the target. As particles are guided into this region a shield of high plasma density builds up in front of the target. Neutral transport is affected by charge exchange collisions with ions acting as a momentum sink for the neutrals and reducing the neutral axial velocity. By this, the resulting total neutral heat flux is reduced. Ion heat flux is increased only weakly, because the radial losses due to the magnetic field and turbulence get stronger. In addition, the simulation was verified against experimental spectroscopy using optical emission analysis. In the free stream region a loss of intensity for all wavelengths appeared, whereas in front of the target an increase of the intensity is observed. Both effects were in good agreement with the experiment.

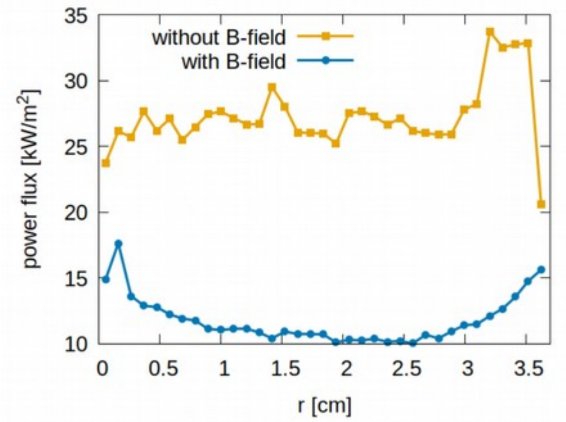

Figure 2: Simulated radial profile of the total heat flux onto the target.

A photo was simulated from the calculated optical emission spectrum. The simulation reproduces the observed optical effects when applying the external magnetic field. These effects are an overall red shift, a smaller bright emission region close to the arc jet exit and an emission region in front of the target.

[1] M.L. Blosser, NASA Technical Memorandum. **110296** (1996).

[2] A. Gülhan et. al., J. of Spacecrafts and Rockets. **46** (2009), 274-283.

[3] D. Tskhakaya et. al., Contributions to Plasma Physics. **47** (2007), 563-594.

[4] K. Matyash et. al., Contributions to Plasma Physics. **47** (2007), 595-634.