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Simulation of an Ablative Thermal Protection System for the Hypersonic Ascend of an Electromagnetic Launched Payload Carrier

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The German Aerospace Center is carrying out a study, to develop a small payload carrier for the ascend to low earth orbit. The vehicle shall be electromagnetically launched by a Lorentz Rail Accelerator. Additionally, it will be propelled by a two stage hybrid rocket engine system to reach the desired orbit. The goal of this concept is to use electric power to achieve a part of the required velocity increment and therefore, to save fuel and structural mass.

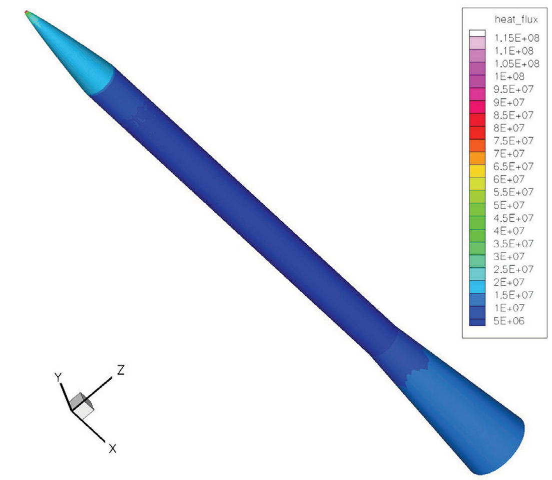
To access the orbit with a hybrid rocket engine system as small as possible, a high initial velocity is required. This again implies high aerothermodynamic loads on the forebody of the payload carrier. From a feasibility study [1] it can be derived that for a vehicle, which carries 3 kg of payload to a 300 km LEO, a launch velocity of about 3.3 km/s at sea level is required. Therefore, the vehicle needs a thermal protection system to withstand these harsh conditions.

As the thermal protection system, an ablative carbon phenolic heat shield is chosen, because of the simple setup, proven concept and the lack of components that are susceptible to the very high acceleration during launch. There are many investigations regarding carbon phenolic ablators, but usually these investigations are carried out for re-entry missions, where the high velocities are given at high altitude and low atmospheric density. In this application the conditions are different, because the highest velocity is given at sea level.

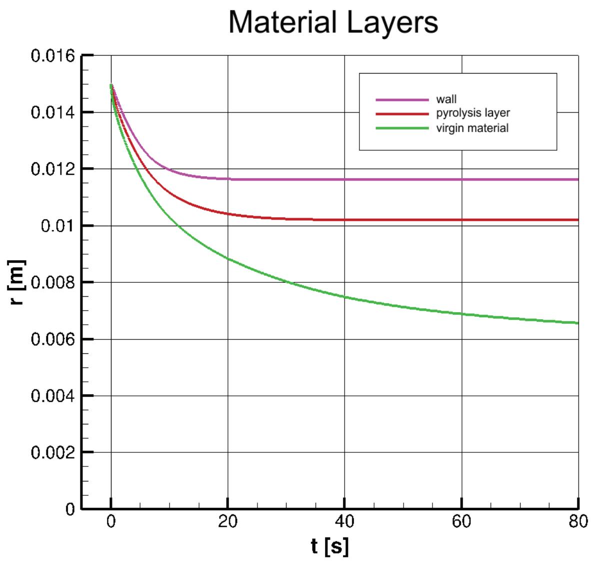
To assess, whether an ablative heat shield can withstand the demands for an electromagnetically accelerated vehicle a material response model is developed that describes a carbon phenolic ablator mounted on a base structure. Thermal conductance, pyrolysis reaction, char erosion and pyrolysis gas production are taken into account. Furthermore, the conditions in the boundary layer near the stagnation point are modelled, including combustion of char and pyrolysis gas, blocking effect and radiation, to determine the heat flux to the ablator. The material response model is coupled to a 6 degree of freedom trajectory simulation tool, which incorporates an aerodynamic and atmospheric model. Therefore, all aspects of the ascend flight can be investigated.

The results show that despite of the high convective heat loads, an ablator of 15 mm thickness at the stagnation region is sufficient to protect the vehicle against the harsh conditions. Fostered by the fast ascend to atmospheric layers of low density, the residence time of the critical heat loads are short. This encourages advancing the development of an electromagnetically launched payload carrier.

[1] O. Božić, T. Eggers, S. Wiggen, "Aerothermal and Flight Mechanic Considerations by Development of Small Launchers for Low Orbit Payloads Started from Lorentz Rail Accelerator," 3rd European Conference for Aero-Space Sciences – EUCASS, 6-9 July 2009, Versailles-Paris, France, Progress in Propulsion Physics, Vol. 2, (edited by L. DeLuca, C. Bonal, O. Heidn, S. Frolov,), EUCASS advances in aerospace sciences book series, EDP sciences, pp. 765-784, Torus Press, 2011



Surface heat flux steady state, radiation adiabatic



Material layer evolution during ascend