Design and Development of Cooling Solutions for Rotating Detonation Engines

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Introduction

One of the main challenges associated with the development of Rotating Detonation Combustion Engines (RDE) is dissipating the tremendous amount of heat generated by the high-frequency rotating detonation waves. The Current research aims to develop cooling designs for RDE.

Quantification of Heat Flux

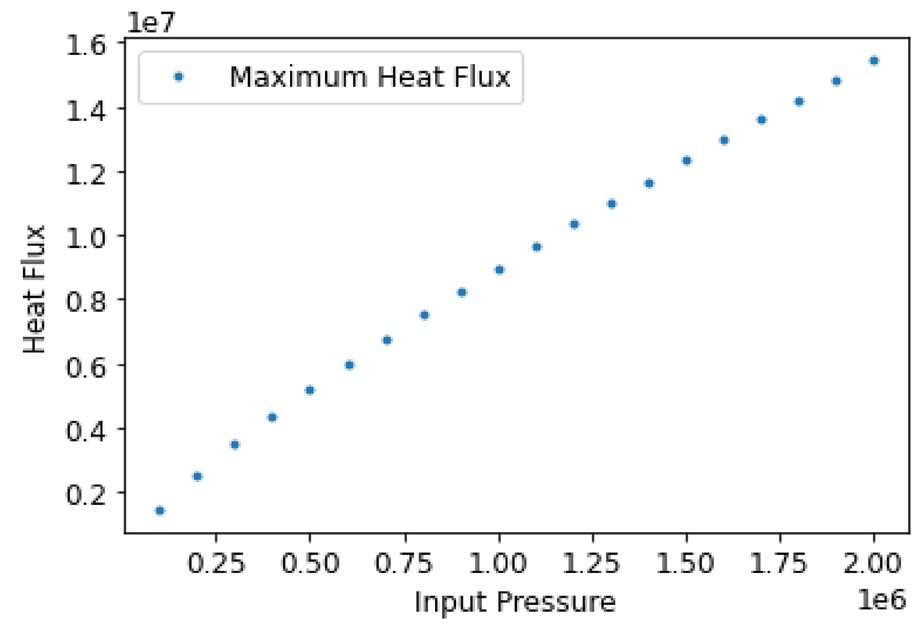
Heat Flux Modelling

The wall heat flux is calculated with the following equation [1].

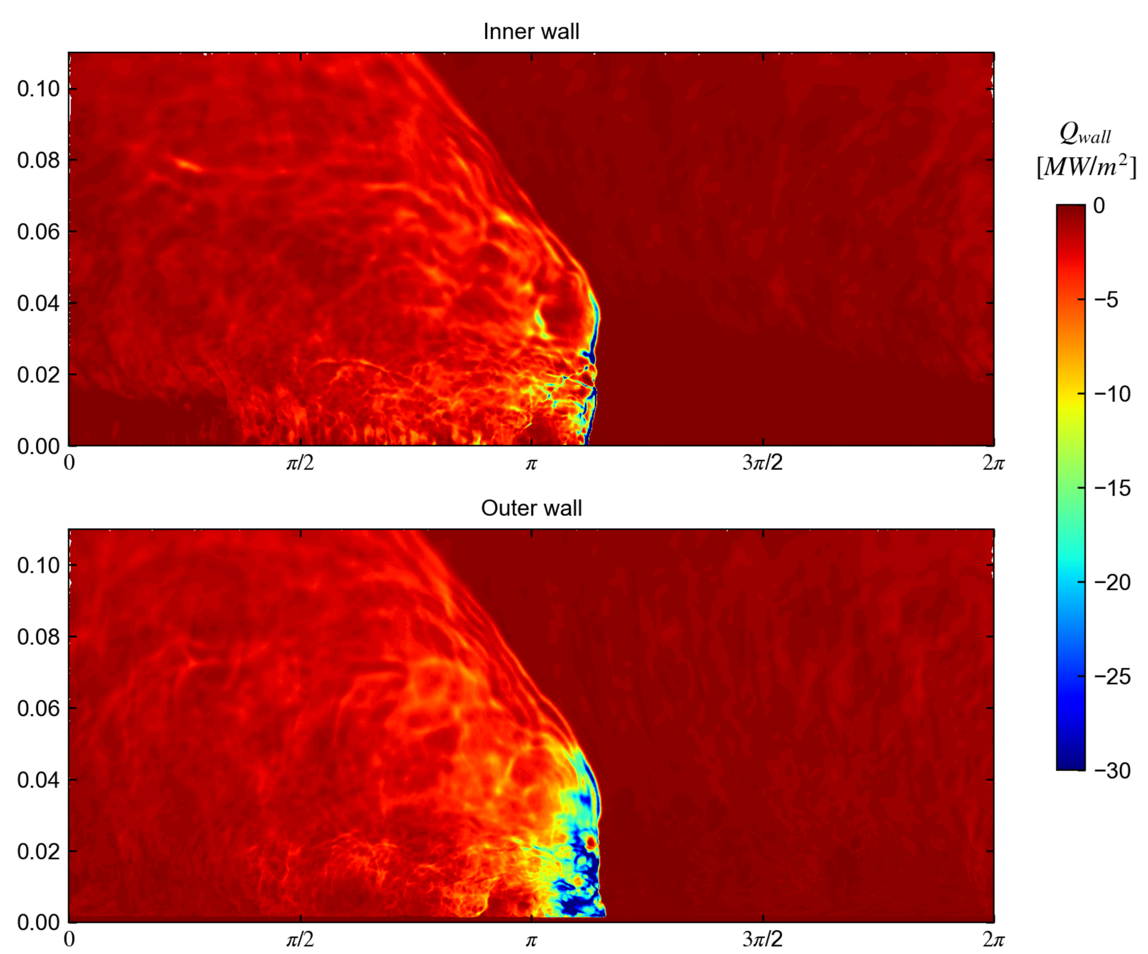
$$St = \frac{0.123 e^{-1.151 H_{i,fp}} \left(\frac{T_e}{T_{ref}}\right)^{0.732}}{\left(\frac{T_0}{T_e}\right)^{0.268} \left(\frac{M_e a_0 \theta_{tr}}{v_0}\right)^{0.268}} Pr_{ref}^{-2/3}$$

$$q_{wall} = \mathrm{St}\ \rho_e u_e (h_{aw} - h_w)$$

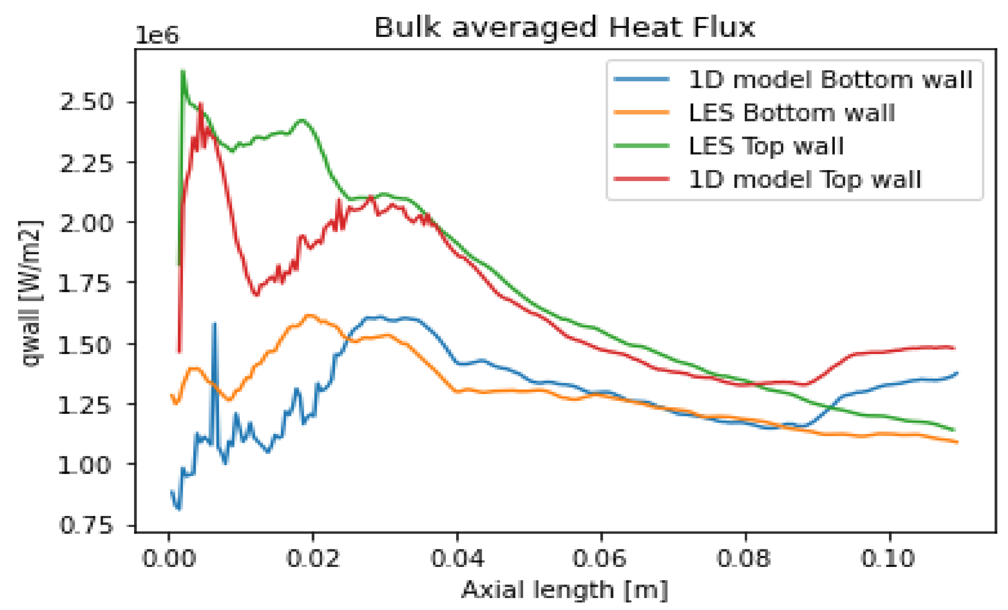
Making an assumption of single rotating detonation wave at all operating pressure. A simple scaling model is built which uses Shock and Detonation tool box [2] to obtain the detonation temperature.



Scaled Heat Flux for different operating pressure. For an operating pressure of 5 bar the peak average heat flux is 6 MW/m2. Very high when compared to GT Engines.



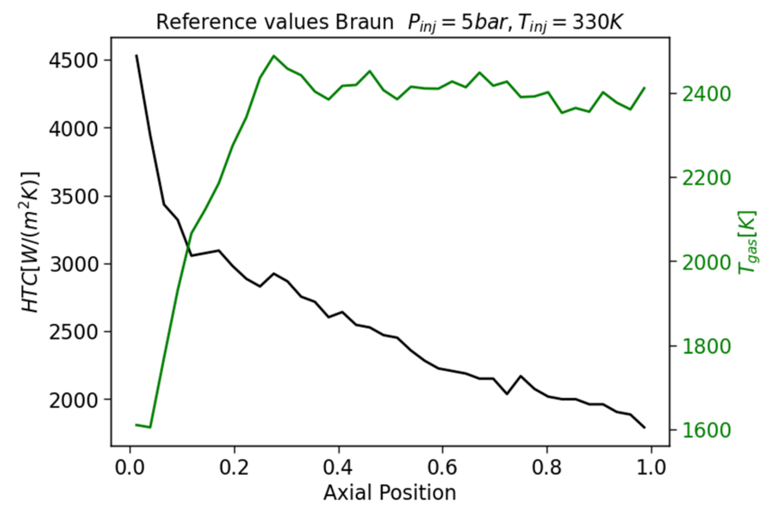
Wall heat flux contour of TU Berlin RDC operating in laboratory conditions obtained from LES simulation [3].



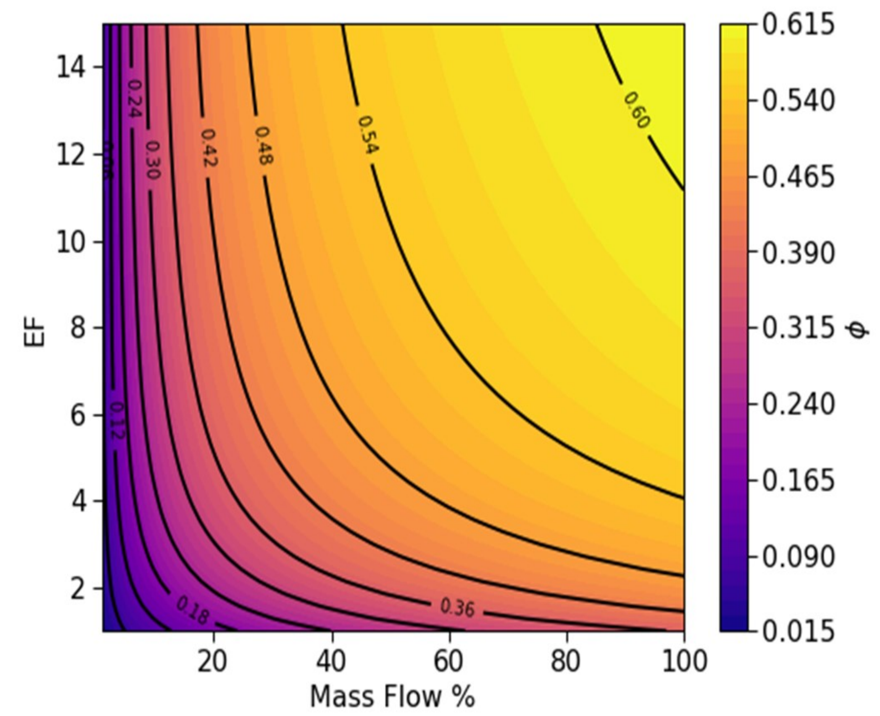
Bulk average heat flux of TU Berlin RDC obtained from LES simulation along with validation of the ROM.

Preliminary assessment of cooling solutions

For aeronautical applications, forced air cooling is the best feasible option.
Feasibility study of available cooling methods is performed.
The cooling effectiveness (ϕ) required to maintain the liner temperature below the limit of 1200K is determined.

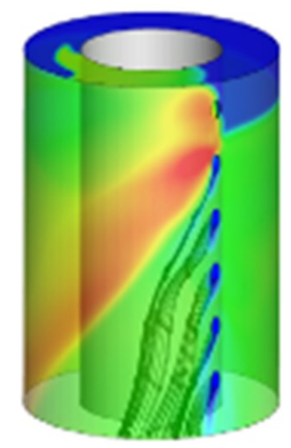


Bulk averaged HTC and Gas Temperature calculated from data obtained from Braun et al. [1].

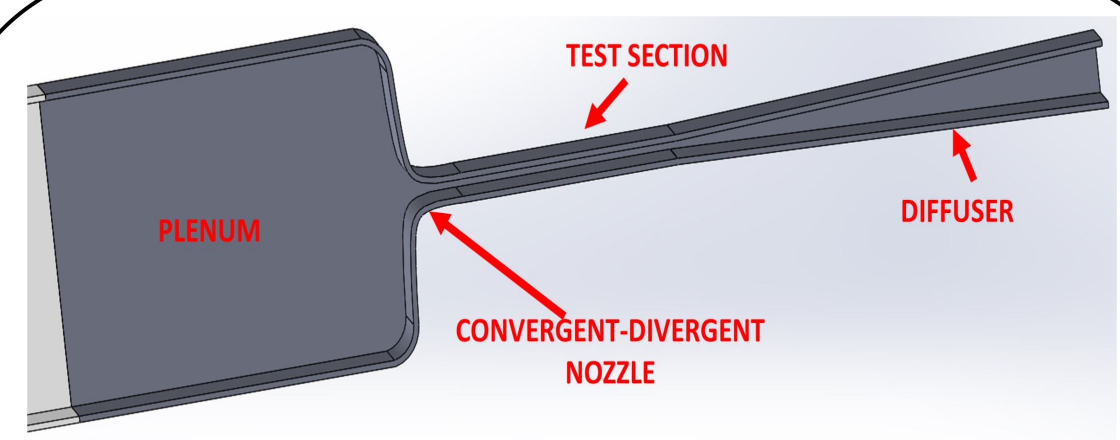


HTC augmentation of 15 with respect to a baseline smooth flat plate is not sufficient to obtain the required ϕ = 0.63. **The current state-of-the-art forced convection cooling schemes are not sufficient, unless the walls are protected.**

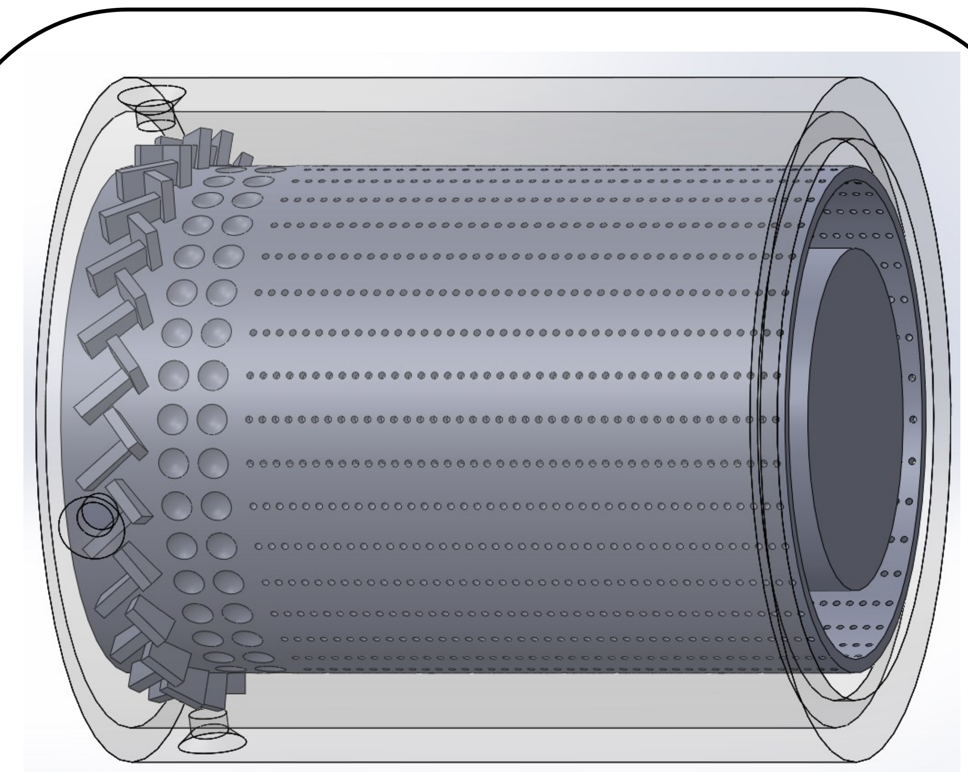
Effusion cooling assessment



Due to detonation the use of TBC is not feasible.
A protective layer which can rebuild itself quickly, even after disrupted by the detonation wave is the only possible solution. Researchers like Tian et al. [4] have already shown it is possible.



As part of INSPIRE-ETN research activity, we are building a test rig to evaluate the experimental performance of effusion cooling in non reactive supersonic mainstream conditions.
A reactive LES simulation of the RDE to assess the feasibility of Effusion cooling will be performed using **AVBP** solver.



A Possible cooling system design of an RDE. Where the first part uses turbulators and effusion cooling for the rest.

References:

[1]Braun et al., Numerical assessment of the convective heat transfer in rotating detonation combustors using a reduced-order model. Applied Sciences, 2018, 8(6).
[2]Browne, S et al., Numerical Solution Methods for Shock and Detonation Jump Conditions; GALCIT Report FM2006.006; GALCIT: San Diego, CA, USA, 2004.
[3]Nassini Pier Carlo, High-fidelity Numerical Investigations of a Hydrogen Rotating Detonation Combustor, PhD Thesis, UniFI, 2022.
[4] Tian et al., Numerical investigation on flow and film cooling characteristics of coolant injection in rotating detonation combustor. Aerospace science and technology, 2022, 122, 107379.

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