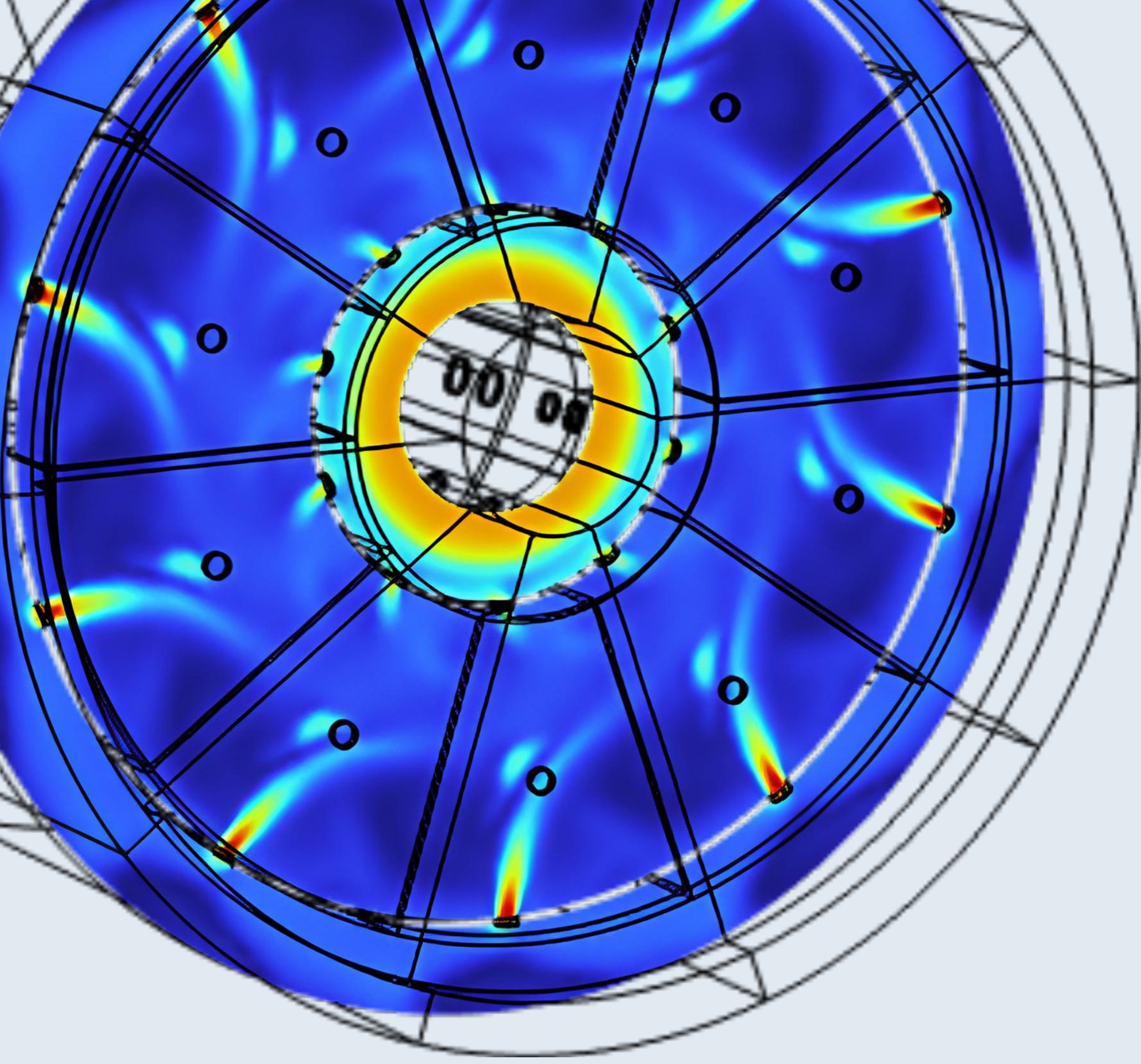




The Design and Optimisation of a Micro-jet Engine Combustion Chamber

Hot-flow CFD simulation of an analytically designed combustor, coupled with surrogate-based optimisation to maximise turbine-inlet temperature uniformity.

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During World War 2, in March of 1941 a pulse jet was mounted upon a radio-controlled airframe, birthing the McDonnell TD2D Katydid, or perhaps more relevantly, the first jet powered unmanned aerial vehicle. This breakthrough in aeronautics, began a multi-decade push of operational envelope and efficiency, leading to the development of micro-jet engines such as the BMW 8025 and Lyulka TS-31M (1950s). Furthermore, input of Arthur H. Lefebvre in 1983 formalised the annular combustor and its governing design principles.

The aviation industry reached a new apex, which when coupled with the speculation of computationally aided design, made the future seem promising. This is not the case. Modern day design - with reliance on legacy analytics, sparse contributions to improvement and limited trace in the open literature – leaves us in absence of novel workflows for combustor design. This is combatted by the integration of a surrogate-based optimisation workflow to the traditional design approach, leading the world to more maintainable and efficient combustion solutions.

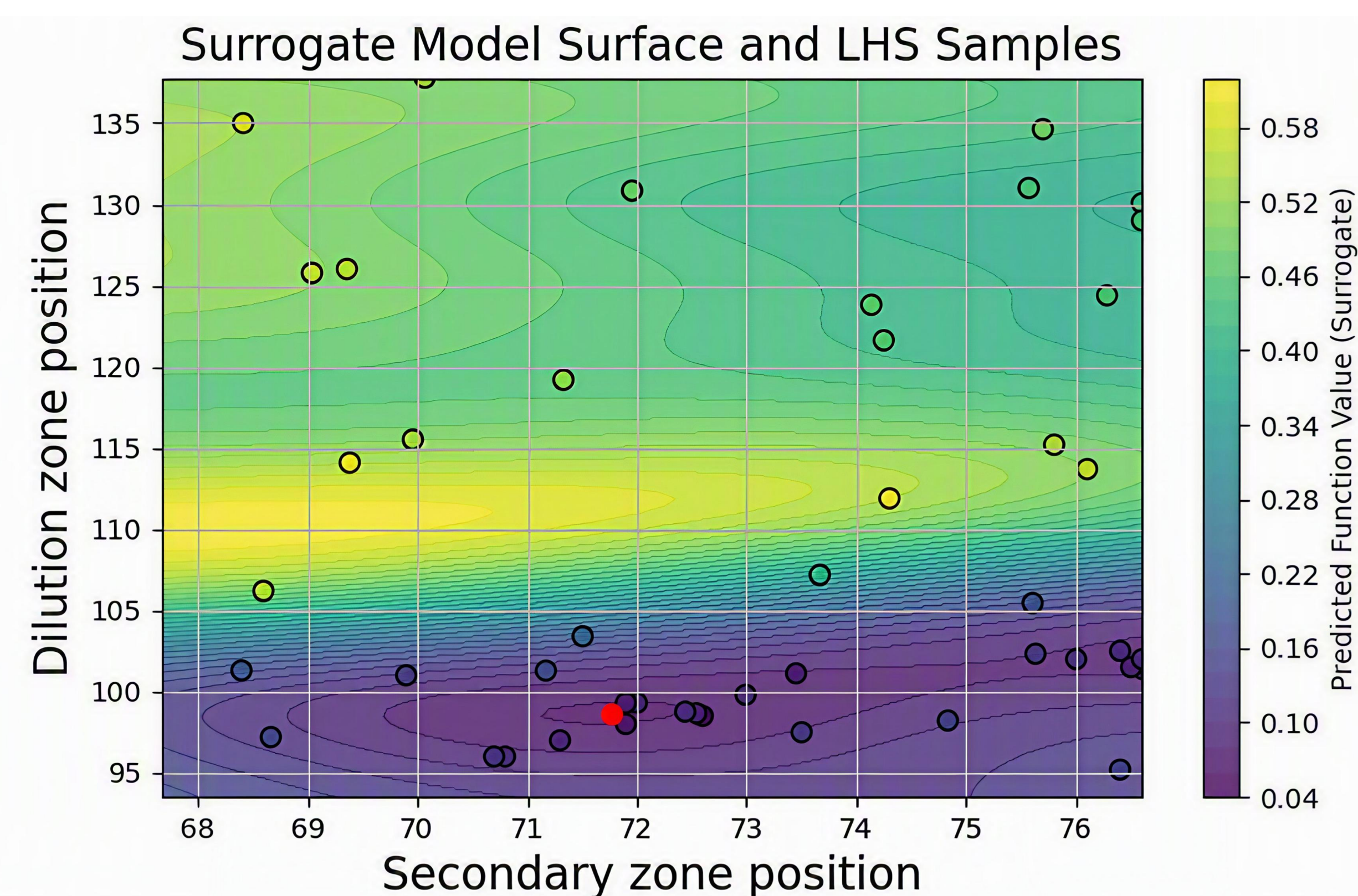


FIGURE 1: Final Optimisation heatmap, L-BFGS-B based

A Brief Methodology

After generating an initial geometry, using a conventional axial bleed hole layout [1], it is proposed that by plotting the bleed holes in accordance with the swirling velocity vector of the compressed air, more turbulent mixing can be propagated into the later stages of the chamber. Validated CFD simulation discloses a disadvantage in the Primary zone (where combustion takes place) as recirculating non turbulent air is required.

However, because of the theoretical improvements, optimisation is conducted on the proposed novel design, concerning the position of the Secondary and Dilution zone bleed holes, with the goals of i) delivering a uniform turbine inlet temperature distribution, and ii) a lower average temperature. Subsequently, Latin Hypercube Sampling [2] begins the workflow, complemented by the L-BFGS-B optimiser.

Results & Future Work

Actuating this achieves an 88.2% improvement in Pattern Factor (a variable used to quantify temperature uniformity, with a lower value representing an improvement) for the design plotting bleed holes with the air's velocity vector, shown in Figure 2. However, this must be coupled with the traditional primary zone to allow sustainable combustion to take place – yielding the Nolan annulus pattern design – with a final pattern factor of 0.182.

This work demonstrates the relevance of optimisation in design work for all components, but locally, a great improvement in combustor maintainability and efficiency; which can likely be improved much further by experimental validation, higher order multi-target optimisation and the proposition of more novel design principles.

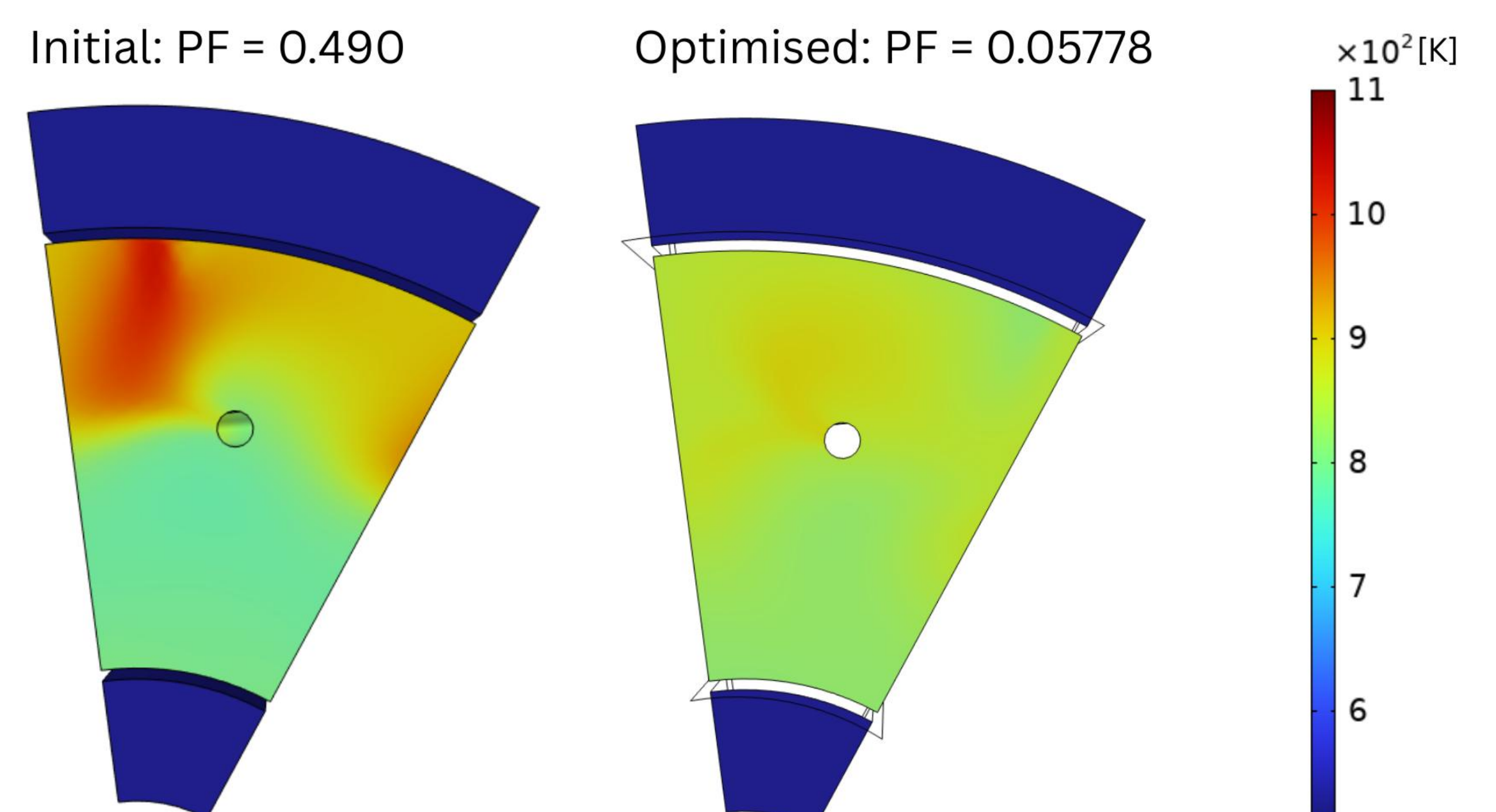


FIGURE 2: Comparison of turbine inlet temperature distributions, before (left) and after optimisation (right)

REFERENCES

[1] A. H. Lefebvre and D. R. Ballal, Gas Turbine Combustion: Alternative Fuels and Emissions, Third Edition. CRC Press (Taylor & Francis Group), 2010.

[2] D. R. Jones, M. Schonlau, and W. J. Welch, Efficient Global Optimization of Expensive Black Box Functions. Springer, 1998. Available at: <https://link.springer.com/article/10.1023/A:1008306431147#citeas>.



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