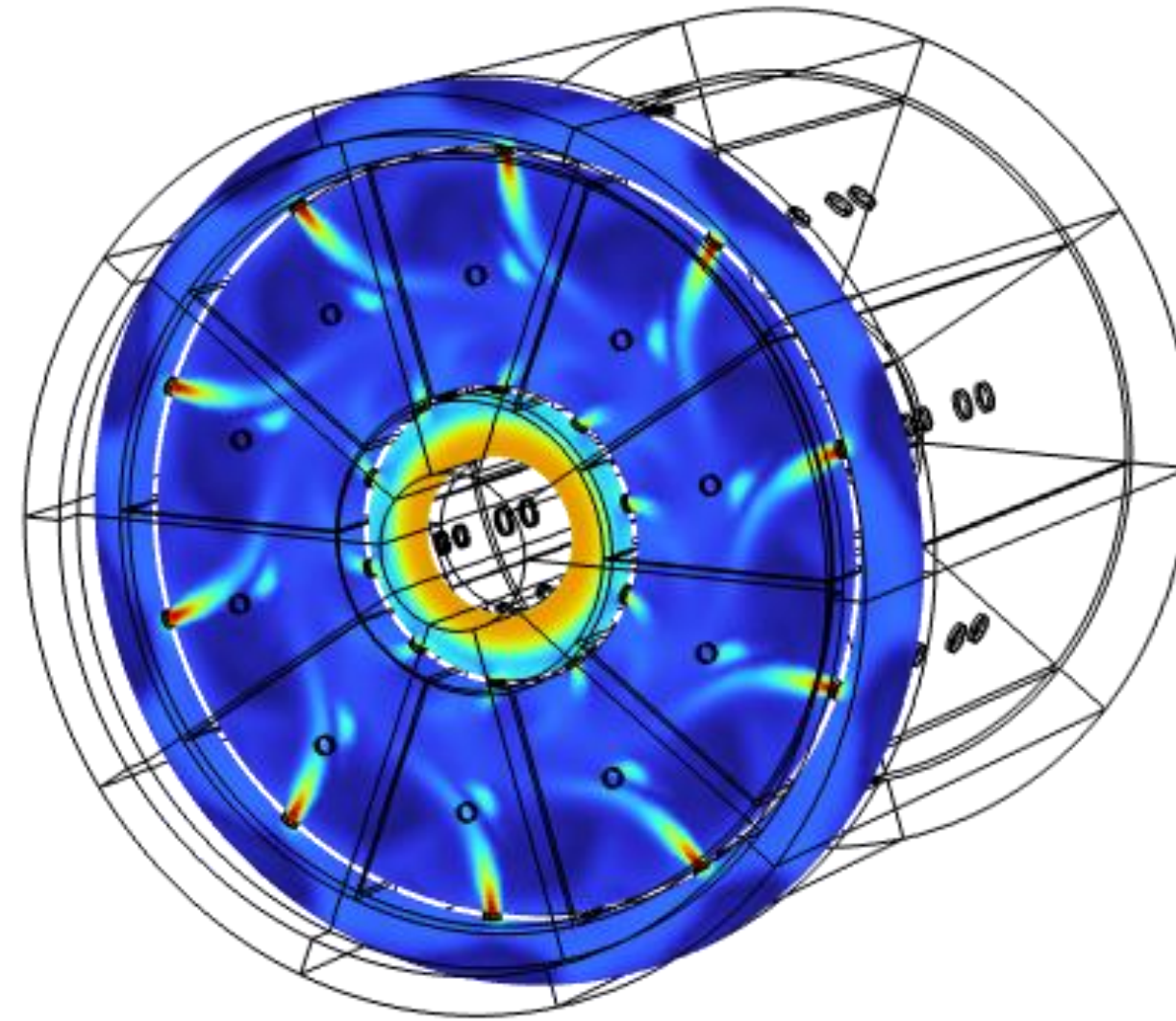


The Design and Optimisation of a Micro-jet Engine Combustor

Presented by Bradley Nolan

MANCHESTER
1824

The University of Manchester



A brief history



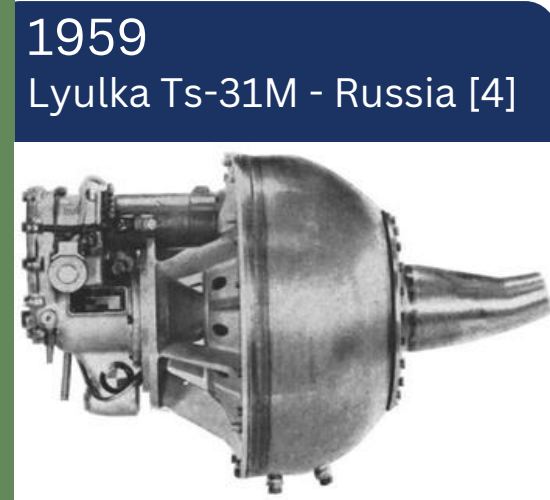
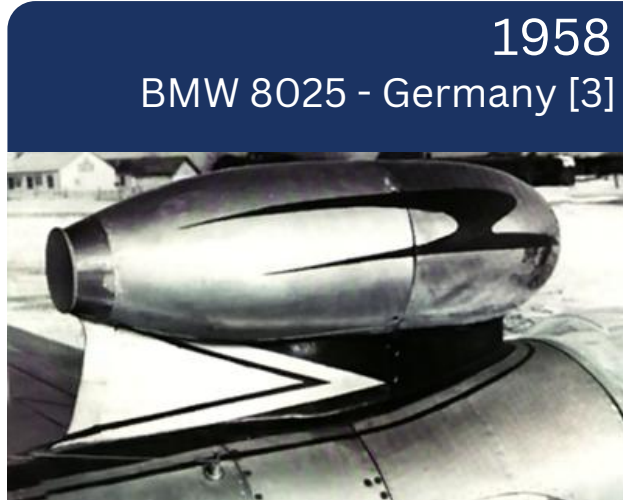
1941

A pulse jet is mounted upon a radio controlled airframe, birthing the McDonnell TD2D Katydid, or perhaps more relevantly the first jet powered unmanned aerial vehicle [2]



1983

Arthur H. Lefebvre published "Gas Turbine Combustion", documenting design principles for annular combustors [5]



The few diehard aviators of the population were lead to a new apex, which coupled with the speculation of computationally aided design, made the future seem bright

A brief history... The present

The present

As desire to miniaturise grew, issues with thermal disturbance, vibration and fatigue become more apparent in combustors

Companies that were successful became apprehensive to publish their findings, and those who failed disappeared

Leading to modern day design, relying upon legacy analytics, under utilising tools available to us

However, the demand for more efficient, maintainable solutions grows as the applications are realised

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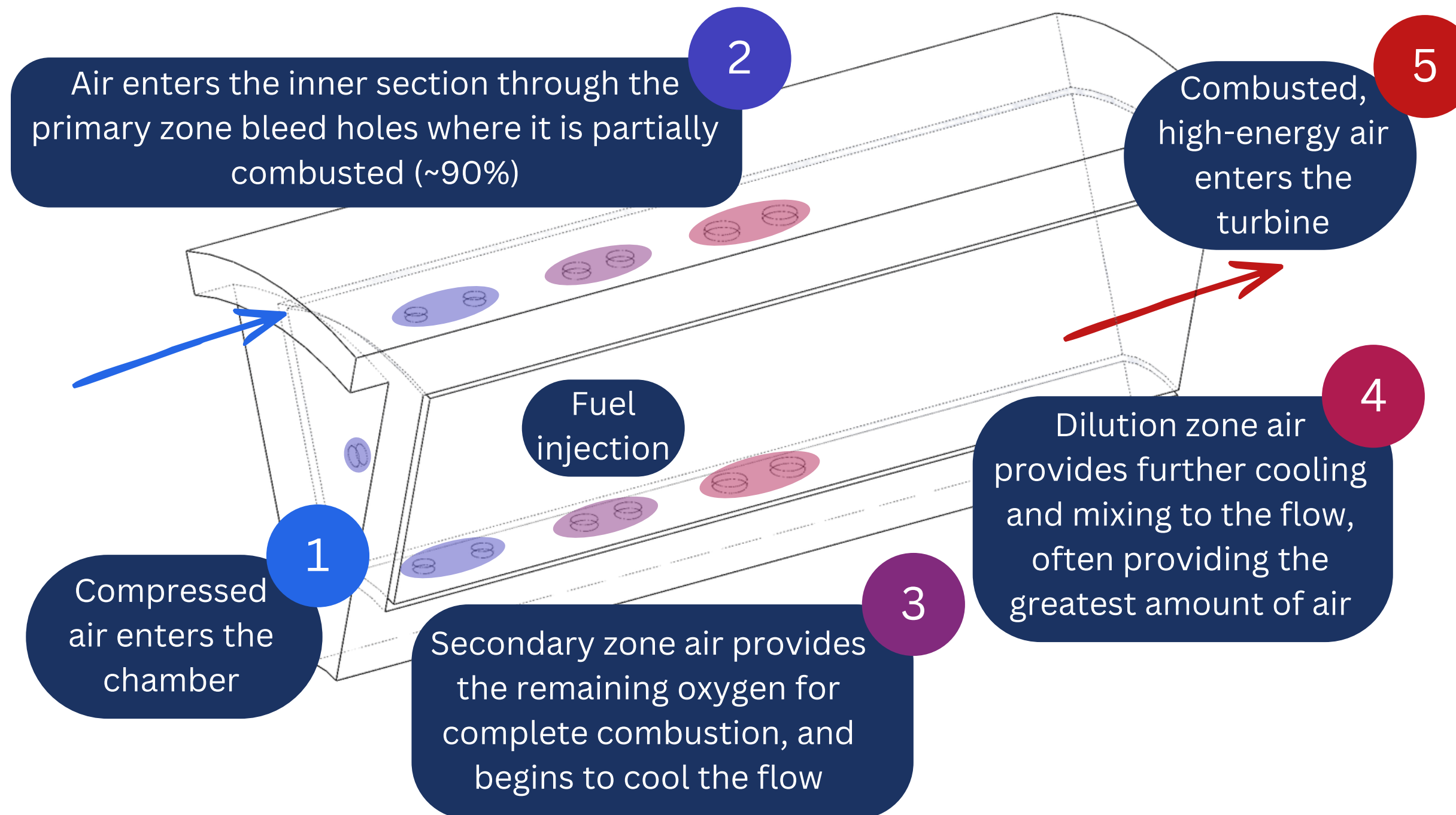
“The global aircraft micro turbines engines market size was valued at USD 3.2 billion in 2024 and is estimated to grow at CAGR of **6.3%** to reach 5.8 billion by 2034” [4]

“The global food and beverages market, valued at \$6.68 trillion in 2024, is projected to hit \$11.61 trillion by 2034, growing at a CAGR of **5.54%**” [3]

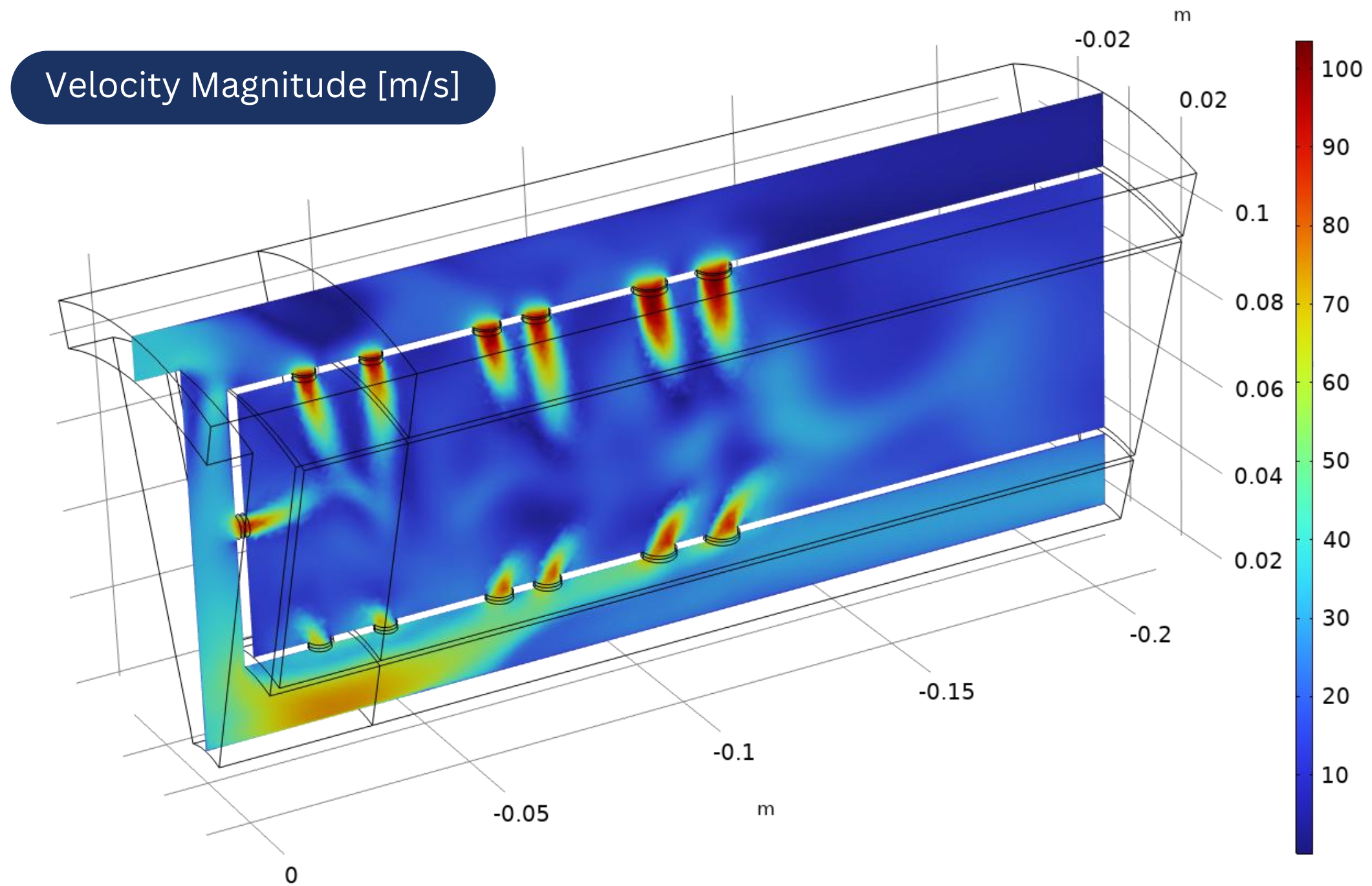
[3] Research and Markets, 11.6 Trillion food and Beverage markets, <https://uk.finance.yahoo.com/news/11-6-trillion-food-beverages-133600633.html>, Yahoo Finance, June 2025

[4] S. Gujar, P. Paul, Aircraft Micro Turbine Engine Market Size, <https://www.gminsights.com/industry-analysis/aircraft-micro-turbine-engines-market>, Global Market Insights, May 2025

What the present gives us



What the present gives us



The issues in “modern” analytics

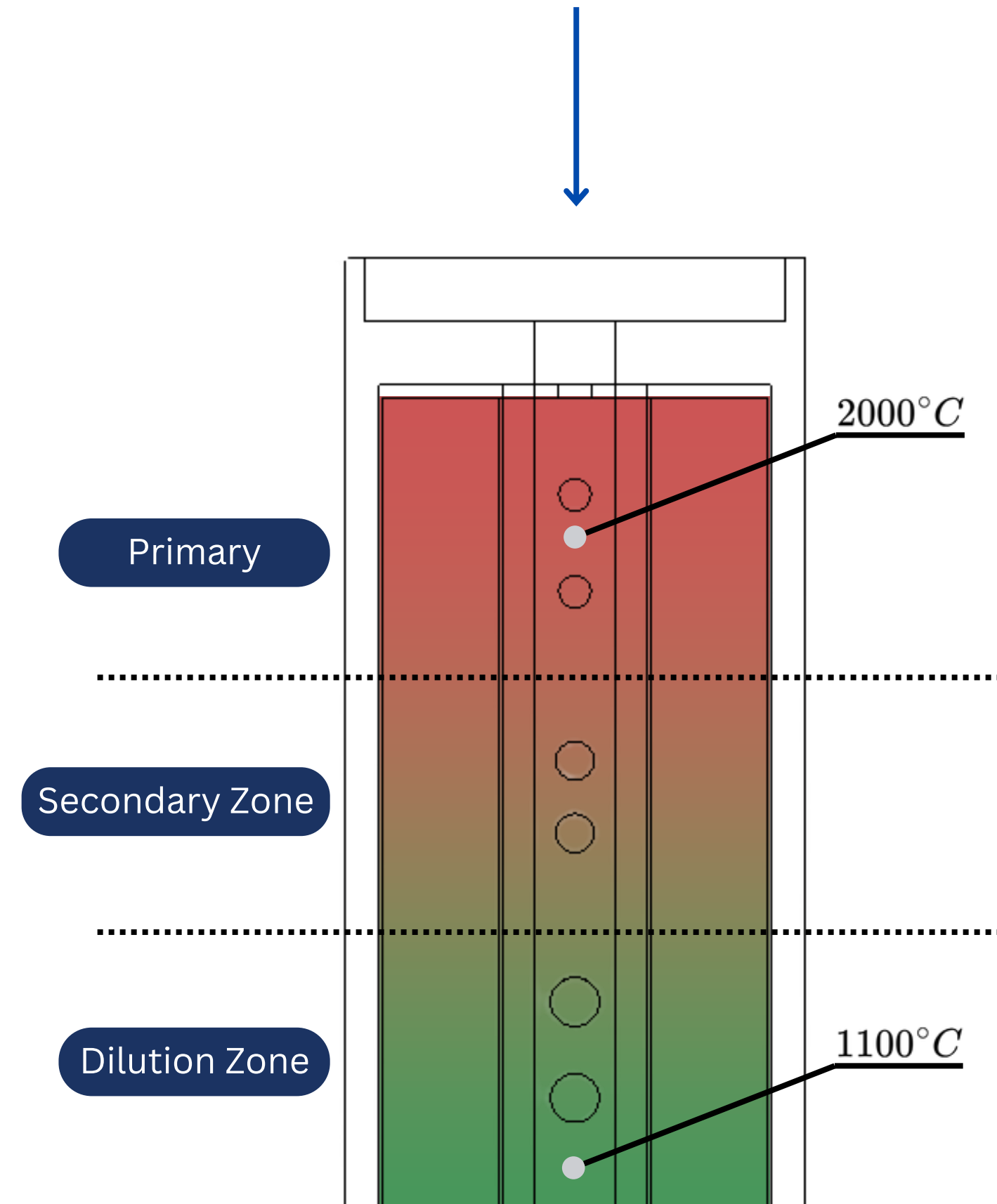
The approximations below are used in combustor design

$$Length_{PrimaryZone} = \frac{2}{3} Diameter_{Liner}^{[4]}$$

$$Length_{SecondaryZone} = \frac{1}{2} Diameter_{Liner}^{[4]}$$

And no real guidance aside from basic mass continuity equations exists to inform...

- i) The number of zone bleed holes present for a given design
- ii) The position of these bleed holes, radially and axially



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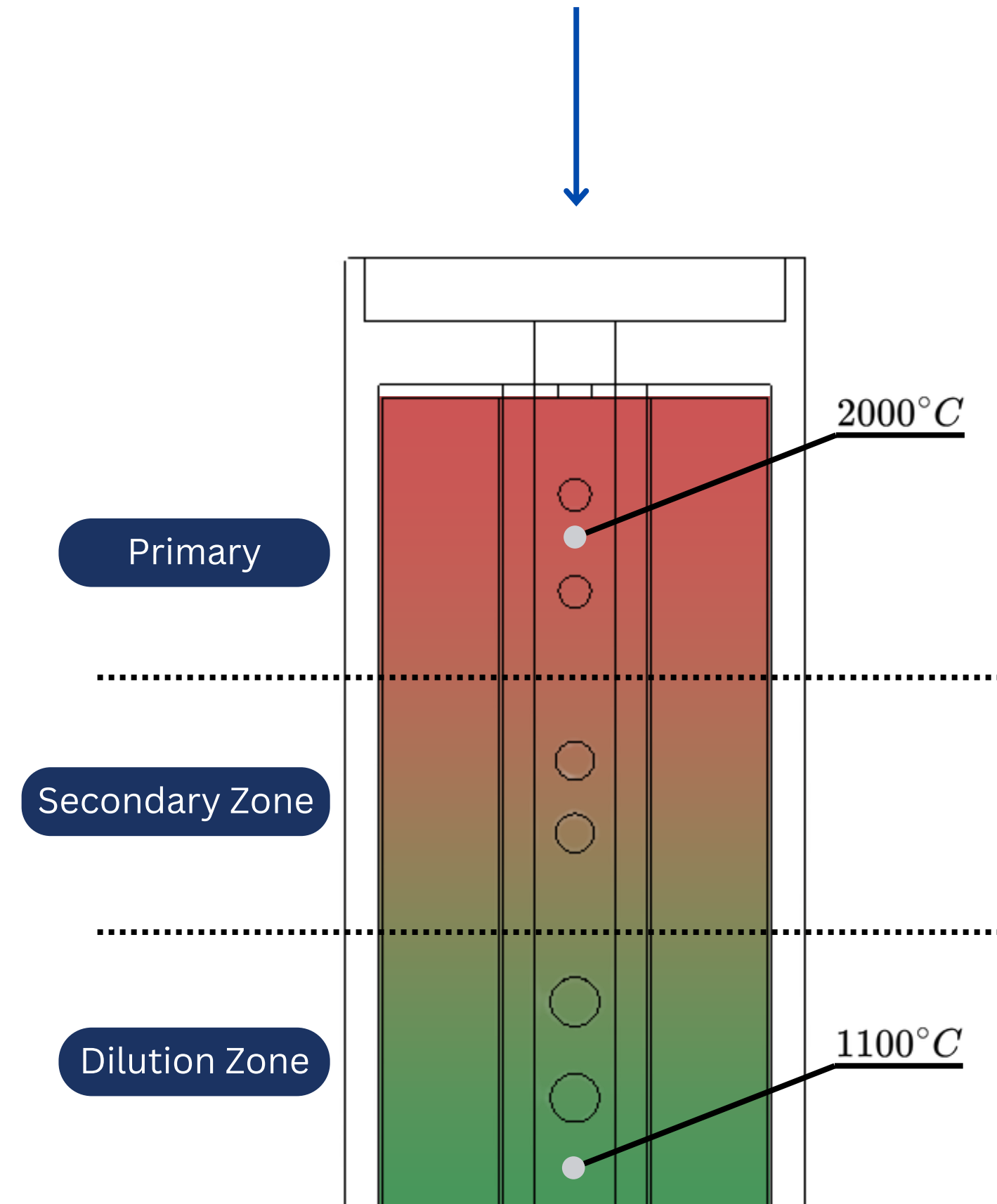
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- ii) The position of these bleed holes, radially and axially

Leading too...

- Poor temperature uniformity in the turbine inlet plane
- Large fractions of combustion occurring in the secondary zone
- Overall lack of confidence in engine design



Evidence of the shortcomings

Upon running CFD of the generated geometry from these analytics, it was noticed that the mass flow rate and hence Oxygen supply in the Primary zone was **10% lower** than the design point

Evidence of the shortcomings

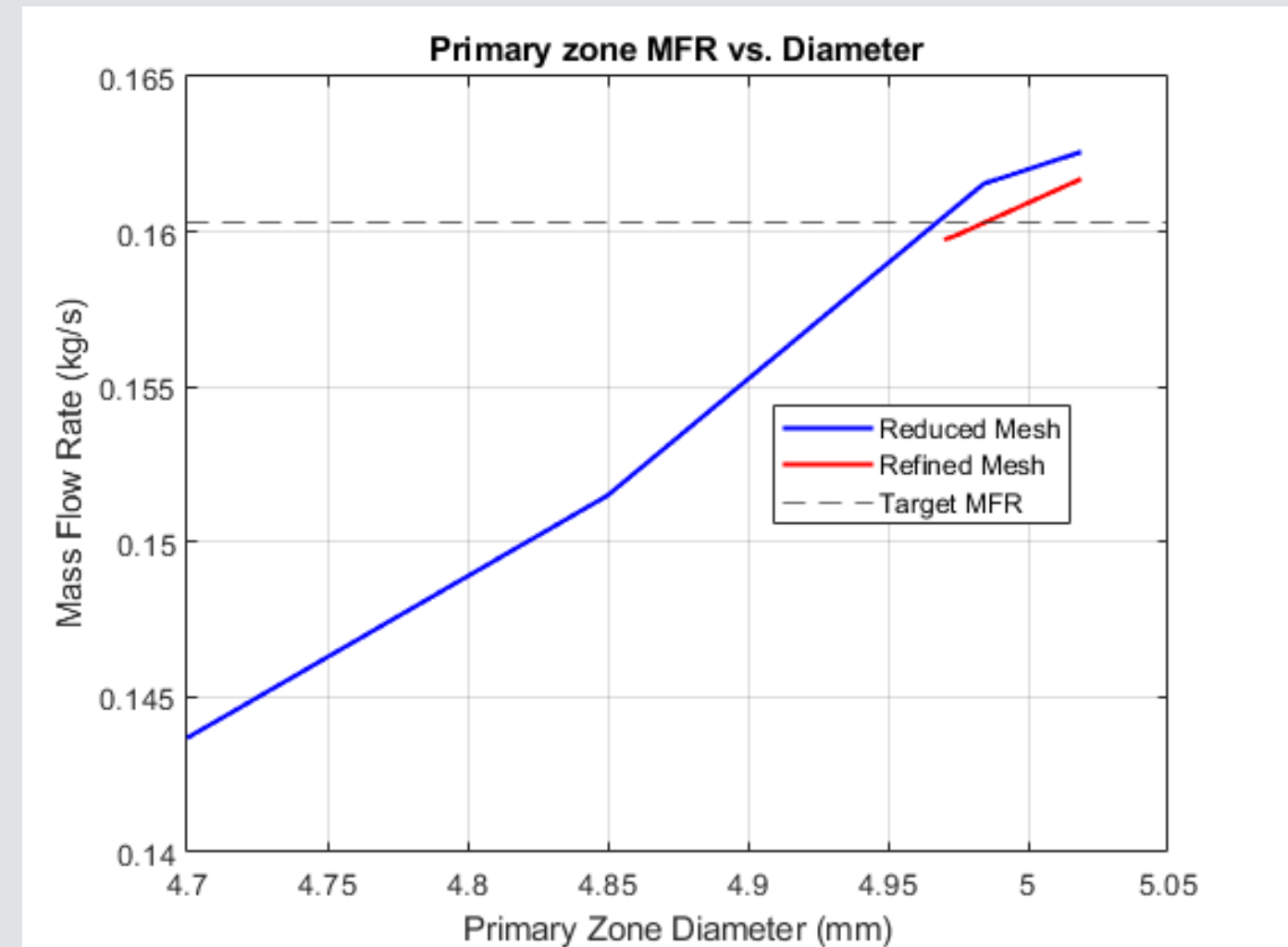
Upon running CFD of the generated geometry from these analytics, it was noticed that the mass flow rate and hence Oxygen supply in the Primary zone was **10% lower** than the design point

To rectify this simple optimisation was used

- Taking samples for increasing the primary zone bleed hole diameter confirmed a linear relationship
- By using a multi-fidelity mesh, we are able to converge quickly upon the target mass flow

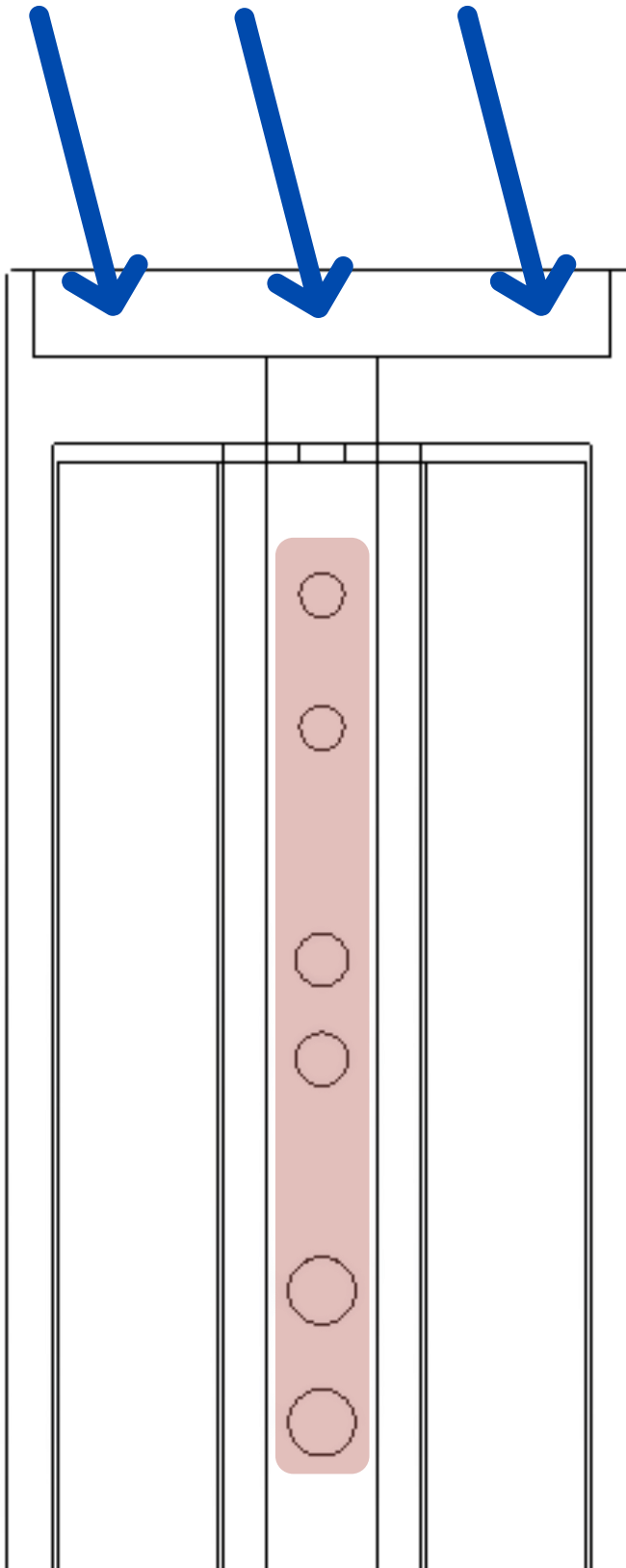
Whilst this work is possible for anyone willing to run a few simulations, a goal of future work is to determine a correction to the analytics across a scale of engine size / pressure ratio.

This would allow researchers and companies to quickly iterate early stages of design, and solve the issues with incomplete combustion in the primary zone.

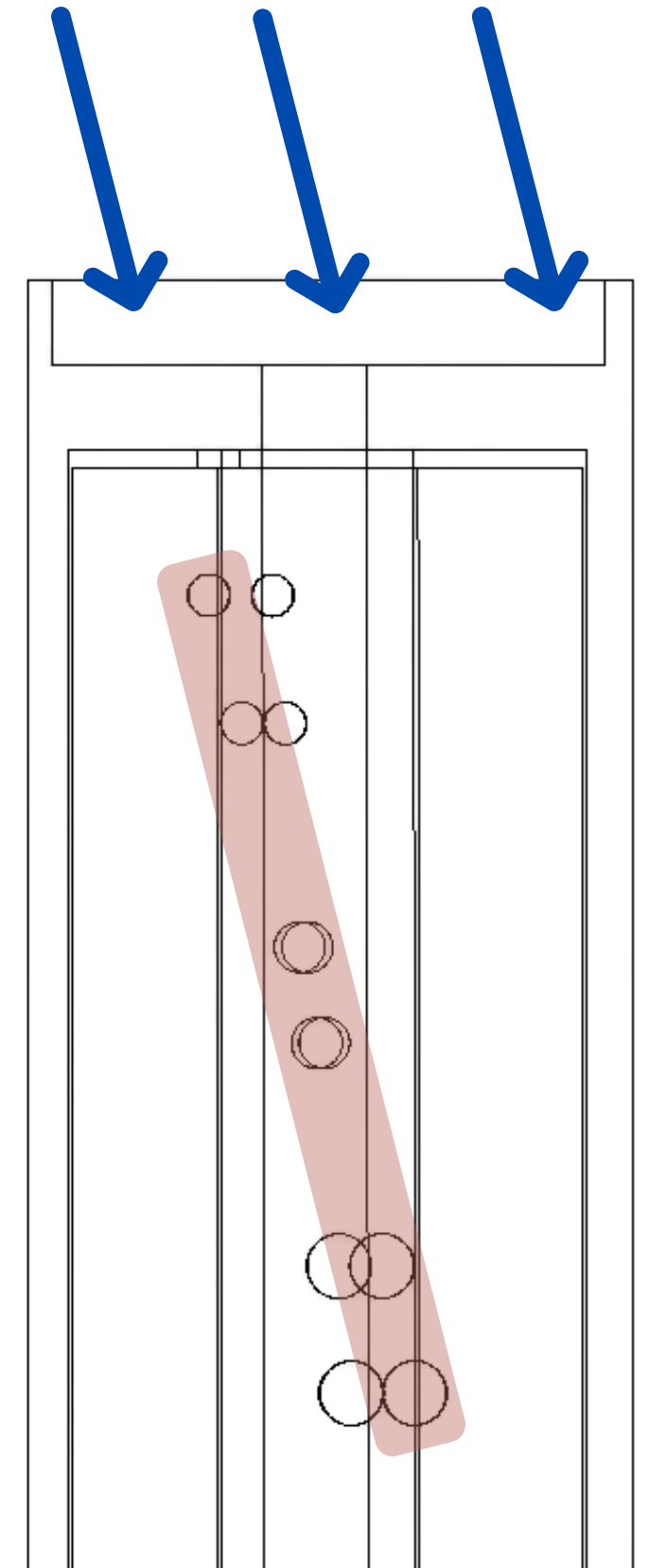


Further design implemented a unique tangential flow annulus principle, or (TAP)

No TAP

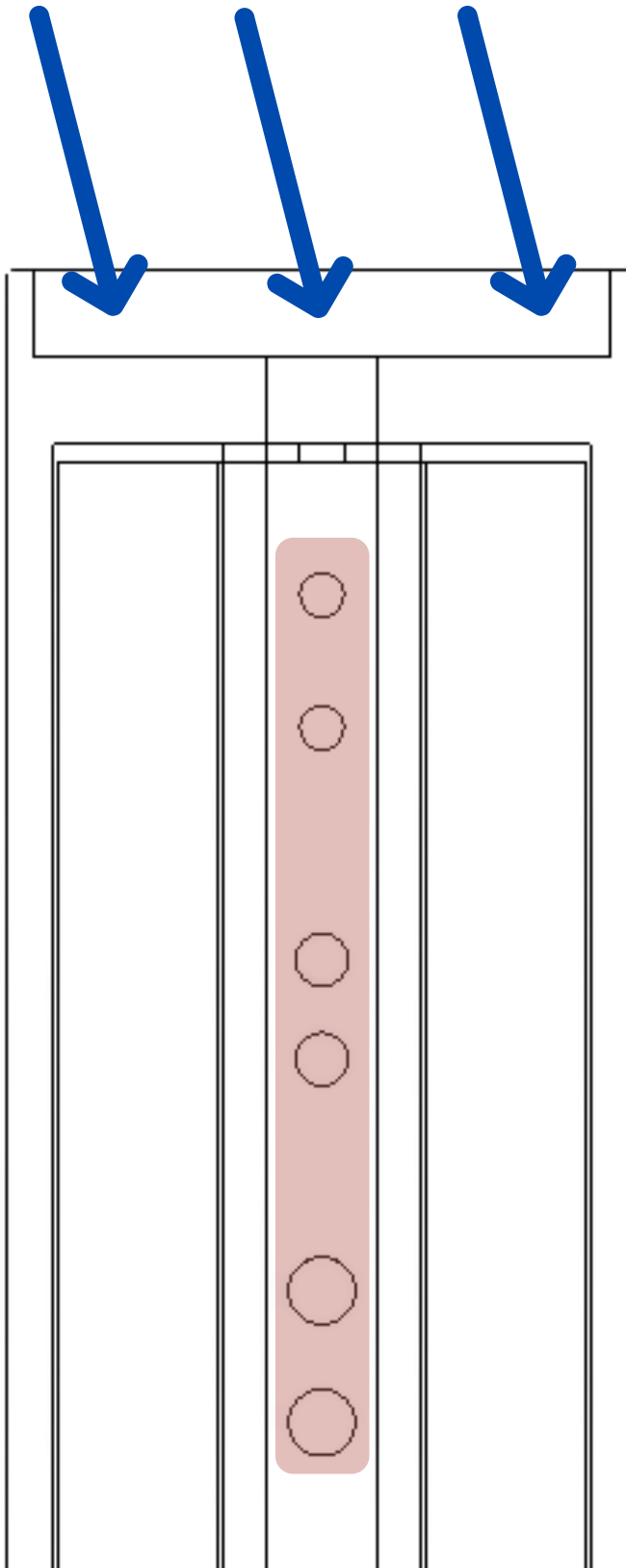


TAP

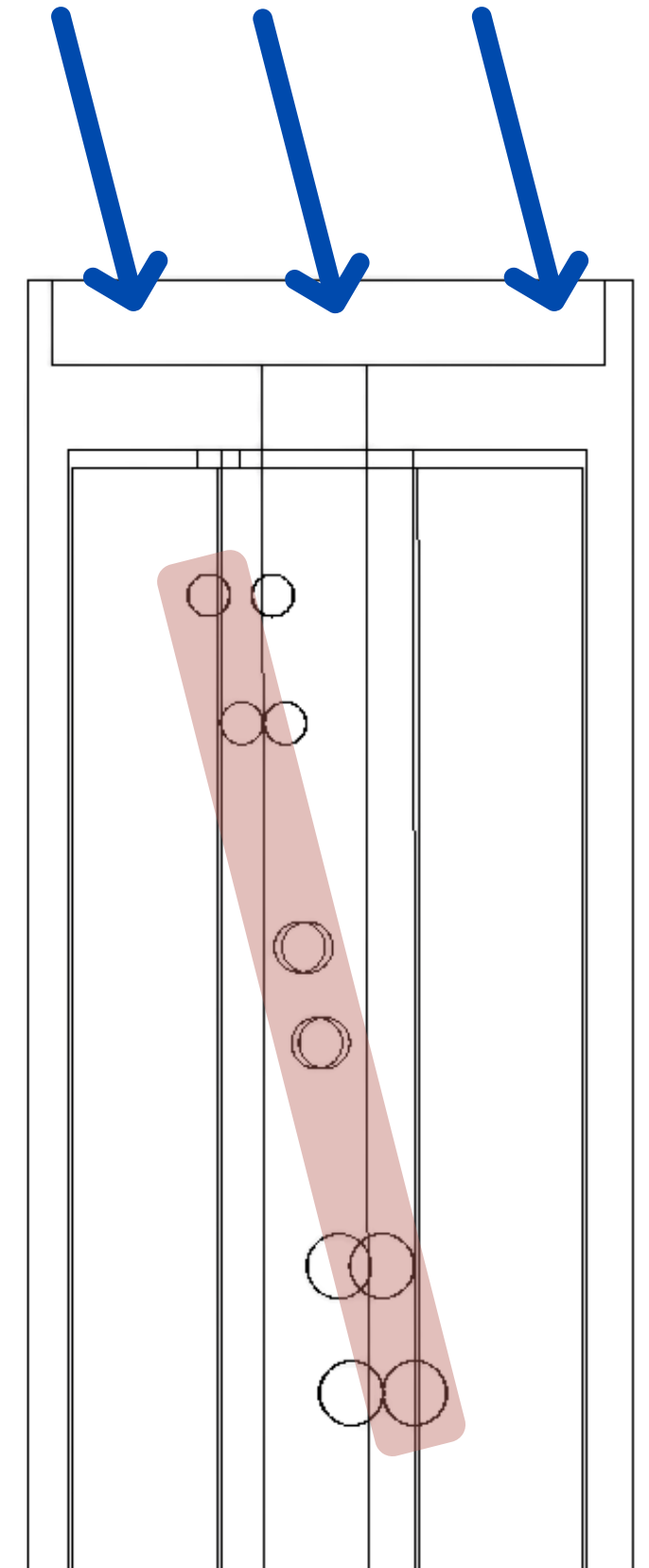


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TA



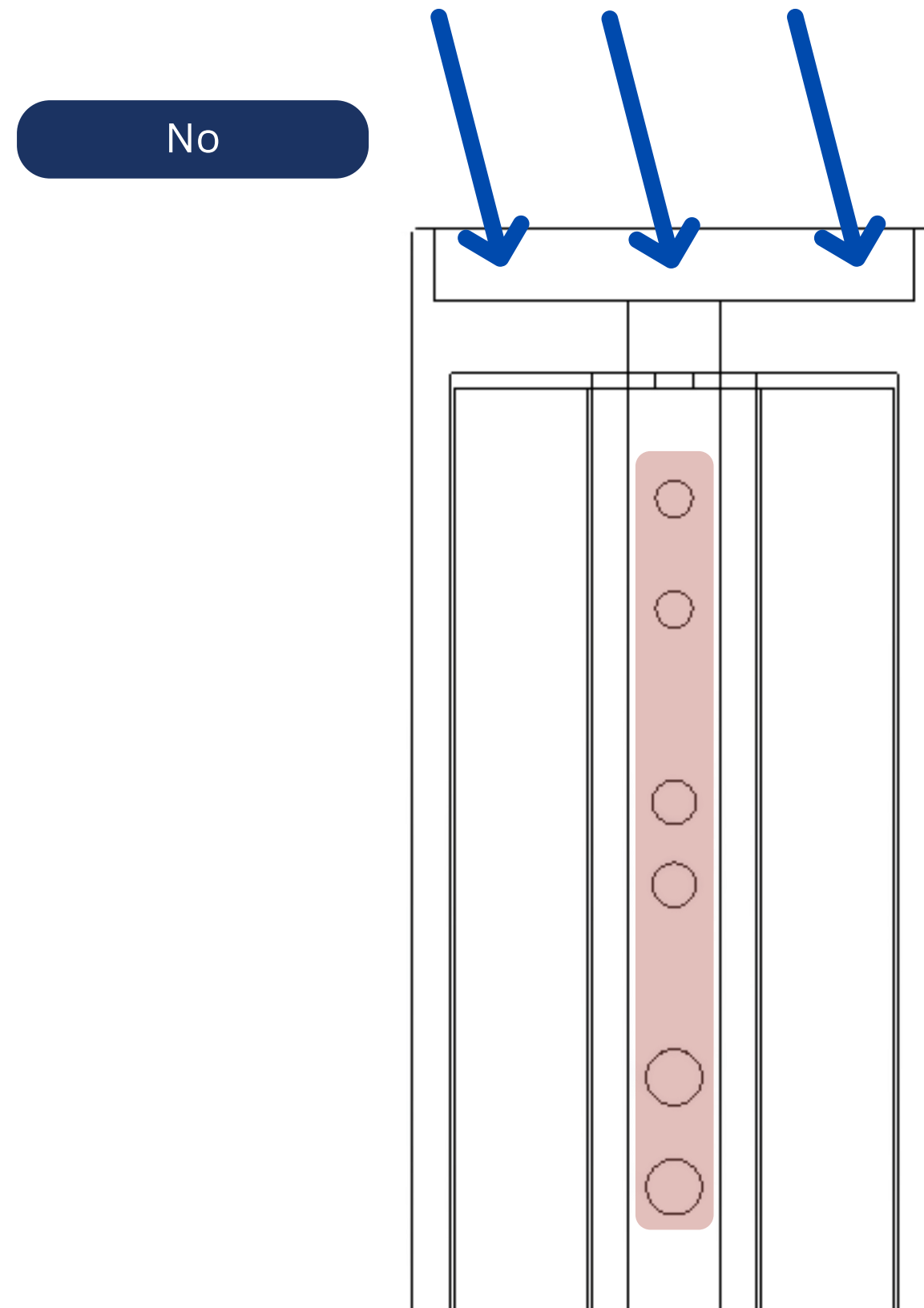
You may be thinking, Why?

By doing this, we allow the same airflow distribution in the primary zone, capturing necessary effects for flame stabilisation.

However, downstream each bleed hole takes in air distorted from the previous bleed hole.

Allowing theoretically, a more turbulent flow in the mixing sections of the combustor, and hence, a more uniform temperature distribution at the outlet.

Further design implemented a unique tangential flow annulus principle, or (TAP)

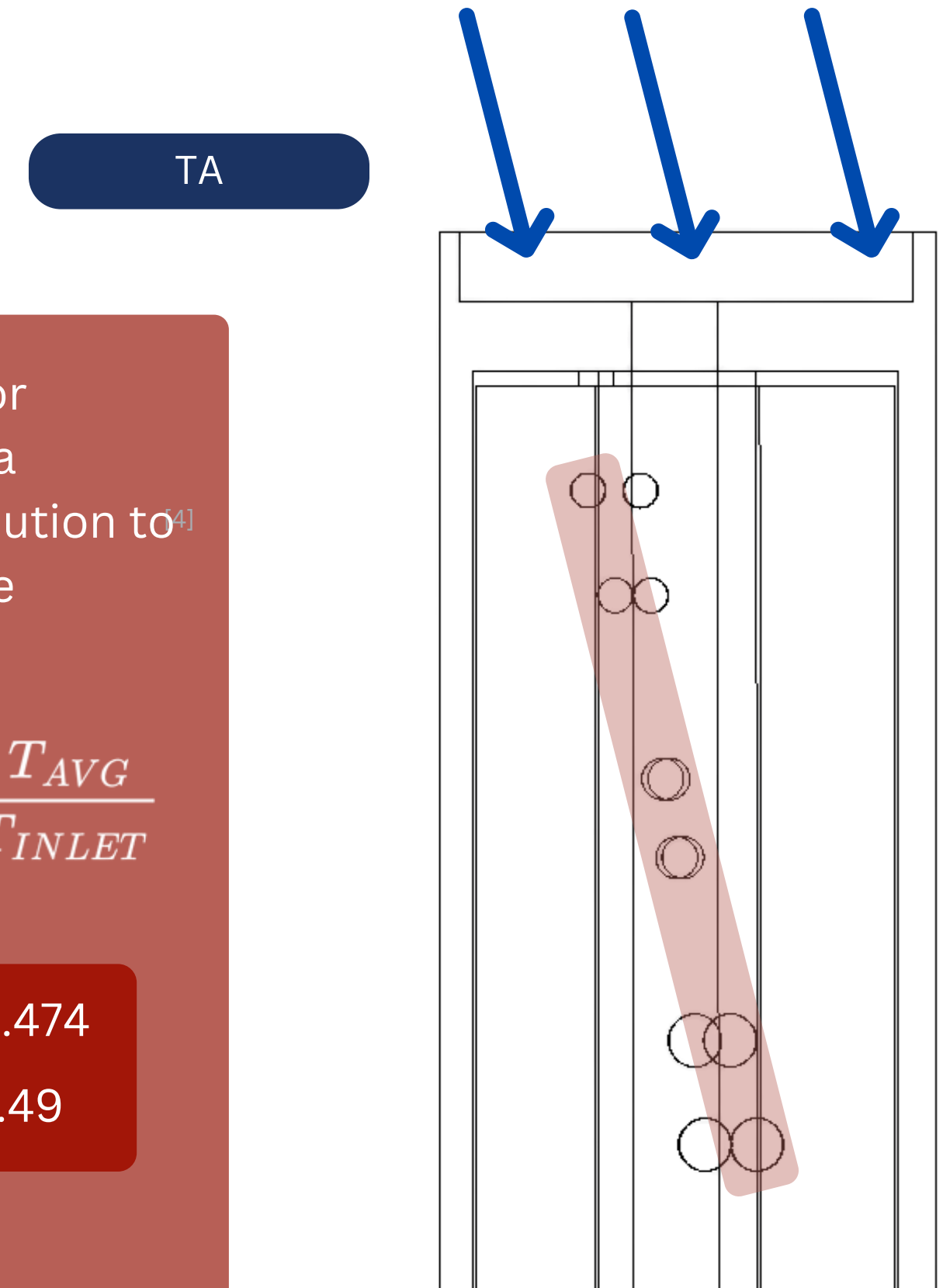


To quantify how a combustor performs as far as delivering a uniform temperature distribution to the turbine we use a variable called...

$$PatterFactor = \frac{T_{MAX} - T_{AVG}}{T_{AVG} - T_{INLET}}$$

Pattern Factor Before → 0.474

Pattern Factor After → 0.49



Optimising the Pattern Factor

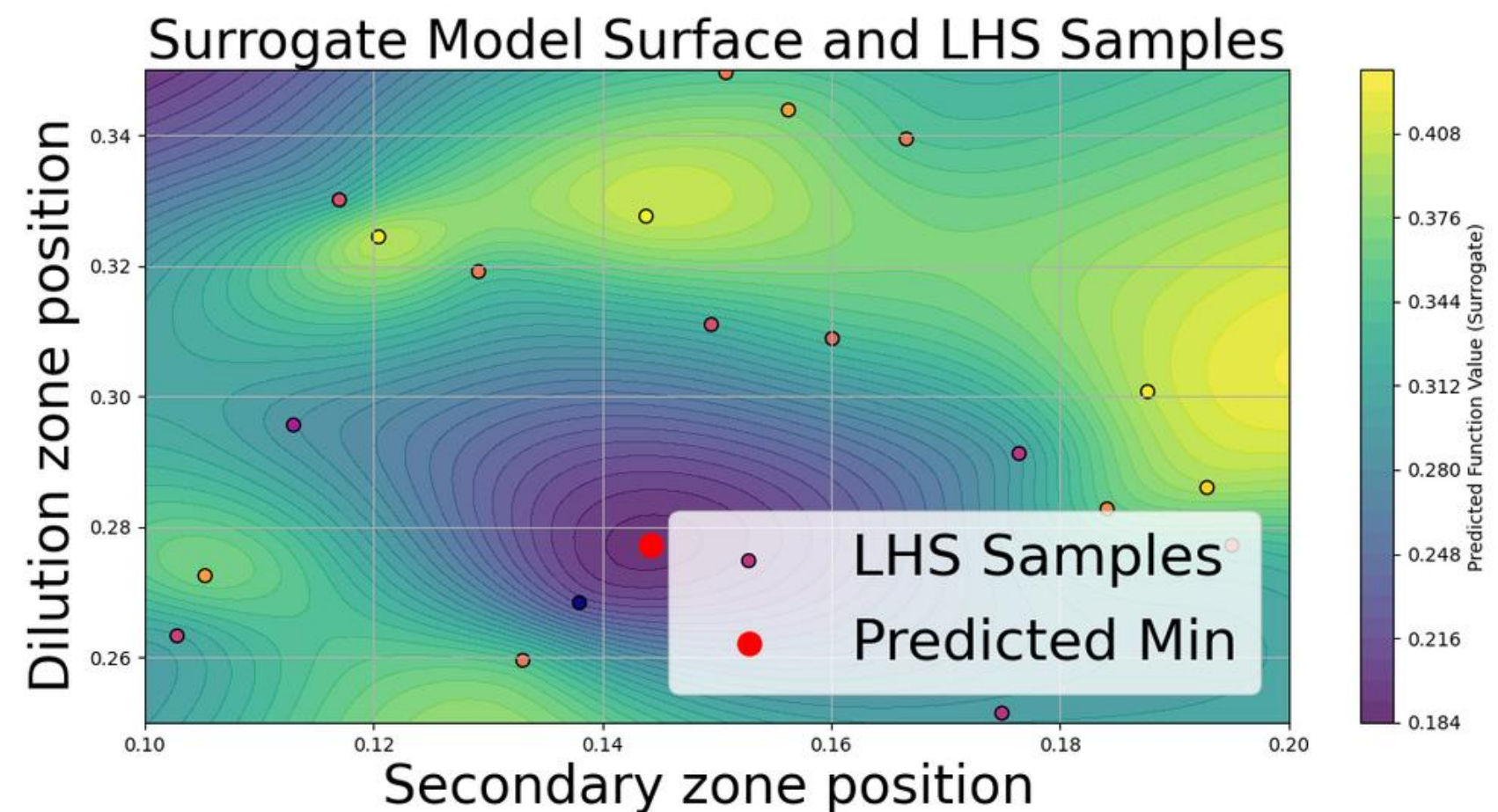
Improvements in this variable are necessary for both designs, as the industry standard is less than 0.2

Aside from an advanced experimental approach, we can do this using an optimisation algorithm

By setting geometrical boundaries for Dilution and Secondary Zone positions, and hence the air they inject into the hot combusted flow

We can take random samples in this space, generating data for an optimiser to predict a minimum Pattern Factor Design

On the right is shown the optimiser working for a set of “dummy” data



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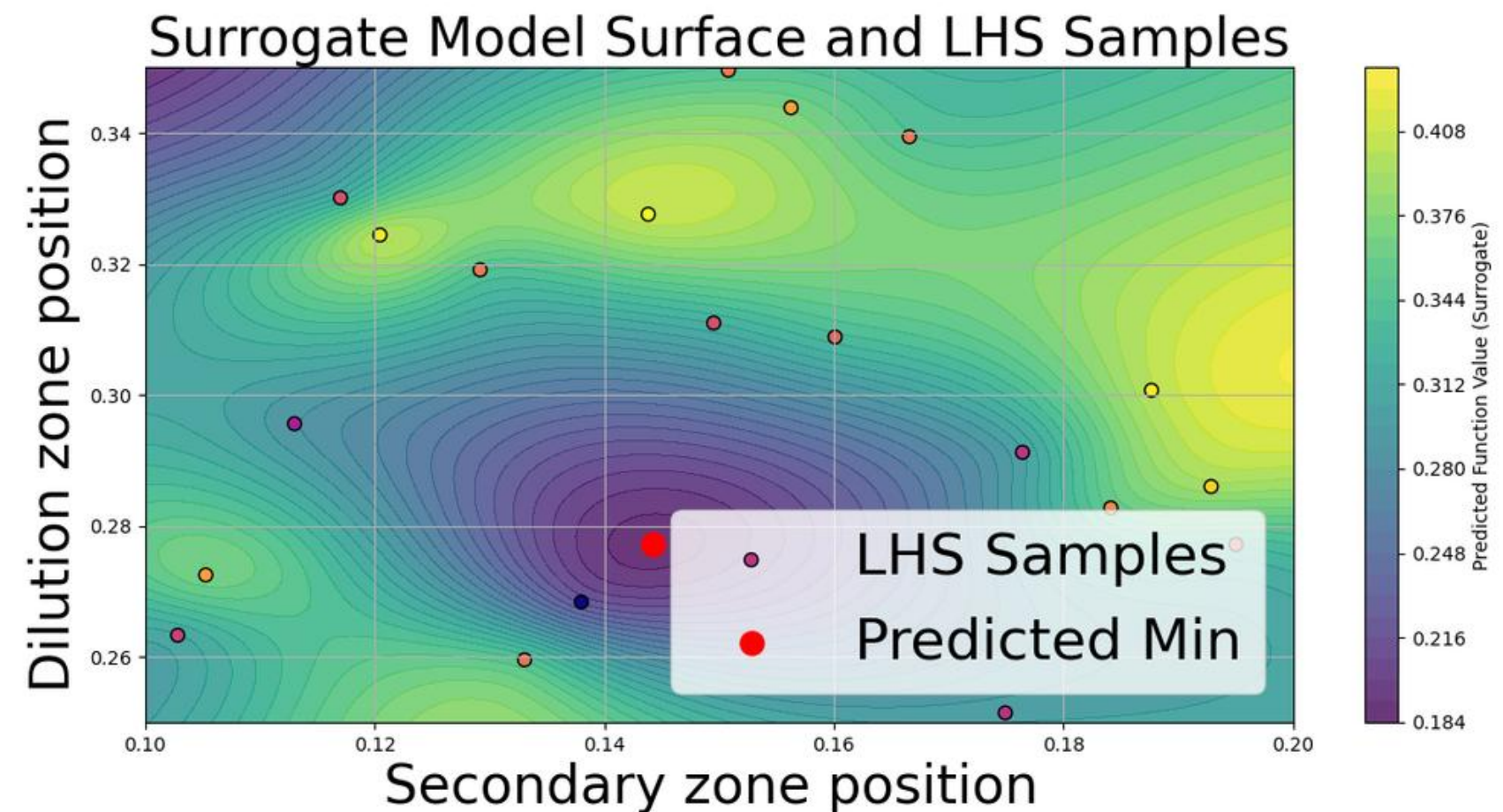
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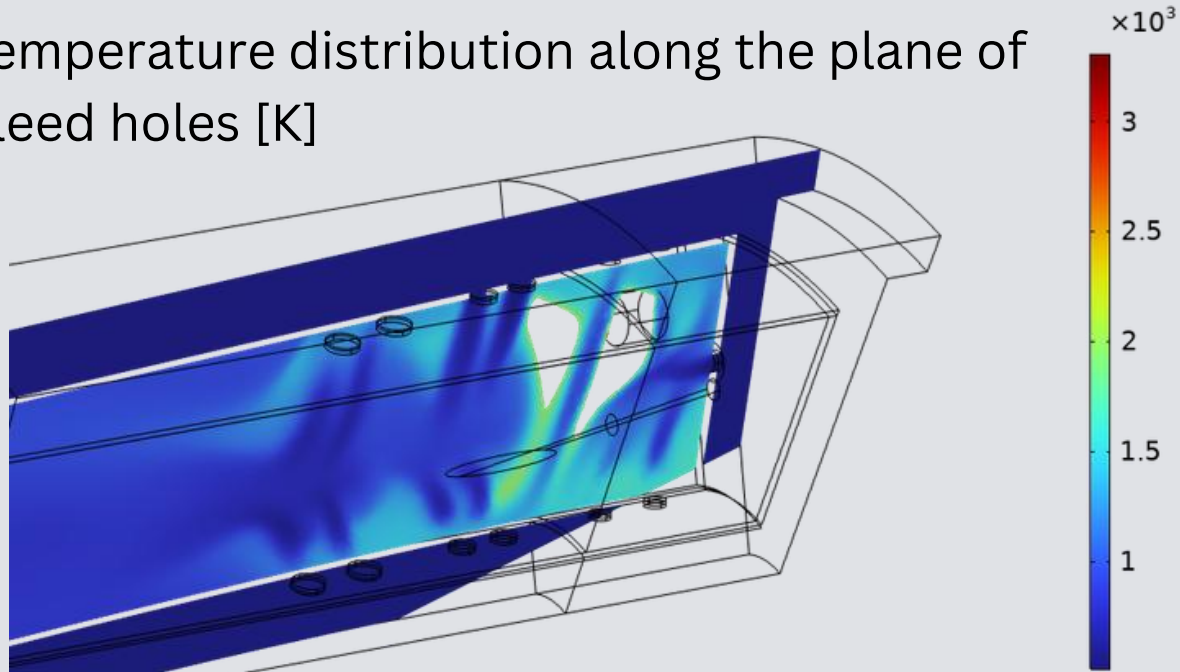
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But no one really cares about “dummy” data

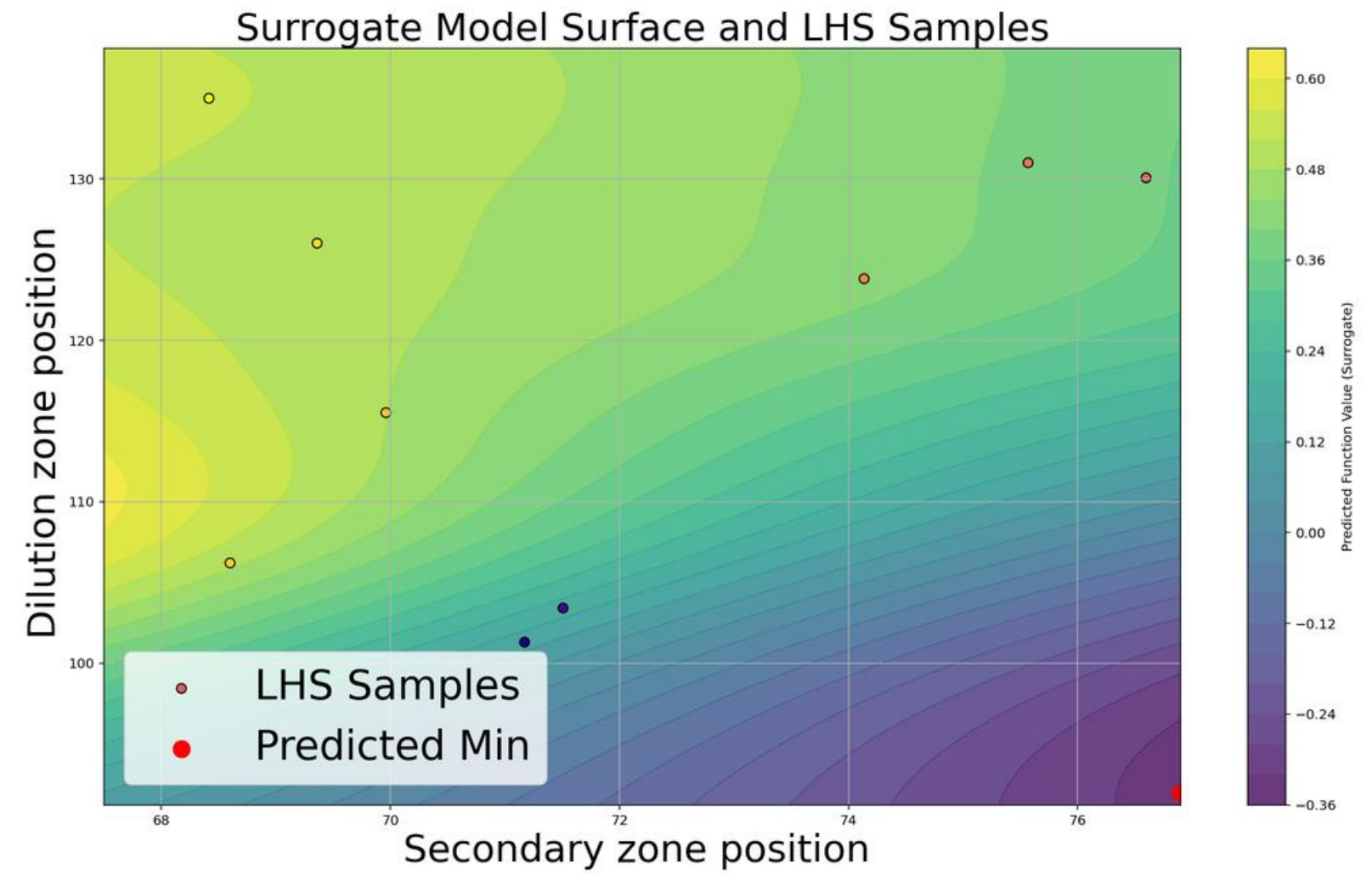
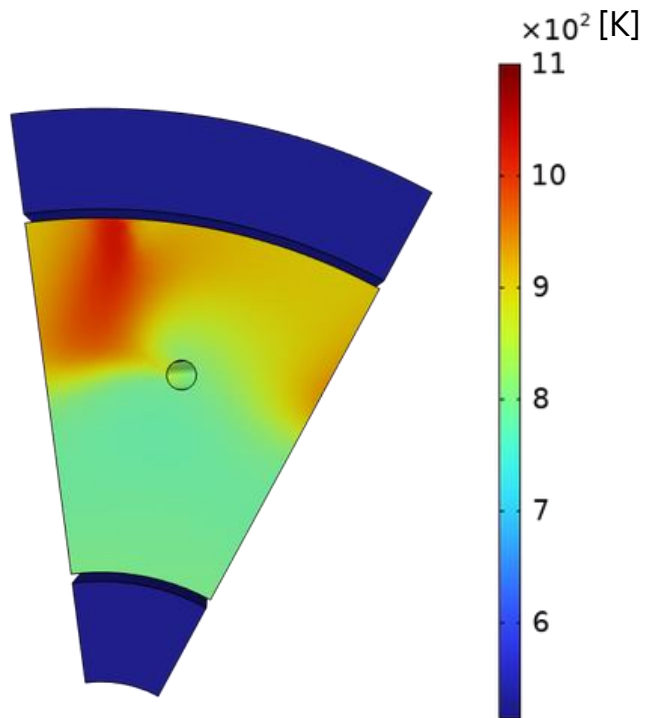


Optimising the Pattern Factor

Temperature distribution along the plane of bleed holes [K]

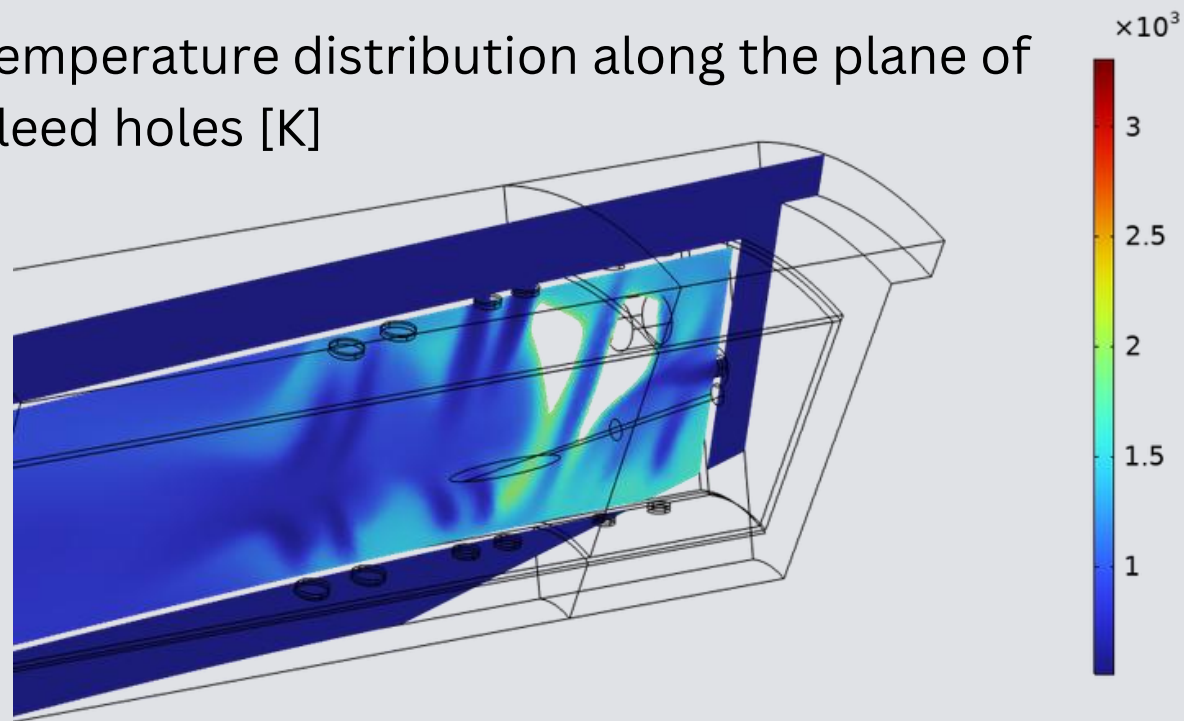


Initial: PF = 0.490



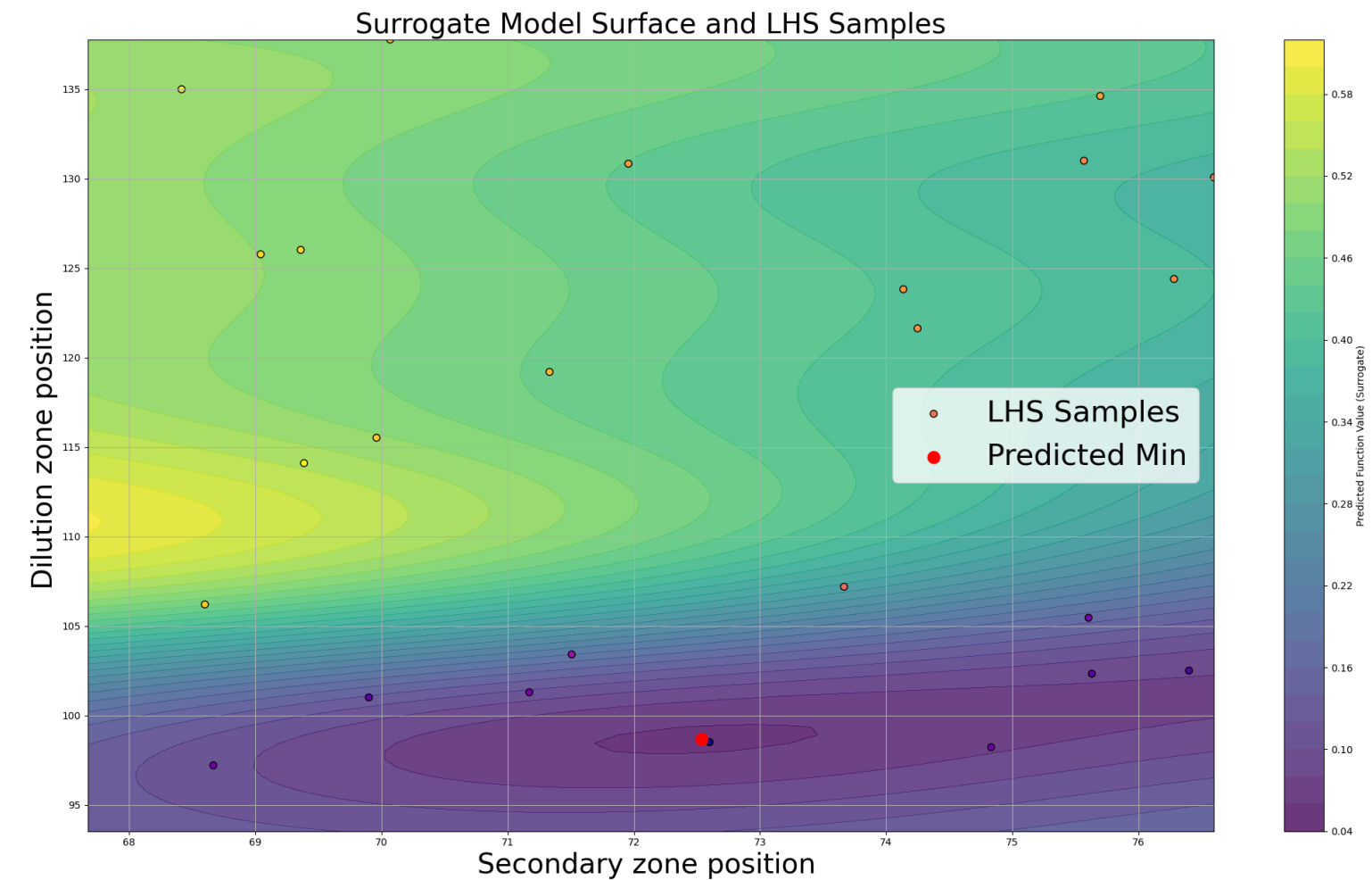
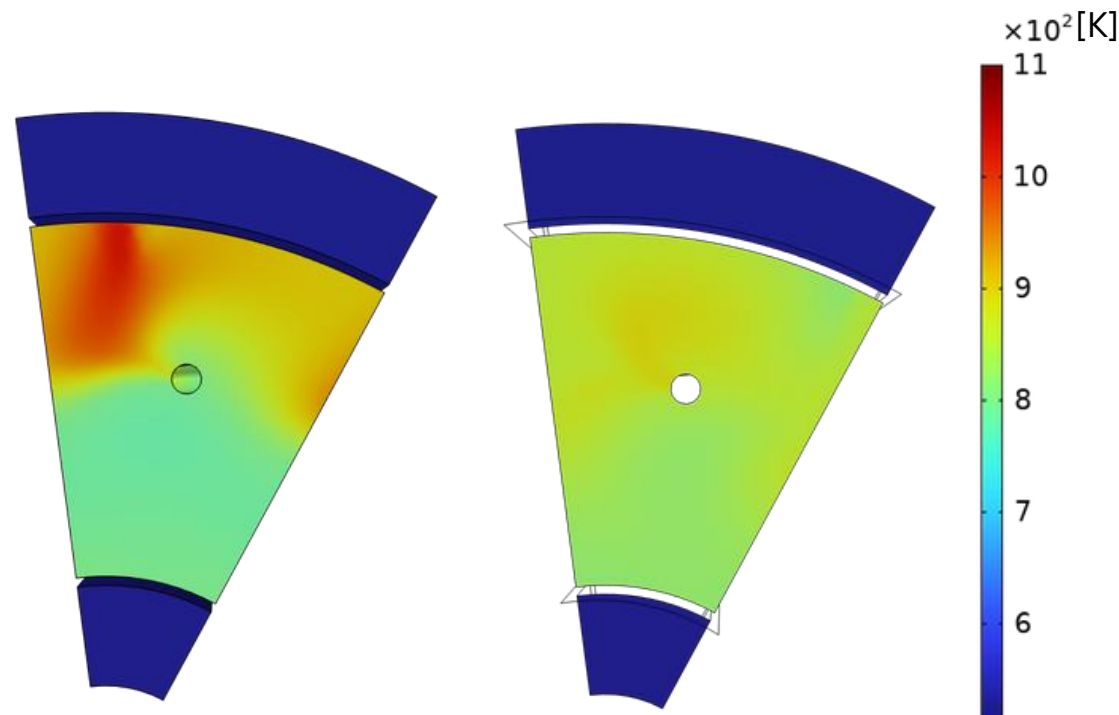
Optimising the Pattern Factor

Temperature distribution along the plane of bleed holes [K]



Initial: PF = 0.490

Optimised: PF = 0.05778

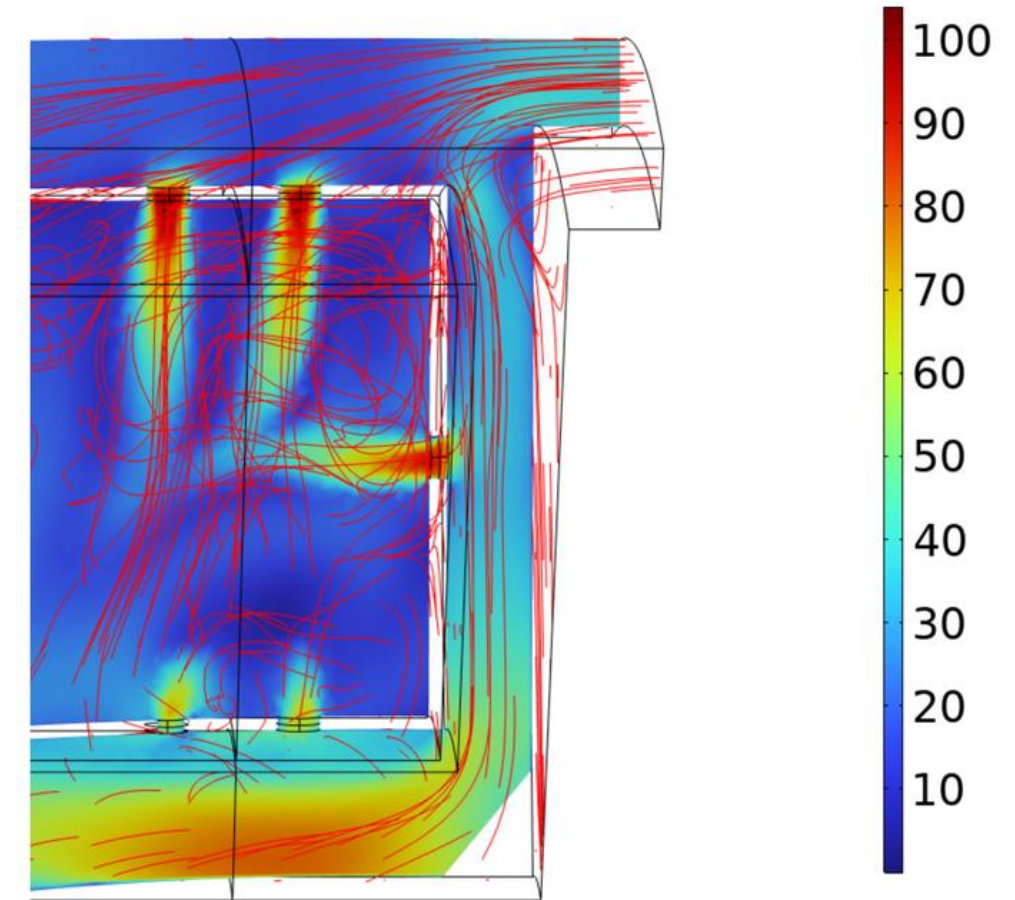


These improvements are essential for successful operation. For this design, a larger fraction of fuel can now be combusted, making it suitable for higher thrust with no added weight or machining complexity.

Too Good to Be True

A prominent issue with this design arose, the Primary Zone airflow is too turbulent, hence the stable flame required for constant combustion is unachievable.

Slice: Velocity magnitude (m/s)

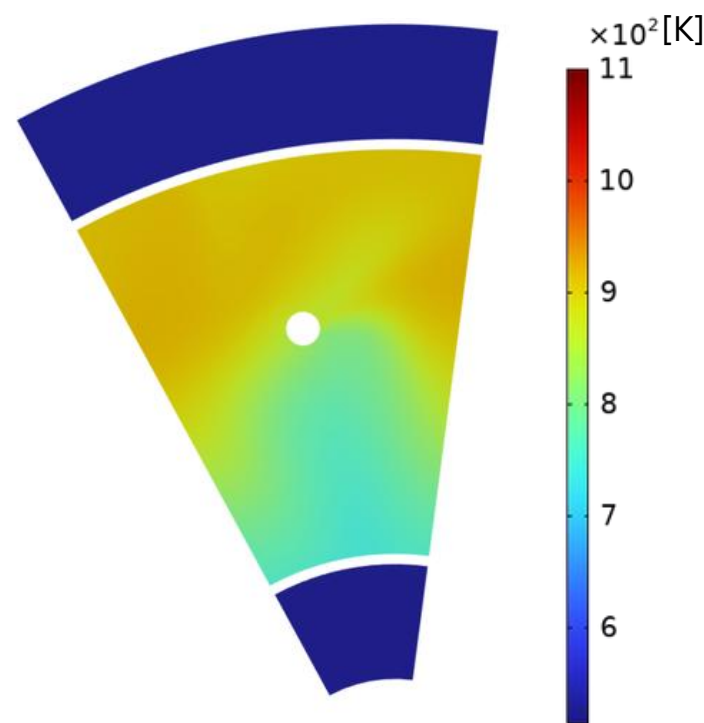


The Nolan Annulus Design Principle

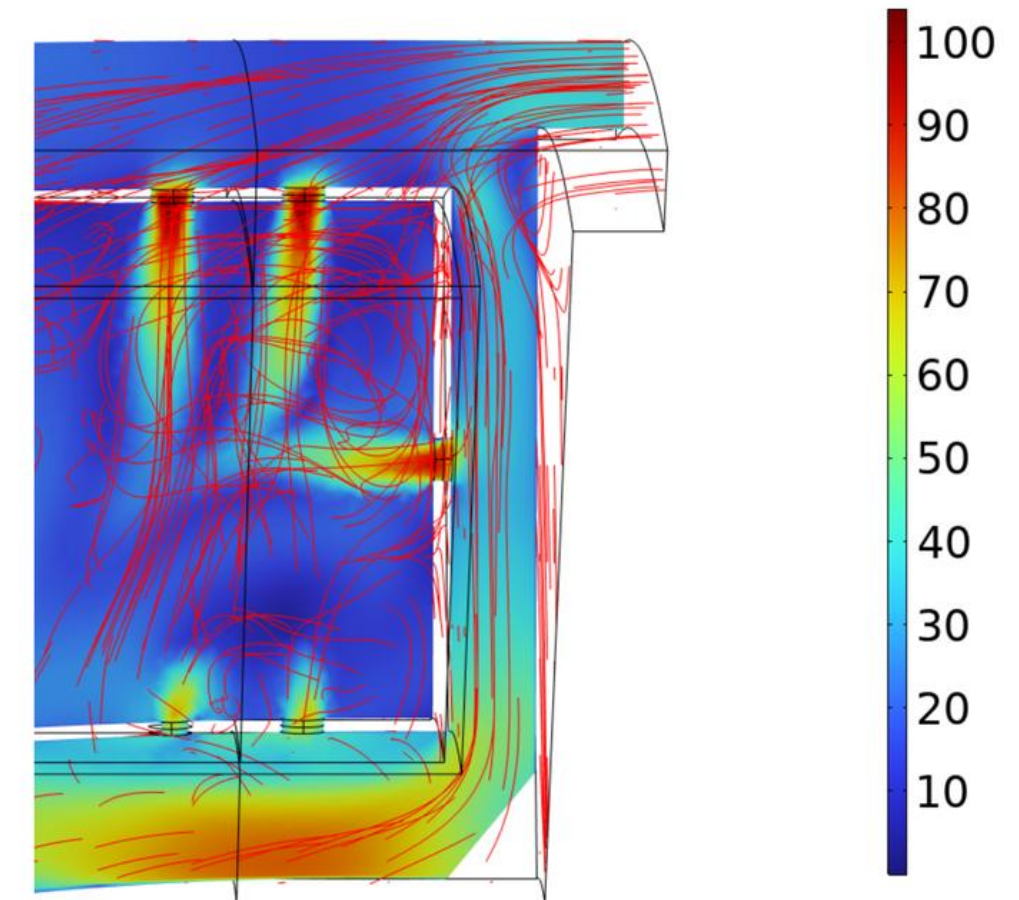
A prominent issue with this design arose, the Primary Zone airflow is too turbulent, hence the stable flame required for constant combustion is unachievable.

In attempts to fix this, the TAP and Conventional designs are combined, birthing the Nolan Annulus Principle - where the Primary Zone bleed holes are aligned axially, and all others aligned with the swirl component of velocity.

Final: PF = 0.182



Slice: Velocity magnitude (m/s)



It can be seen here that through implementing optimisation workflows into design, target operational parameters can be easily reached.

It is now a matter of conducting optimisation on the Nolan design to likely reduce the Pattern Factor even further, prior to applying this methodology to entire engine design.

Questions?