Simulations of Oxygen Enrichment for High Mach Number Scramjets

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Dr. Nick Gibbons and Prof. Vincent Wheatley

The University of Queensland

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About Me!

I am Nick:

- PhD in supersonic combustion, 2019
- Started as postdoctoral fellow @ UQ in 2020
- CFD code dev (Eilmer) and HPC sims expert
- This work sponsored by ARC grant DP230102601

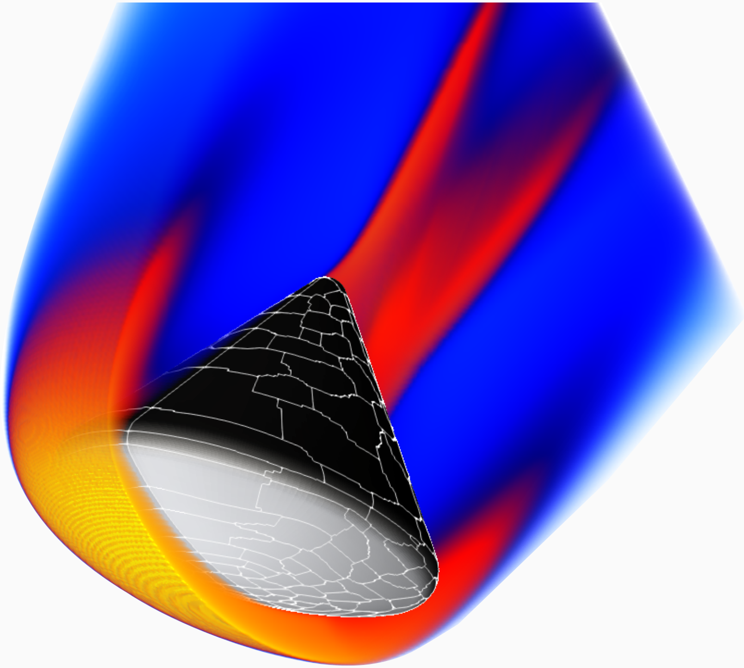
n.gibbons@uq.edu.au

nicholas-gibbons-67342555

What is Eilmer?

Eilmer is our flagship open-source supersonic CFD code:
- Part of the Gasdynamic Toolkit (GDTk)
- Maintained at UQ and UniSQ

Try the code: gdtk.uqcloud.net
- Free and open-source (Paper: [1])
- Very capable nonequilibrium thermochemistry models
- Parallel scaling to 1000's of cores
- LES/DNS/RANS enabled on complex geometries
- Extensively validated against decades of experiments



Apollo capsule at 18.6° angle of attack

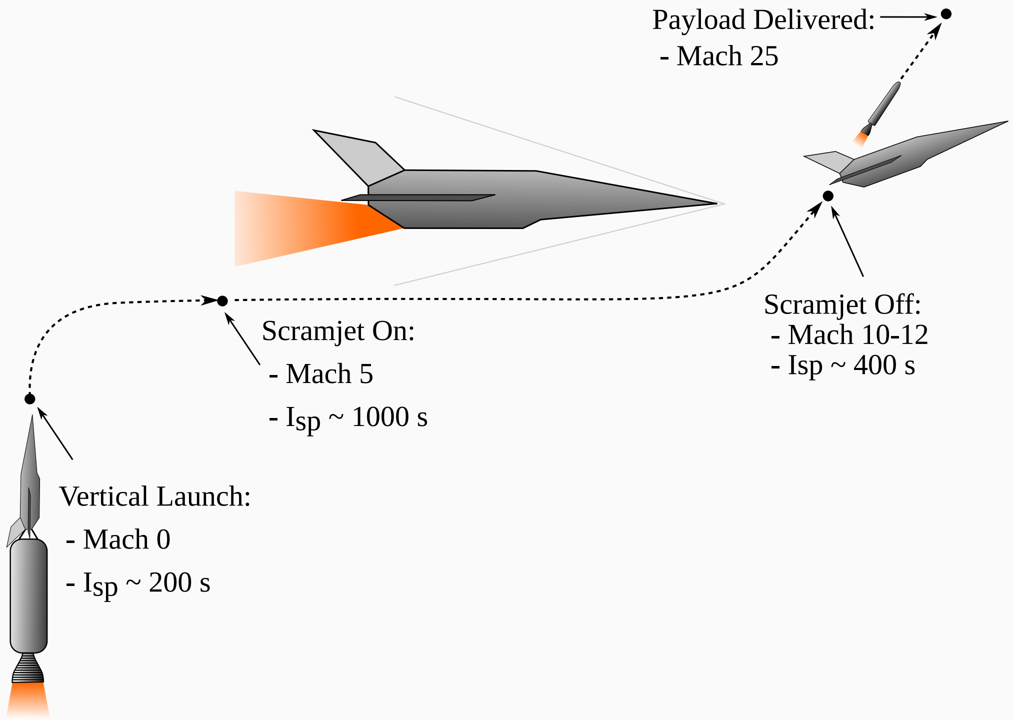
An Airbreathing 3-Stage to Orbit System for Launching Small Satellites:

Developed by Michael Smart and Matthew Tetlow [2]

- Thomas Jazra [3]
- Dawid Preller [4]
- Sholto Forbes-Spyratos [5]
- Alex Ward [6]

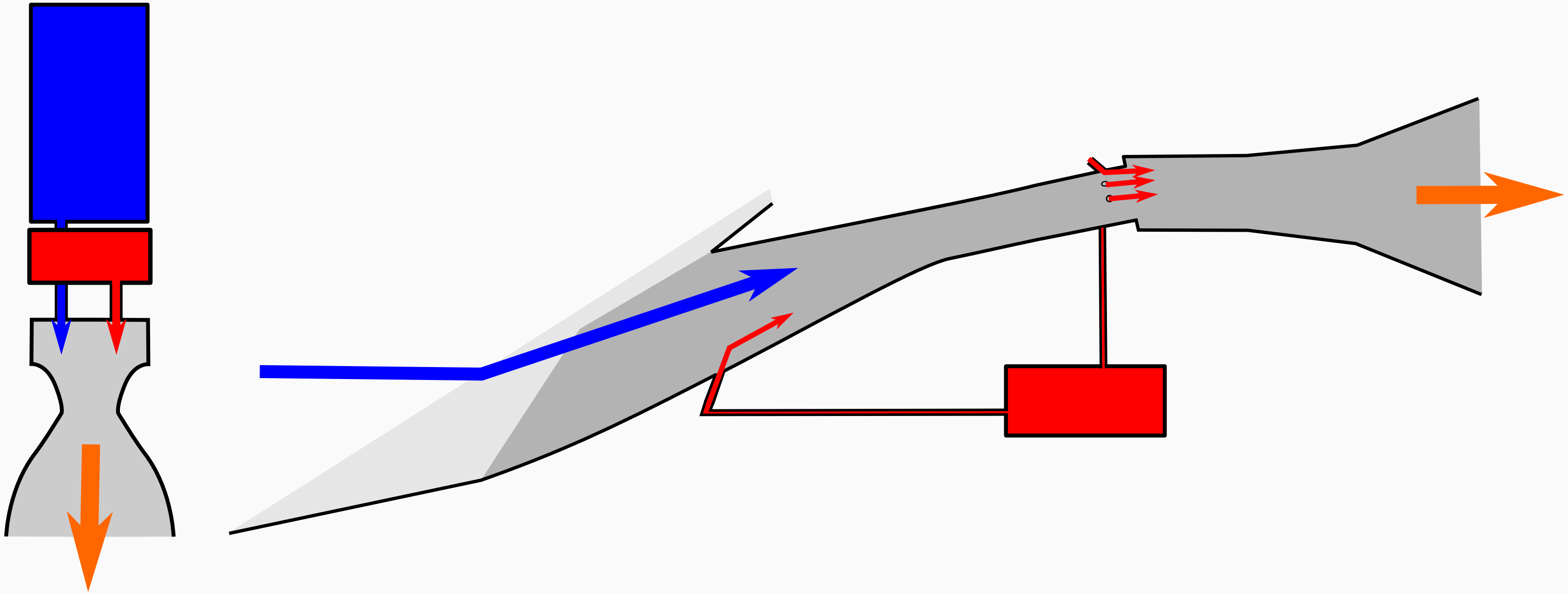
Scramjet Off point is important:

- Marginal thrust/drag performance
- Uncertainty about best Mach number
- Room for improvement with added O2?



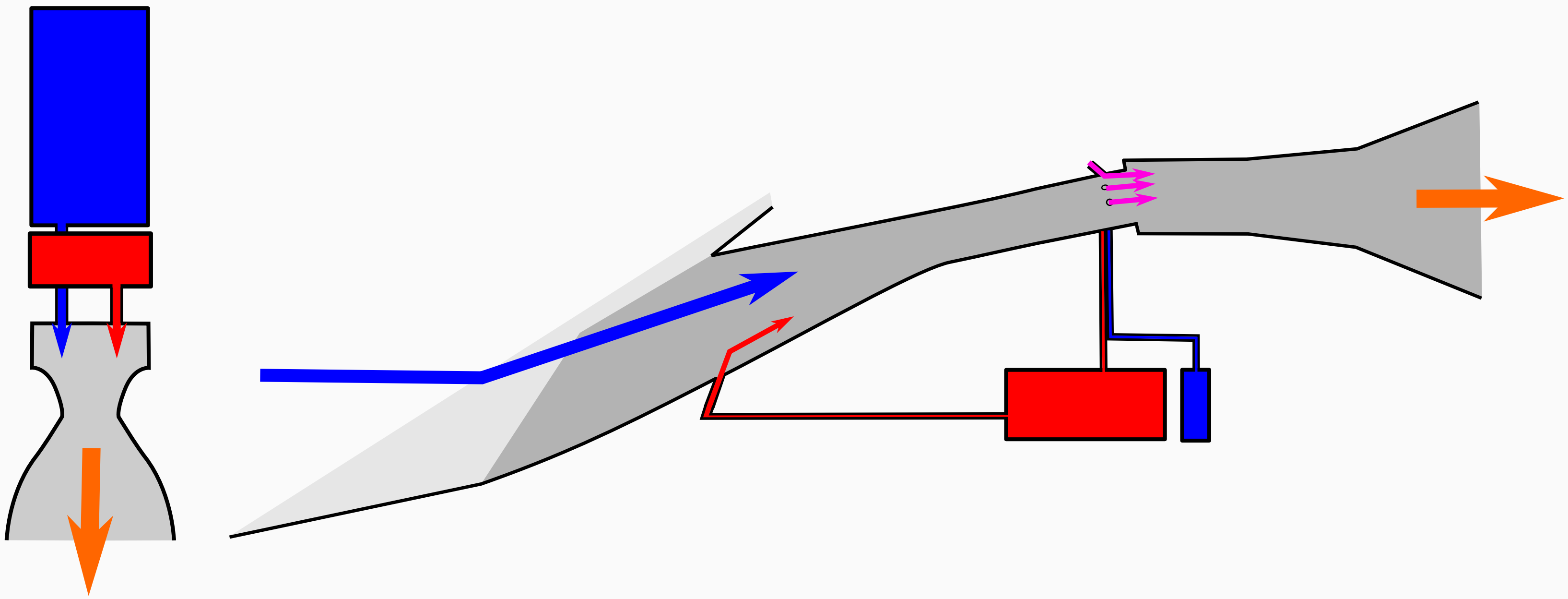
How do scramjets work again?

- Scramjet engines get high performance by harvesting oxygen from the atmosphere
- Significantly better Isp and size compared to a rocket



Accelerator scramjets start to struggle at high altitude/Mach numbers:

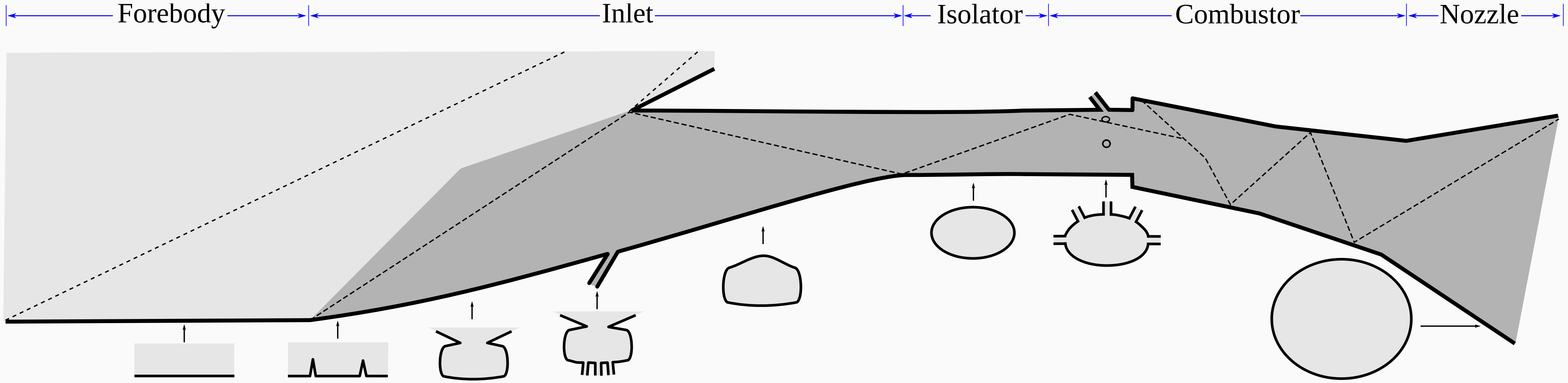
- Can we carry a *little* bit of onboard oxygen to help at the end?
- First let's simulate this problem with Eilmer



Let's start with an existing, published design: The M12REST Engine

Originally developed by Suraweera and Smart [7]:

- Improvements by James Barth and Vince Wheatley [8]
- Experimental testing Dylan Wise and Michael Smart [9]
- More improvements by Will Landsberg and Anand Veeraragavan [10]



This Work: Preliminary Validation and Exploratory Simulations with Eilmer

3D, Steady-State, Reacting, RANS calculations with Eilmer v4:

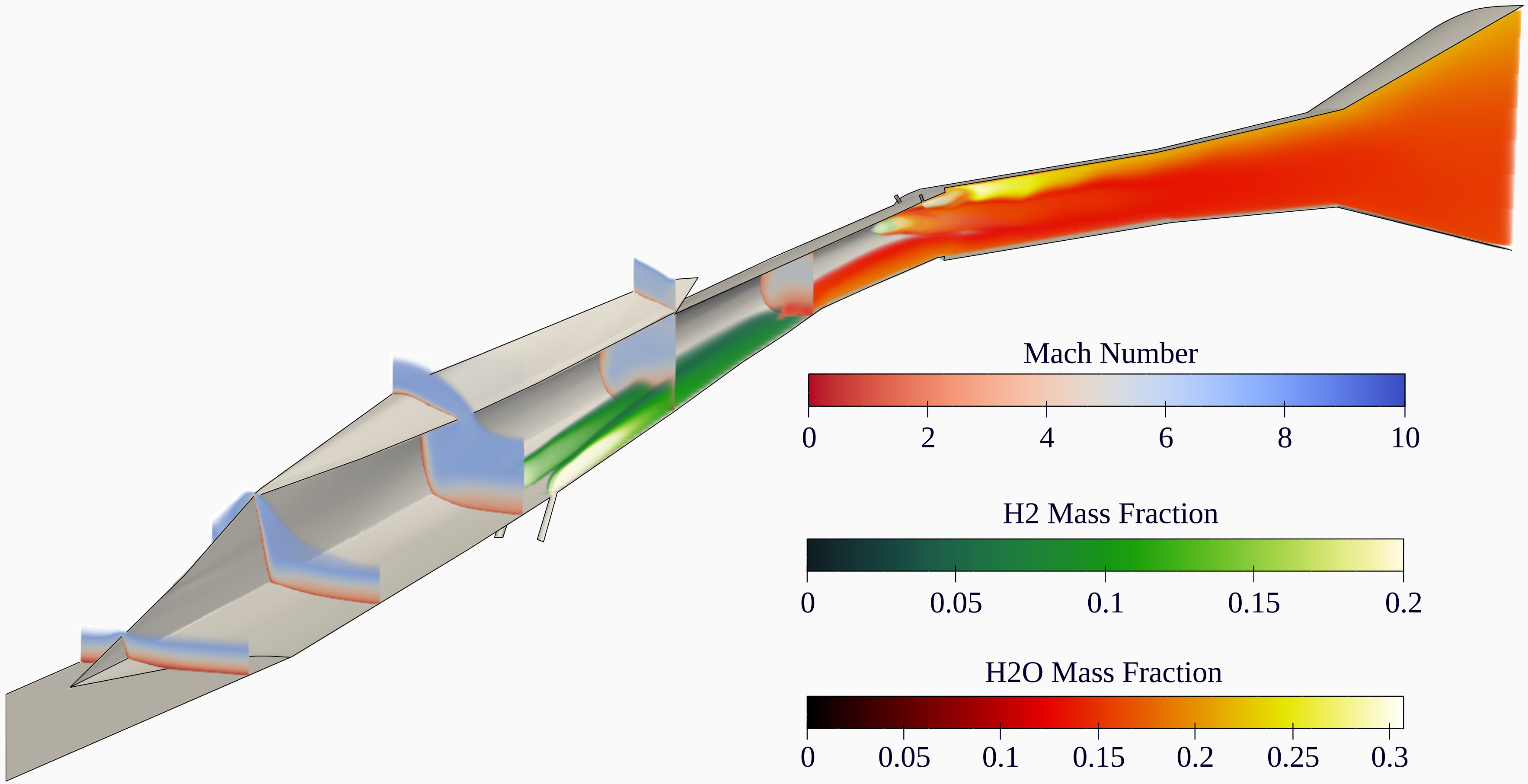
- 9M and 27M cell medium and fine grids
- Spalart-Allmaras-Edwards single-equation RANS turbulence model
- Chemical Reactions with 13 species, 33 reaction model of Jachimowski
- Uses Eilmer's Jacobian-Free Newton-Krylov (JFNK) [11] steady-state solver.

Flow conditions are based on a James Barth experiment in T4, shot 11491:

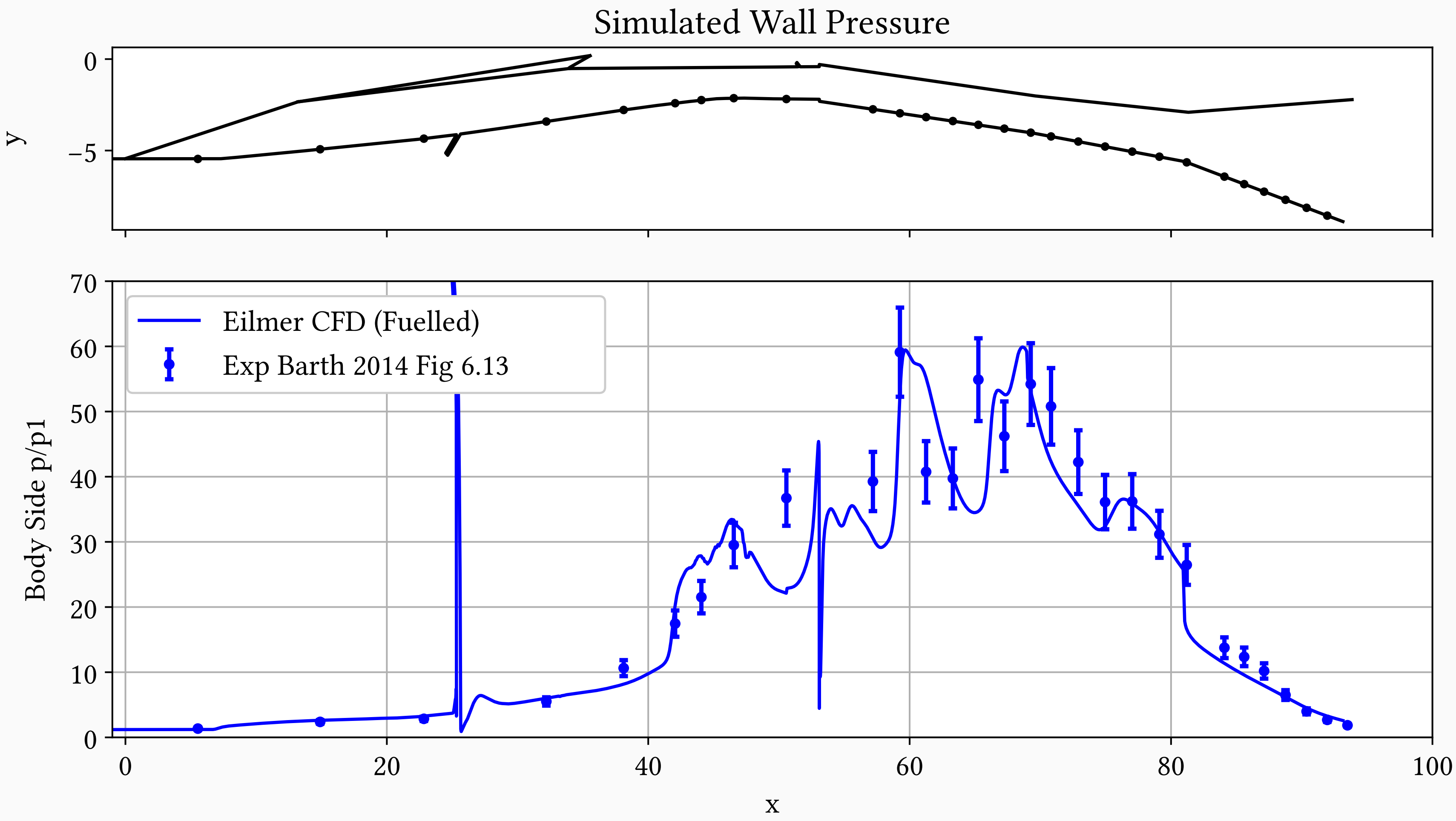
- Mach 12 flight enthalpy at 37.38 km, through the Mach 10 nozzle
- Fuelled to equivalence ratio of 1.24, with 30/70 split

	p (Pa)	T (K)	u (m/s)	M	H_0 (MJ/kg)	Radicals
Actual Flow:	1176.6	386.79	3630.2	9.183	7.01	Present
Flight Eqv:	398.66	243.71	3678.4	11.75	7.01	Absent

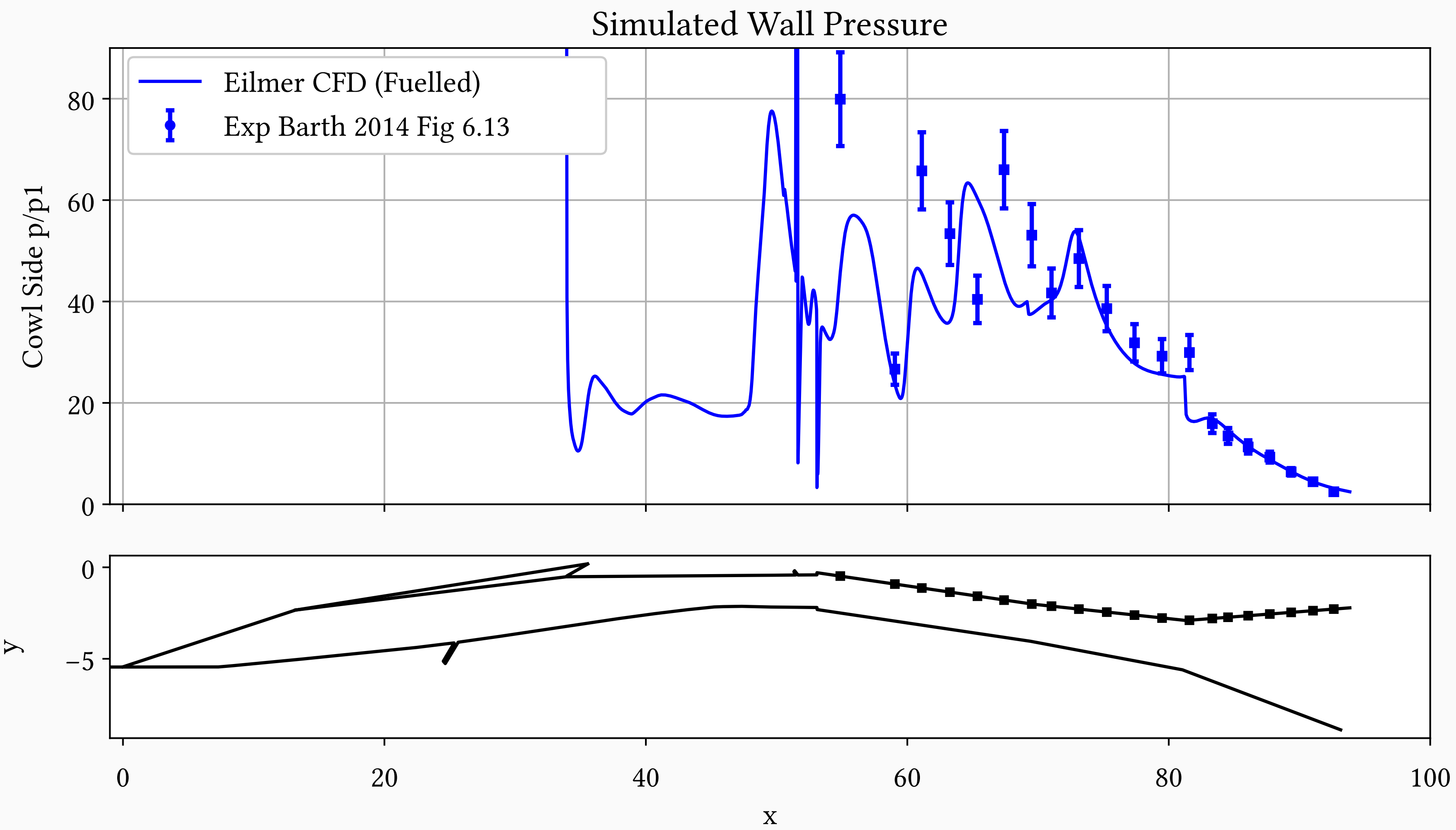
This Work: Preliminary Validation and Exploratory Simulations with Eilmer



Comparison to Experiment



Comparison to Experiment



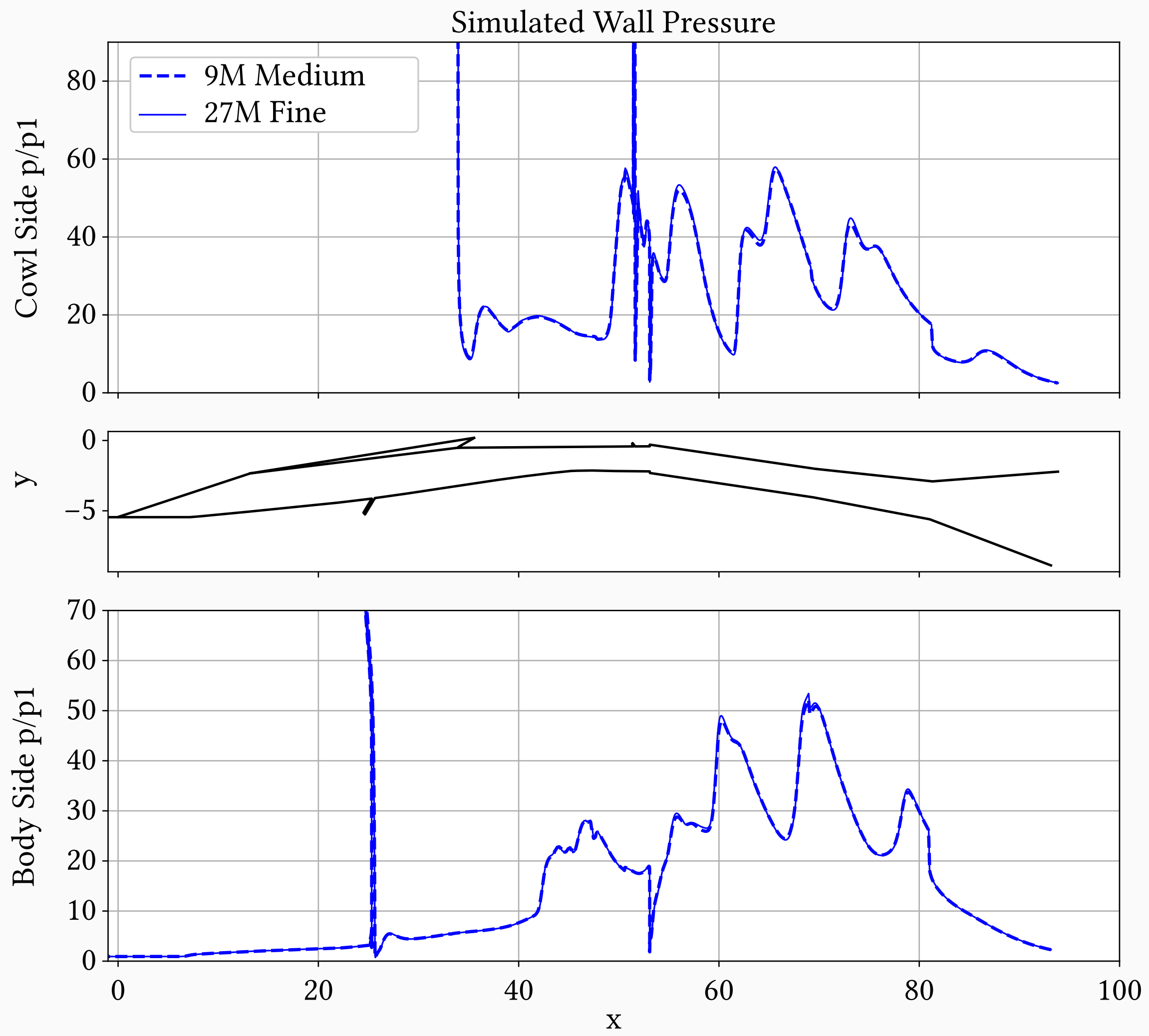
Spatial Convergence

Medium Mesh:

- 9,356,036 hexahedral cells
- Partitioned into 1280 blocks
- Walls clustered to 2 µm

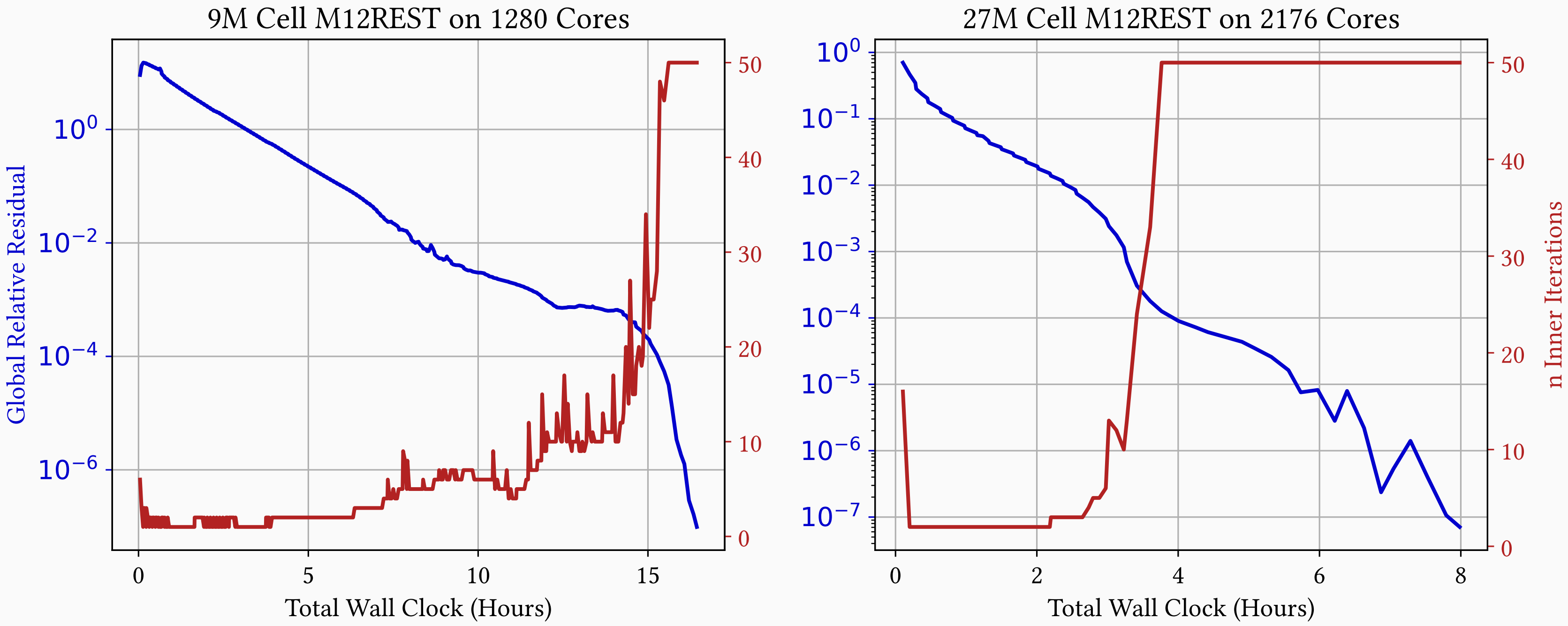
Fine Mesh:

- 27,451,851 hexahedral cells
- Partitioned into 2176 blocks
- Walls clustered to 2 µm



Temporal Convergence

Assess convergence in time using the Global Relative Residual: $\left| \frac{dU}{dt} \right| / \left| \frac{dU}{dt} \right|_0$

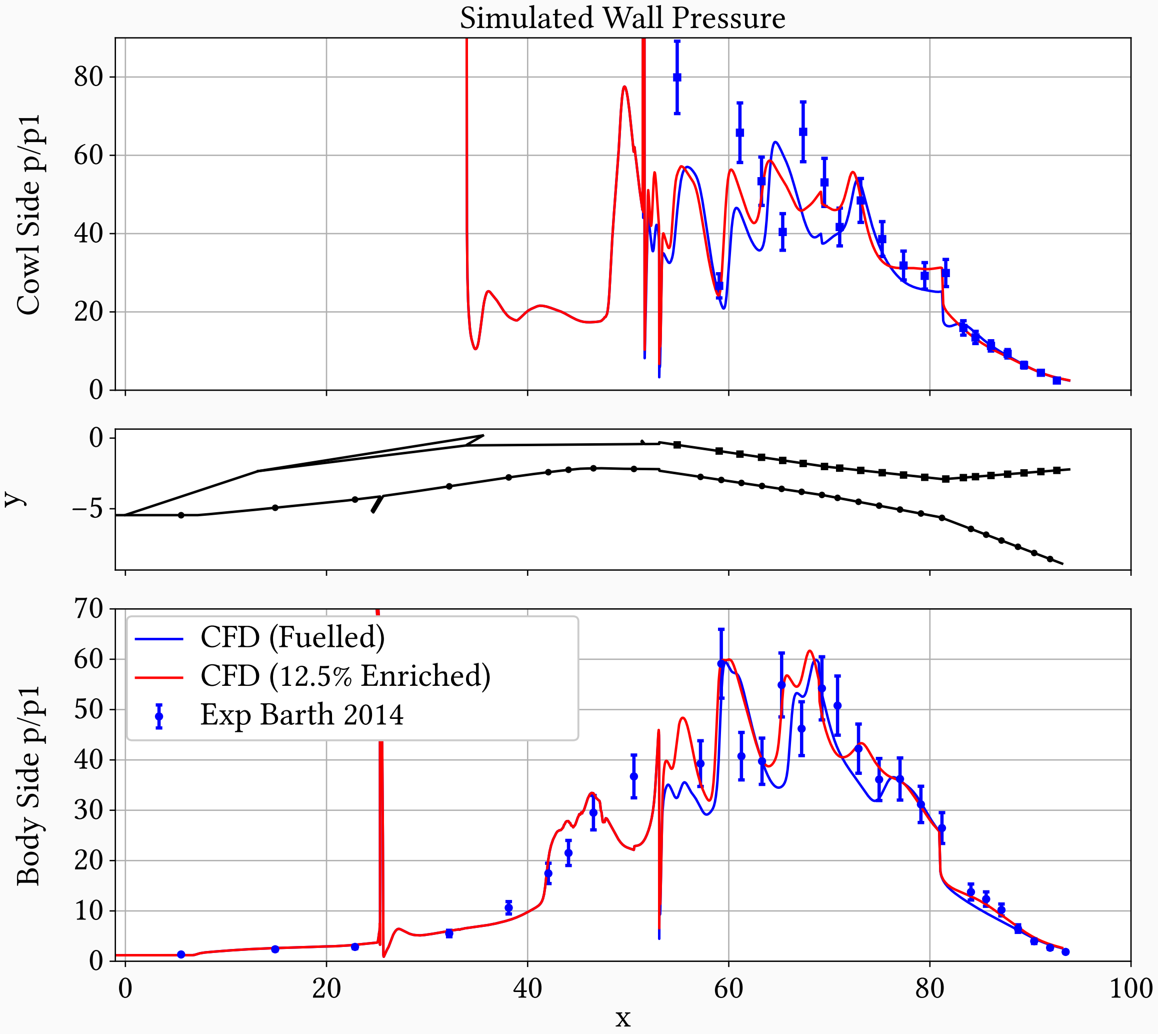


Oxygen Premixing:

$$\mathrm{EP} = \frac{1}{8}\frac{\dot{m}_{O_2}}{\dot{m}_{H_2}} \times 100\%$$

Try EP=12.5%:

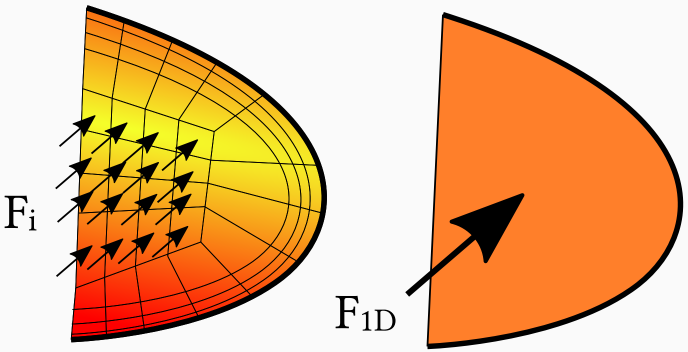
- Premixed only in main injectors
- Otherwise match shot 11491



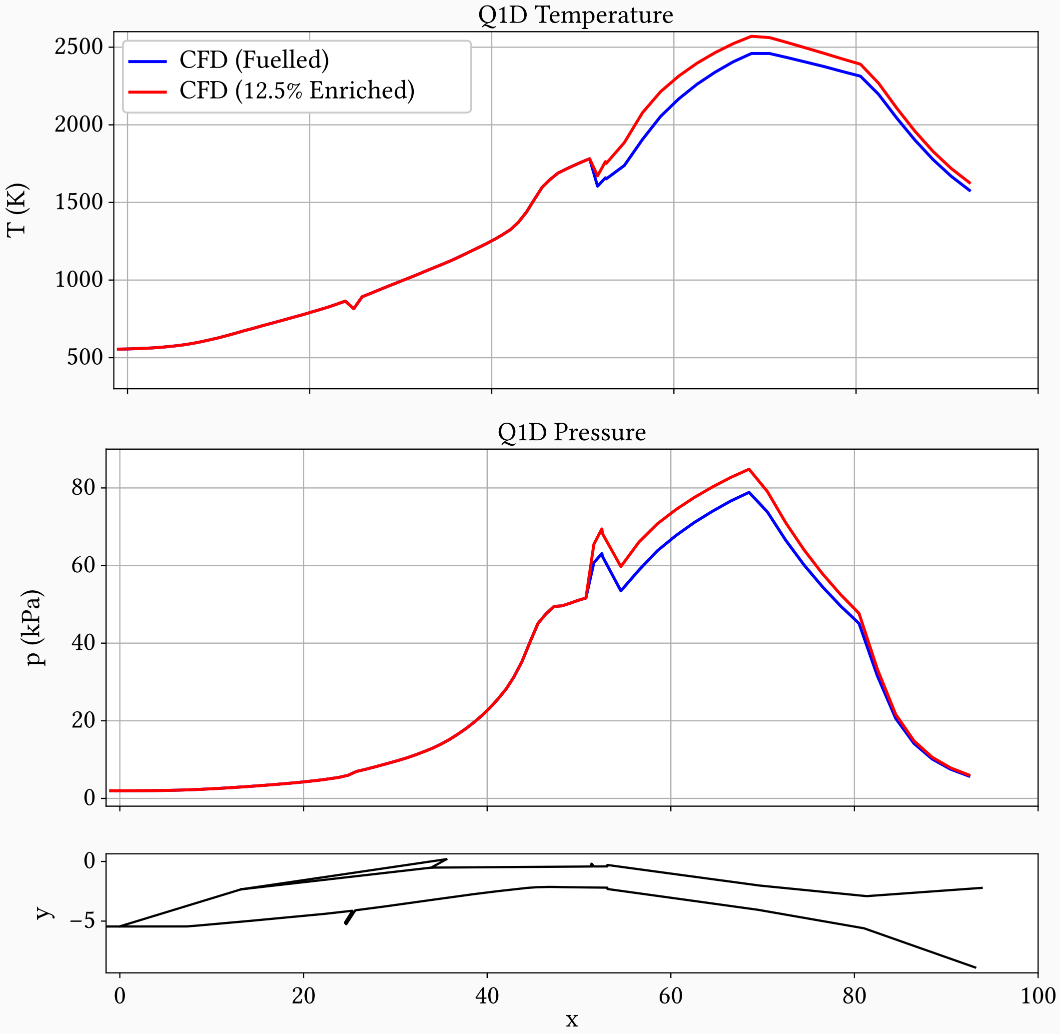
Q1D Flow Analysis

Collapse 3D flow into 1D:

- Slice the flow at x stations
- Sum up total flux through slice
- Find flowstate with the same total



$$F_{1D}(T, \rho, v, Y_s) = \frac{\sum_i F_i A_i}{\sum_i A_i}$$



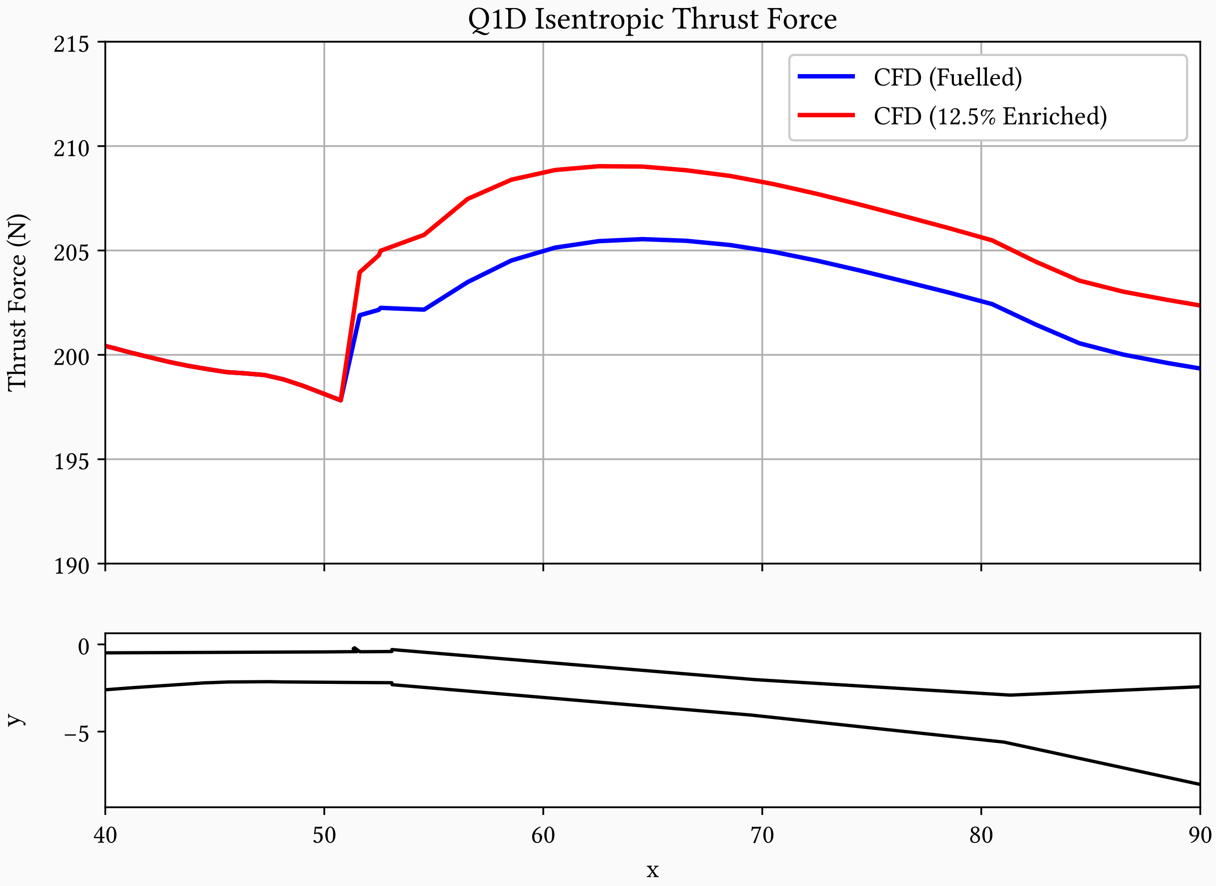
Q1D Flow Analysis: Thrust

Calculate idealised thrust force:

- Choose an ambient pressure
- Frozen, isentropic expansion at each point

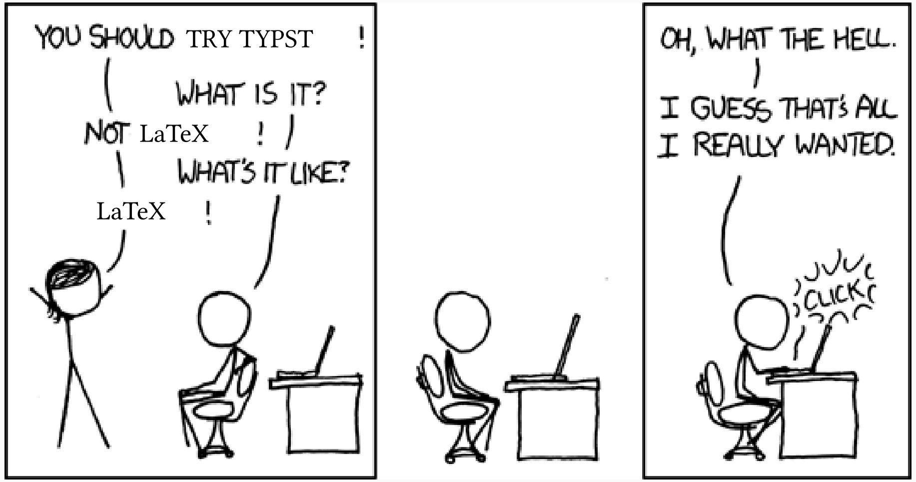
Nice Improvement!

- Increased thrust from EP=12.5%
- No signs of overheating
- Probably just excess fuel burning



Thanks!

- The GDTK Team: PJ, Rowan, Kyle, and Reece
- Vince Wheatley
- Pawsey Supercomputing Centre
- Typst



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