GKN AEROSPACE

Aerothermal Performance of an Open Source Methane-Fueled Rocket Engine

Alexander Hansson[1]
Atle Nyberg[1]
Alexandre Capitao Patrao[2]
Jan Östlund[2]
Tomas Grönstedt[1]

[1]Chalmers University of Technology
[2]GKN Aerospace

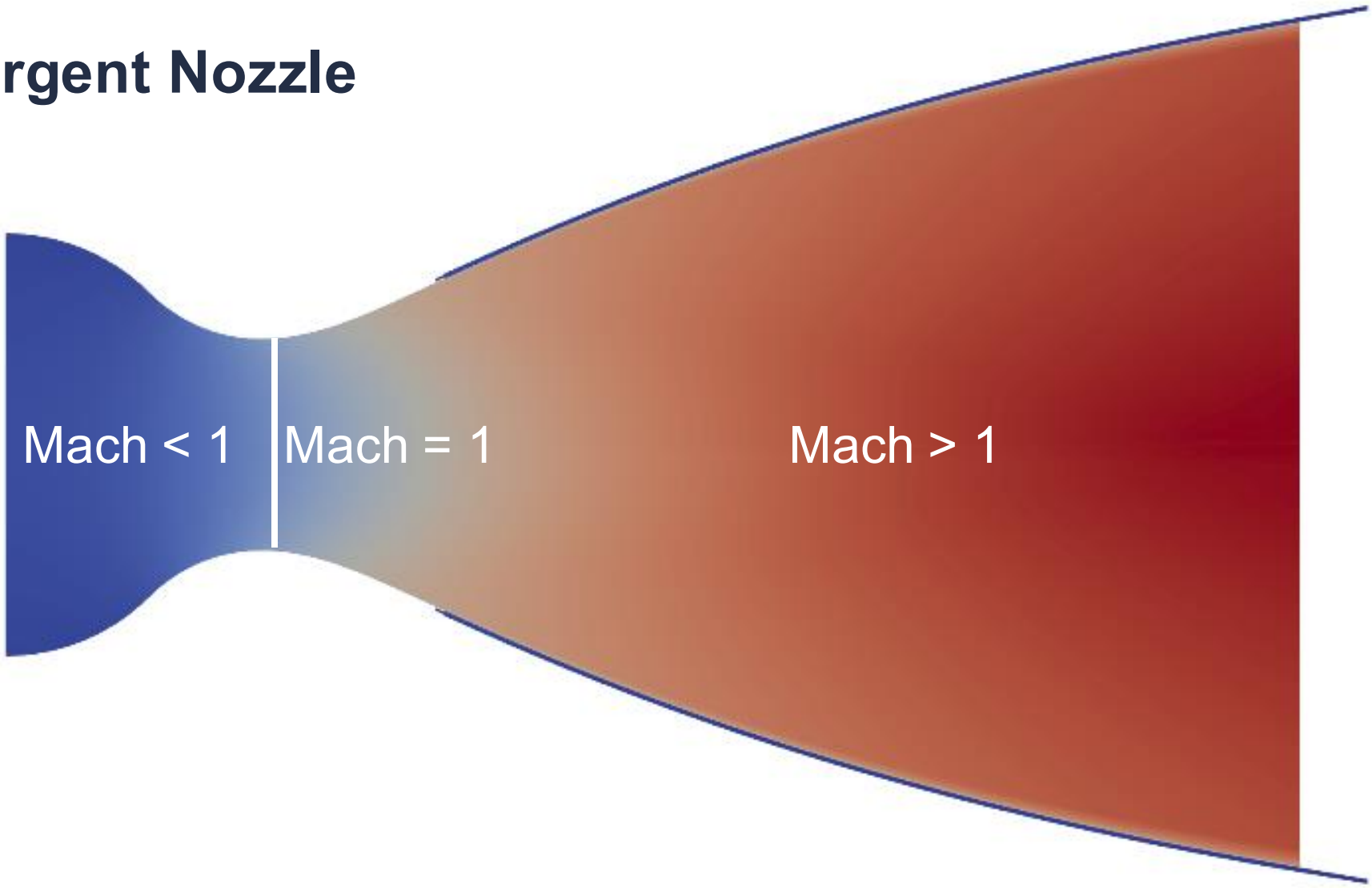
MAKING THINGS FLY

Goal

- Capture both the coolant flow and the nozzle flow in a single simulation
- Traditional approach: Separate simulations
- Determine suitability of CFD codes: Ansys Fluent and Star-CCM+
- Focus on the thermal loads on the nozzle extension

Convergent-Divergent Nozzle

$$\frac{dA}{A} = (M^2 - 1)\frac{dV}{V}$$



Wide Range of Scales

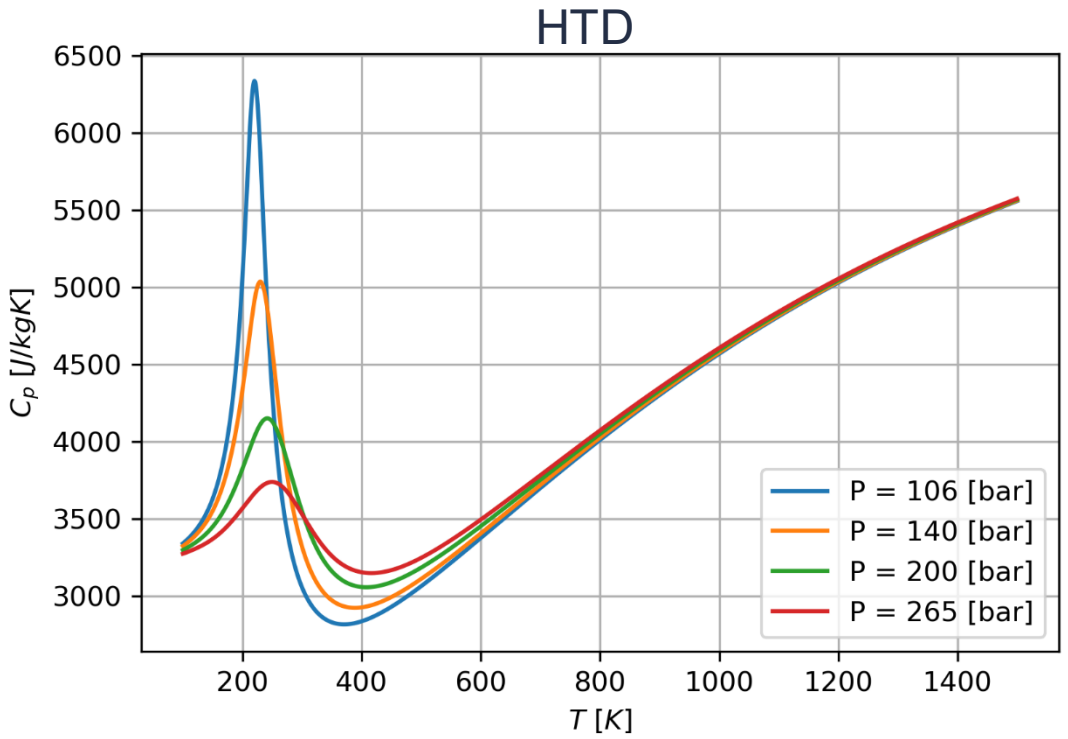
- **Temporal:** Large velocity differences
- **Spatial:** Size difference
- **High pressure in coolant:** Thin boundary layers
- **Large temperature gradients:**
  - Coolant: -136 C
  - Flame: 3300 C

Models and Schemes

- **Spatial scheme:** 2nd order upwind
- **Solver:** Steady Coupled Implicit
  - Pressure based
- **Turbulence:** RANS k-ω SST (Menter 1994)
- **Energy:** On
- **Materials:** Seen in the following slides

Materials: Coolant

- **Cryogenic, supercritical methane**
- **Ideal gas assumption no longer holds**
  - Represented as a real gas using RGP-tables
- **Problematic Phenomena:** Heat transfer deterioration



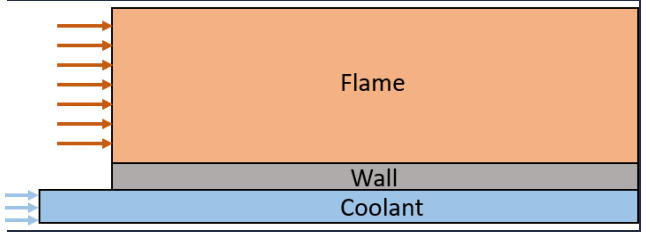
Materials: Flame

- **Combustion of oxygen and methane**
  - Reaction scheme with data of the kinetic, transport and thermodynamic properties
- **The properties are averaged to describe the mixture**
- **Zhukov-Kong scheme:**
  - 23 gases and 51 reactions

Project Structure

Case 1

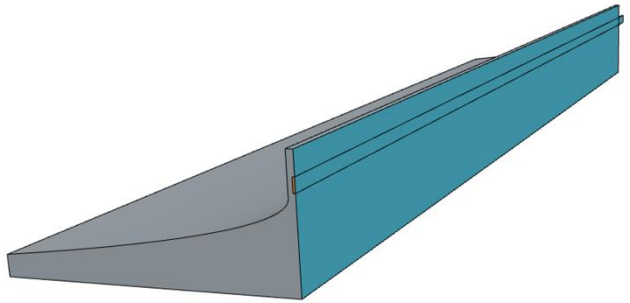
2D flow over a flat plate



- Computationally cheap
- Method development

Case 2

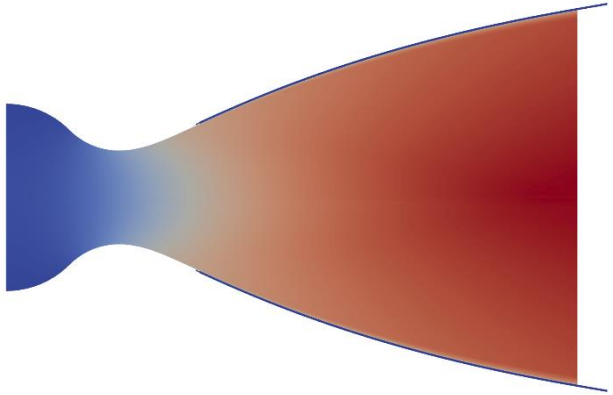
3D representative cooling channel



Validate the simulation approach for the methane

Case 3

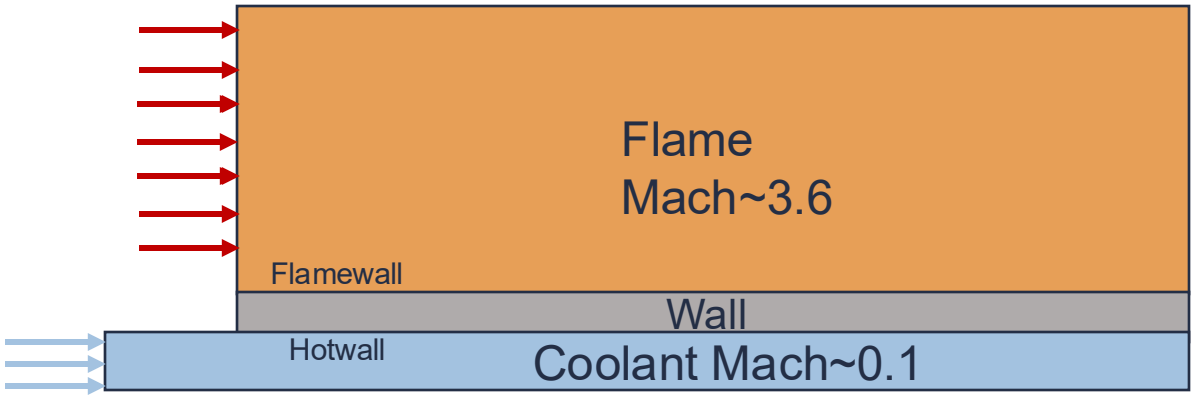
3D nozzle with cooling

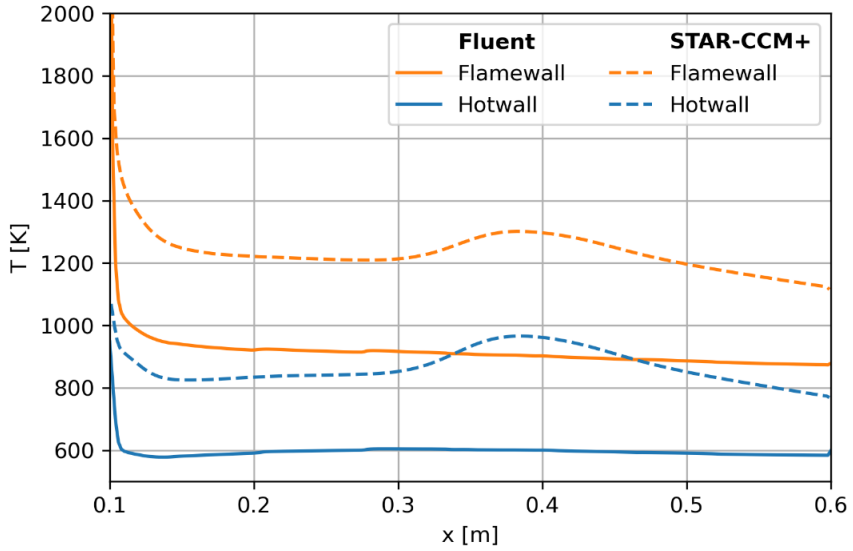


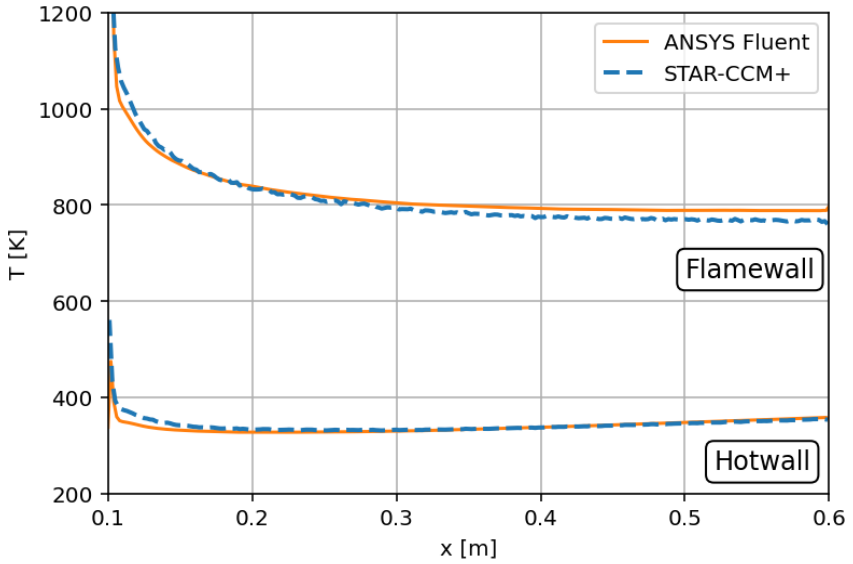
Full simulation of a 3D nozzle

Case 1: Flow Over Flat Plate

- **Purpose**
  - Investigate code differences in cheap 2D simulations
  - Minimize resulting difference while maintaining accuracy

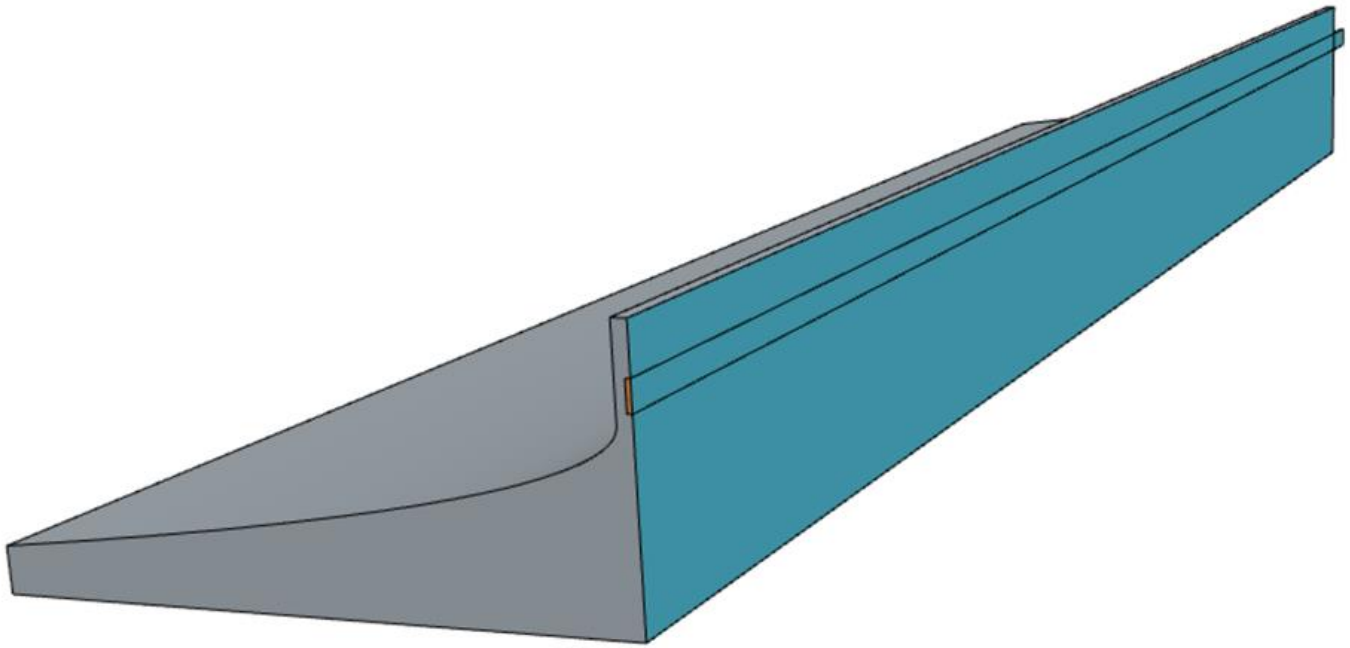


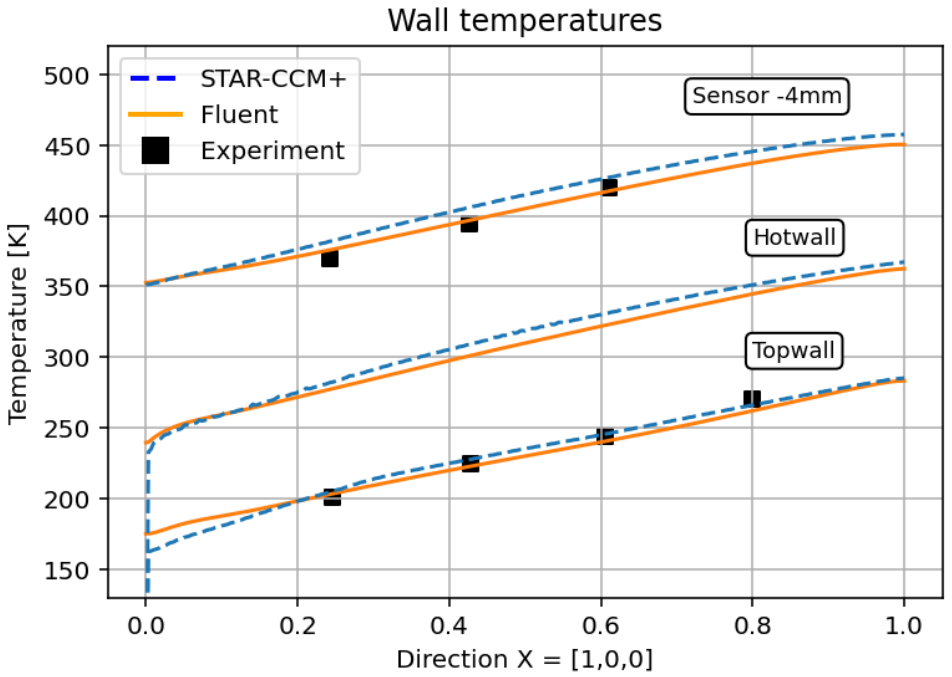




Case 2: Representative Cooling Channel

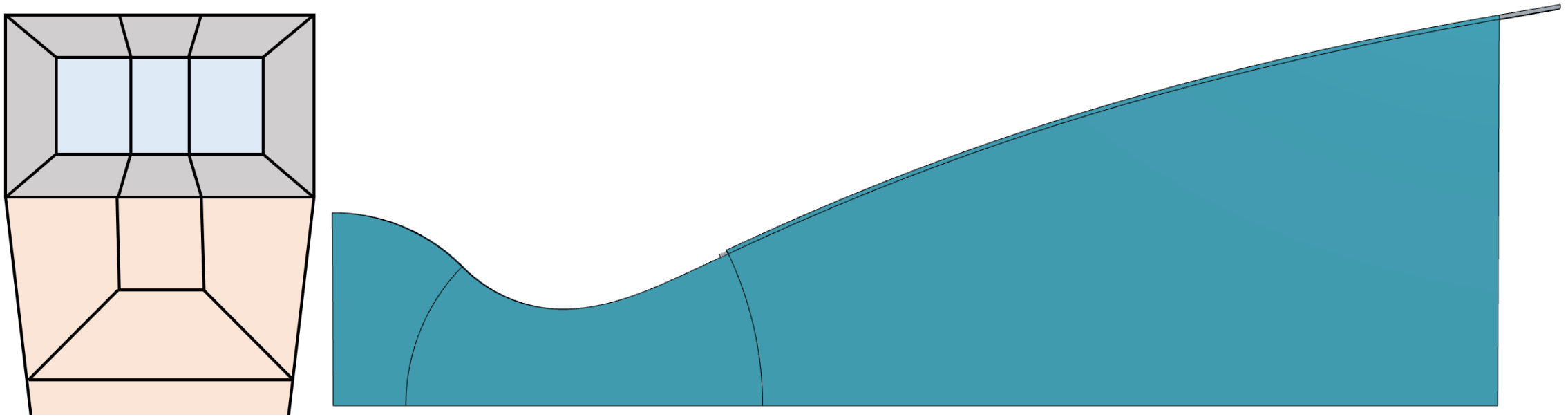
- **Purpose:**
  - Verify the results against experiments
  - Maintain matching results while keeping the simulations realistic





Case 3: Representative Rocket Nozzle

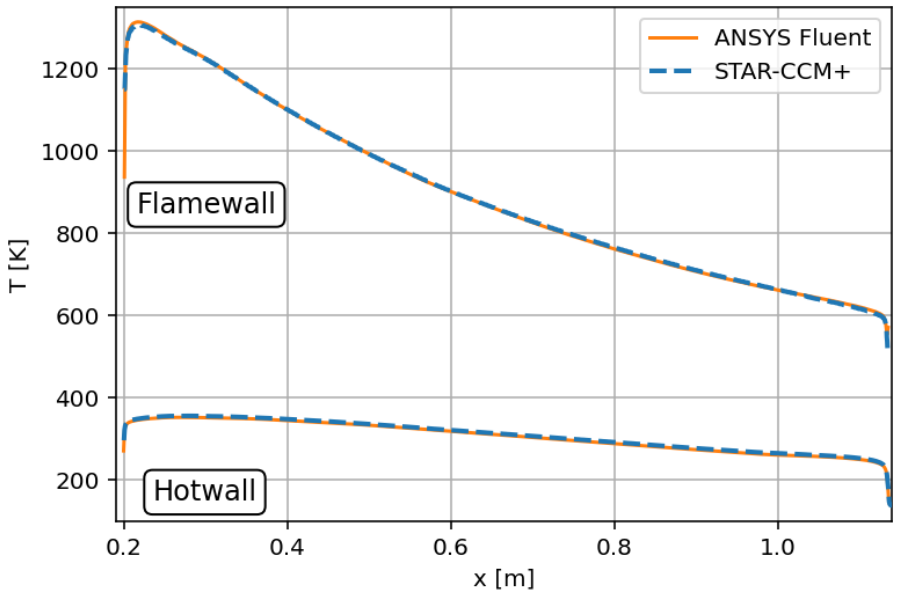
- **3D geometry, structured, hexa mesh using ICEM CFD**
  - One channel, 1 degree slice of nozzle
  - Nozzle contour from a HiSST report designing an open source nozzle geometry
  - Representative Nozzle geometry and operating conditions



Case 3: Results

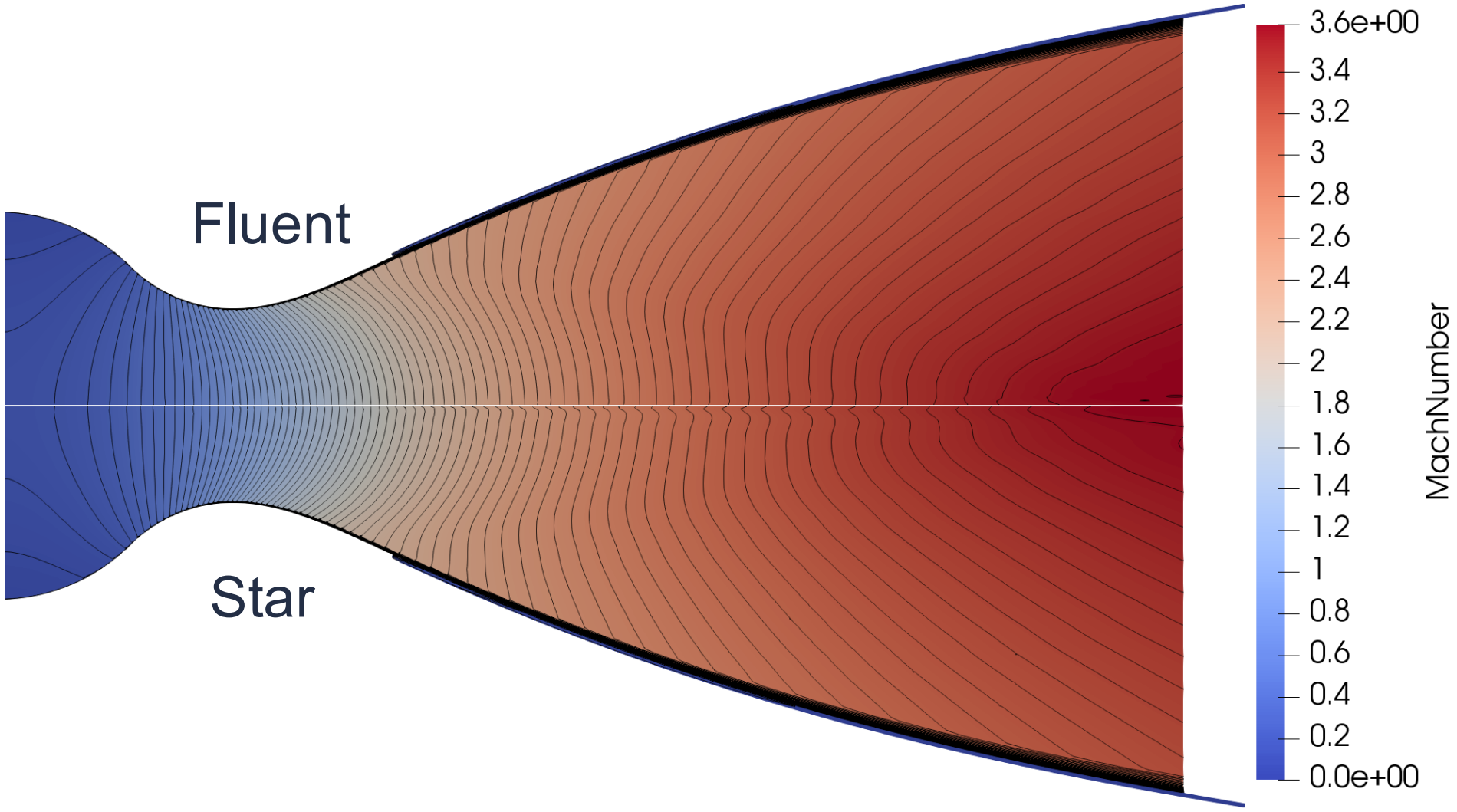
- **The two CFD codes produced similar results**
  - Difference in the first cells
  - Average difference of 3 K at both walls

Wall Temperatures



Par/Source	Fluent	Star	Ref
Massflow	+3,9%	+3,8%	321.8 kg/s
Thrust	-0.16%	-0.21%	809.3 kN
ISP	+3,8%	+3,7%	3427 m/s

Case 3: Results



Discussion and Future Work

- **The codes have shown a good match with experiments and each other**
  - Remaining differences

- **In further work:**
  - Validate flame against experiments
  - Testing against GKN internal methods

Code Comparison

Accuracy

- Both produce results matching each other and previous work

Time to set up

- Star: Takes long but reliable
- Fluent: Tricky to initiate but fast setup

Time consumption

- Fluent required more time to converge (5500 vs 4300 core hours)

Manual input

- Star: Iterations, easy to automate
- Fluent: Set up and click play

User Experience

- Star: Server mode, mesh
- Fluent: Batch mode

Other

- Fluent experienced more errors during simulation

Thank You for Listening!

- **Authors:** Alexander Hansson, Atle Nyberg
- **Co-Authors:** Alexandre Capitao Patrao, Jan Östlund, Tomas Grönstedt
- **Organisation:** Chalmers and GKN Aerospace
- **Institution:** Mechanics and Maritime Sciences