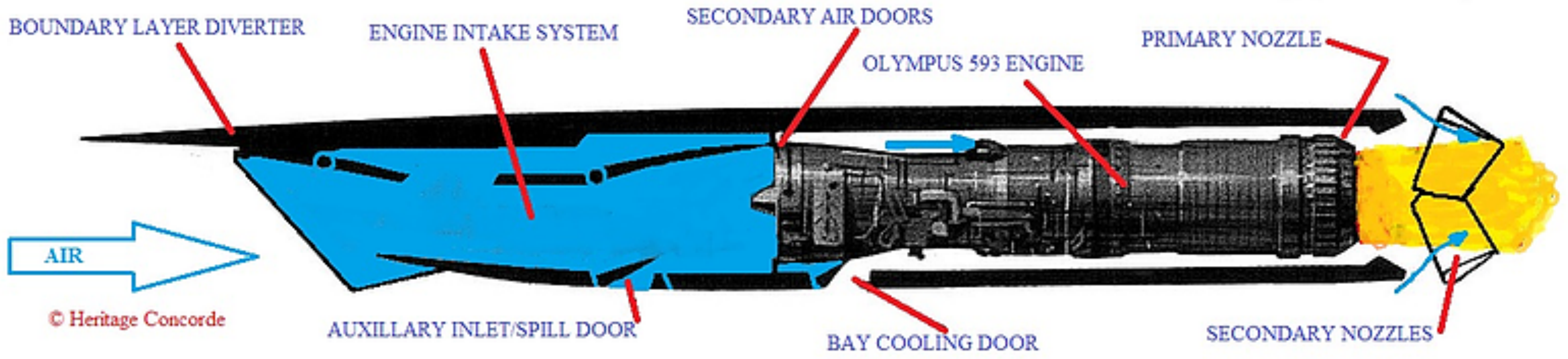
A 2D finite-volume compressible Navier-Stokes solver to simulate inlets of supersonic engines

Thursday May 16, 2019

Laurens Voet


BRITISH AIRWAYS


BRITISH AIRWAYS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ENGINE INTAKE SYSTEM
SECONDARY AIR DOORS
OLYMPUS 593 ENGINE
PRIMARY NOZZLE
AIR
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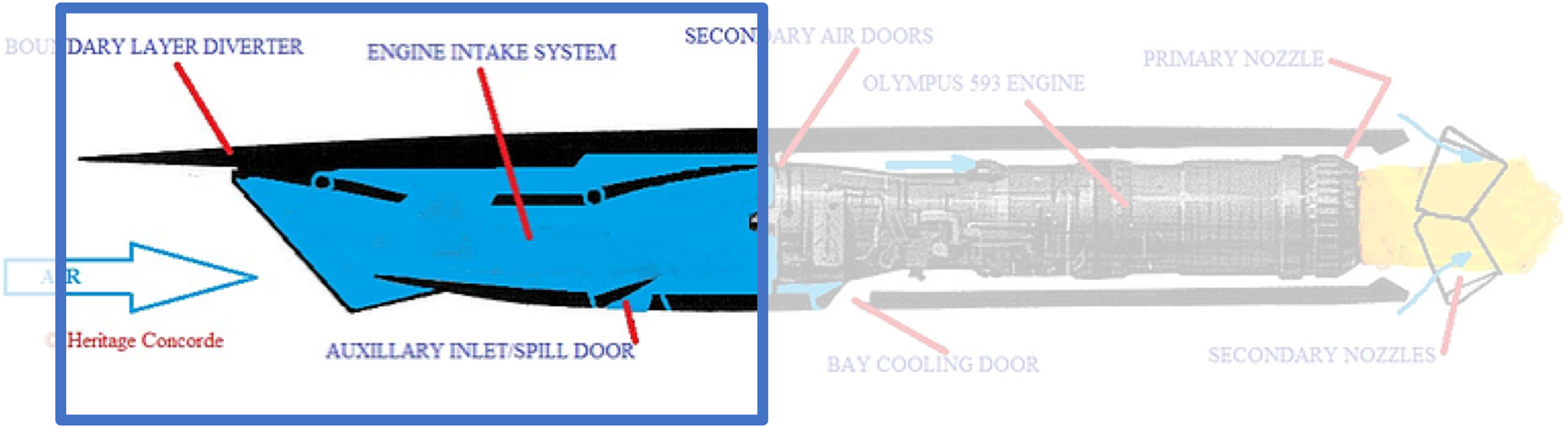
AUXILLARY INLET/SPILL DOOR
BAY COOLING DOOR
SECONDARY NOZZLES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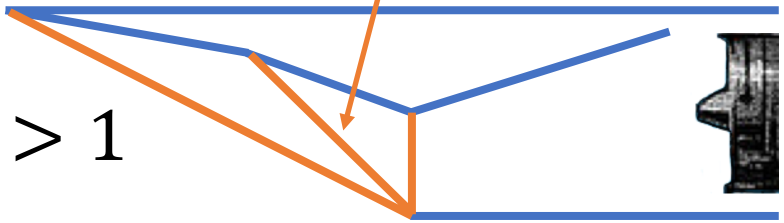
Motivation

- Inlet design of engine for supersonic airplanes ≈ wedge flow



- Objective: minimize total pressure loss for optimal performance

FV solver setup

- Geometry
- Mesh
- IC and BC
- Flux reconstruction
- Time integration
- Results

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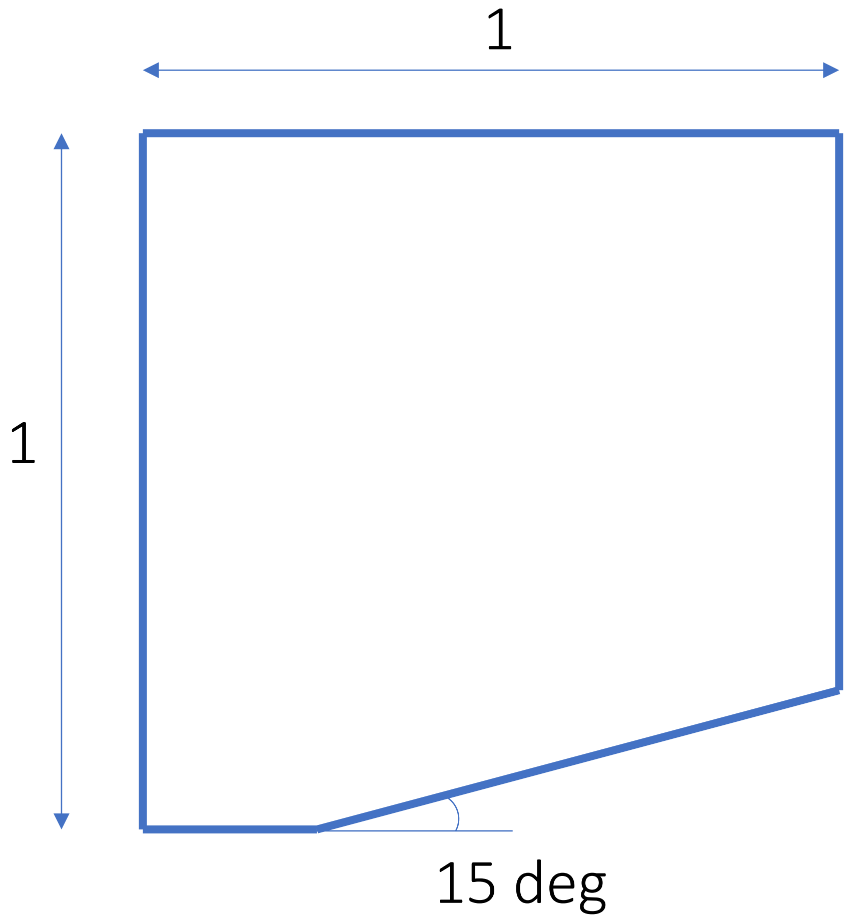

FV solver setup

- Geometry
- **Mesh**
- IC and BC
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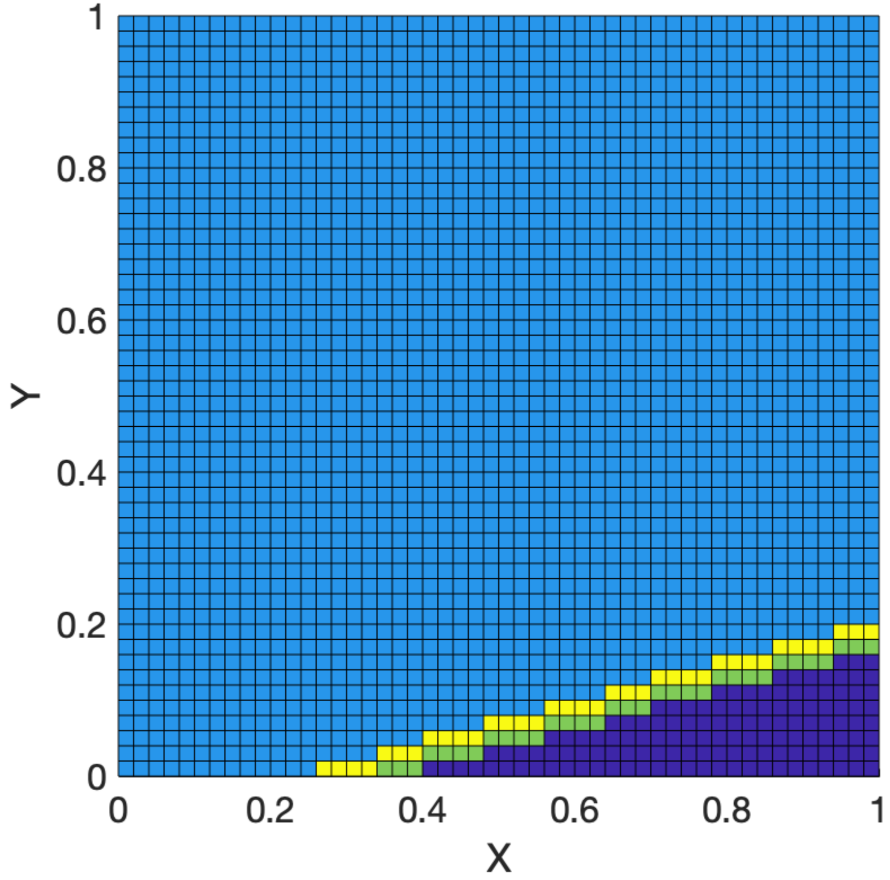
- Time integration
- Results

Cartesian grid
Immersed boundary method



FV solver setup

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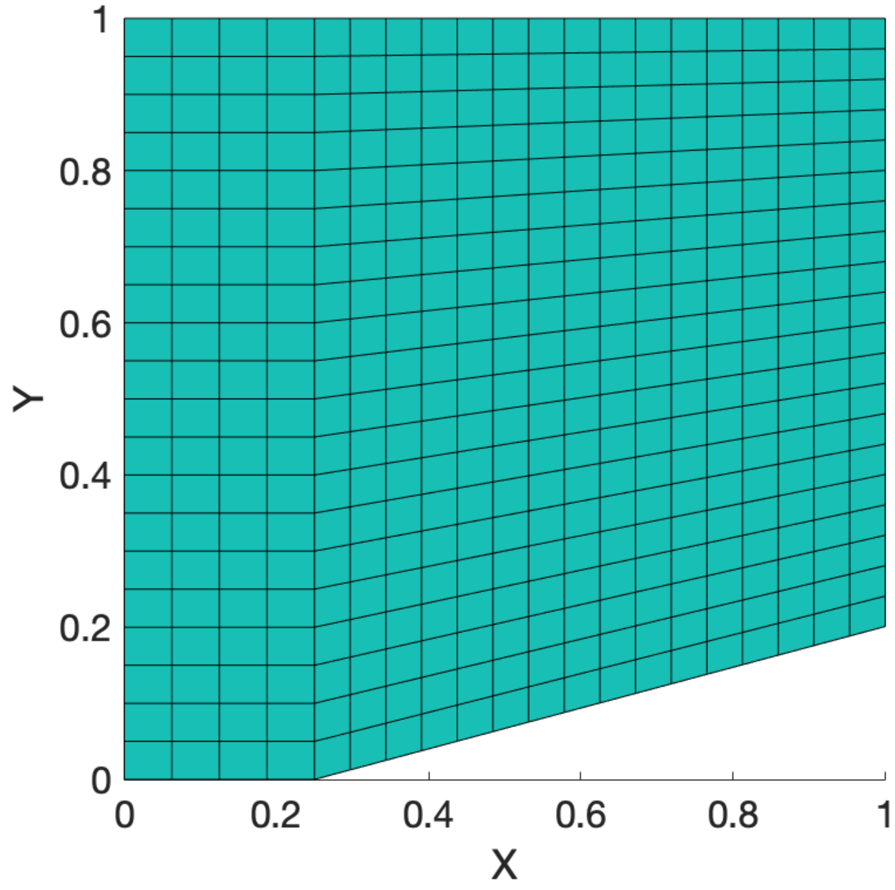
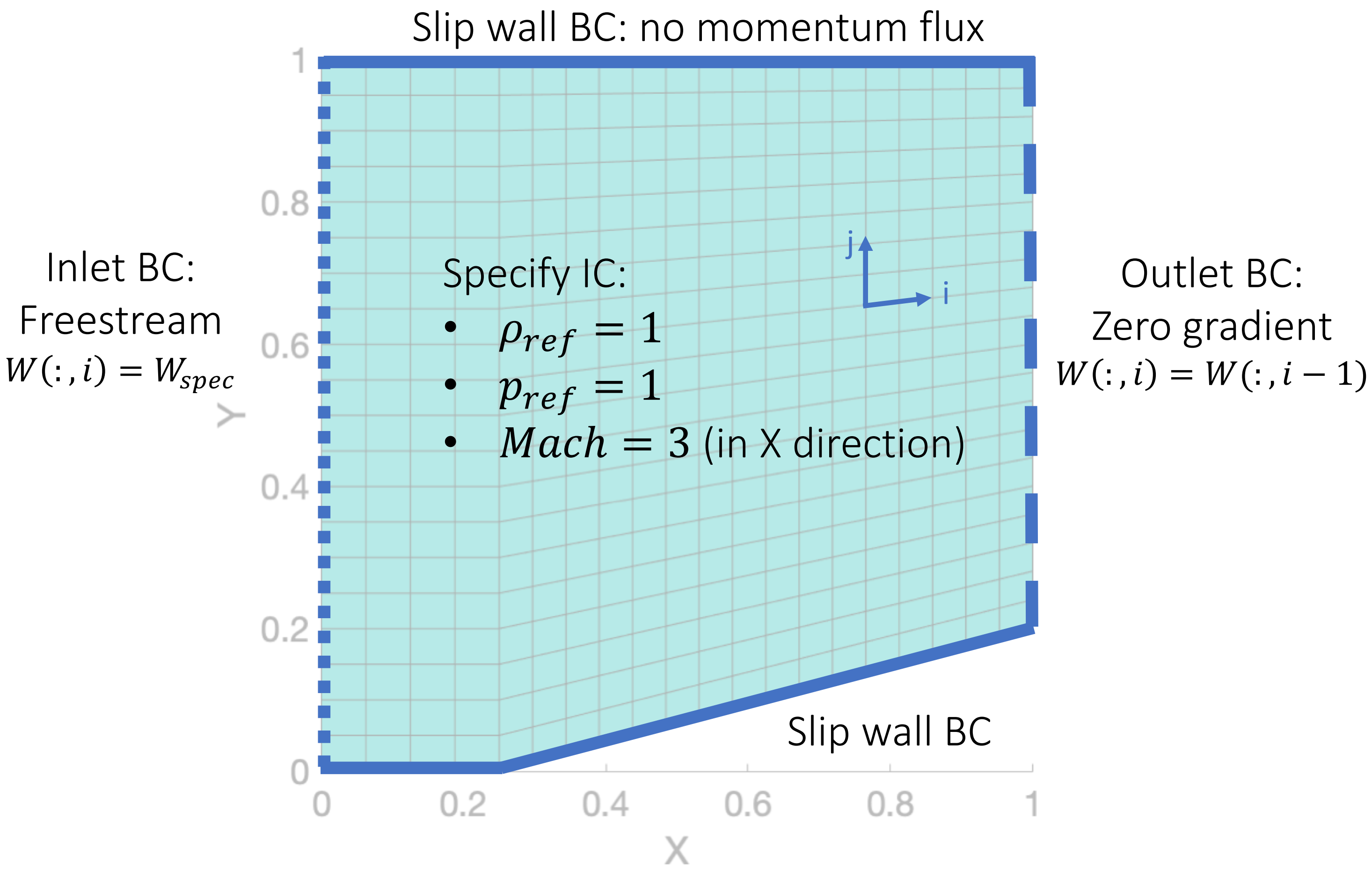
Non-uniform structured grid
Finite-volume method



Solver setup

- Geometry
- Mesh
- **IC and BC**
- Flux reconstruction
- Time integration
- Results



Solver setup

- Geometry
- Mesh
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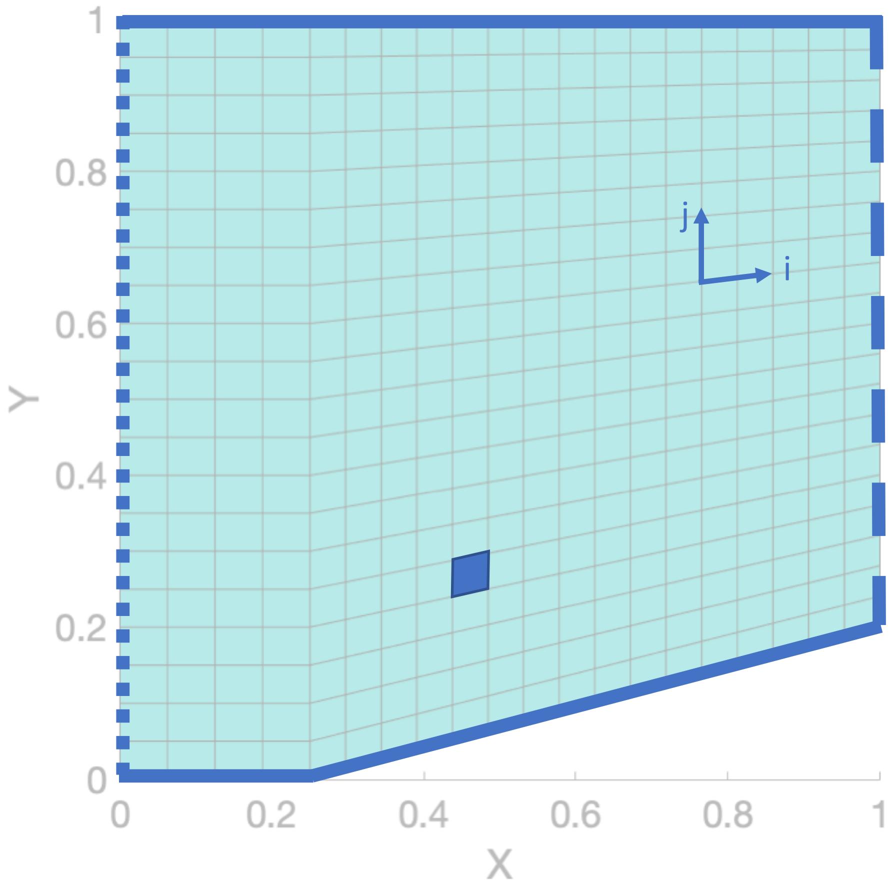
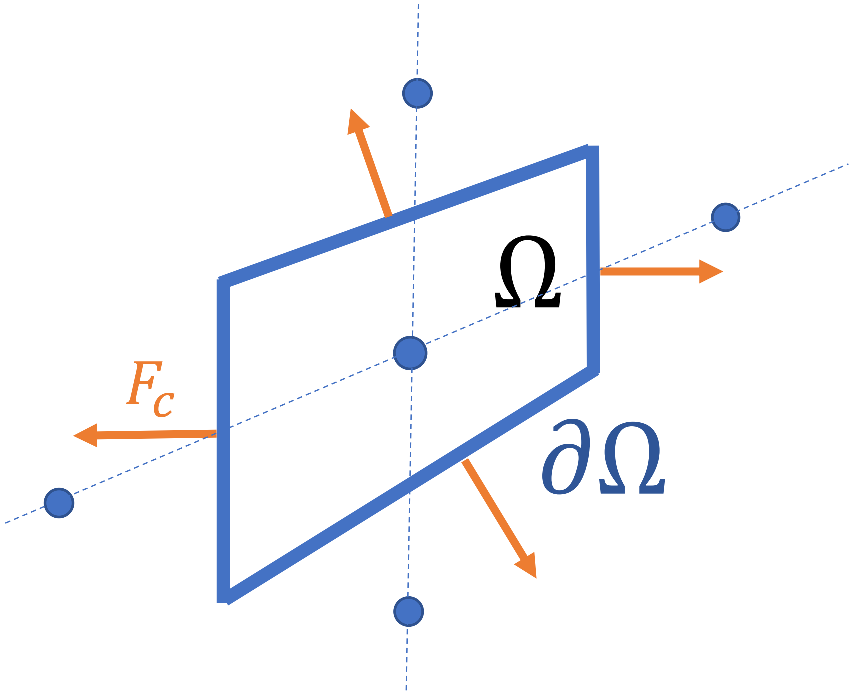
- Results



Flux reconstruction



- Equation of motion: Euler equations

$$\frac{\partial}{\partial t}\int_{\Omega}\bar{W}d\Omega + \oint_{\partial\Omega}\bar{F}_c\cdot\bar{n}dS = 0$$

$$\bar{W} = \begin{bmatrix}\rho\\ \rho u\\ \rho v\\ \rho e\end{bmatrix} \quad and \quad \bar{F}_c \begin{bmatrix}\rho V\\ \rho u V + p e_x\\ \rho v V + p e_y\\ \rho(e+p/\rho)V\end{bmatrix} \quad with \quad V = \begin{bmatrix}u\\ v\end{bmatrix}\cdot\begin{bmatrix}n_x\\ n_y\end{bmatrix}$$

- Flux calculation at face:

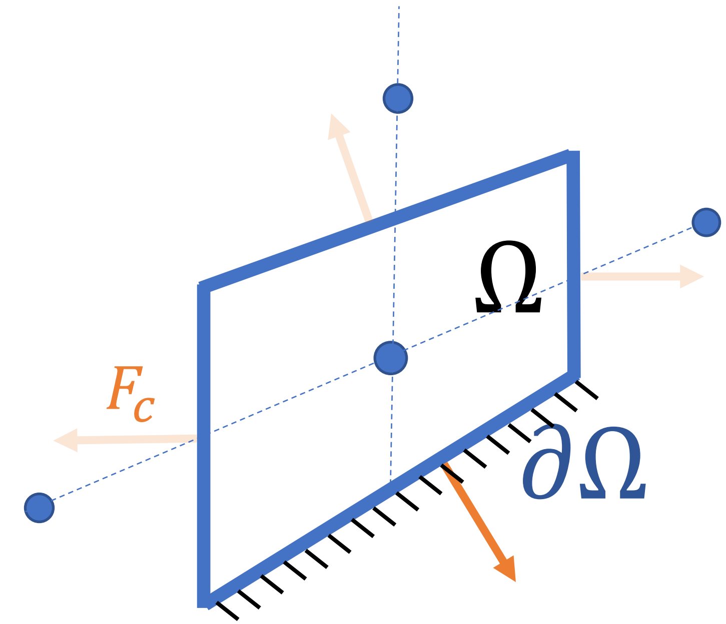
$$F_\phi = \left(\frac{u_{up}-u_{down}}{2}\right)\left[\left(\frac{1}{2}+\epsilon\right)\cdot\phi_{up} + \left(\frac{1}{2}-\epsilon\right)\cdot\phi_{down}\right] \qquad \begin{cases}\epsilon\in[0,0.5] & if\ \frac{u_{up}-u_{down}}{2}\geq 0\\ \epsilon\in[-0.5,0] & if\ \frac{u_{up}-u_{down}}{2}< 0\end{cases}$$

  - Upwind ($\epsilon = 0.5$) ≈ smoothing due to 2nd order derivative in truncation error

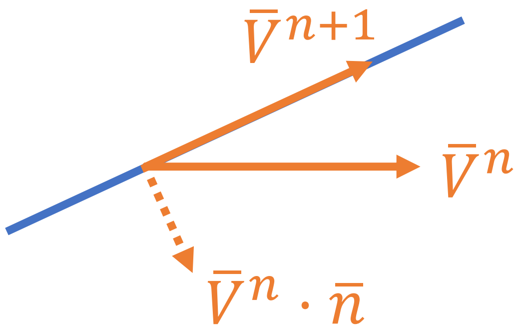
Flux reconstruction

- Flux reconstruction at slip wall boundary

$$\bar{W} = \begin{bmatrix} \rho \\ \rho u \\ \rho v \\ \rho e \end{bmatrix} \quad and \quad \bar{F}_c \begin{bmatrix} \rho V \\ \rho u V + p e_x \\ \rho v V + p e_y \\ \rho (e + p/\rho) V \end{bmatrix} \quad with \quad V = \begin{bmatrix} u \\ v \end{bmatrix} \cdot \begin{bmatrix} n_x \\ n_y \end{bmatrix}$$



- After update $\bar{W}^n \rightarrow \bar{W}^{n+1}$: take out any normal component of velocity at the wall



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Steady solver: 3 step Runge-Kutta method (AERK3J) with pseudo time step

- 1st order accurate

$$\bar{W}_i^{(1)} = \bar{W}_i^{(n)} - 0.1481 \frac{\Delta t}{\Omega_i} \sum_{n=1}^{NF} (\bar{F}_n S_n)$$

$$\bar{W}_i^{(2)} = \bar{W}_i^{(n)} - 0.4 \frac{\Delta t}{\Omega_i} \sum_{n=1}^{NF} (\bar{F}_n S_n)$$

$$\bar{W}_i^{(n+1)} = \bar{W}_i^{(n)} - 1.0 \frac{\Delta t}{\Omega_i} \sum_{n=1}^{NF} (\bar{F}_n S_n)$$

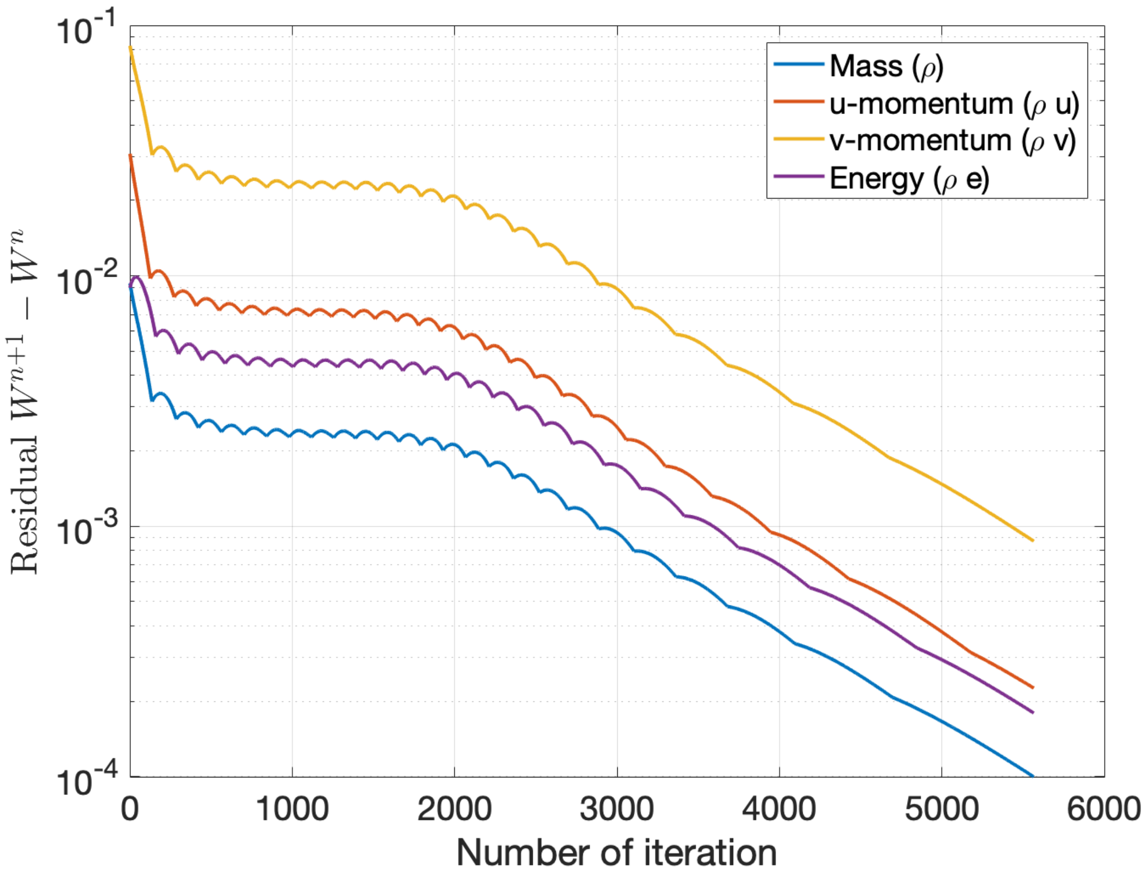
- Stopping criterium: residuals

$$\bar{W}^{n+1} - \bar{W}^{n} < tol \quad with \quad tol = 10^{-3}$$

Results

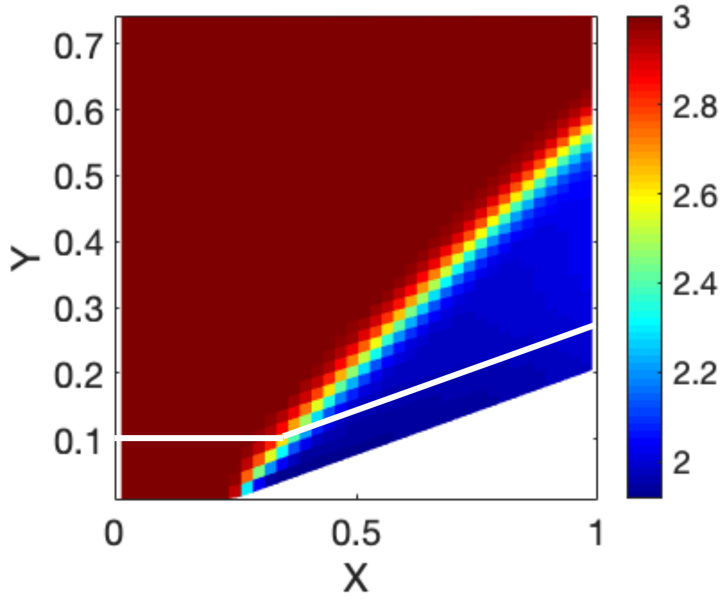
Rate of convergence of the solver

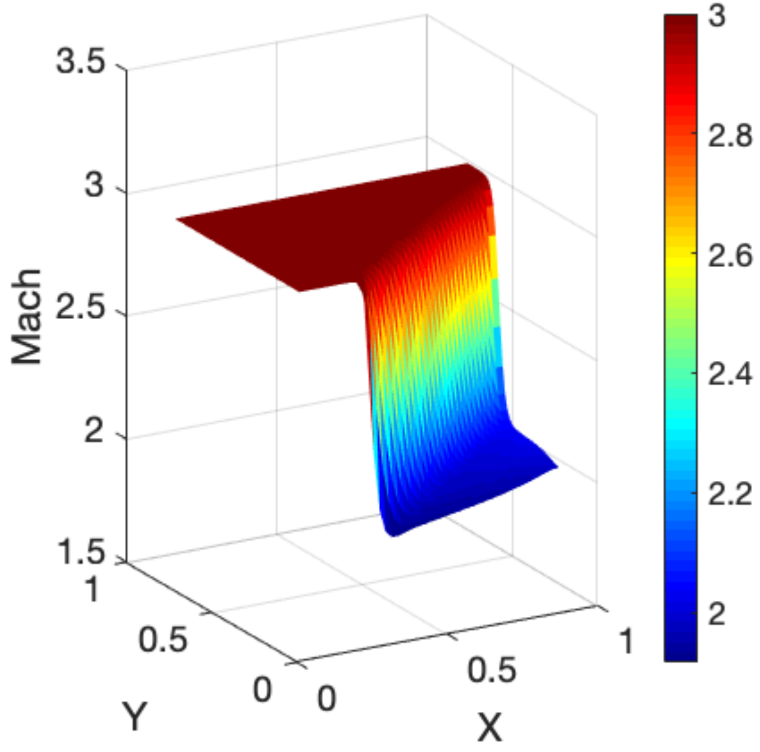
(mesh: 40x40)

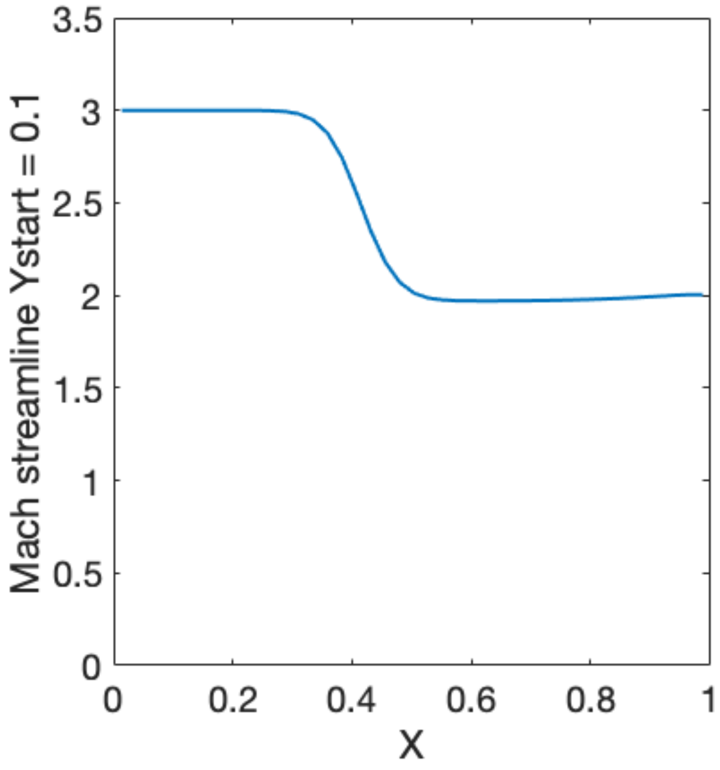


Results

Mach in fluid domain (mesh: 40x40)

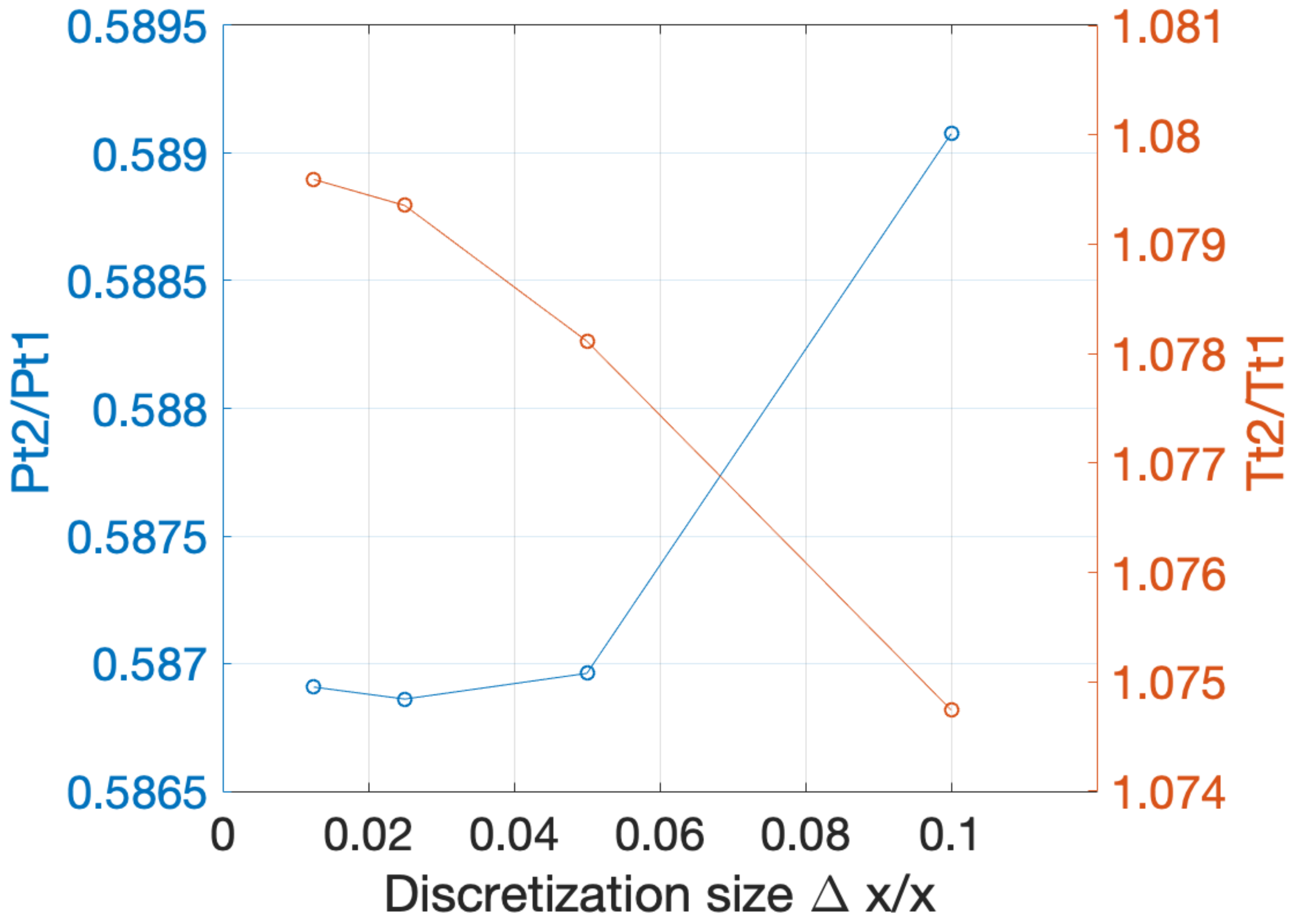




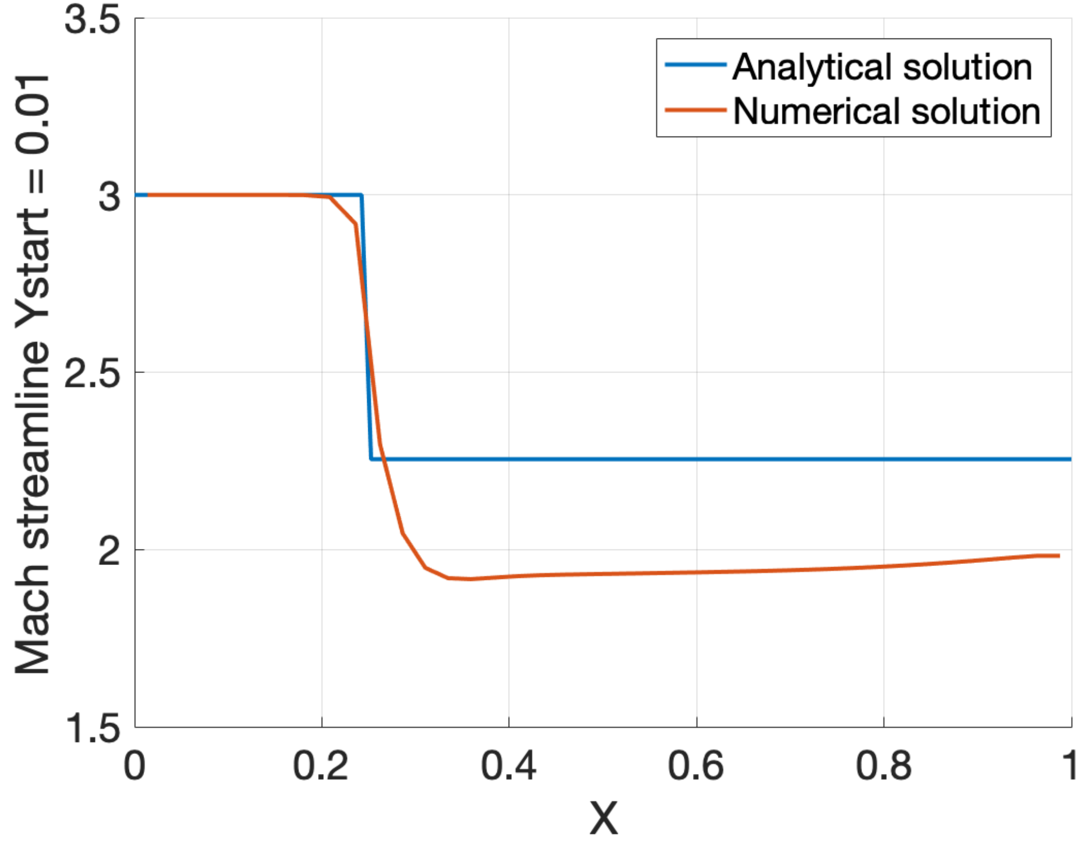


Results

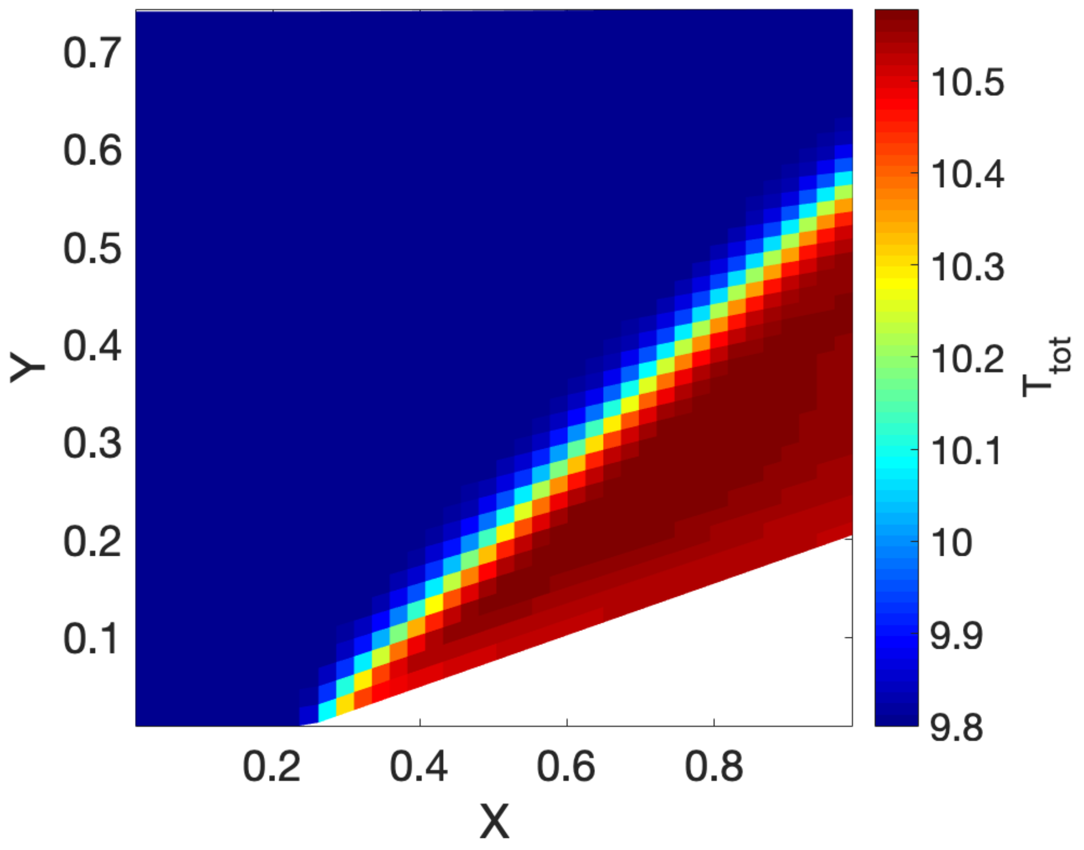
Mesh convergence



Results



$$\frac{T_{t2}}{T_{t1}} \leq 1.08$$



Future work

Debug the code to get closer to analytical solution

Model Prandtl-Meyer expansion fan

Calculate engine inlet geometry

Optimize geometry for total pressure loss

Questions