Application of a Preconditioned Density Based Solver to Transonic Nozzle Flows

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Outline

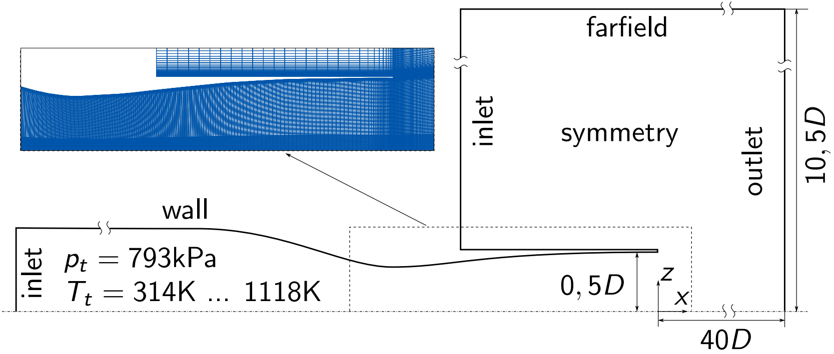
- Introduction
- Solver
- Turbulence Models
- Concluding remarks

Supersonic Jets

Importance for jet engines

- Engine performance
- Noise emission
- Infrared signature

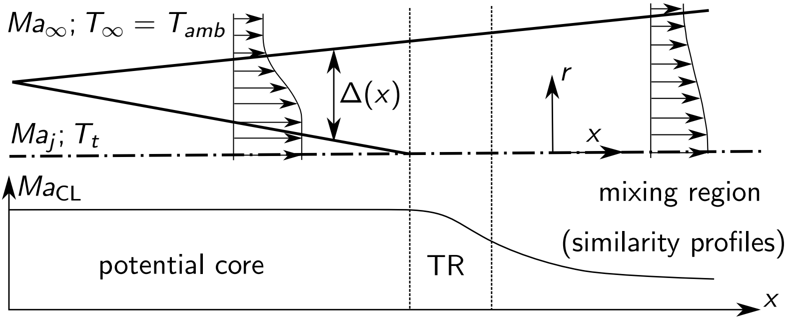
Seiner Nozzle (Mach-2-Jet) [4]



Challenges

- Compressible jet and low Mach-number region
- Turbulence
- Temperature gradients

Perfectly Expanded and Subsonic Jets



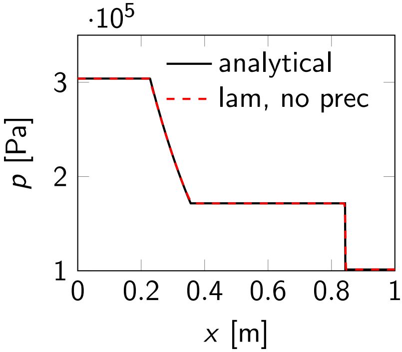
Shear layer growth $\frac{\partial \Delta}{\partial x}$

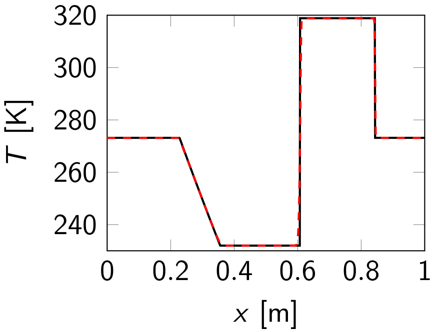
- Decreases with increasing compressibility
- Increases with increasing jet temperature

Density Based Solver (Shock Tube)

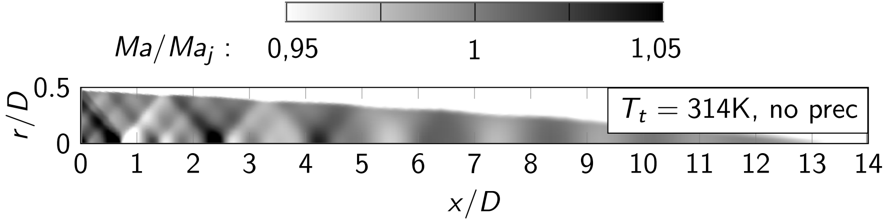
dbnsTurbFoam (foam-extend 3.1)

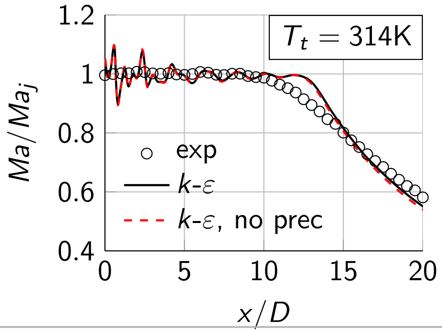
- Explicit density based solver
- Roe flux-difference splitting scheme [2]
- Venkatakrishnan limiter [6]

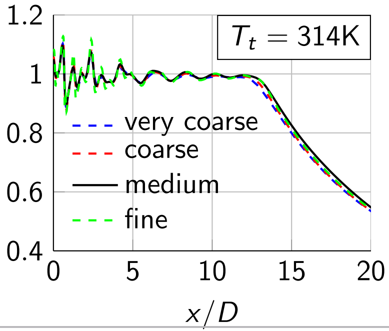




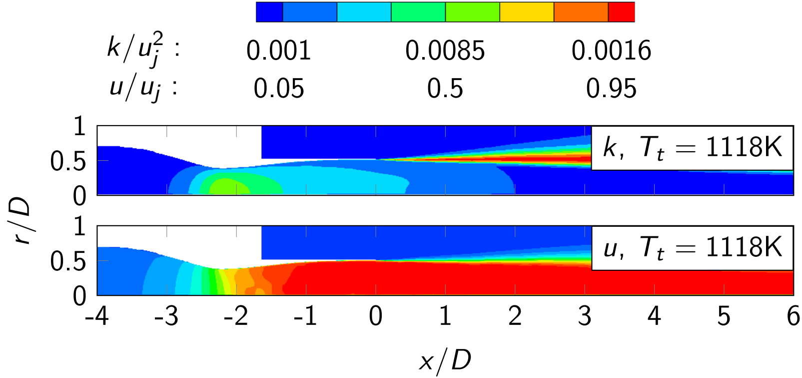
Preconditioner of Weiss and Smith [7]







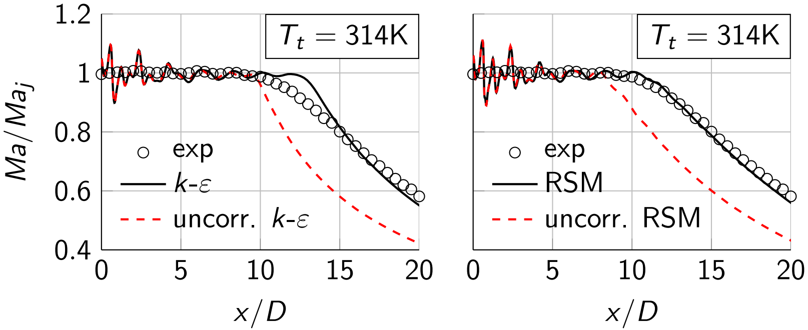
Production Limiter for Two-Equation-Models



Unphysical TKE-production with the k-ε-model

- Problem known from stagnation points
- Solved by limitation of the production term to $10\rho\varepsilon$ [1]

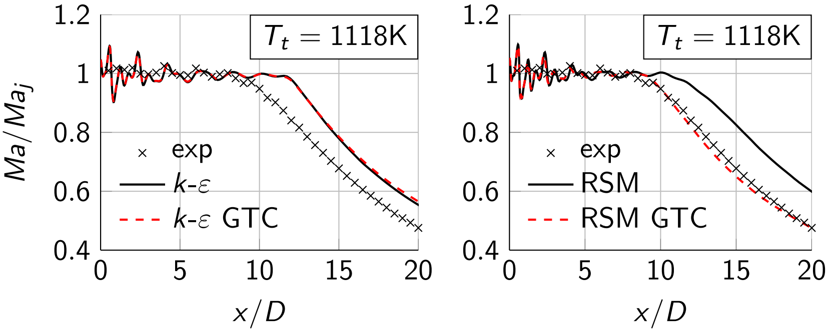
Compressibility Correction



Overpredicted TKE in compressible shear flows

- Dilatiation dissipation becomes important
- Compressibility correction of Sarkar et al. [3] improves results

Temperature Correction for Heated Jets (T_t=1118K)



Stronger mixing with increasing temperature

- Stronger fluctuations in (initial) shear layers with density gradients
- Generalized temperature correction improves results for RSM (ASME GT2017-63084) [5]

Concluding remarks

Solutions for transonic nozzle flows

- Low convergence rates in flows with low Mach-number region $\Rightarrow$ preconditioner
- Shock patterns at the beginning of the potential core $\Rightarrow$?
- Unphysical production with k-ε-model $\Rightarrow$ production limiter
- Overpredicted TKE in compressible flows $\Rightarrow$ compressibility correction
- Underestimated mixing in heated jets $\Rightarrow$ temperature correction

Thank you for your attention!

[1] Florian R. Menter. "Zonal Two Equation k-omega Turbulence Models for Aerodynamic Flows". In: *24th Fluid Dynamics Conference*. 1993.

[2] P.L. Roe. "Approximate Riemann Solvers, Parameter Vectors, and Difference Schemes". In: *Journal of Computational Physics* 43 (1981), pp. 357–372.

[3] S. Sarkar et al. "The analysis and modelling of dilatational terms in compressible turbulence". In: *Journal of Fluid Mechanics* 227 (1991), pp. 473–493.

[4] John M. Seiner et al. "The Effects of Temperature on Supersonic Jet Noise Emission". In: *14th DGLR/AIAA Aero-acoustics Conference*. Vol. 46. 1992.

[5] Jens Trümner and Christian Mundt. "Total Temperature Based Correction of the Turbulence Production in Hot Jets". In: *Proceedings of ASME Turbo Expo*. 2017.

[6] V. Venkatakrishnan. "Convergence to Steady State Solutions of the Euler Equations on Unstructured Grids with Limiters". In: *Journal of Computational Physics* 118 (1995), pp. 120–130.

[7] Jonathan M. Weiss and Wayne A. Smith. "Preconditioning Applied to Variable and Constant Density Flows". en. In: *AIAA Journal* 33.11 (1995), pp. 2050–2057.