Application of a Preconditioned Density Based Solver to Transonic Nozzle Flows

Jens Trümner*, Christian Mundt

*mail: jens.truemner@unibw.de
*phone: +49 (0)89 6004 2104

Universität der Bundeswehr München
Department of Aerospace Engineering
Institute for Thermodynamics

December 1, 2017
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

\[ Ma_\infty; \ T_\infty = T_{amb} \]

\[ Ma_j; \ T_t \]

\[ Ma_{CL} \]

Potential core

Mixing region

(similarity profiles)

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]

\[ \frac{Ma}{Ma_j} : 0.95 \quad 1 \quad 1.05 \]

\[ T_t = 314K, \text{ no prec} \]

\[ x/D \]

\[ r/D \]

\[ r/D \]

\[ T_t = 314K \]

\[ \frac{Ma}{Ma_j} \]

"exp"  
"k-\varepsilon"  
"k-\varepsilon, no prec"

very coarse  
coarse  
medium  
fine

\[ x/D \]

\[ x/D \]
Production Limiter for Two-Equation-Models

Unphysical TKE-production with the $k$-$\varepsilon$-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

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

---

**Graphs:**

1. **Left Graph:**
   - Legend:
     - exp
     - \( k-\varepsilon \)
     - uncorr. \( k-\varepsilon \)
   - Axes:
     - \( x/D \) on the x-axis
     - \( Ma/Ma_j \) on the y-axis
   - Graph shows data comparison of experimental (exp) and theoretical (\( k-\varepsilon \)) models with and without compressibility correction.

2. **Right Graph:**
   - Legend:
     - exp
     - RSM
     - uncorr. RSM
   - Axes:
     - \( x/D \) on the x-axis
     - \( Ma/Ma_j \) on the y-axis
   - Graph shows data comparison of experimental (exp) and theoretical (RSM) models with and without compressibility correction.

---

**Equation:**

\[ T_t = 314K \]

\[ x/D \]

\[ Ma/Ma_j \]

\[ \text{exp} \]

\[ k-\varepsilon \]

\[ \text{uncorr.} \ k-\varepsilon \]

\[ \text{exp} \]

\[ \text{RSM} \]

\[ \text{uncorr.} \ \text{RSM} \]
Temperature Correction for Heated Jets (\(T_t=1118\text{K}\))

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 ⇒ preconditioner
- Shock patterns at the beginning of the potential core ⇒ ?
- Unphysical production with $k$-$\varepsilon$-model ⇒ production limiter
- Overpredicted TKE in compressible flows ⇒ compressibility correction
- Underestimated mixing in heated jets ⇒ temperature correction
Thank you for your attention!


