Simulation of Sub- Trans- and Supersonic flow fields with DES by the DLR TAU-code

Heinrich Lüdeke
DLR - German Aerospace Center
Institute of Aerodynamics and Flow Technology
Outlines

- Introduction
- Supersonic Validation: The blunt cylinder wake
- Transonic simulation of the ARIANE-5 launcher
- Subsonic NACA 0021 simulations
- Conclusion
Motivation

- Simulation of unsteady turbulent wake flow for realistic configurations…

- In the Supersonic regime: for re-entry vehicle wakes and interactions with pods.

- In the transonic regime: Buffeting coupling and resulting side loads in the nozzle section during launcher ascent.

- In the subsonic regime: profiles at high angle of attack and incompressible validation cases.

- Getting experience with time accurate DES prediction of turbulent separated flow with one code in all regimes.
Numerical tools

DLR-TAU-Code

- Hybrid code (tetrahedra, hexahedra, prisms and pyramids)
- Solution of RANS and DES turbulence models
- Explicit Runge-Kutta and implicit backward Euler scheme
- Local time stepping, residual smoothing, multigrid
- Second order central and upwind schemes
- Dual-time stepping for unsteady applications
- Adaptation (refinement/derefinement)
- Parallelization
Section 2
Supersonic Validation: The blunt cylinder wake
Axisymmetric Base Flow: Expansion and Shock Waves

- $M_\infty : 2.46$
- $\rho_\infty : 0.7579 \text{ Kg/m}^3$
- $p_\infty : 3.14 \cdot 10^4 \text{ N/m}^2$
- $T_\infty : 145 \text{ K}$
- $Re : 45 \cdot 10^6 \text{ 1/m}$
- $R : 31.75 \text{ mm}$
- $U_\infty : 593.8 \text{ m/sec}$

Pressure distribution and Instantaneous vorticity contours behind cylinder base.
Hexahedral cylinder grid, 350,000 cells
Tetrahedral cylinder grid, 2,000,000 cells
Averaged Mach-number behind the base. RANS and DES results on hexahedral grid

RANS simulation

DES simulation
Resolved turbulent kinetic energy behind the base. DES results

Hexahedral grid

Tetrahedral grid
Resolved streamwise turbulent intensity behind the base. DES results

Hexahedral grid

Tetrahedral grid

Numerical

Experimental

Numerical

Experimental
Averaged centerline velocity and pressure along the base for different turbulence models
Section 3

Transonic simulation of the ARIANE-5 launcher
Ariane-5 structured grid
Density contours of Ariane-5 at Mach 0.9 steady RANS simulation
Flow conditions

\( M_\infty : 0.8 \)
\( \rho_\infty : 0.7568 \text{ Kg/m}^3 \)
\( p_\infty : 6.04 \cdot 10^4 \text{ N/m}^2 \)
\( T_\infty : 278 \text{ K} \)
\( Re : 11 \cdot 10^6 \text{ 1/m} \)
\( U_\infty : 267 \text{ m/sec} \)
\( T_{thrust} : 377 \text{ K} \)
\( p_{thrust} : 3.30 \cdot 10^6 \text{ N/m}^2 \)
RMS-distribution of the wall pressure
temporal pressure variation $C_{prms}$ and time averaged streamlines
Comparison of RMS-pressure values
experimental data and DES-results

\[ \sigma C_p \]

- **DES: Left hand side**
- **DES: Right hand side**
- **NLR PHST: with helium bol**
- **NLR PHST: without bol**

X-axis: [0.04, -0.04]
Y-axis: [0, 0.1]
Unsteady force on the EPC-nozzle in the Booster plane

NLR-Model without Heliumbol
Spectral density of the force on the EPC-nozzle
NLR-Model without Heliumbol, force in booster plane
Spectral density of the force on the EPC-nozzle

NLR-Model without Heliumbol, normal force relative to the booster plane
Local sound pressure level of the EPC-nozzle

NLR-Model with Heliumbol

![Graph showing local sound pressure level data for different frequencies and locations.](image-url)
Section 4

Subsonic NACA0021 simulations
NACA 0021: Grid and flow conditions

- $M_\infty : 0.1$
- $T_\infty : 300 \text{ K}$
- $Re : 27 \cdot 10^4 \text{ 1/m}$
- $U_\infty : 34.72 \text{ m/sec}$
- $L_{ref} : 1 \text{ m}$
- $\alpha : 60 \degree$

Overall grid and detail near airfoil for NACA0021.
Unsteady drag in comparison with experimental data
NACA 0021, computed by TAU-DES. Averages over time included.
Comparison of spectra for different force components
NACA 0021, computed by TAU-DES. Comparison with experimental data from Swalwell
Unsteady drag in comparison with experimental data
NACA 0021, computed by FLOWER-DES. Averages over time included.
Comparison of spectra for different force components
NACA 0021, computed by TAU-DES. Comparison with experimental data from Swalwell
Conclusion

- DES computations result in well resolved time dependent turbulent flow for the chosen grid density.
- DES validation successfully carried out for different regimes.
- Ariane-5 DES simulations including jet are carried out successfully.
- Subsonic NACA 0021 test-case started for structured and unstructured code including preliminary analysis.
Thank You
Thank You
Thank You
Ariane-5 velocity vectors at nozzle outflow.
steady turbulent simulation with jet
Resolved turbulent kinetic energy behind the base. Standard DES: hexahedral grid
Principles of Detached-Eddy Simulation

- Motivation: combination of Large-Eddy and RANS approach
- Formulation bases on the Spalart-Allmaras one equation RANS model
- Modification of wall distance terms for time accurate computation transforms the SA formulation into LES
- Use of SA model in boundary layers and LES for free turbulence
- In practice: replace wall distance $d$ by $\tilde{d} = \min(d, C_{DES} \cdot \Delta)$ with $\Delta = \max(\Delta x, \Delta y, \Delta z)$ as the filter length
Principles of Detached-Eddy Simulation II

- **Advantages:** combination of the best features of both models
  - simple implementation
  - time accurate results

- **Disadvantages:** switching between models is grid dependent
  - time- and memory consuming simulations

- Additional low-Reynolds number corrections to improve the LES part of the model are possible (see Shur and Strelets)