Aeroacoustic Simulation of 30P30N High-Lift Configuration using Lattice Boltzmann Method

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Outline

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  • Equilibrium wall model
• Computational condition/mesh
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Background/Objective

• **Challenge of Industrial CFD**
  - Unsteady phenomena (e.g. CAA)
  - Complex geometry
  - Low computational cost
    (Wall clock time to solution: Less than a week with $O(100)$ cores)

• **Lattice Boltzmann Method**
  - Lower dissipation error than DRP scheme with 6th order RK※
    (but higher dispersion error)
  - 10 – 50 times speed up can be achieved with LBM

**Objective:**
Development of practical LBM solver for industrial use

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**MHI-LBM solver [Overview]**

Developed from scratch and now …

• D3Q27 model
• Building Cube Method
• Cumulant collision model
• Interpolated Bounced Back
• Implicit LES
• Equilibrium wall model (Conventional stress model)


MHI-LBM solver [Cumulant collision model]

- Cumulant collision model

The biggest issue of LBM was numerical instability at High Re.

\[ f_i(t+\Delta t, \mathbf{x}+\mathbf{e}_i\Delta t) = f_i(t, \mathbf{x}) + \Omega_i, \quad i = 0, \ldots, b-1 \]

Collision Operator
- LBGK model (i.e. Single relaxation model)
- Multiple relaxation model
  - Raw moments
  - Central moments

\[
\text{raw moments} = \sum f_i \rho e_{ix}^m
\]

\[
\text{central moments} = \sum f_i \rho (e_{ix}^m - v_x^m)
\]

The Galilean invariance and the numerical stability is greatly improved!

MHI-LBM solver [Equilibrium wall model]

- Equilibrium wall model

Similar to implementation presented in Ref[1] or Ref[2]

1. Choose reference point \( X_R \) (length = 1.75\( \Delta x \))
2. Interpolation rho and \( V \) at \( X_R \)
3. Calculation \( U_i \) by Spalding law with newton iteration
4. Calculation tangential velocity at boundary node
   (1st order approximation )
5. Interpolated bounced back for moving boundary

Computational details

- Total # of cells: 150 million
- Minimum grid space: $1.0 \times 10^{-3}$C
  => Insufficient mesh resolution to resolve trailing edge noise of slat
- Span length: 0.25C
- $y^+ \approx 200$ (at 5.5 deg)
- Upper limit of resolved frequency: about 6KHz
  [PPW $\approx 10$ and Rossiter mode is assumed]

Data sampling

- # of iteration for unsteady data sampling: 98304
  (Total # of iteration including transient simulation: 320000)
- $\Delta t: 7.48 \times 10^{-7}$ sec
- Total sampling time: 0.074 sec
- # of averages for spectrum: 11

Wall clock time to solution: 3.5 days with 640 cores
Results [Cp distributions]

- Cp distributions agree with Exp.

Results [PSD at AoA=5.5deg]

- Spectrums reasonably agree with experimental results.
- Simulation tends to be overestimated at every sampling points especially in high frequency.
Results [PSD at AoA=9.5deg]

- Spectrums are reasonably agreement with Exp.
- The effects of AoA (Tonal frequency shift and reduction of PSD) are well captured.

![Graphs showing PSD at different AoAs](image1)

Results [Cf distributions]

- Cf distributions unphysically oscillated.

![Graphs showing Cf distributions at different AoAs](image2)
**Results [Cf distributions]**

- Oscillation occurs at steps
- Stair geometric representation may cause Cf oscillation.

**Summary**

- **Efficient and practical MHI-LBM code has been developed**
  - MHI-LBM code can stably compute for 30P30N even if high Re number flow. Cumulant collision model and equilibrium wall model worked well.
  - Cp distributions agree with Exp.
  - PSD shows reasonable agreement with Exp.
  - Cf is oscillated due to stair geometry representation.

Interpolation procedure must be modified.
(e.g. Increase interpolation data)
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