ultraFluidX

NEXT-GENERATION CFD FOR GROUND TRANSPORTATION
AGENDA

• Introduction
• Technology Overview
  • Key Features and Main Advantages
  • Basic Concept of LBM
  • Lattice Boltzmann and GPUs
  • Preprocessing and Wall Treatment
  • Turbulence and Wall Modeling
  • Superior Features
ULTRAFLUIDX – OVERVIEW

• Next Generation LBM Technology
  • GPU-based Solver
  • Extensible Platform for Rapid Use-Case Expansion
    ➢ Aero-acoustics / Coupled Analysis / Thermal Management / etc…
  • Altair Modeling and Visualization

• Superior Features
  • Turn-Around-Time
  • Accuracy
  • High-Fidelity Modeling

• Validation and Commercialization
  • Initially through Altair Ground Transportation CFD Advisory Board
  • Several Automotive OEMs from Asia, US, Europe
TECHNOLOGY OVERVIEW
ULTRAFLUIDX – MAIN FEATURES

- D3Q27 Cumulant Lattice Boltzmann model for isothermal, unsteady 3D single-phase flows
- CUDA-aware MPI support for multi-GPU and multi-node usage
- Case Setup via Altair’s Virtual Wind Tunnel (support for box-shaped simulation domains)
- Automated volume mesh generation with local grid refinement and support for baffle parts
- LBM-consistent Smagorinsky LES turbulence model and TBLE-based wall modeling
- Porous media model (pressure drop) for simulation of multiple heat exchangers
- Handling of rotating geometries via wall-velocity boundary condition
- Support for moving floors (single & 5-belt system) and static floors with boundary layer suction
- Advanced post-processing capabilities (e.g., window averaging, spatial drag/lift contribution, probe output, section cut output)
ULTRAFLUIDX – MAIN ADVANTAGES

- **Complex automotive geometries**
  - Low surface mesh requirements
  - Straightforward volume mesh generation
  - Easy part replacement ("virtual wind tunnel")
  - Well-suited for automation (→WLTP!)

- **Transient simulations**
  - Capture unsteady nature of bluff body wake
  - 5 years ago: 1 sec physical time
    - Today: 2 sec Sedan / 5 sec SUV / 30+ sec Truck
  - Good performance for (V)LES-class resolved flows
    (explicit, scalable LBM algorithm)
  - Low numerical dissipation
  - Aero-acoustics with same model
    + new disciplines (crosswind, overtaking, etc.)
ULTRAFLUIDX – BASIC CONCEPT (LATTICE BOLTZMANN)

• LBM vs Conventional CFD
# ULTRAFLUIDX – BASIC CONCEPT (LATTICE BOLTZMANN)

- Unique benefits of LBM

<table>
<thead>
<tr>
<th></th>
<th>Conventional CFD</th>
<th>LBM</th>
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<tbody>
<tr>
<td>Discretization</td>
<td><em>Discrete approximation of PDE</em></td>
<td><em>No discrete</em></td>
</tr>
<tr>
<td>Solving method</td>
<td><em>Complex and Costly</em></td>
<td><em>Simple and Fast</em></td>
</tr>
<tr>
<td>Time Dependent</td>
<td><em>Unsteady, Steady</em></td>
<td><em>Unconditionally unsteady</em></td>
</tr>
<tr>
<td>Time Step</td>
<td><em>Need to define adaptive time stepping</em></td>
<td><em>Automatically determined</em></td>
</tr>
<tr>
<td>Geometry setup</td>
<td><em>Slow and Difficult</em></td>
<td><em>Fast and Easy</em></td>
</tr>
<tr>
<td>Parallel</td>
<td><em>Limited parallel performance</em></td>
<td><em>Local and Fully parallel</em></td>
</tr>
<tr>
<td>Complex physics</td>
<td><em>Complex</em></td>
<td><em>Simple</em></td>
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ULTRAFLUIDX – BASIC CONCEPT (LATTICE BOLTZMANN)

• Boltzmann equation is solved on a discrete lattice
  • Underlying principle can be described as movement (streaming) and collision of particles on the lattice
  • Streaming takes place at distinct speeds/directions according to the chosen model, e.g., D3Q27

• Physical behavior is determined by viscosity of fluid

• **Transient nature of flow is inherently respected**

• Time step according to CFL=1 with adequate sub-time stepping in refinement zones (octree-based 2:1 refinement)

• Macroscopic properties like density and velocity can be recovered from the moments of the distribution functions and vice versa

• Explicit (time) and local (space): **perfect for massively parallel execution**
ULTRAFLUIDX – EXPLOITING GPU COMPUTING POWER

• Tremendous speed for explicit, local algorithms: **LBM is a perfect match**
• Achieve over-night runs on one server node
• High pace of GPU technology development
• Similar or even lower investment costs compared to CPU-clusters of same performance
• Low energy consumption

![CPU + GPU](http://www.nvidia.com/object/tesla-p100.html)

**NVIDIA Tesla P100**

10.6 TFLOPS (SP)
ULTRAFLUIDX – MODELLING AND VISUALIZATION

HyperMesh

Pre-processing

Post-processing

Simulation

AcuFieldView

ultraFluidX
ULTRAFLUIDX – ALTAIR’S VIRTUAL WIND TUNNEL

Efficient case setup (meshing & physics)

Standardized process (templates)

Automotive external aero

Short turn-around-time
ULTRAFLUIDX – SURFACE MESH REQUIREMENTS

• Surface mesh only defines the geometry (fluid/solid regions, wall distance)
• No need for boundary layer compliance

➢ Lower surface mesh requirements than Navier-Stokes

➢ Strongly skewed surface triangles allowed
• Gaps smaller than the smallest voxel size allowed (no “leakage” caused)

➢ Surface mesh from other CFD solvers generally runnable without modification
ULTRAFLUIDX – GENERAL WALL TREATMENT

• Geometrical Modeling
  • Volume mesh is intersected with surface mesh
  • Selection of fluid/solid regions based on location of volume mesh nodes (voxel centers) w.r.t. the surface mesh (outside/inside)
  • Effective wall-normal distance for each fluid node for use in wall modeling:
    - evaluation of subgrid wall distance in direction of each lattice link (connections between neighboring nodes)
    - weighting of lattice link contributions

• Little memory consumption, fast discretization

• No influence on simulation performance by overly refined input geometry
ULTRAFLUIDX – PREPROCESSING ADVANTAGES

• Kinks and thin parts are fully resolved in the volumetric preprocessing
  • Automatic adaptation to geometrical features of the surface w.r.t. the chosen resolution for the volume mesh

• Automatic selection of appropriate physical modeling in tight gaps and cavities
  • Surface normal is not well-defined if surface is present on opposing sides of a voxel, wall modeling cannot be used

• Fast generation of typical production-level volume meshes
ULTRAFLUIDX – PREPROCESSING ADVANTAGES

• Two boxes

Preparation components

Local refinement levels
ULTRAFLUIDX – PREPROCESSING ADVANTAGES

• Simulation results

Averaged velocity magnitude

Transient velocity magnitude
ULTRAFLUIDX – SUPERIOR FEATURES

• Short turn-around-time
  • Need only surface mesh: automatic volume mesh generation with local grid refinements
  • Automatically determined time step size
  • Easy to modify and replace geometries
  • Well-suited for automation
  • Automatic post-processing with user templates

• Accurate flow simulation
  • Smagorinsky LES turbulence model and TBLE-based wall modeling
  • Low numerical dissipation
  • Fully transient simulations
THANK YOU