2次元静電場と正則関数:
静電誘導の簡単な例

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Outline

- Motivation: Dense Sprays and LES Calculations.
- Spatial Filtering of Multiphase Flow Equations.
- An Example of a Partly-Resolved Particle Model. 例
- Results for Various Particle Sizes. 種々の粒子サイズに対する結果
- Grid Requirements for Filtered Multiphase Calculations.
- Filtering and Point Particle Models.
- Conclusions.

Motivation

- Atomization models in combustion codes:

- Dense-region mass, momentum transfers are significant.
  - How much transfer should there be?
  - How should it be distributed?
- Multiphase models need to be consistent with LES.
- Filtered-Phase Method (FPM) provides analysis path.

What is the Filtered-Phase Method?

- Apply the turbulent LES methodology for fluid surfaces as well as turbulent eddies:
  - Rigorously extend fluid equations to cover entire domain, including regions outside the fluids.
  - Flow phases and variable fields are divided into large- and small-scale parts by spatial filtering.
  - Large-scale liquid features and gas-phase interaction appear directly in the resolved-scale calculation.
  - Small-scale effects such as individual droplets and secondary breakup are included by models.
- As in LES, the interaction between small scales and large scales can be derived explicitly.

Spatially-Filtered Multiphase Flow Equations

- Filtered momentum equation (simplified form):
- Simplifying assumptions: one phase (plus particles), incompressible flow, constant properties, no outflow.
- Unclosed terms:
  - Correction terms for surface motion.
  - Surface stress term.
  - Subfilter-scale convection (LES model term).

Model Problem

- Laminar flow around a fixed cylindrical “particle”.
- Flow conditions: Uniform freestream, $\mathrm{Re}_D = 26$.
  - Steady flow, with significant recirculation zone.
  - Wake continues for many diameters downstream.
  - Can be simulated with a 2-D calculation.

Parametric Particle Model

- Unclosed terms approximated by parametric models:
  - Surface force represented by a multi-point interpolation over the particle surface.
  - Subfilter-scale convection represented by three filtered point forces.

Initial Model Results

- Computation parameters (in units of $\mathrm{D}_{particle}$):
  - 16×16 flow domain.
  - $\Delta \mathrm{x}_{grid} = 1/16$, for grid-converged results.
- The resulting simulation is a close match for the exact filtered flow, both qualitatively and quantitatively.

Results from Partial Models

- With the subfilter-scale convection neglected:
  - Wake centerline velocity is higher.
  - Volume-displacement effects are greatly reduced.
  - Total wake momentum defect, however, is the same.

Results from Partial Models

- With the drag force uniformly distributed over the particle's surface (and without the subfilter term):
  - The wake is offset downstream because the centroid of the force is in the wrong place.
  - The results are otherwise nearly identical.

Initial and Partial Model Results

Momentum flux defects (in units of ρU_0^2).

- The wake defect consists of two parts:
  - Momentum loss due to drag force (all models).
  - Momentum flux temporarily “hidden” in subfilter scales (with subfilter convection term).
- The surface force distribution has very little effect.

Results for Various Particle Sizes

- Filter = 0.5 particle diameter:
  - Results are still very good.
  - Some minor effects from limited sfs-term coverage.

Results for Various Particle Sizes

- Filter = 0.1 particle diameter:
  - No sfs term (three-point is insufficient)
  - Results close, but sfs term still needed even at this fine resolution.

Results for Various Particle Sizes

- Filter = 4.0 particle diameter:
  - Still reasonably good results (comparable to 1.0 case).
  - Some domain-size issues.

Results for Various Particle Sizes

- SFS momentum term increases with increasing filter.
- Net wake defect is constant.
- Wake width converges to same size downstream..

Results for Grid Resolution Study

- Grid = 0.5 filter radius:
    - Qualitatively very good results
    - Some primary grid-coarsening effects. (Max wake defect slightly washed-out.)

Results for Grid Resolution Study

- Grid = 1.0 filter radius:
  - Expected to be ill-resolved.
  - Qualitatively still reasonable.
  - Wake defect very “smeared out”.

Results for Grid Resolution Study

- Wake width results are good over all grid range, even for most ill-resolved case.

Filtering and the Point Particle Model

- Even for a case where the particle is two orders of magnitude smaller than the filter, the subfilter-scale convection term is a significant fraction (around 25%, at peak) of the filtered surface force.

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Summary and Conclusions

- We have derived LES-compatible equations for multiscale, multiphase flow by spatial filtering, and used these equations to develop models for typical partly-resolved particles.
- The particle models produce accurate results over a range of scales.
- Grid resolution requirements are comparable to requirements for turbulence LES.
- Subfilter-scale term is important over a wide range of scales, well into the “resolved” and “point-particle” regimes.
- This provides clear, rigorous guidance for distributing particle forces in particle-laden LES computations.