Efficiently Modeling Primary Liquid Atomization using an Eulerian-Lagrangian Hybrid Model in ANSYS Fluent

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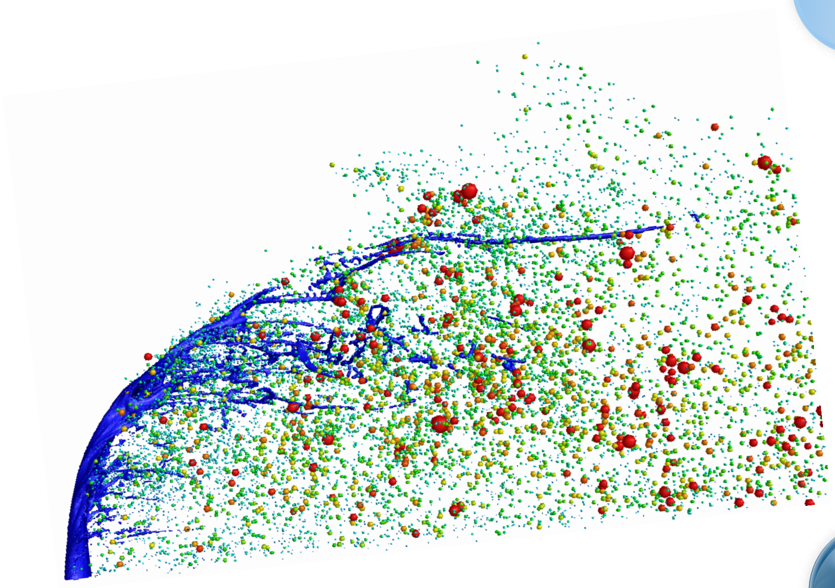
Outline



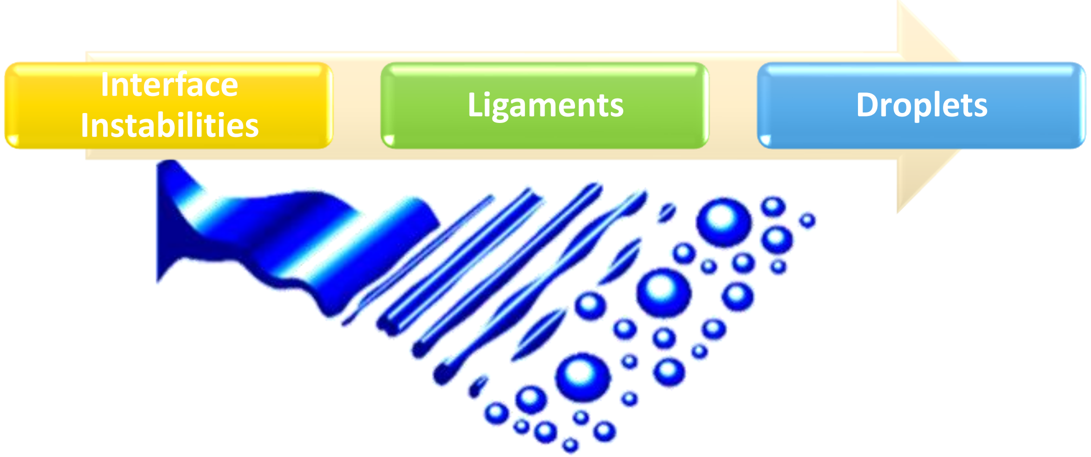
Spray applications

Eulerian-Lagrangian (VOF-DPM) Hybrid Model
Transition criterion, Dynamic Mesh Adaption

Case study and comparison with experiments

Summary

Spray Applications



Evaporation

Spray Drying
- Milk powder, pharma
- Cooling towers

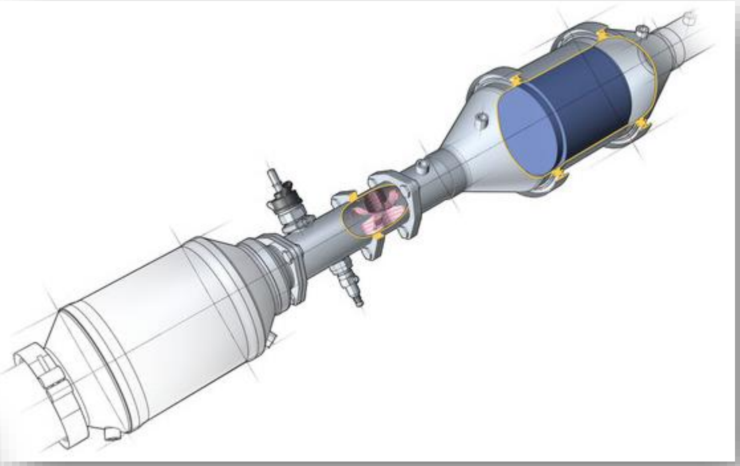
Vapor-gas mixing
- SCR

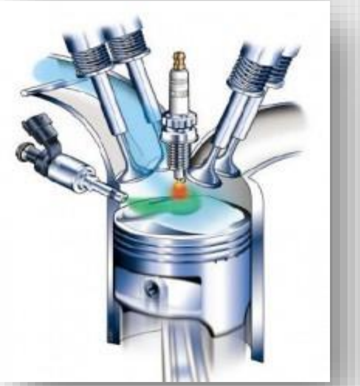
Liquid fuel combustion
- Piston engines
- Gas turbines

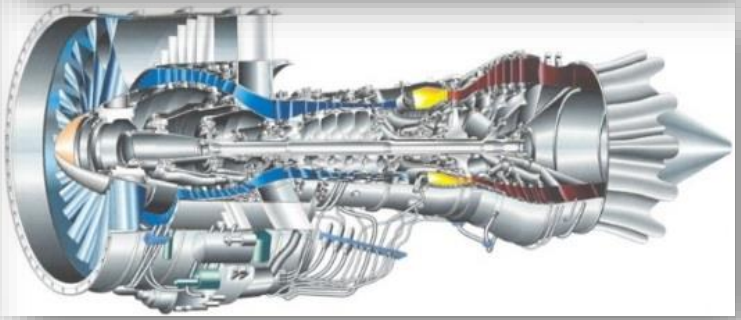
Spreading of Liquid

Fire suppression, Agriculture

Surface Coating, Surface Cleaning, Surface Cooling

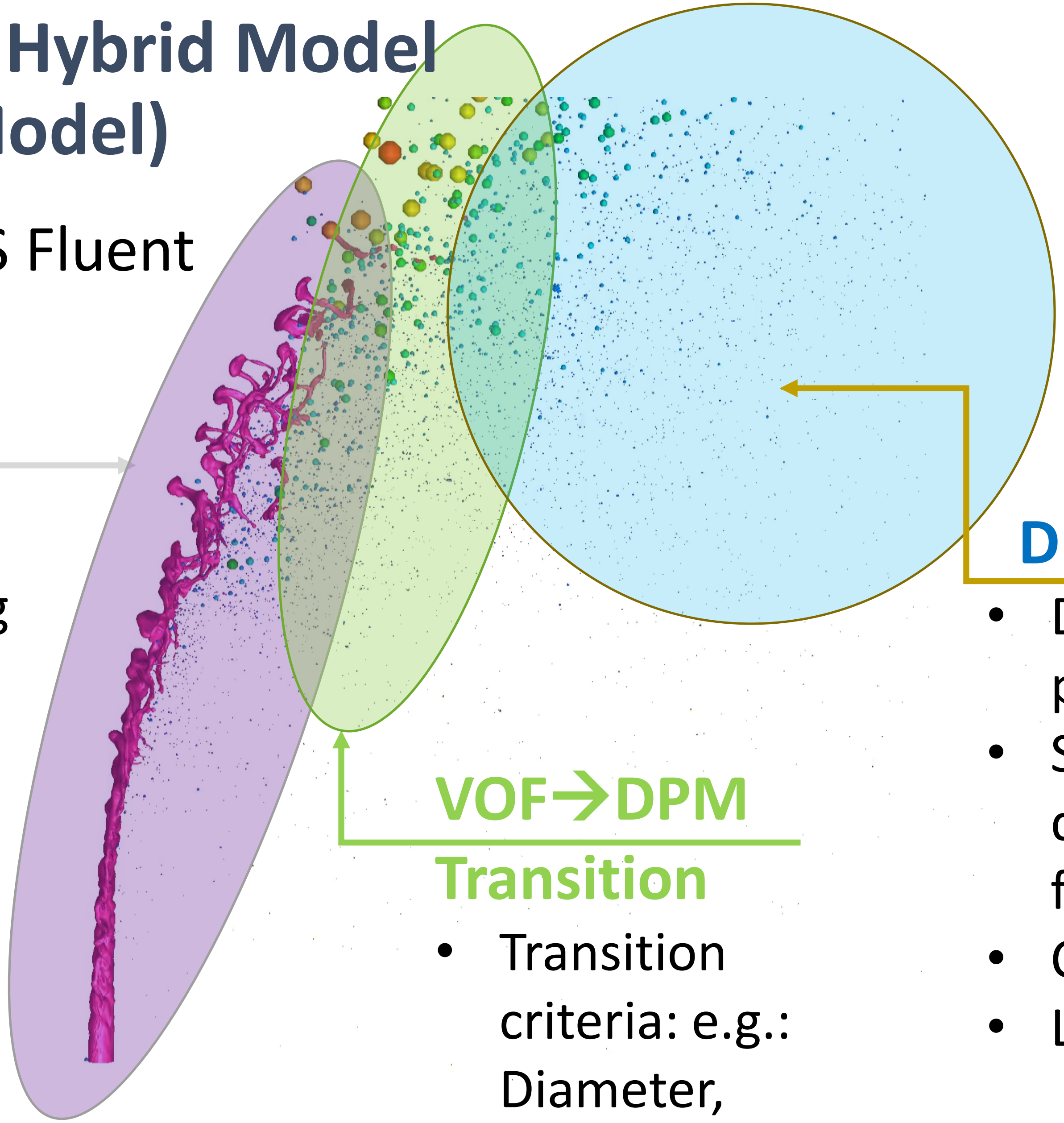






Eulerian-Lagrangian Hybrid Model (VOF-DPM Hybrid Model)

Released in R19.0 ANSYS Fluent



VOF

- Interface Tracking
- Capture instabilities and large structures
- Fine mesh
- Small time steps

VOF→DPM Transition

- Transition criteria: e.g.: Diameter, Asphericity

DPM

- Disperse (largest) part of spray
- Small, spherical droplets undergoing further changes
- Coarse mesh
- Large time steps

Eulerian-Lagrangian Hybrid Model Methodology

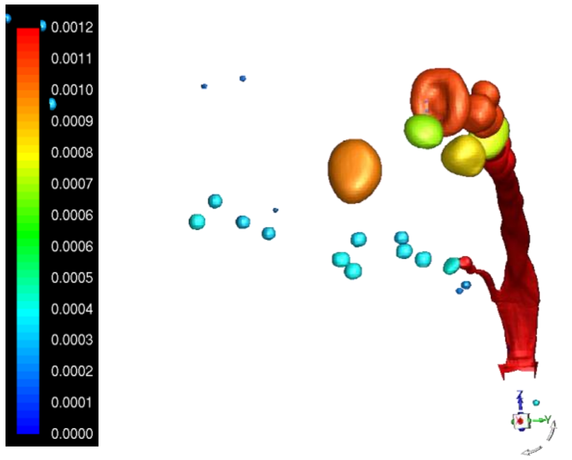
- VOF to DPM Transition Criteria
- Transition Control
- Dynamic Mesh Adaption

VOF to DPM Transition Criteria

Algorithm seeks to detect lumps which satisfy following two criteria:

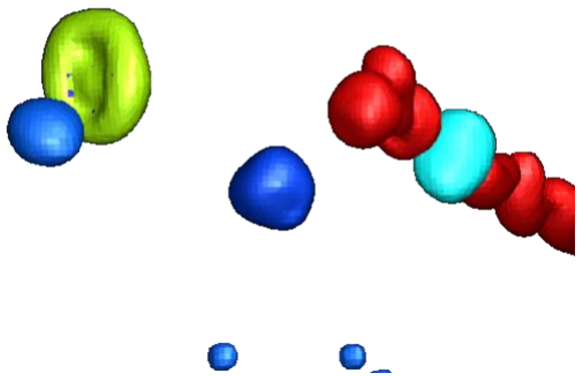
1. **Size Range** (Minimum and Maximum volume-equivalent diameter)
    - Volume equivalent sphere diameter of the lump
2. **Shape**
    - Lumps with shape close to spherical shape
    - Asphericity measure calculated in two ways
        - Normalized radius standard deviation (or variance)
        - Average radius-surface orthogonality

Lump must satisfy both size and shape based criteria to get elected for transition.



Above: Lumps colored by volume-equivalent diameter

Below: Lumps colored by asphericity criteria



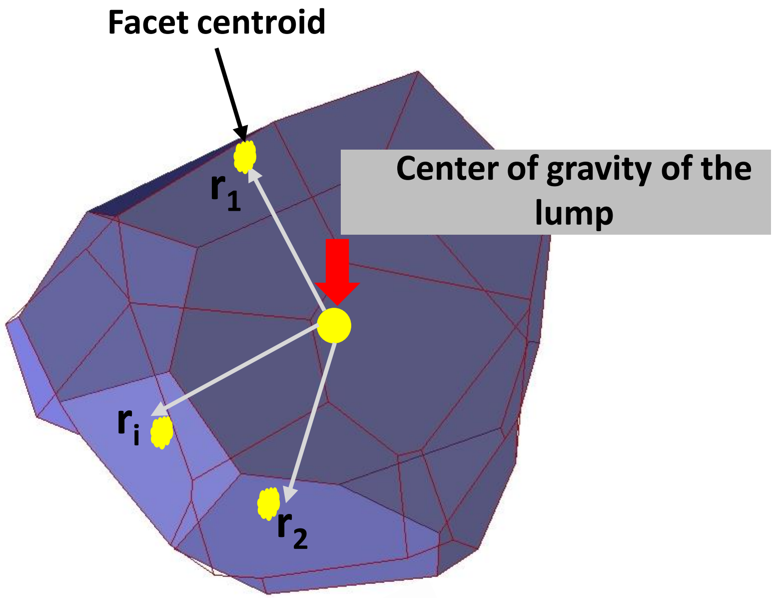
Blue - **almost spherical (good candidate for transition)**
Red - **highly aspherical (Further breakage possible, not considered for transition)**

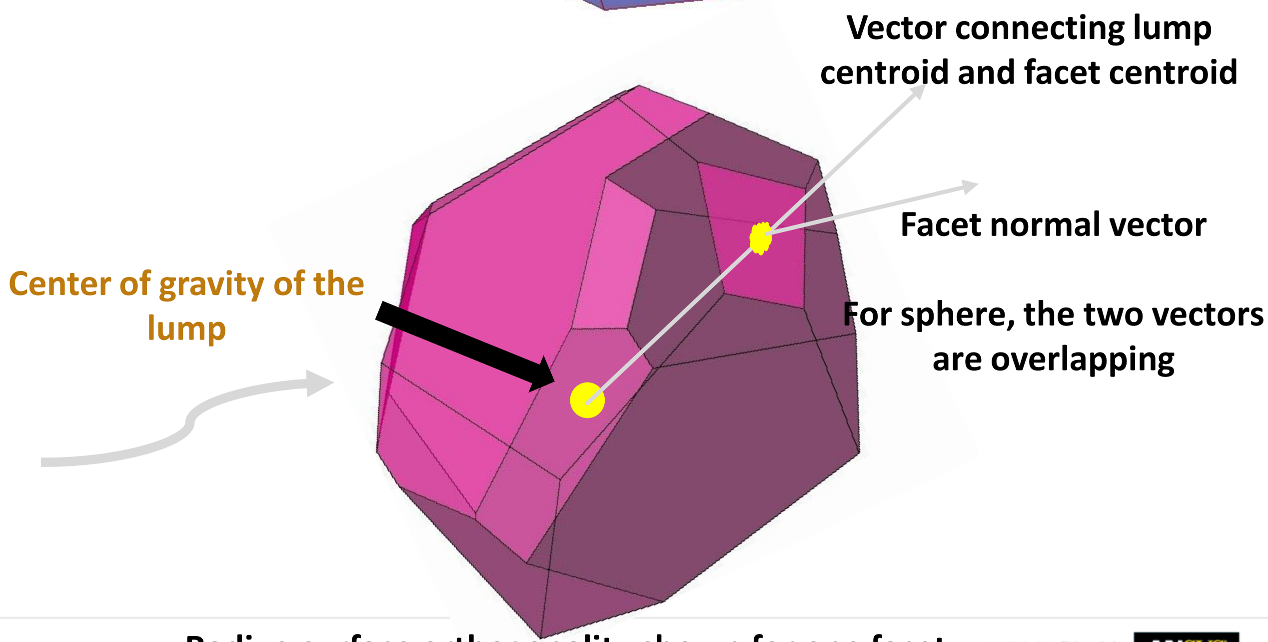
Lump election using shape/asphericity

Goal is to identify lumps which are close to spherical shape using following criteria.

Asphericity = (1 – sphericity), i.e.
0 for perfect spheres, > 0 for eggs, leaves,etc.

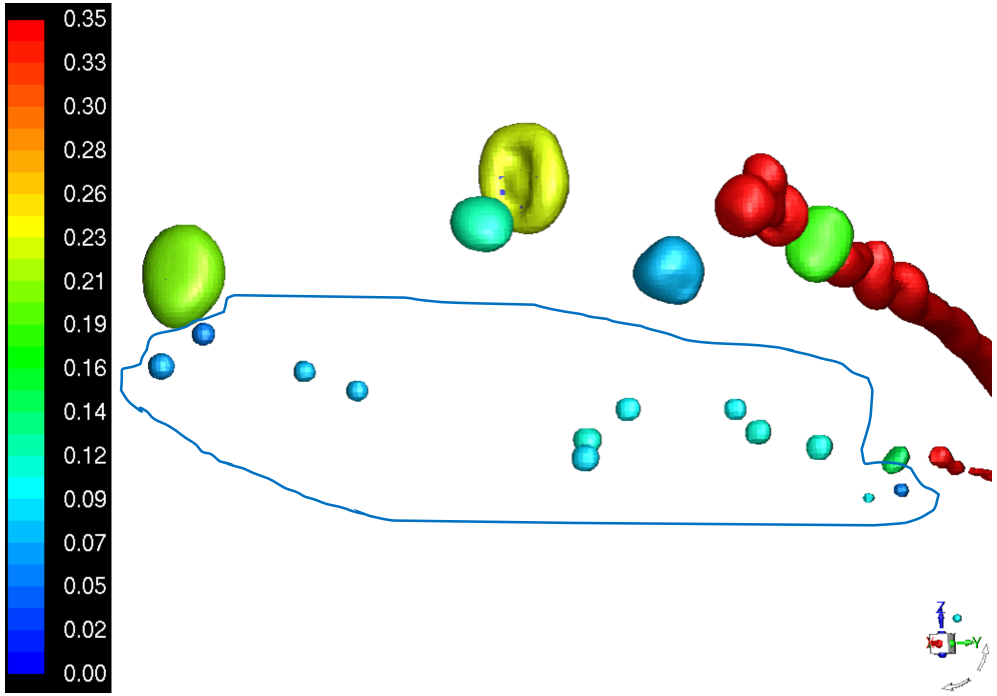
- **Normalized radius standard deviation**
  - Standard deviation of the distance between the facet center and the lump center of gravity (r_1, r_2, … r_i)
  - Asphericity → standard deviation normalized by the average radius
- **Average radius-surface orthogonality**
  - Calculated from relative orthogonality of every facet of the lump surface
  - Relative orthogonality range from 0 to 1

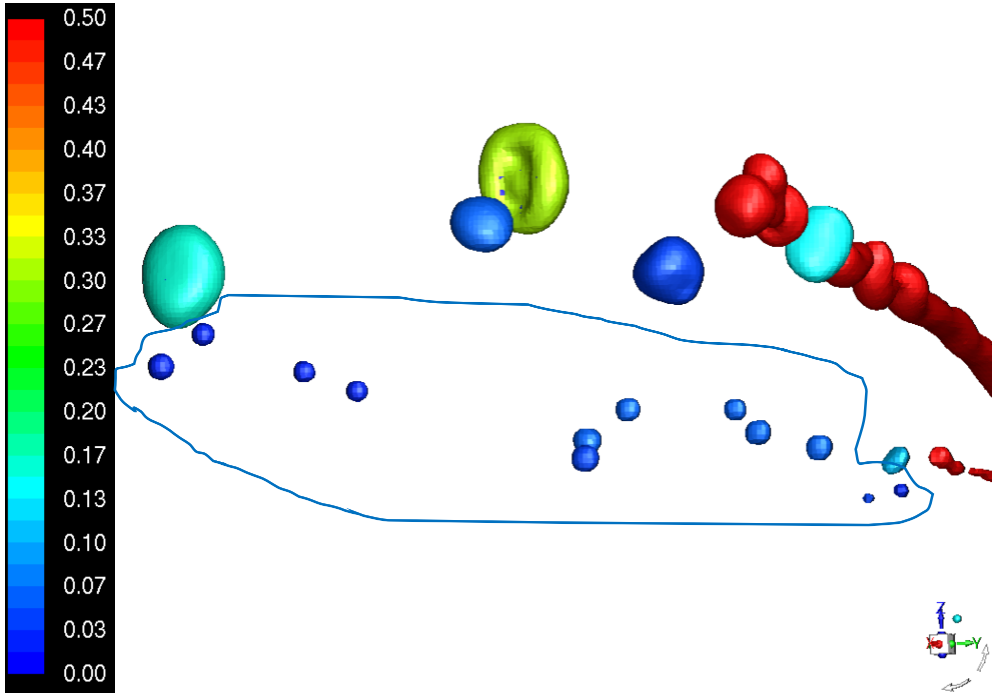




Radius-surface orthogonality shown for one facet

Lump election using shape/asphericity





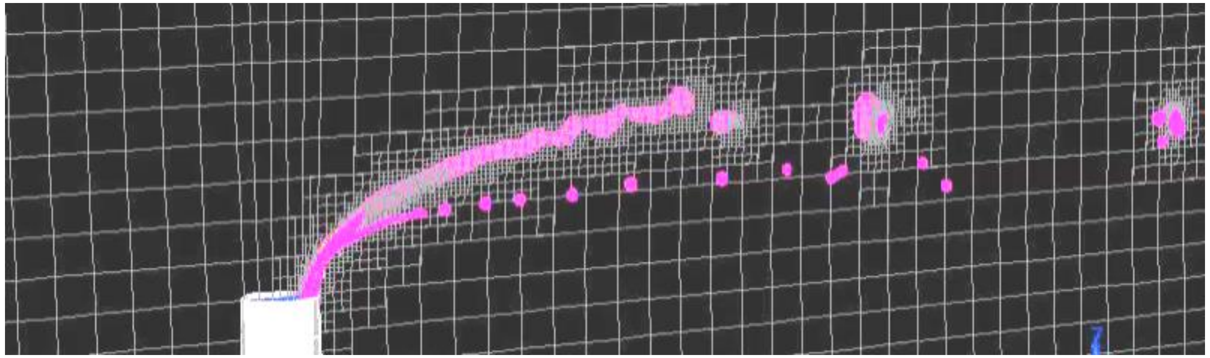
Normalized standard deviation of drop radius

1-[radius-surface orthogonality]

Dynamic Mesh Adaption

Mesh Refinement

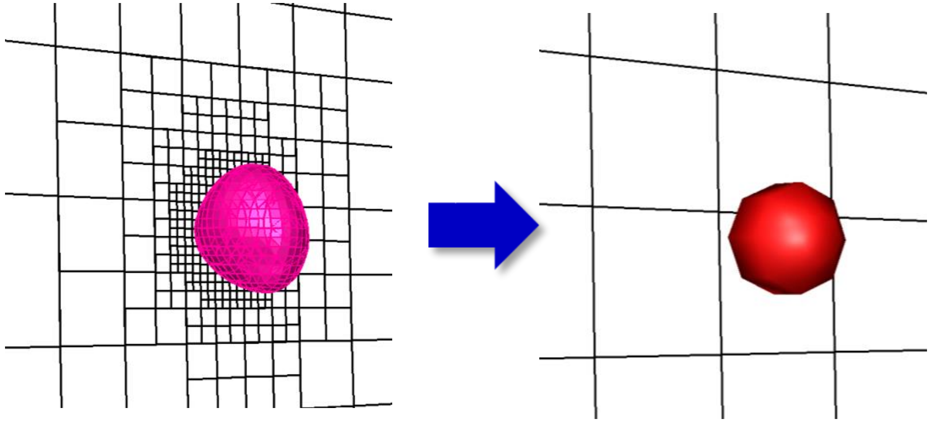
- Resolves gas-liquid interface
- Travels with the interface



Mesh continuously refined with moving interface

Mesh Coarsening

- Resolved Liquid to Lagrangian Droplets
- Need lesser mesh resolution



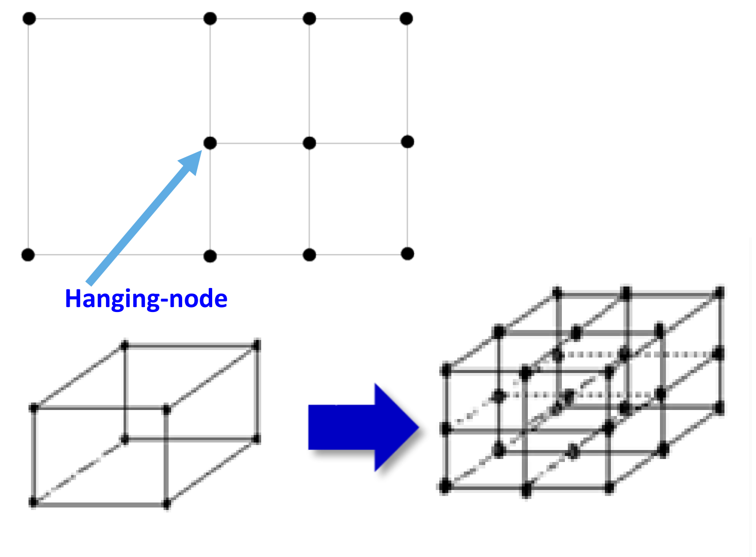
Lagrangian parcels are injected after mesh coarsening

Lump detection algorithm works with all different mesh topologies (hex, tet, polyhedral) and different mesh adaption algorithms including PUMA!!

Dynamic Adaption Methods

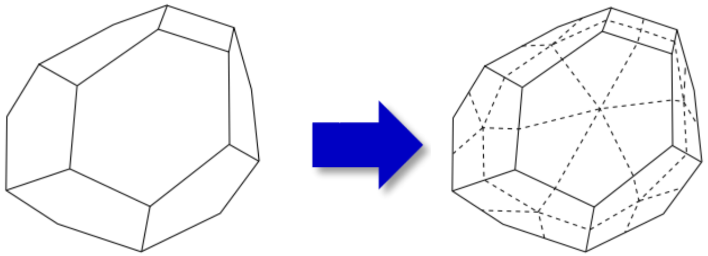
Hanging Node Adaption

- Available for all mesh topologies except Polyhedra



Polyhedral unstructured mesh adaption (PUMA)

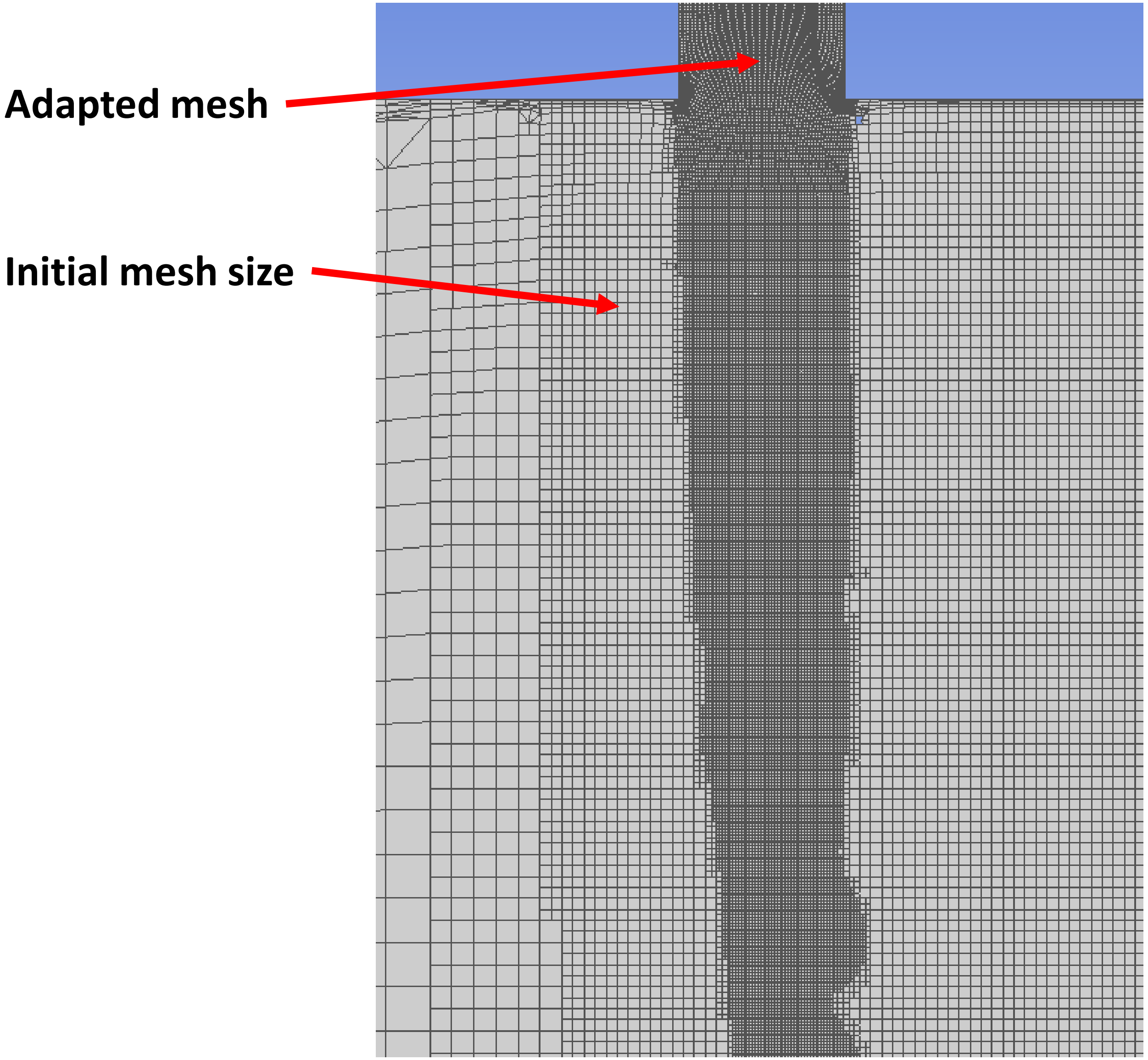
- Refine all 3D cell types (polyhedra, tetrahedra, hexahedra, and so on)
- Consumes less memory

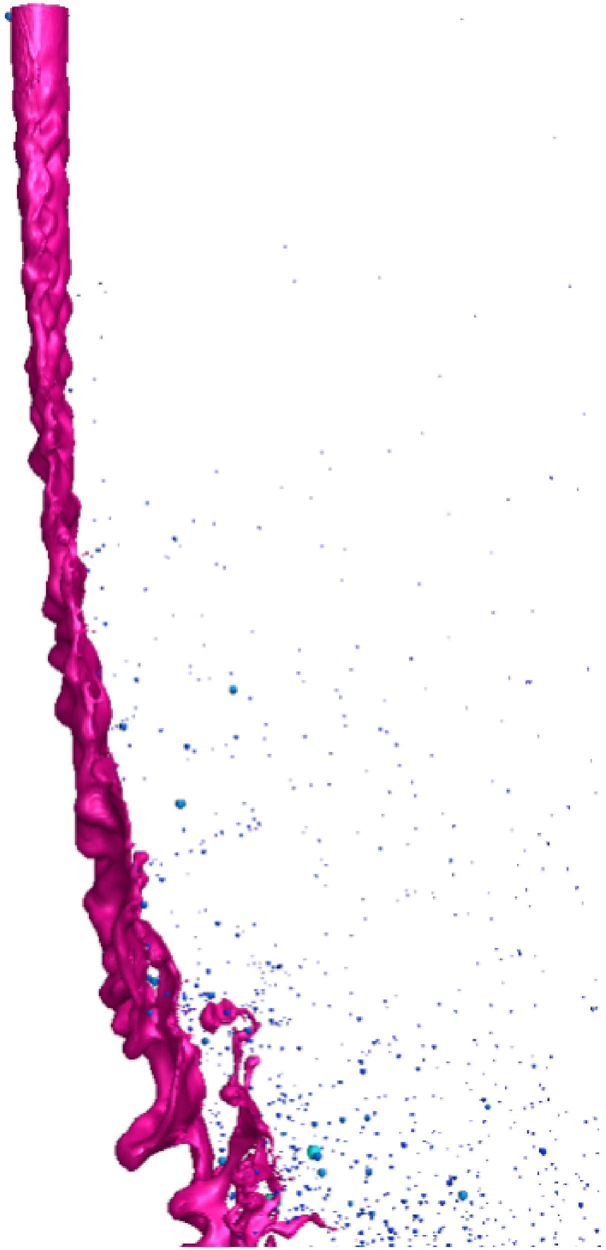


Case study: Liquid Jet in Crossflow

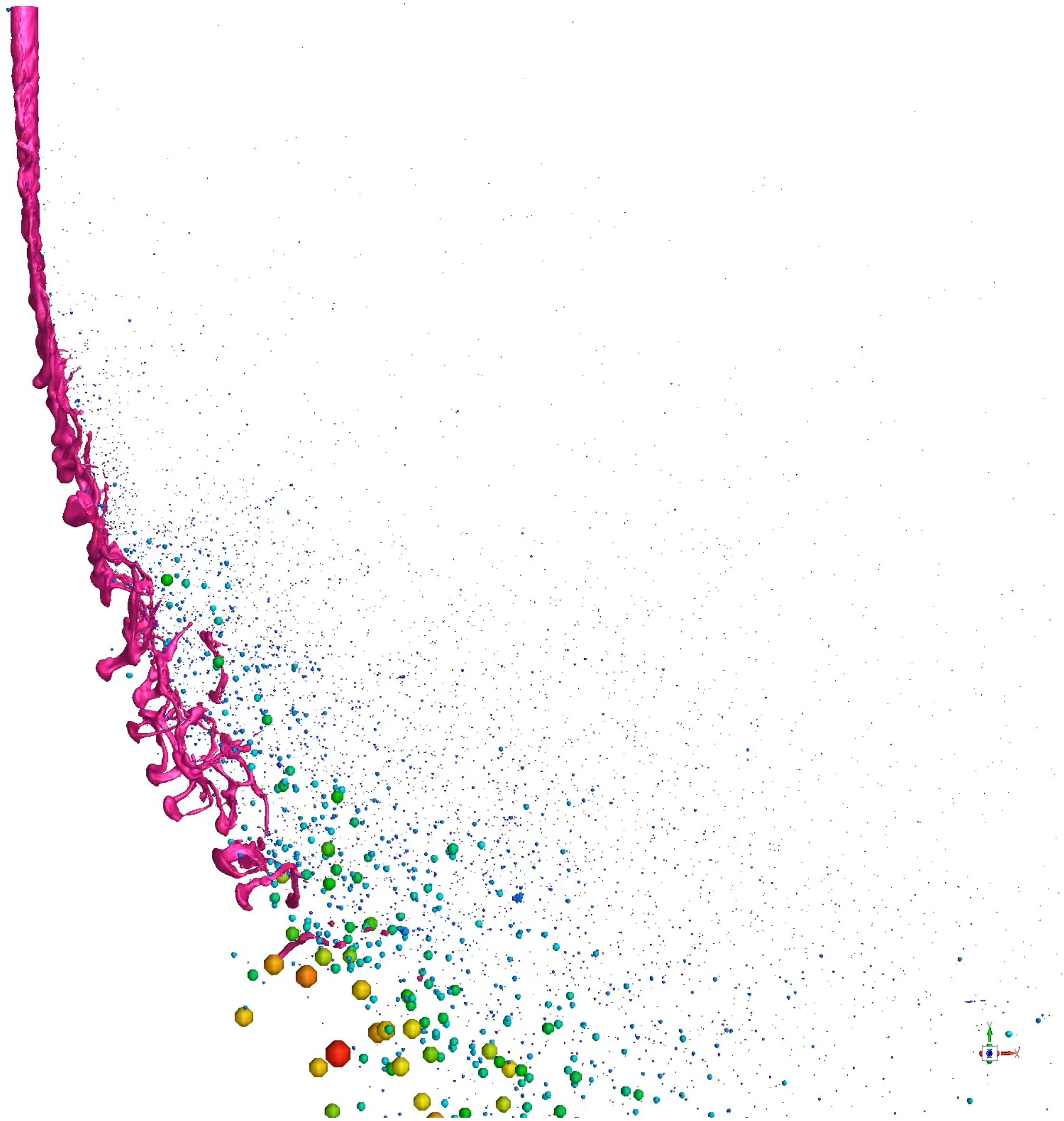
Crossflow Weber number	16 (bag breakup regime)
Momentum flux ratio	121
Nozzle state	TURBULENT
Nozzle diameter	2 mm
Split factor	1e6 (splitting inhibited)
Turbulence	SST K-Omega with SBES
P-v coupling	PISO
Pressure discretisation	PRESTO!
VOF scheme	Explicit
VOF discretisation	Geo-reconstruct
URF	Pres=0.9,Mom=0.95
AMG settings	Conservative+Aggressive coarsening
Initial mesh	6.9 million hex cells – 15 cells across nozzle in breakup region
Adapted mesh	14.9 million – max 2 levels of refinement - 60 cells across nozzle
Mesh adaption	Normalised vf gradient (0.01 to 0.05) + isovalue adaption 0.45 to 0.55
Secondary Break-Up	No

Liquid Jet in Crossflow





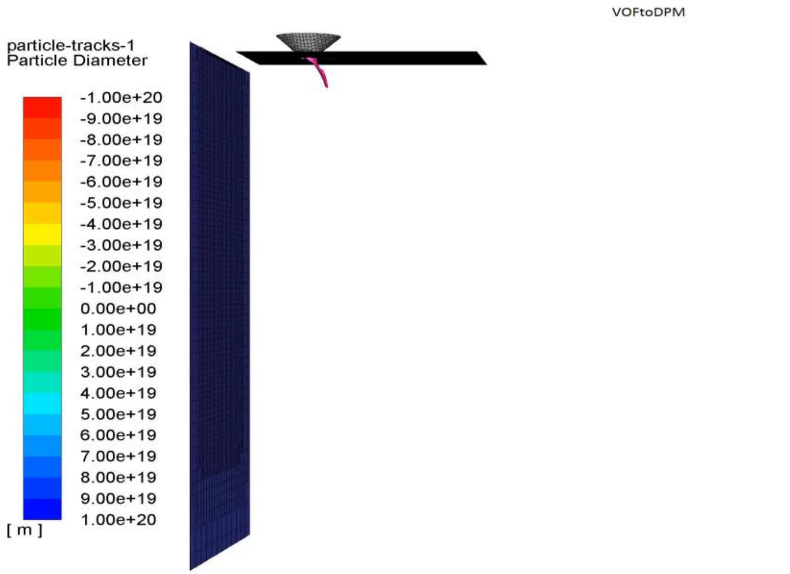
Liquid Jet in Crossflow



DPM data collection for faster DPM only simulation

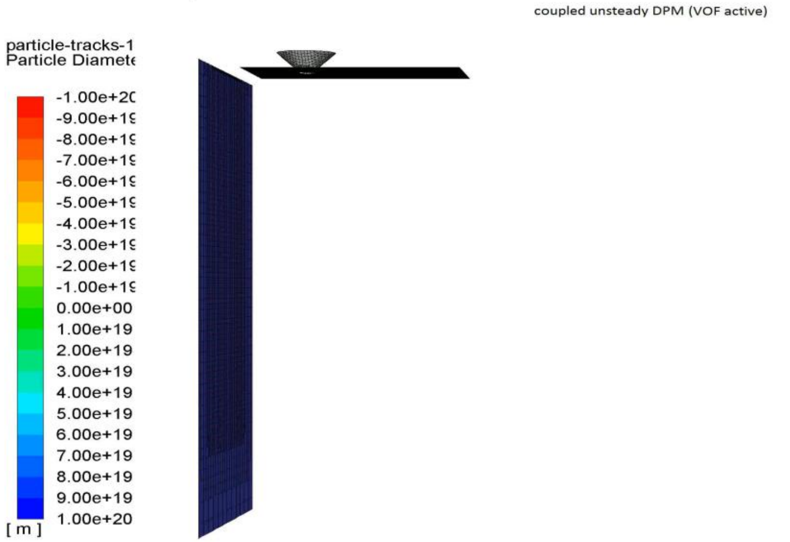
VOF to DPM Hybrid Model

- Collection of DPM statistics



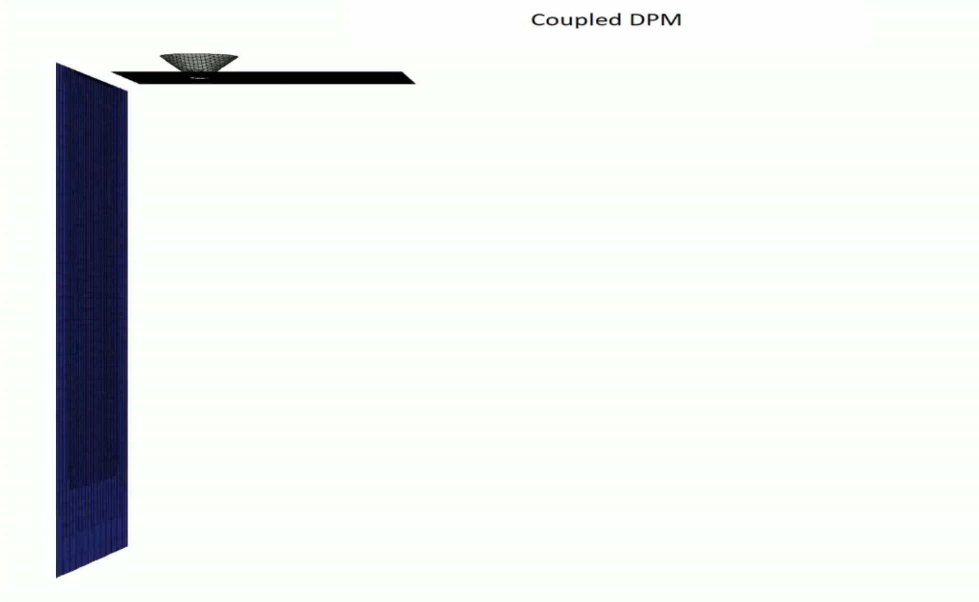
DPM only simulation

- Using DPM statistics to perform DPM only simulation

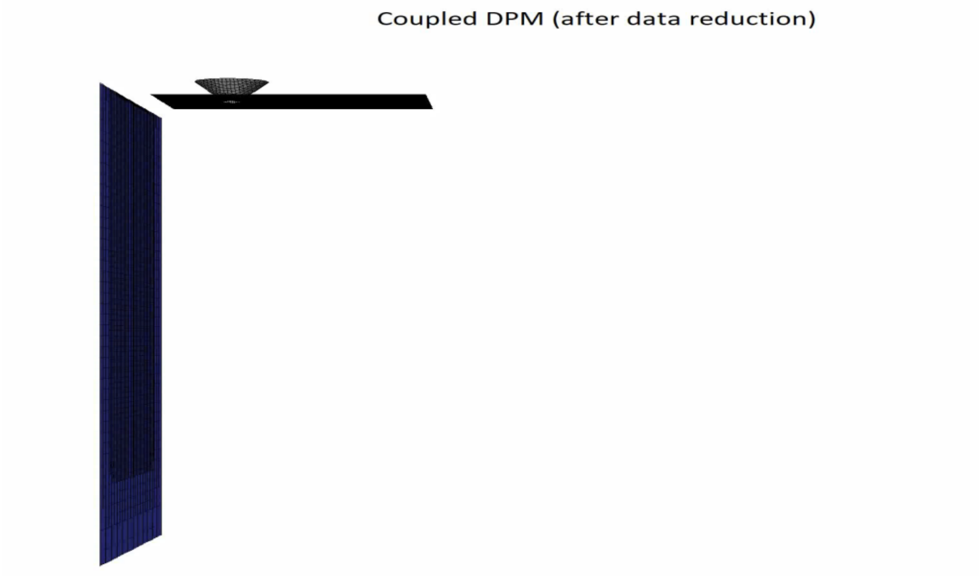


DPM sample data reduction

Approximately 3000 parcels

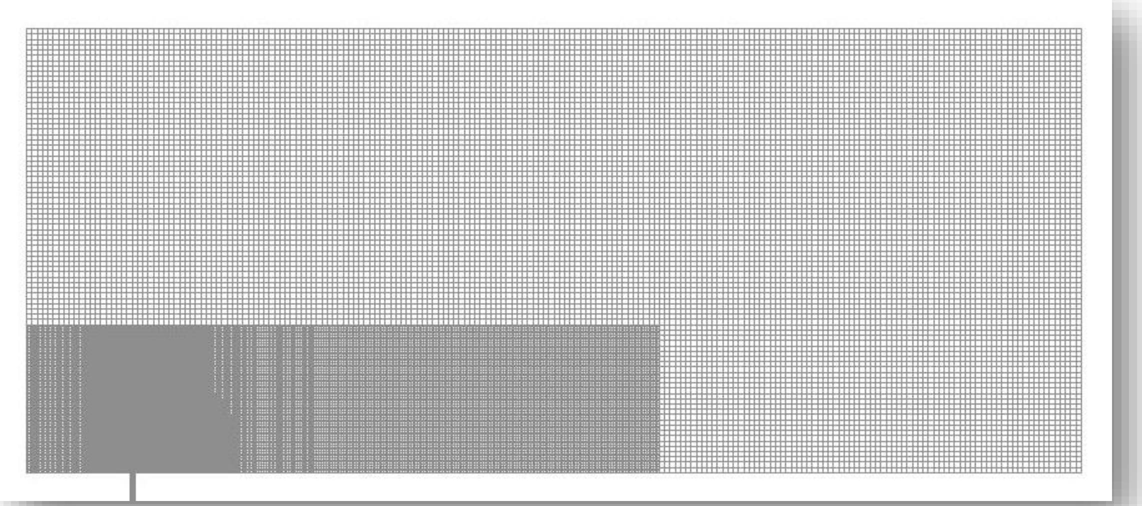


Approximately 1500 parcels

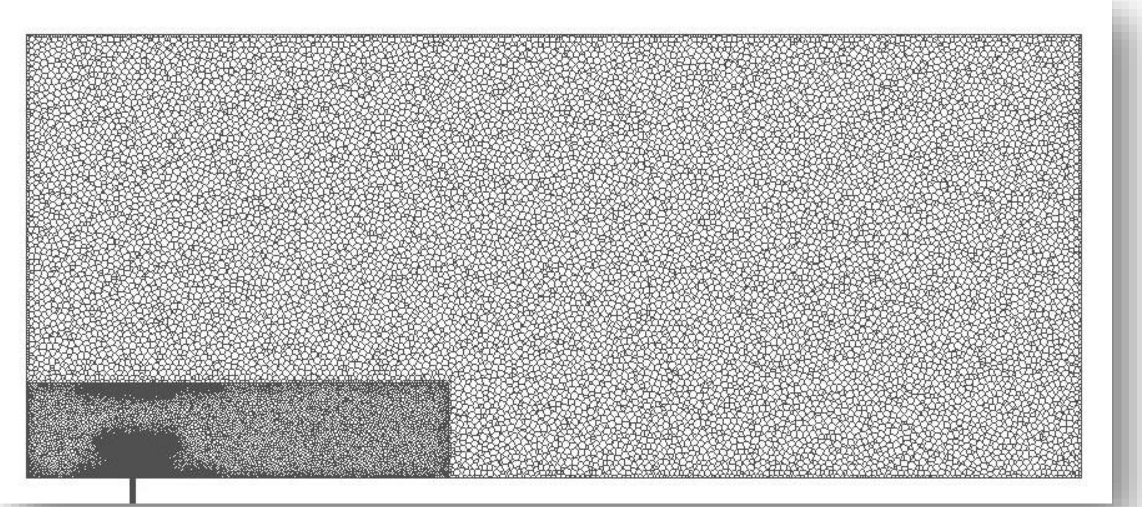


Liquid Jet in Cross Flow – Comparison with experimental data

Operating Conditions	
V_{Liq} (m/s)	32
$\dot{m}_{Liq}$ (kg/s)	0.004
D_{liq} (mm)	0.458
Liquid Density (kg/m³)	780.6
Liquid viscosity (Pa.s)	0.0007
Air Density (kg/m³)	5.88
Chamber Temperature (K)	300
Operating Pressure (psi)	73.48
Surface Tension (N/m)	0.0197
Secondary breakup	Wave
Air flow rate	Inlet Profile
Weber Number (We)	1000 & 1500
Momentum Flux Ratio (J)	10 & 20
Mesh Topology	Hex and Poly
Mesh Count	10M (Hex); 4.5M (Poly)



Hex Mesh (10M)

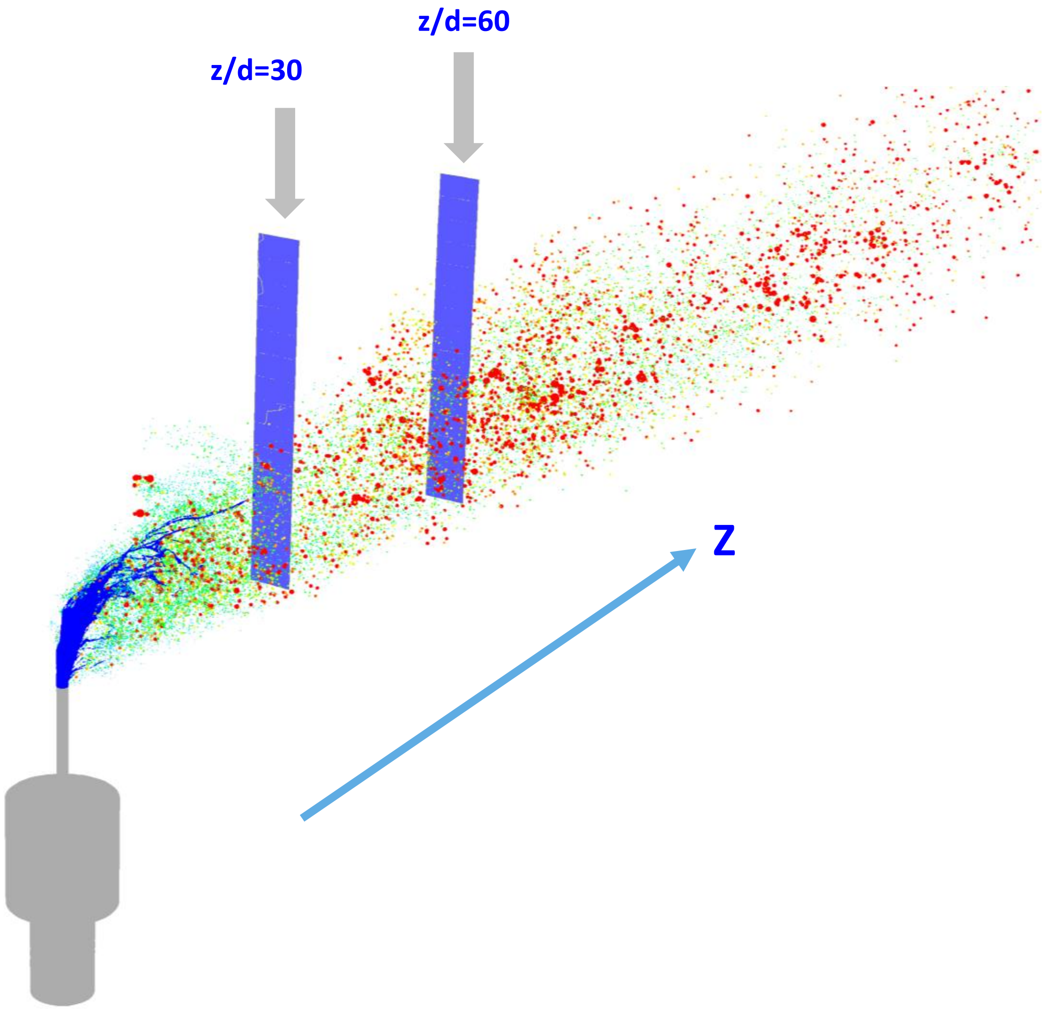


Poly Mesh (4.5M)

Sekar, J.,Rao, A., Pillutla, S., Danis, A., Hsieh, S., Proceedings of ASME Turbo Expo 2014

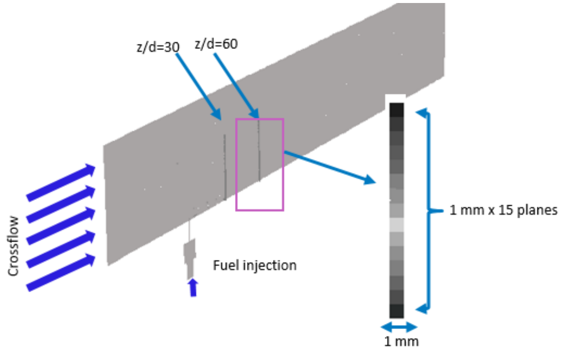
Generating Sauter Mean Diameter Data

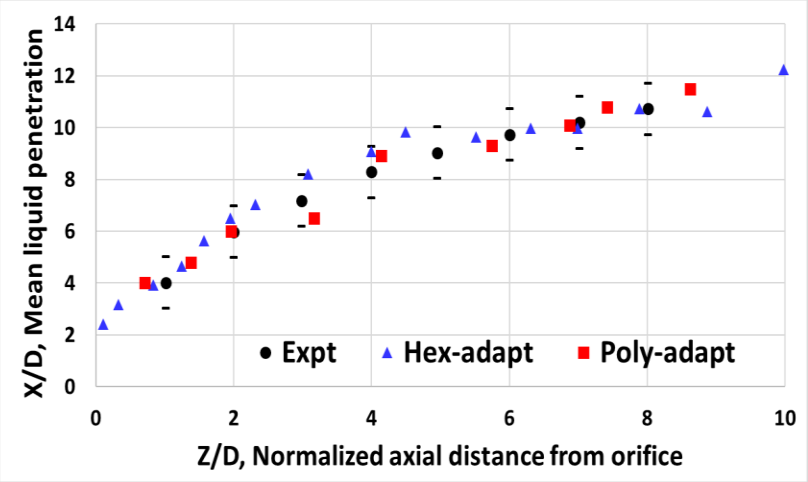
- Several 1 mm x1 mm bounded planes stacked up at z/d=30 and z/d=60 locations (d=diameter of orifice)
  - Act as probes
- Every time a particle hits the probe, the data is recorded in a file
- These probes collect data for several liquid passes
- Time averaged Sauter Mean diameter values for each probe compared to measured data



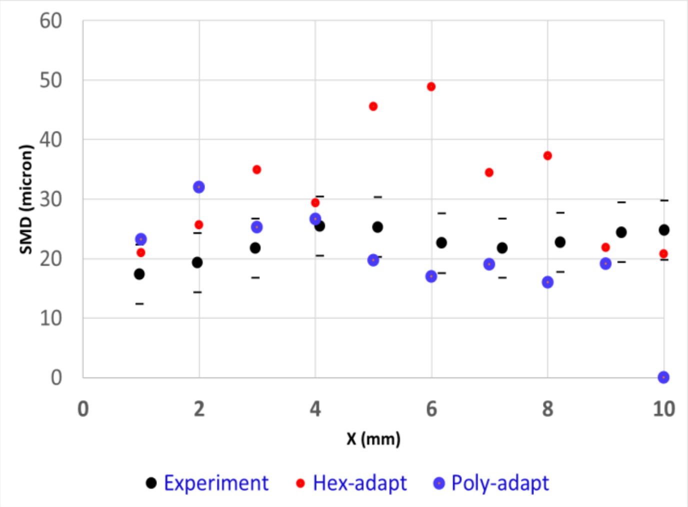
Results: Dynamic Mesh Adaption

- Uniform background
  - Hex ~ 2.2 Mil. Cells
  - Poly ~ 2 Mil. Cells
- Mesh adaption based on gradient of liquid volume fraction
  - 2 Levels of Mesh adaption
- Liquid penetration for both mesh types are in good agreement with measurements
- Sauter mean diameter predictions are overall good at both locations
  - Some discrepancies found for hex mesh type

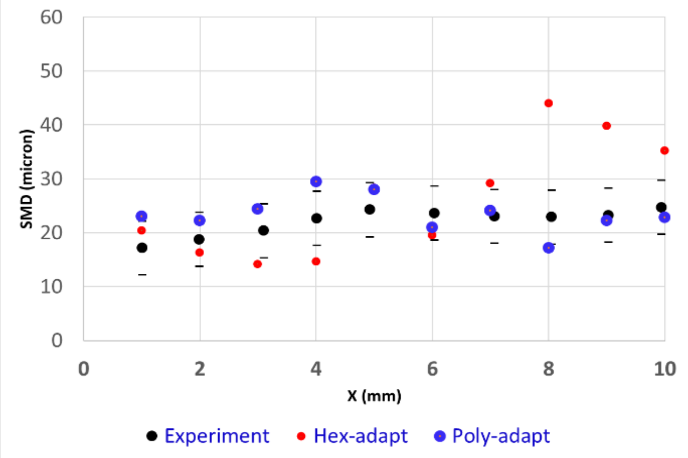




Jet trajectory into the cross-flow



Comparison of the SMDs along the wall-normal center line at z/d=30



Comparison of the SMDs along the wall-normal center line at z/d=60

Summary

- A new VOF-DPM transition model in ANSYS Fluent
- VOF-DPM transition tool combined with dynamic mesh adaption enables to carry out a detailed numerical analysis of spray behavior at affordable computational cost.
- Application of the VOF-DPM hybrid model on industry relevant jet in crossflow and diesel sprays shows encouraging results.