LES/VOF Simulation of Engine Spray Primary Atomization

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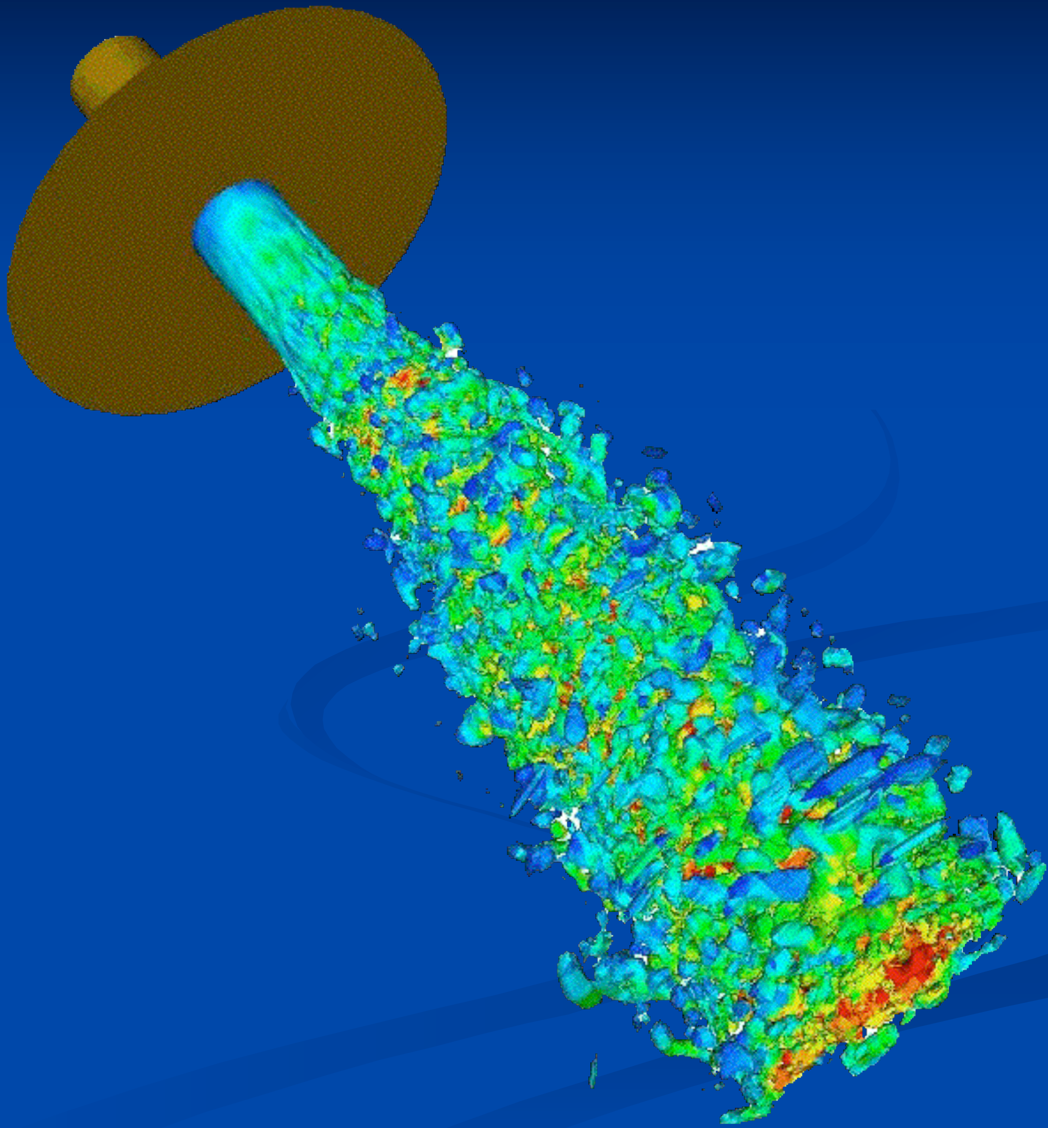
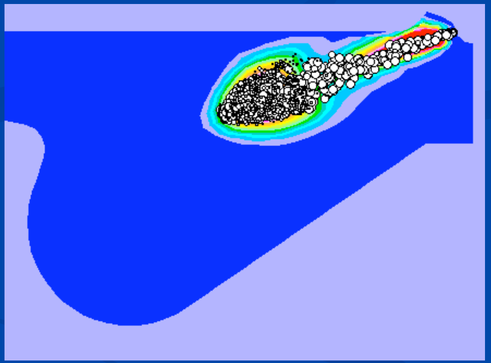
- Introduction
- Methodology
- Spray Dynamics
- Spray Statistics
- Summary



Introduction

1. Importance of atomisation to engine spray behaviour
   - Droplet sizes, velocity -> penetration, evaporation, (ignition, combustion)
   - Controlled by injector design, injection pressure.

2. Need for detailed understanding
   - Guide injection system development
   - Assist engine combustion modelling



3. Difficult to study
   - Experiments hampered by small scales, obscuration
   - Conventional CFD requires atomisation submodels

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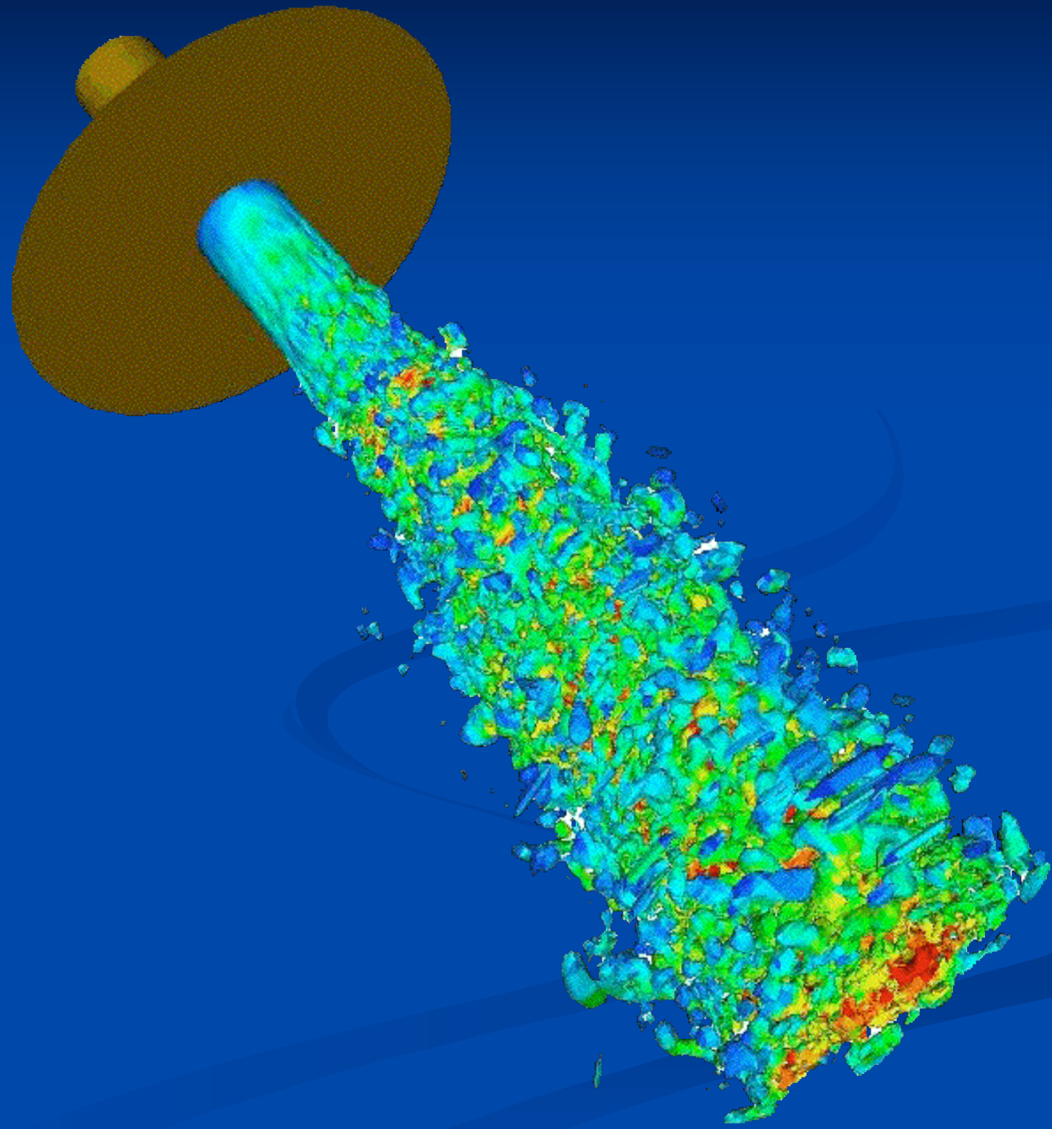
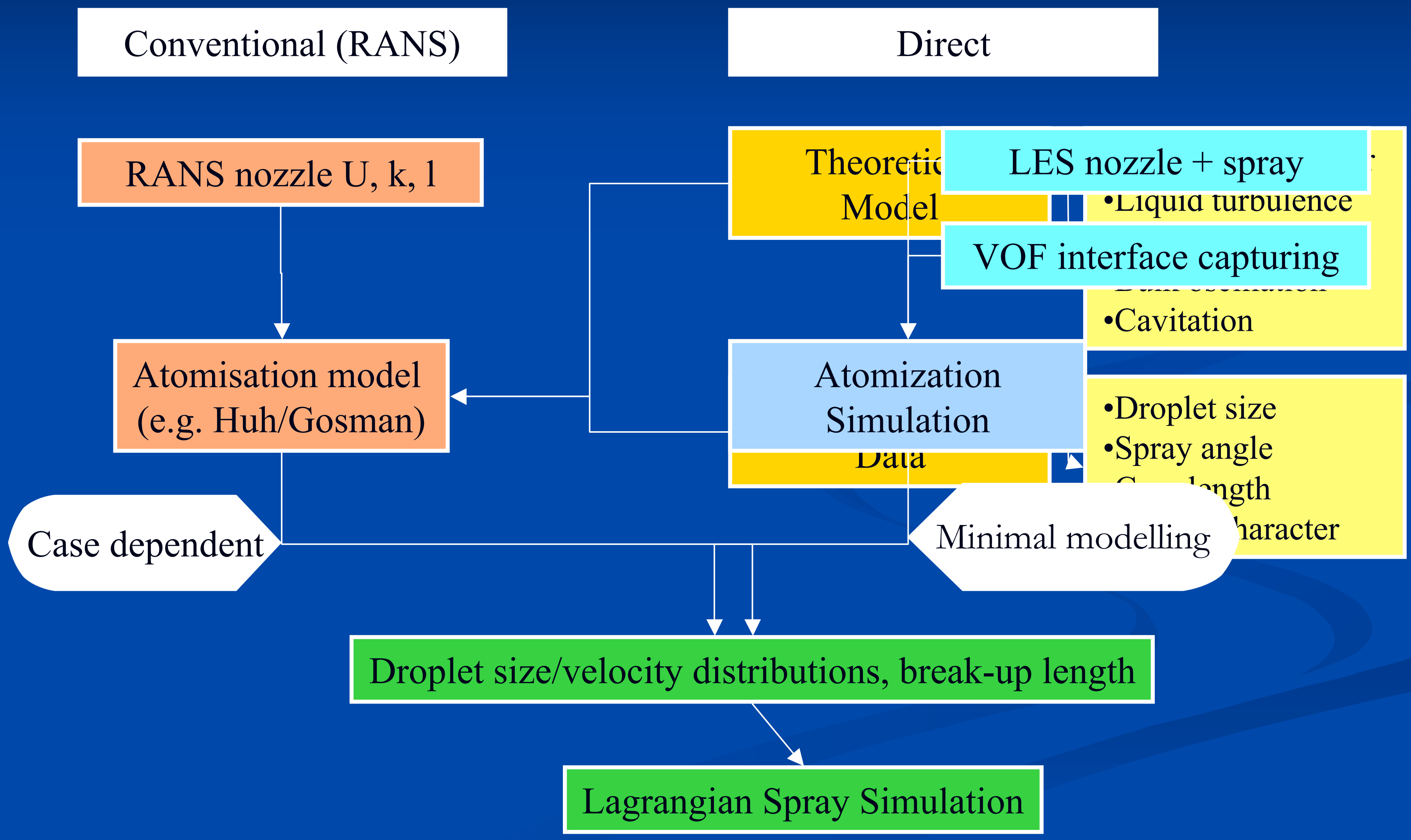
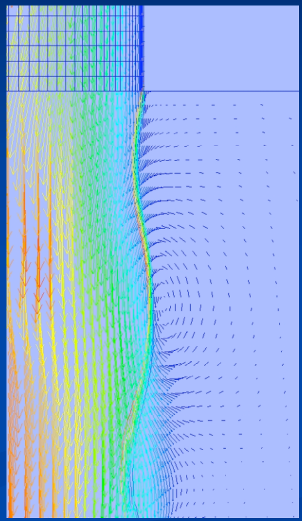


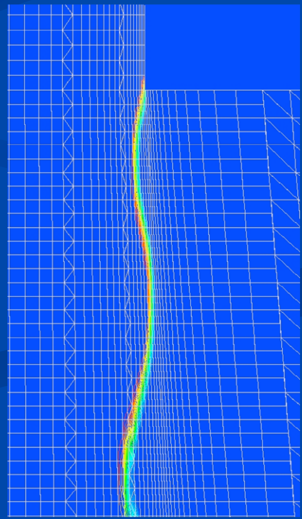
Methodology: overview



Methodology: LES + VOF

1. **Modelling:**
   - **LES: filtered 3D Navier Stokes equations, including surface tension force**
   - **Subgrid turbulence model: *k-l* (transport eqn for k)**
   - **VOF: interface tracking**
2. **Numerics**
   - **Algorithm: unstructured, implicit, finite volume**
   - **Discretisation: second order space and time**
   - **VOF discretisation: interface compression scheme**
   - **PISO algorithm, conjugate gradient solver**
   - **Code: FOAM**

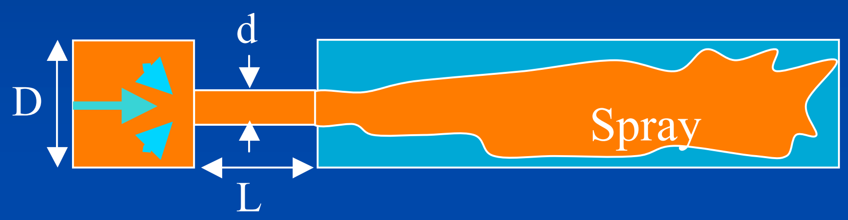




Methodology: Applications

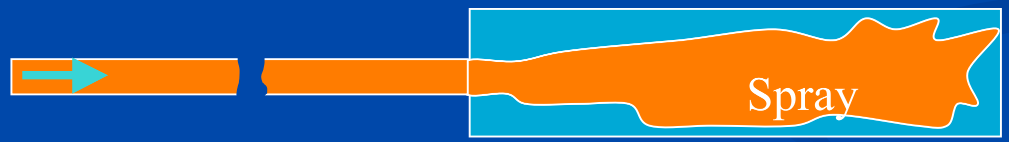
1. NOZZLE GEOMETRY

- Plenum (sac)



d = 0.2 mm
L/d = 5
D/d = 3

- Long pipe

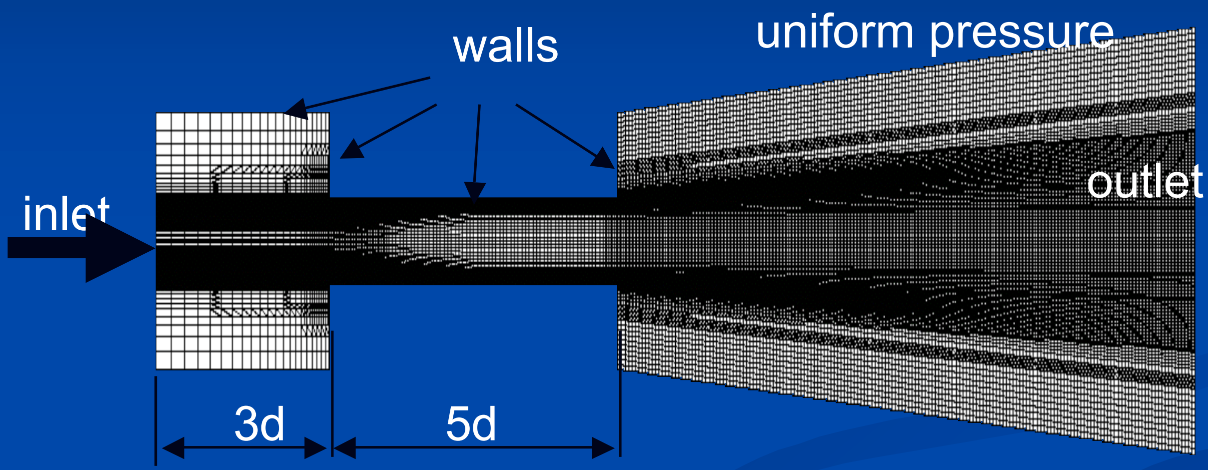


L/d > 40
(Fully developed)

2. CONDITIONS

- Diesel fuel
- Constant injection velocity = 460 m/s
- Environment T, P = 900 K, 5.2 Mpa
- No cavitation, evaporation

Methodology: numerical setup



- Mesh size ~ 10-15 μm in atomisation zone
- Time step ~ 10^{-8} s
- Simulation to statistical steady state

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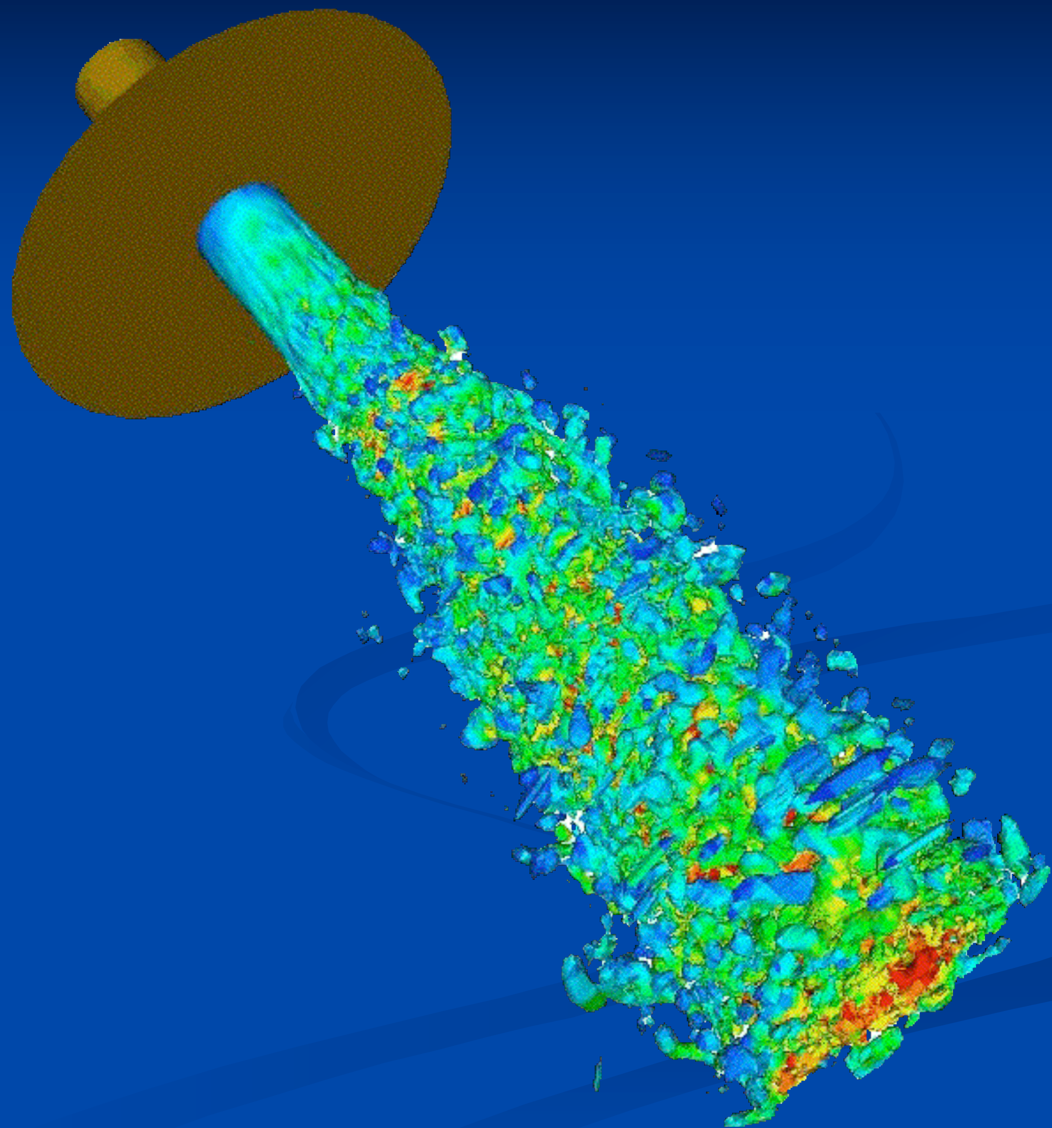
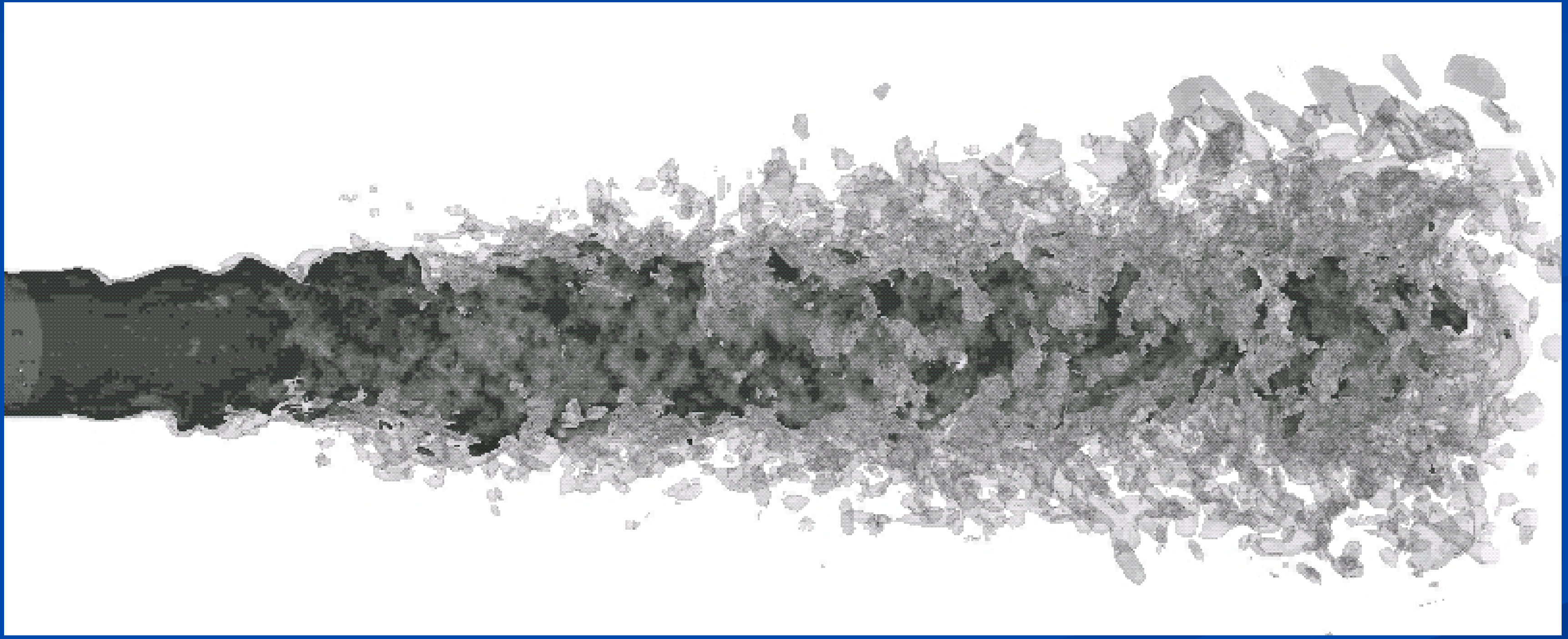


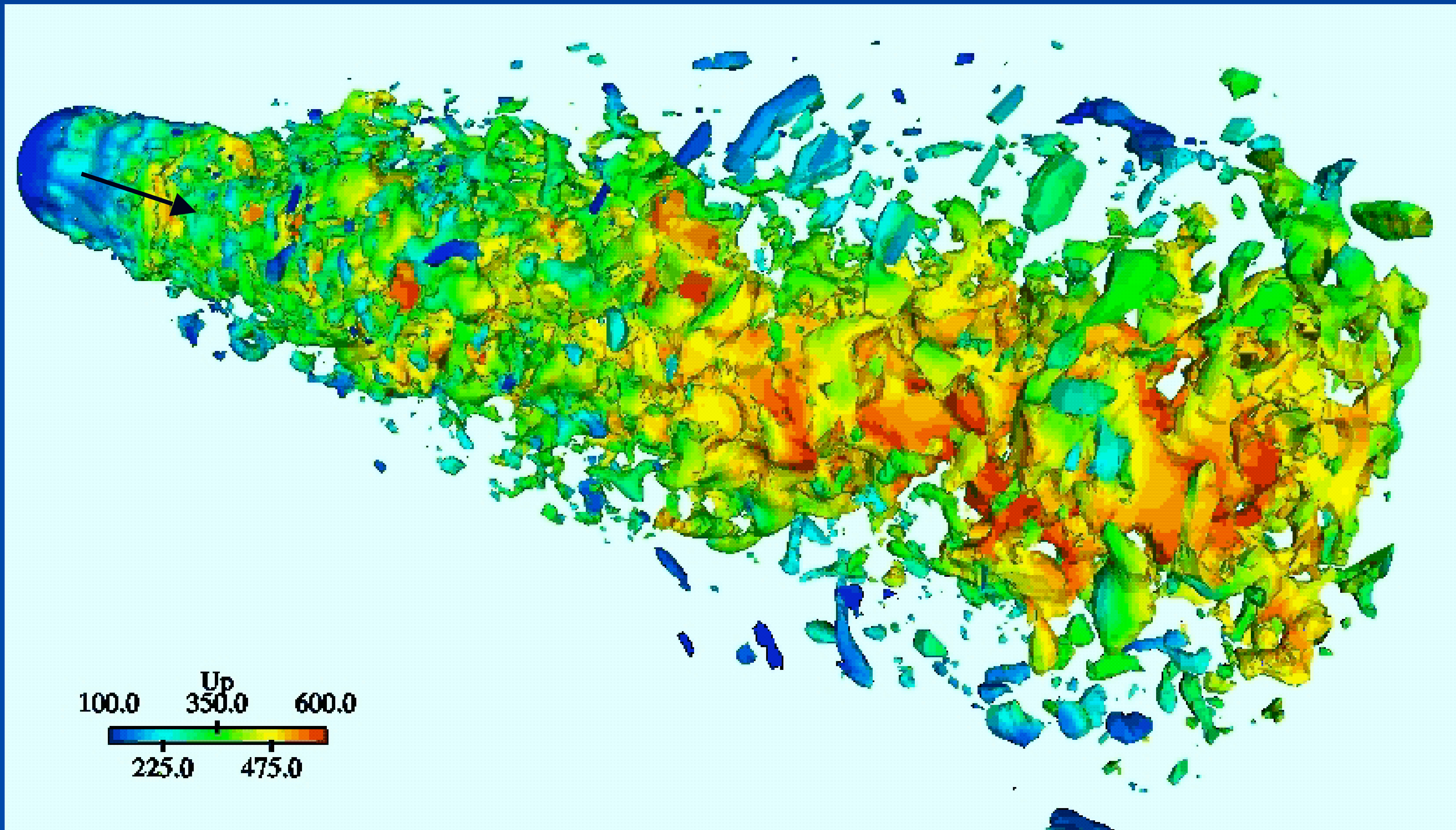
Spray Dynamics (long pipe inlet)

- Spray Morphology (γ =0.2 & γ = 0.9)



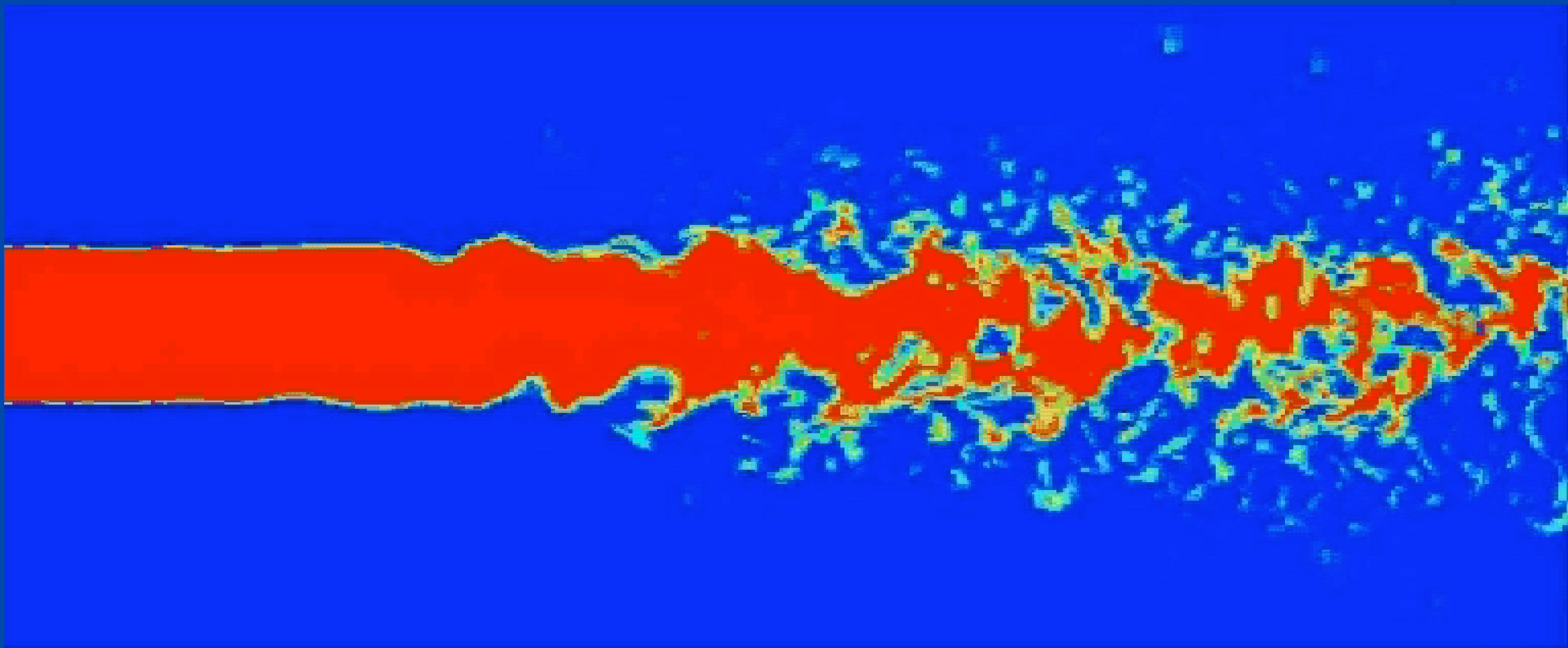
Spray Dynamics

- Surface structure velocity ($\gamma = 0.5$)



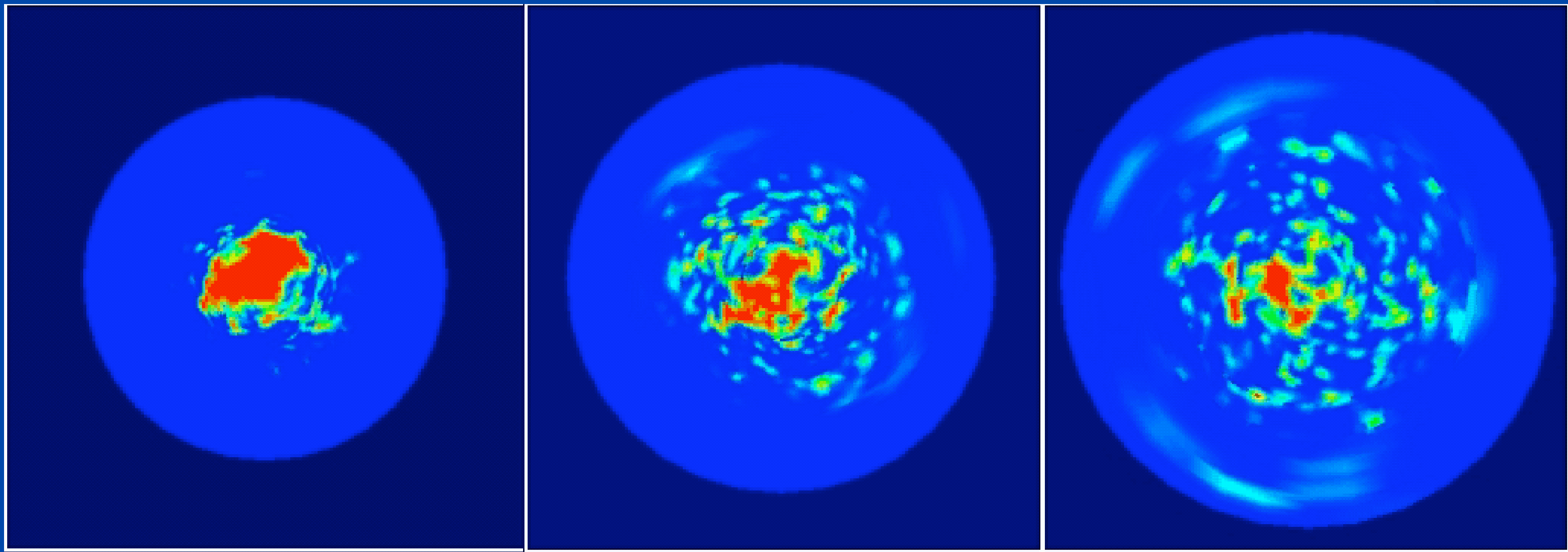
Spray Dynamics

- Centre plane: γ contours (red = liquid)
  - Perturbations -> Ligaments -> droplets
  - Core break-up through wave growth



Spray Dynamics

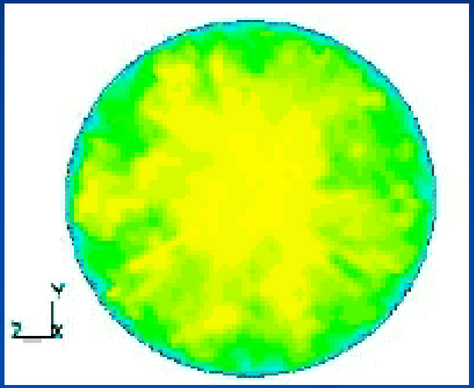
- Cross sectional structures: gamma contours
  - at x/d =2 circumferential ribbing
  - highly 3-dimensional

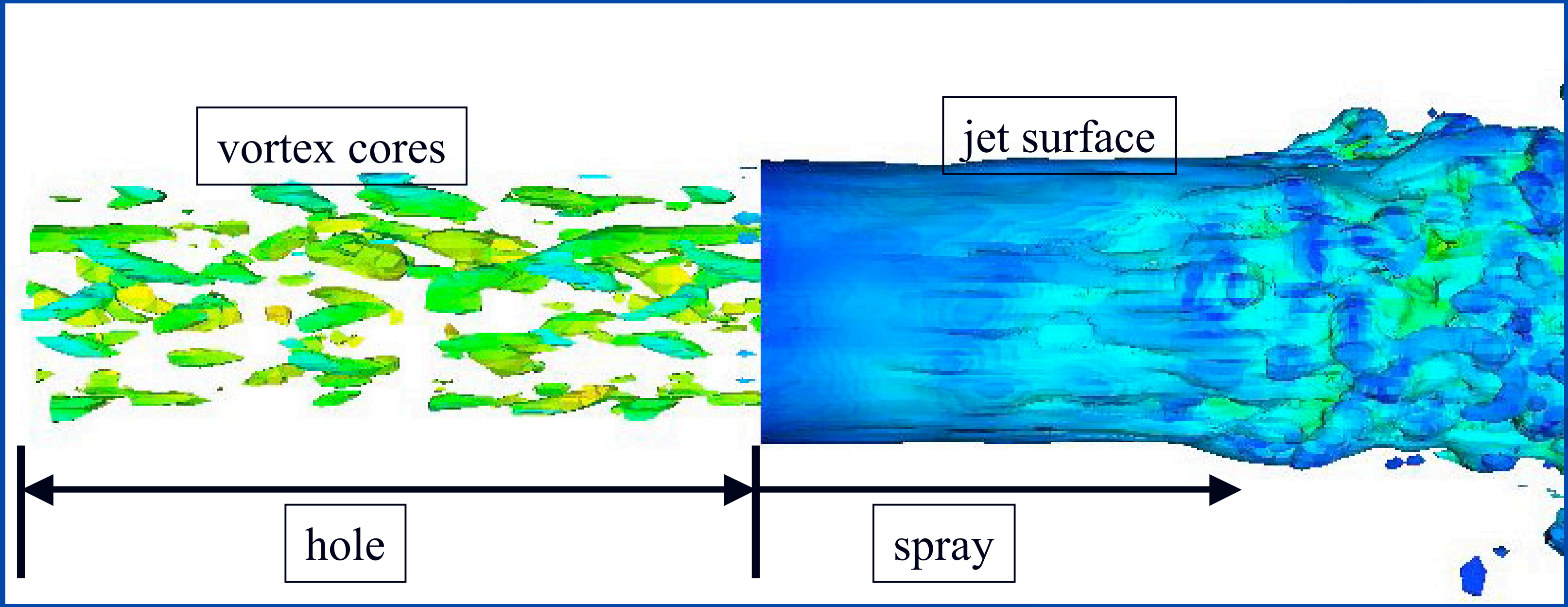


x/d=2 x/d=5 x/d=8

Spray Dynamics

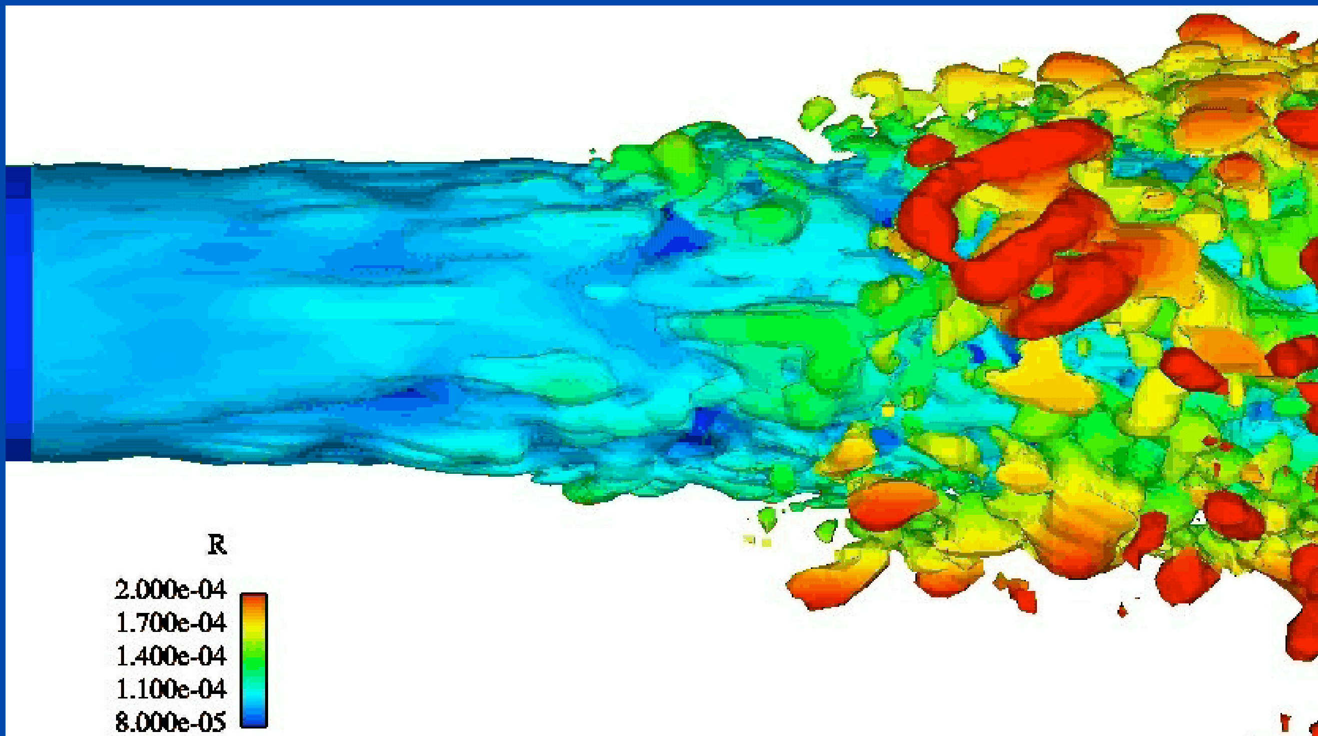
- Turbulence – Surface interaction
  - Streamwise turbulent vortices induce radial fluid motion
  - Radial fluid motion in jet produces streamwise surface perturbations (waves)





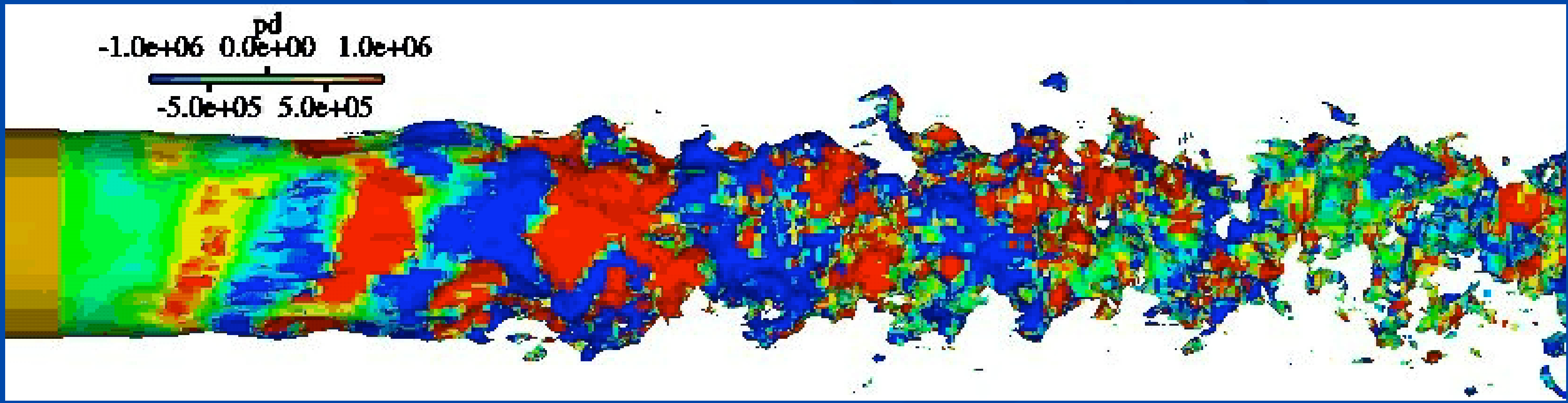
Spray Dynamics

- Advent of jet surface break-up
  - $\gamma = 0.1$, colour denotes distance from spray axis
  - Break-up at superposition of circumferential and streamwise wave crests



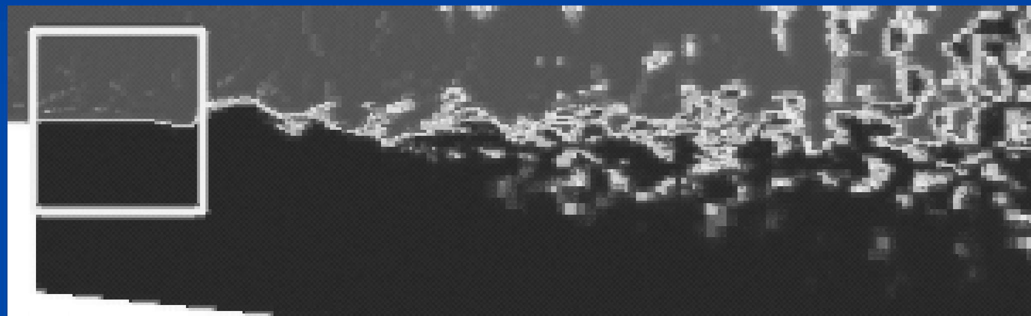
Spray Dynamics

- Pressure on core surface
  - γ= 0.95, does not display atomised liquid
  - Circumferentially banded alternating pressure
  - Low pressure at top and rear of perturbations
  - High pressure on valleys and fronts
- Initial waves experience rapid circumferential wave growth
- Proposed initial source mechanism:
  - Jet contraction due to kinetic energy conservation
  - Asymmetric oscillations in contraction from turbulent excitation

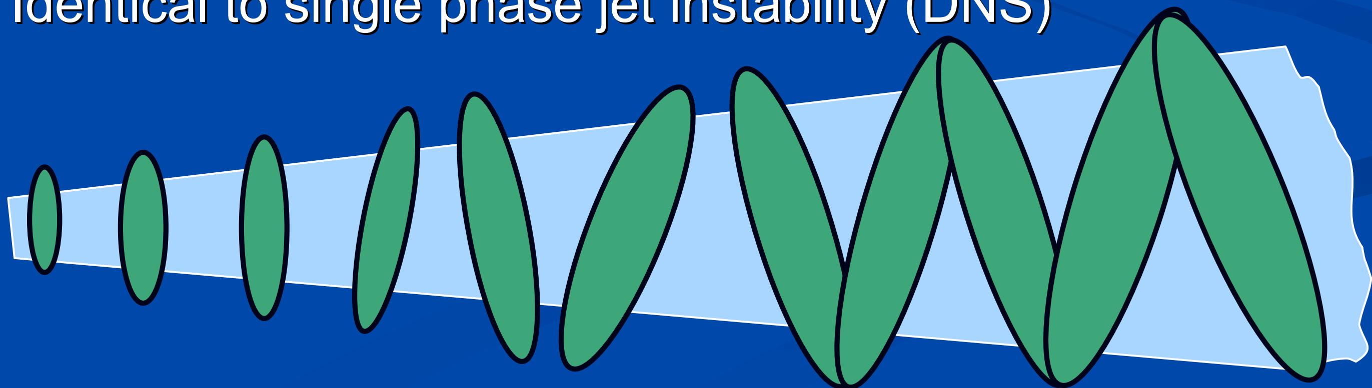


Spray Dynamics

- Atomization pathways
  - Droplet formation: small scale
    - Small wave growth
    - Ligament shredding

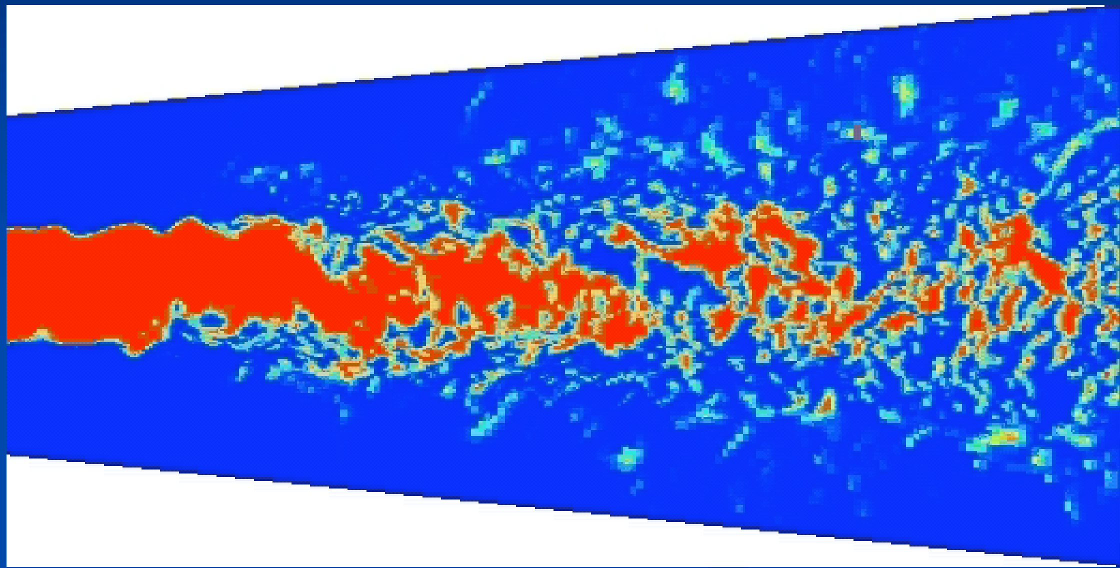


  - Core breakup
    - Large scale wave growth
    - Initiated by toriodal perturbations, incline to form double helix
    - Identical to single phase jet instability (DNS)

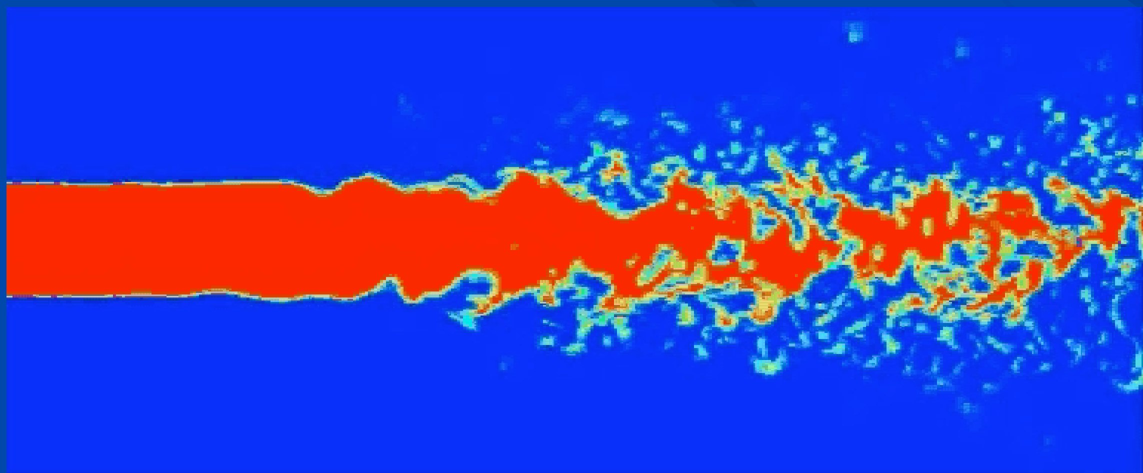


Spray Dynamics: plenum and long pipe inlets

L/D = 5

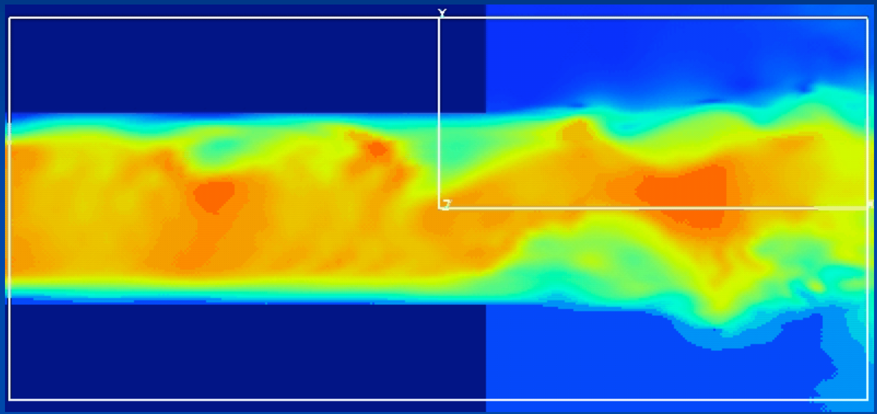


L/D > 40

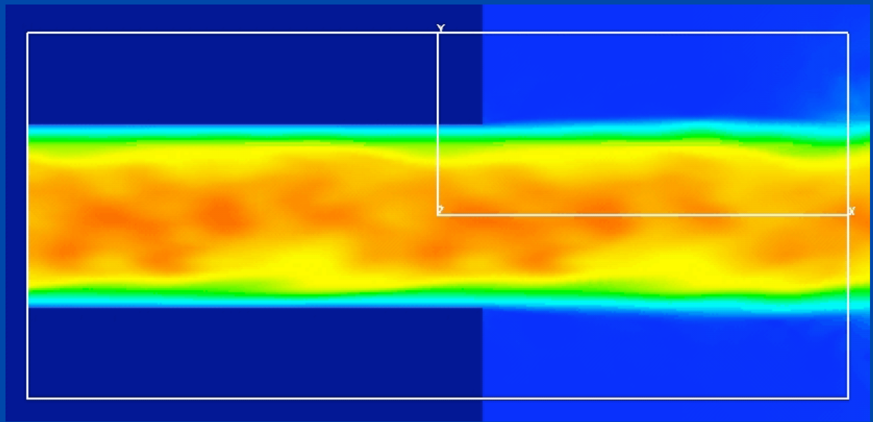


Spray Dynamics: plenum and long pipe inlets

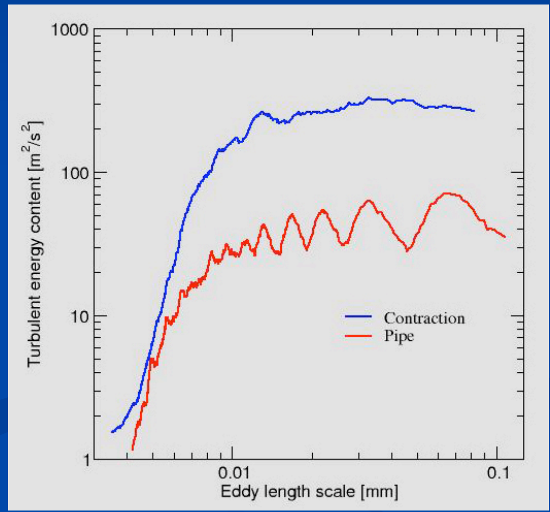
velocity magnitude



L/d = 5



L/d > 40



Energy Spectra

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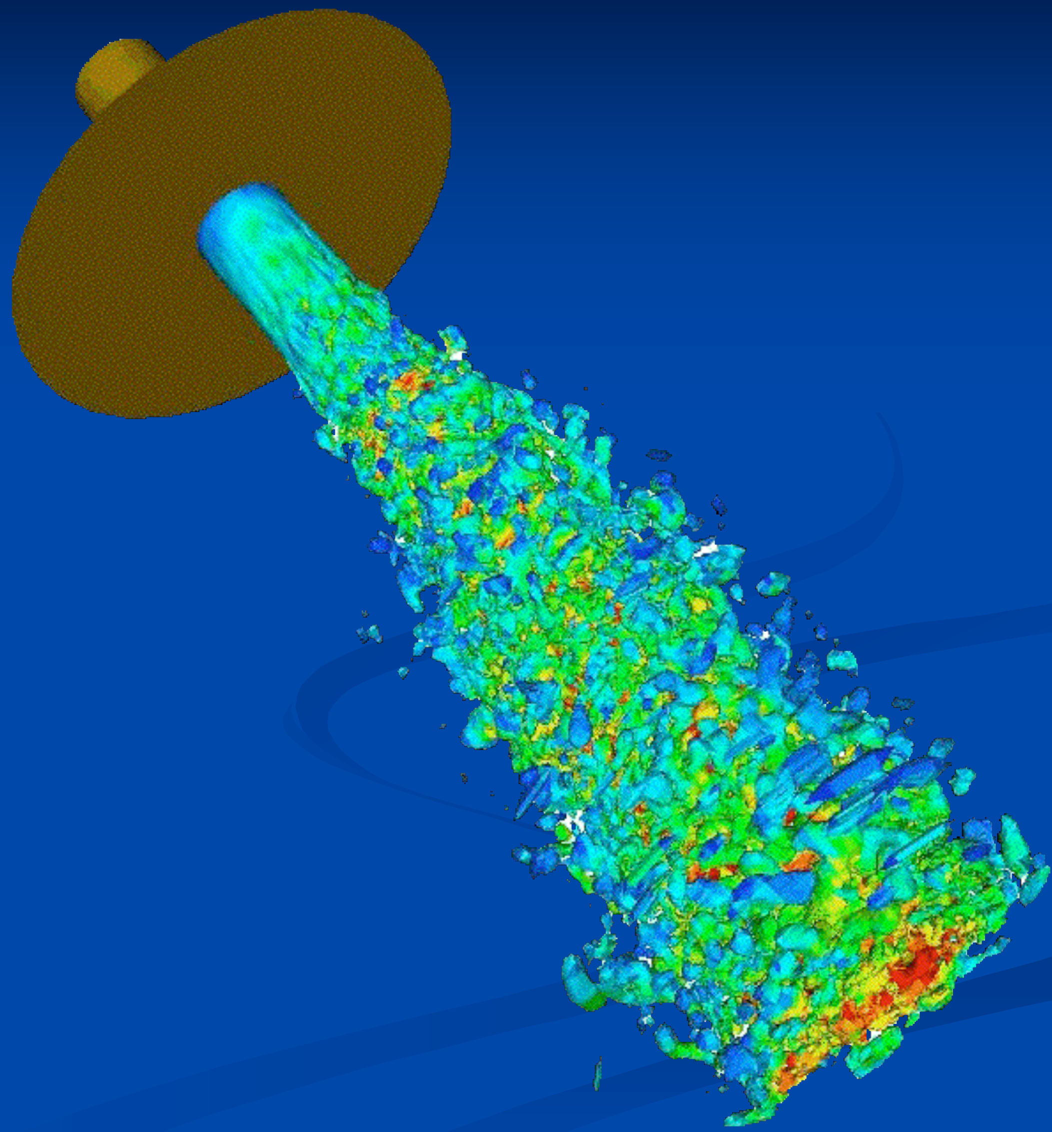
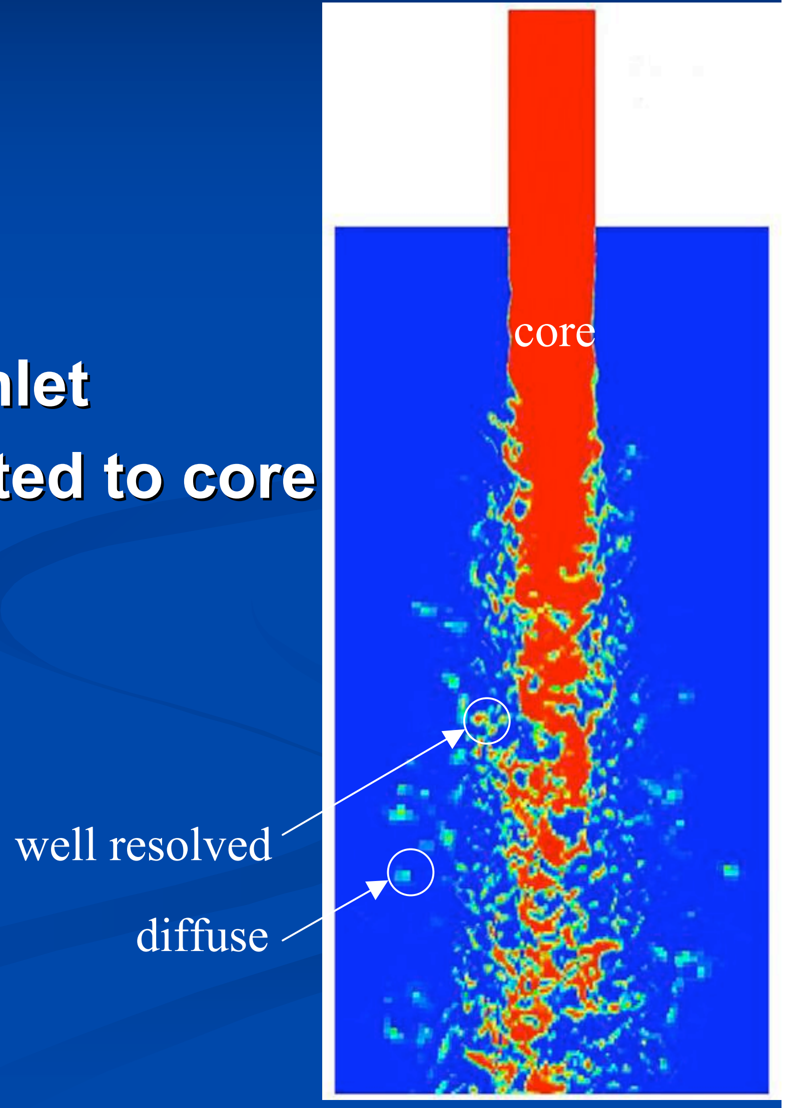


Spray Statistics: structure identification

- γ cut-off
- Spray structure types:
  - Core liquid – connected to inlet
  - Atomised liquid – unconnected to core
    - well resolved – above γ cut-off
    - unresolved – below γ cut-off

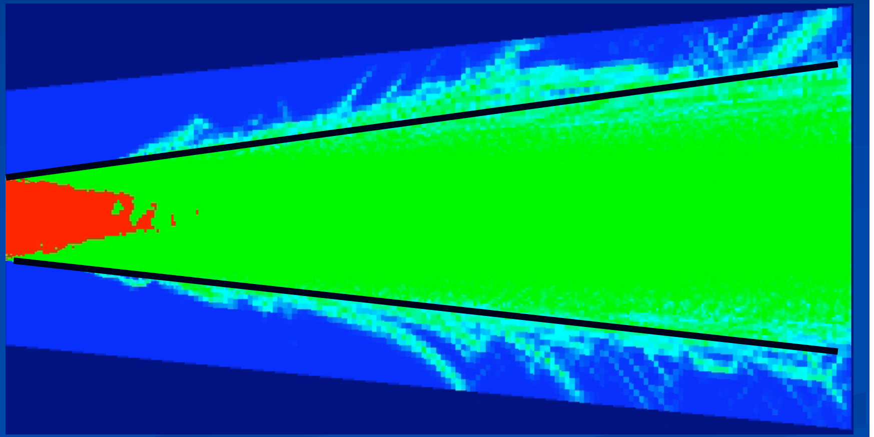


Spray statistics: penetration and spray angle

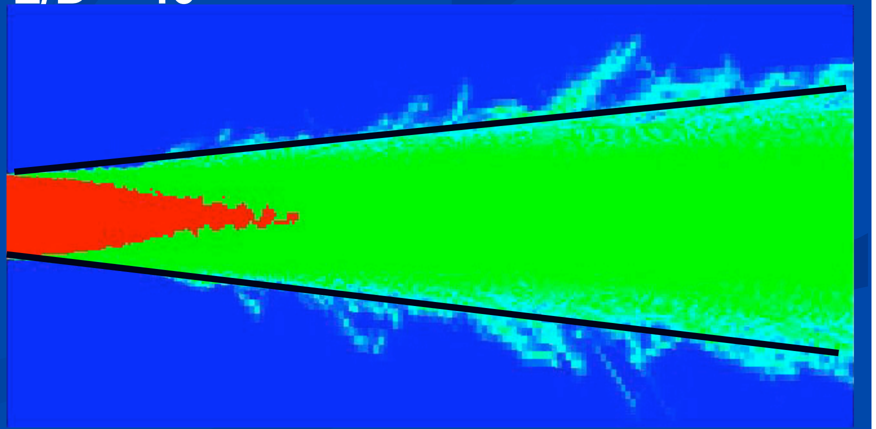
Case	Angle	Length
L/D > 40	12.5 ± 0.5°	3.5
L/D = 5	14.2 ± 0.7°	2.0
Reitz	13°	3-7
Arai	17.5°	

- **Larger spray angle for L/d = 5**
- **Shorter breakup length**
- **Within measurement variation**

L/D = 5

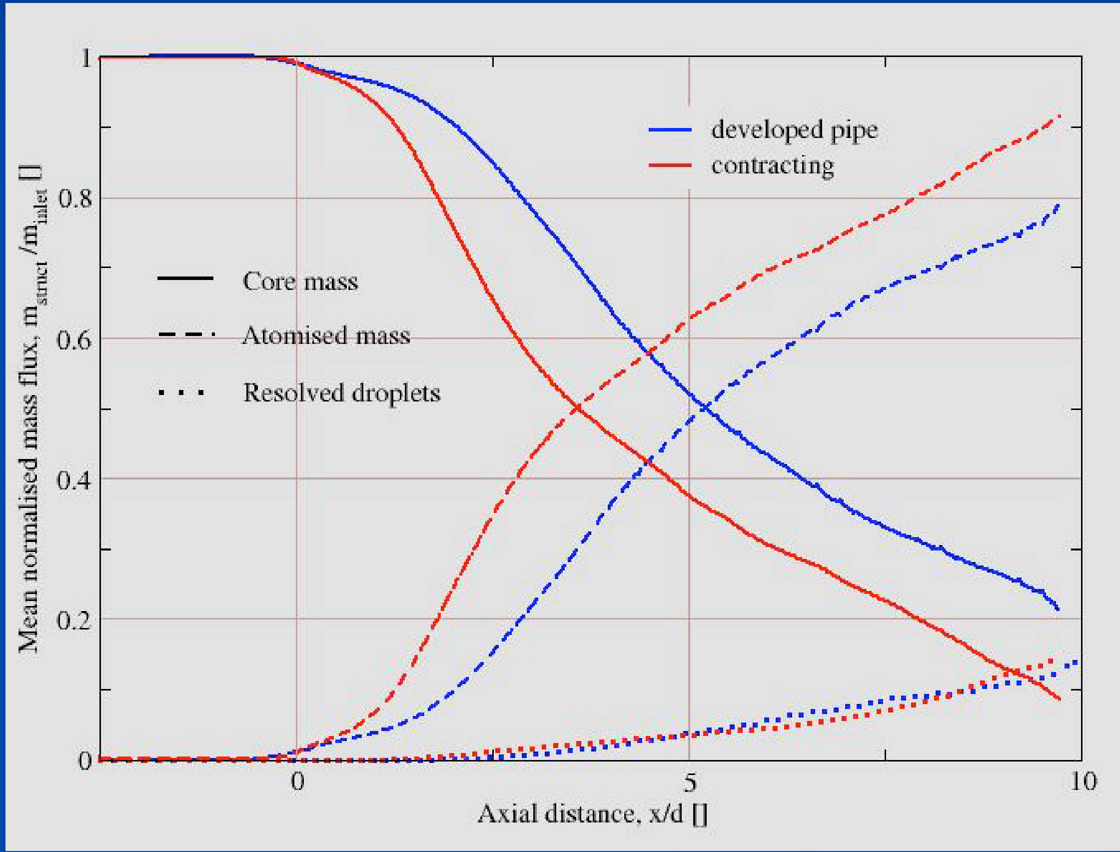


L/D > 40



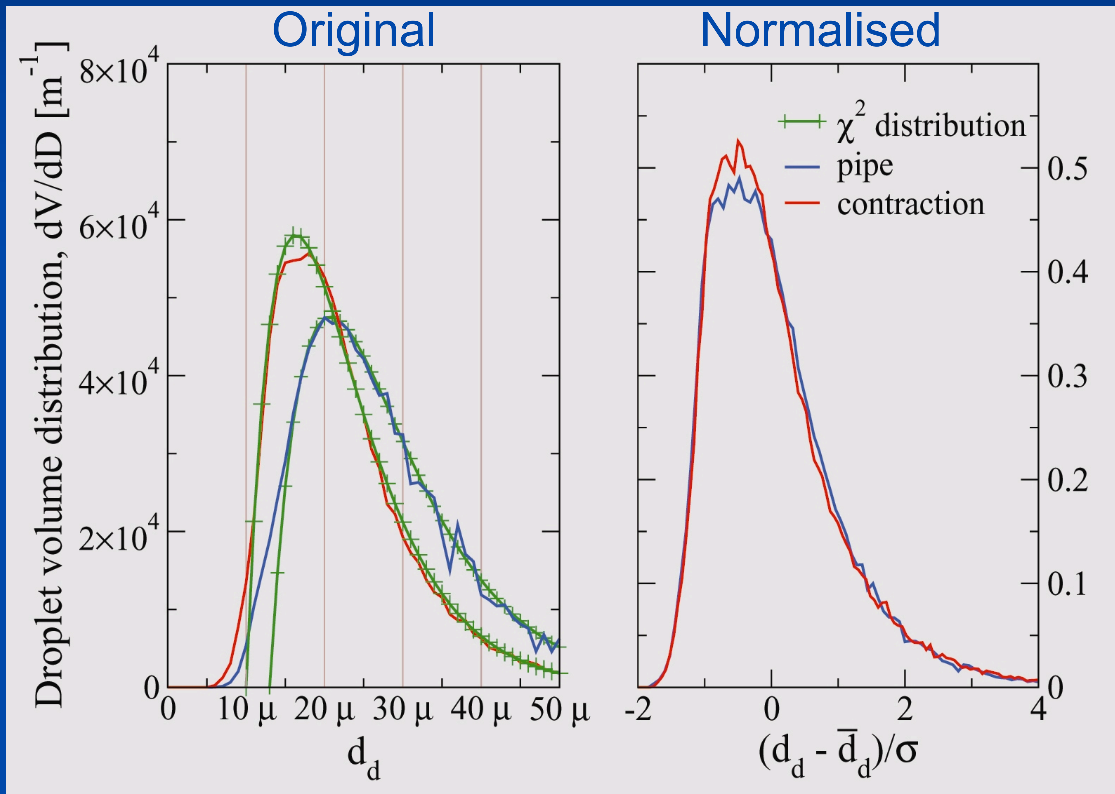
Spray statistics: time average fluxes

LIQUID MASS FLUX DISTRIBUTION ALONG SPRAY AXIS



- **Faster initial breakup for L/d = 5**

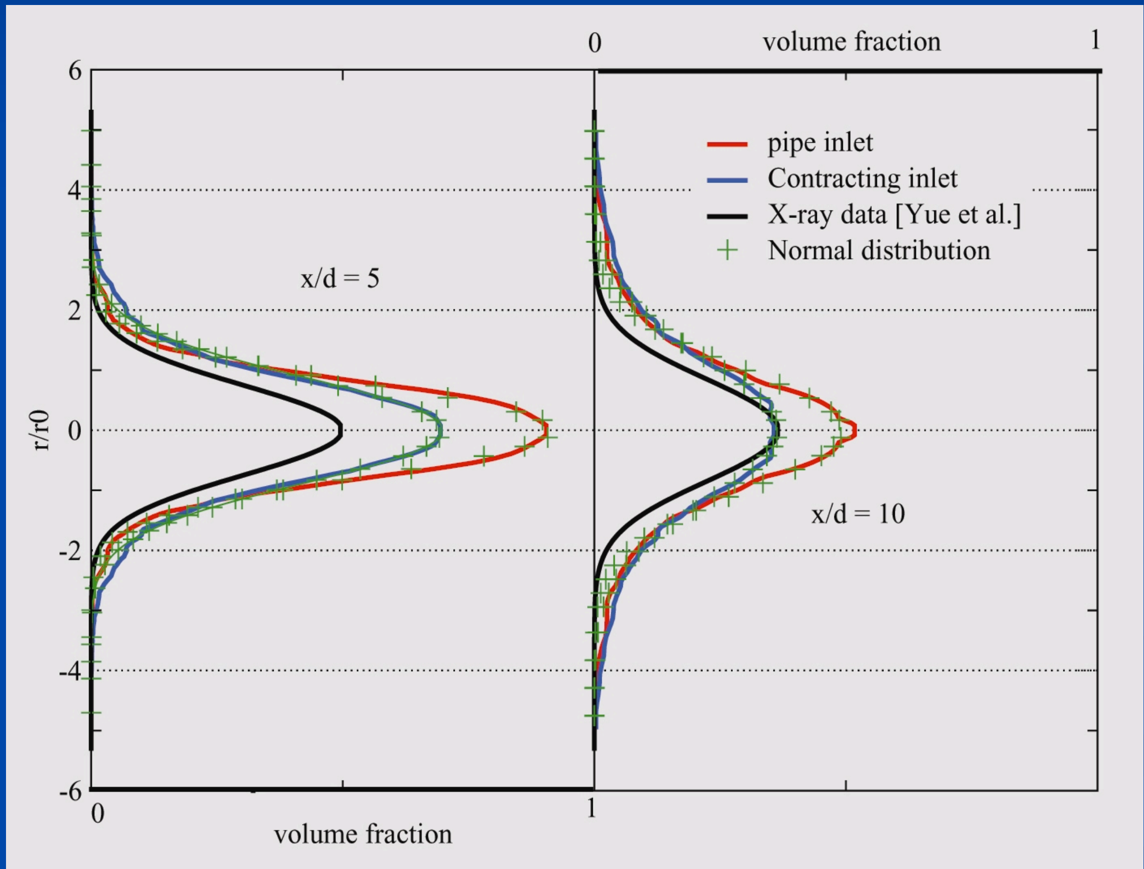
Spray statistics: resolved droplet size distribution



- Very good agreement with experimental χ^2 distribution
- PDF collapse suggests scaling law

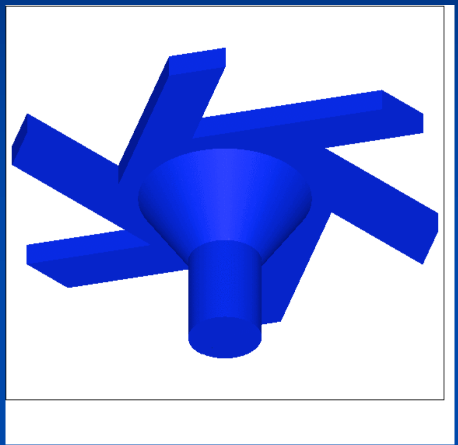
Spray statistics: time average volume fraction

RADIAL LIQUID VOLUME FRACTION DISTRIBUTIONS

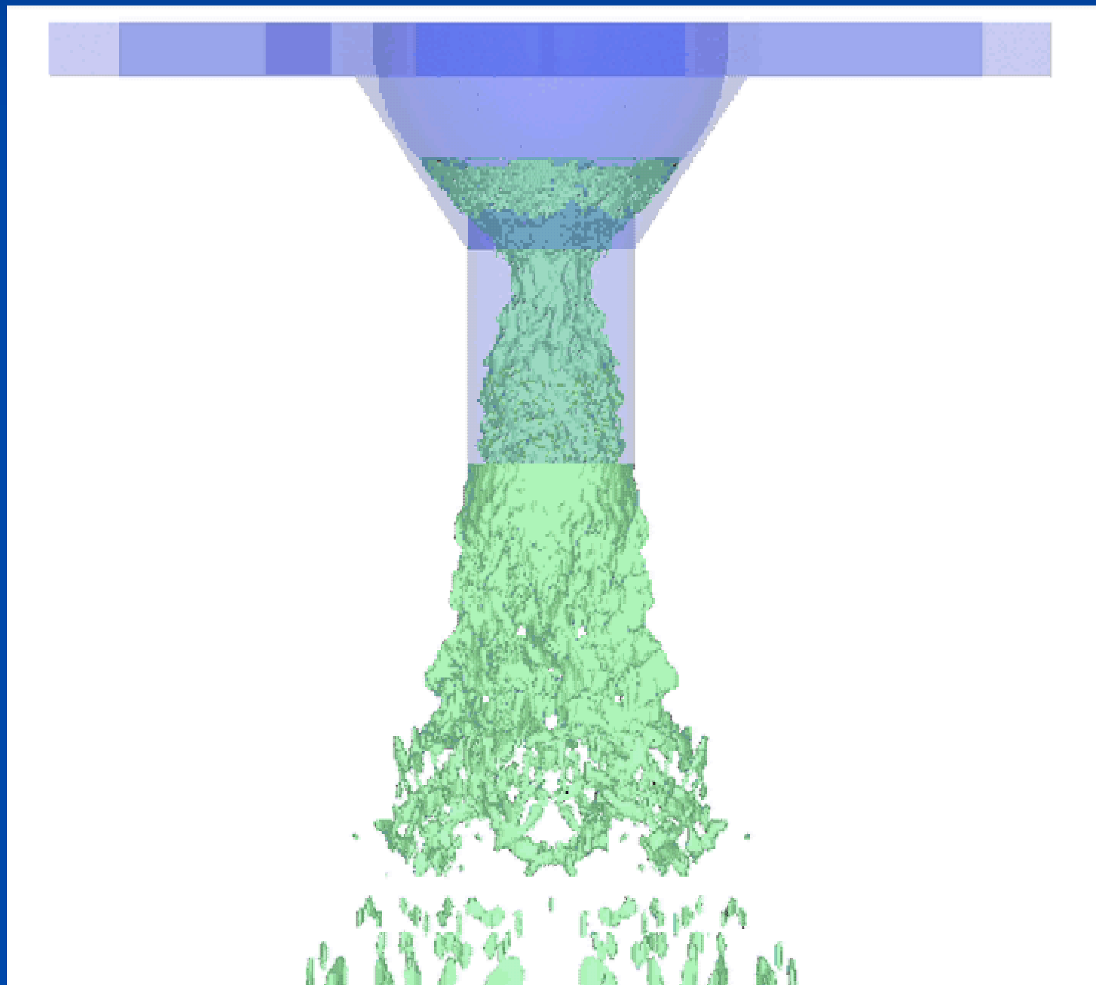


- **Qualitative agreement with data [Yue et al]**

Recent work: pressure/swirl (Simplex) nozzle



Code: STAR-CD



Summary

- LES + VOF methodology allows quasi-direct simulation of primary atomisation
- Link between nozzle-generated ‘turbulence’ and onset of atomisation identified.
- Other sources of perturbation, e.g. cavitation, likely to be important
- Big potential for fundamental and applied studies of spray atomisation

References

de Villiers E, Gosman A D and Weller H “Large Eddy Simulation of Primary Diesel Spray Atomisation”, SAE Journal of Engines, Vol 3, 2004.

de Villiers E, Gosman A D and Weller H “Detailed Investigation of Diesel Spray Atomisation Using Quasi-Direct CFD Simulation” Proc. COMODIA, Yokohama, 2004.