Unsteady Wetness Effects in LP Steam Turbines

Kane Chandler, Alex White and John Young

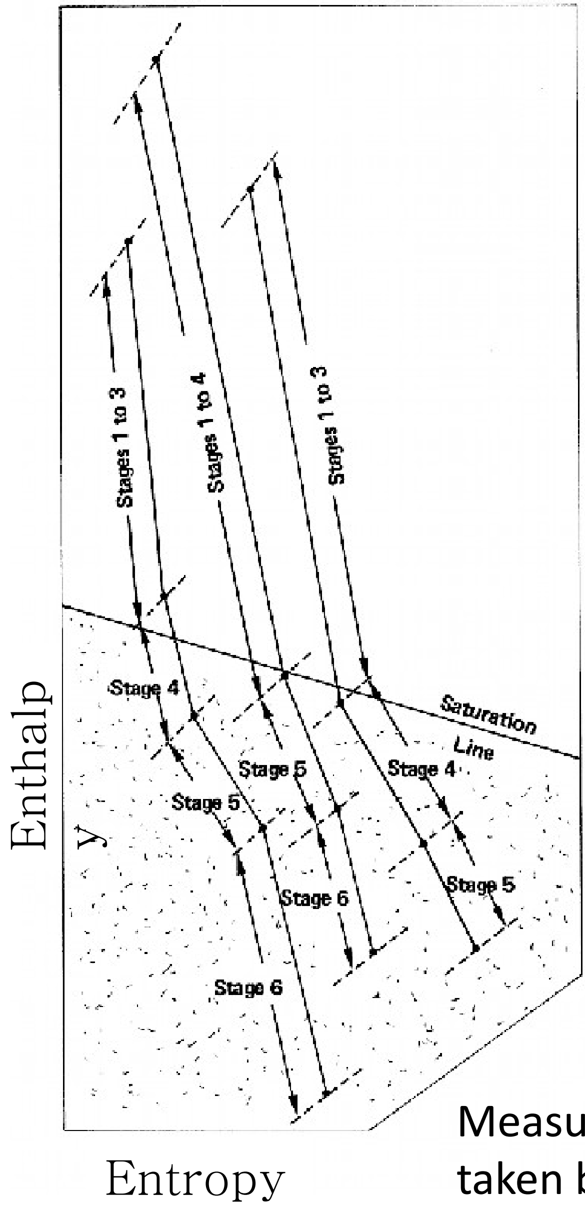
Hopkinson Laboratory

Cambridge University Engineering Department

Supported by EPSRC and Alstom

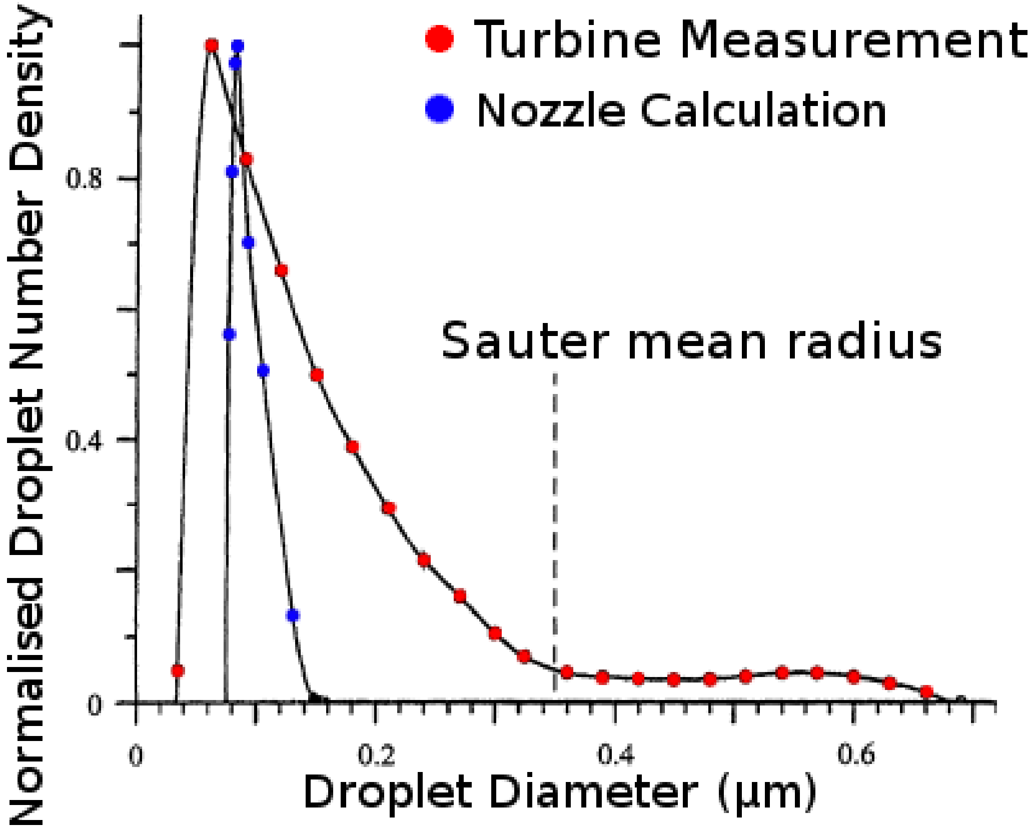
Introduction

- Steam condenses into fog of droplets in LP turbine
- High losses in nucleating stage
- Droplet size information required to predict loss



Measurements taken by P.T. Walters

Broad Droplet Size Distributions



Hypothesis

Caused by unsteady wake-chopping effects

Previous Work

Gyarmathy & Spengler 1974

Total temperature fluctuations observed in exit flows

Bakhtar & Heaton 1988

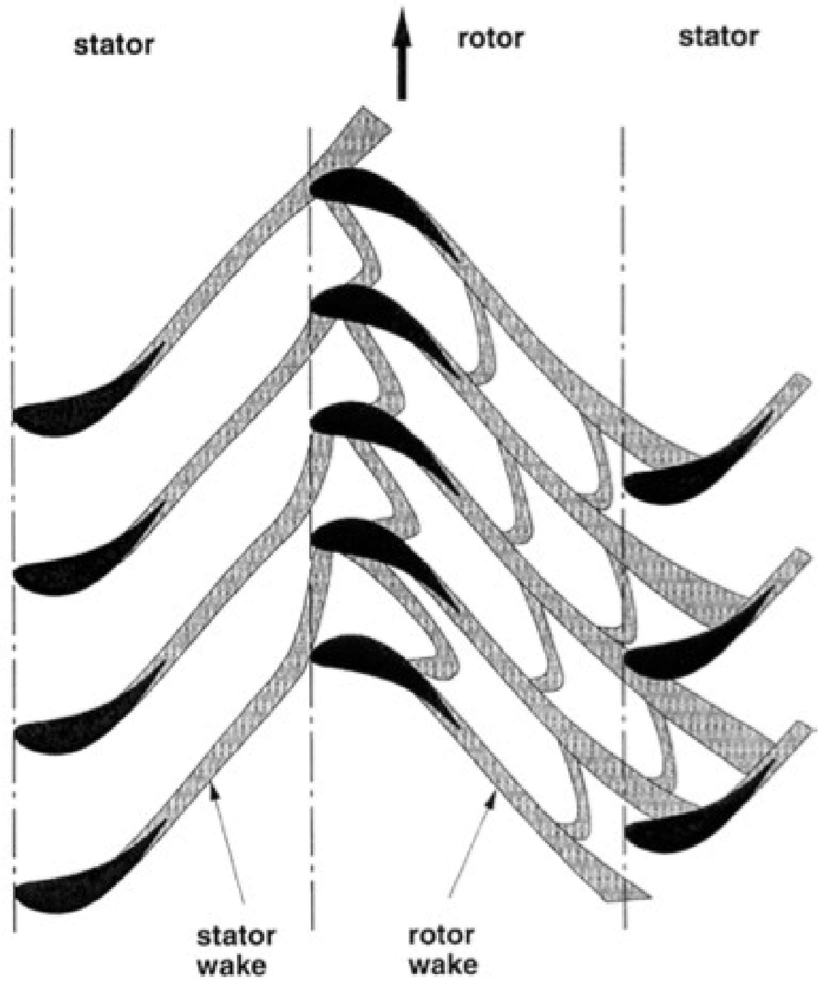
Estimation of effect on droplet sizes by statistical model

Guha & Young 1994

Refined the statistical model using Lagrangian style nucleation and droplet growth calculations

Petr & Kolovratnik 2000

Compared statistical calculations to measurements for a 200 MW LP turbine



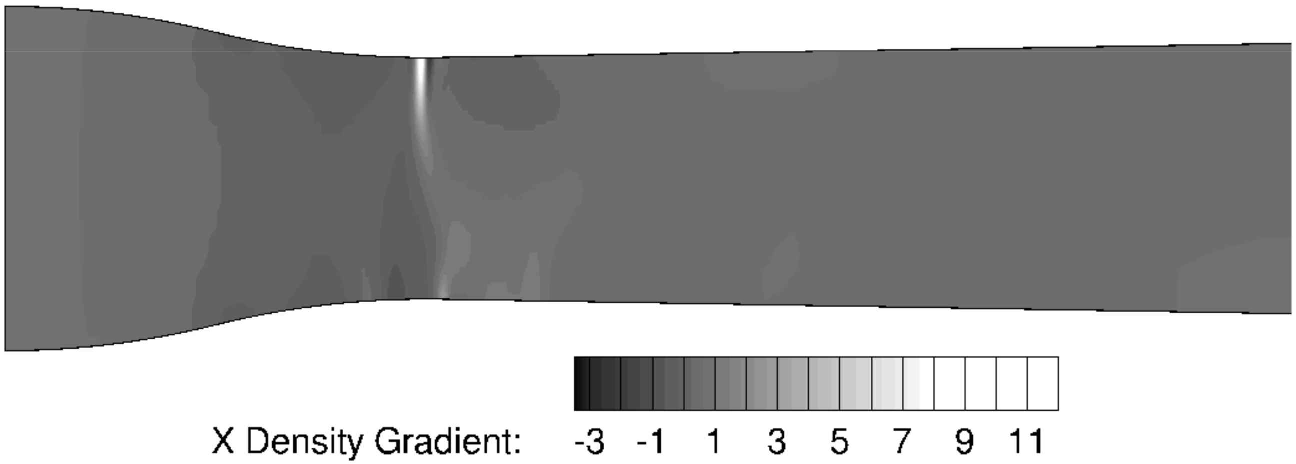
Numerical Scheme

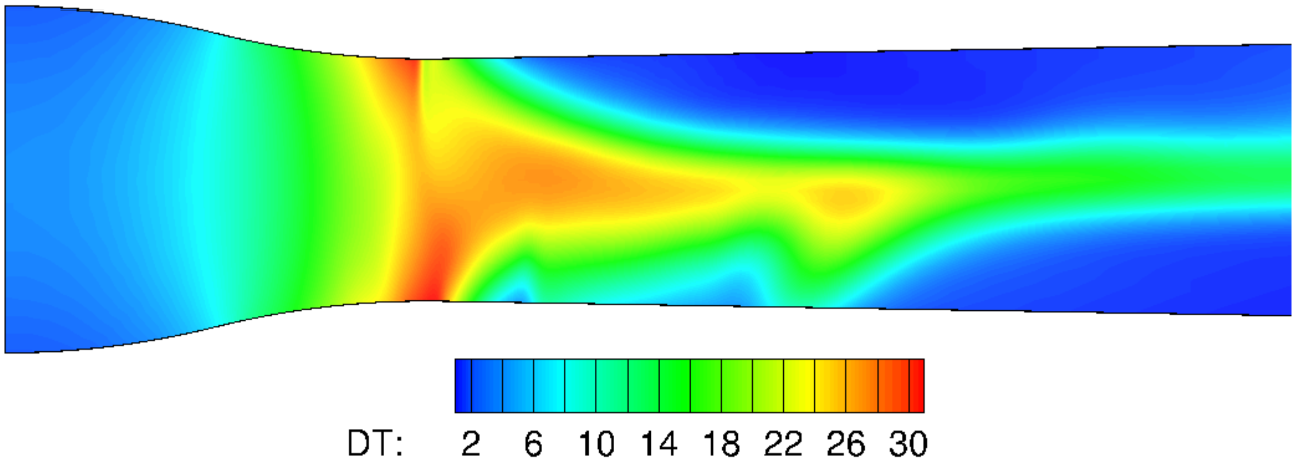
- TBLOCK by John Denton
  - Dedicated turbomachinery gas flow solver
- Steady and unsteady calculations
  - Dual time stepping
  - Viscous effects using body force model
  - Turbulence using mixing length model
- Steam properties included in lookup tables
  - Based on Virial Equation of state truncated at 2nd term
  - Accurate up to 5 bar
- Poly-dispersed droplets treated by moments

Validation: Unsteady Nozzle Calculations

- Supercritical heat addition from condensation causes unsteadiness
- Asymmetric mode possible in nozzles with low expansion rates
- Observed in moist air experiments
- True time step must be less than ~1 μs

Validation: Unsteady Nozzle Calculations





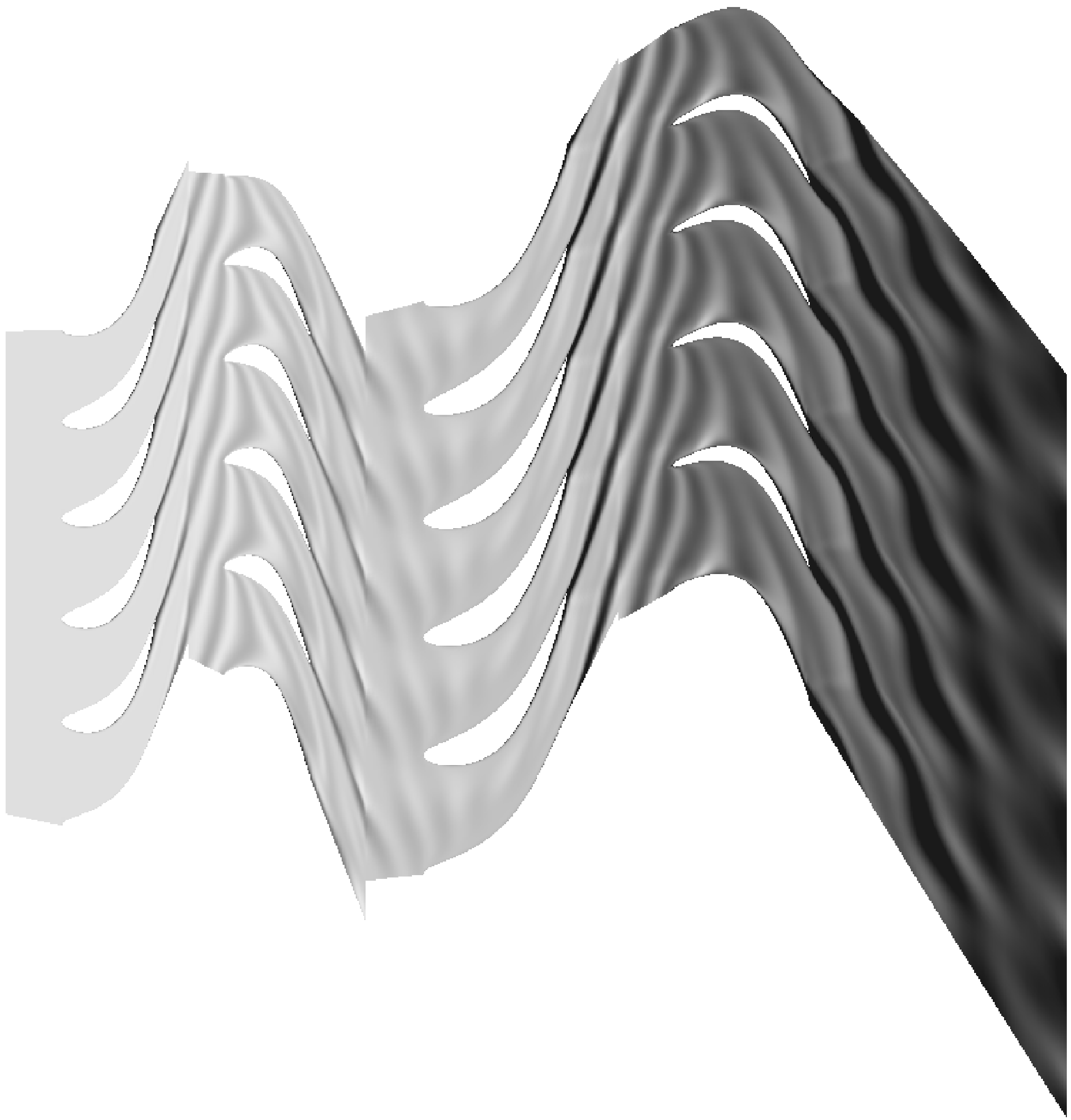
Q3D Calculation for a Two Stage LP Turbine

- Final stages based on model turbine geometry
- Perfect gas calculation used to create Q3D geometry at mid span
- Compare steady and unsteady calculations
- Steady calculation averages the variables in a plane between the rows

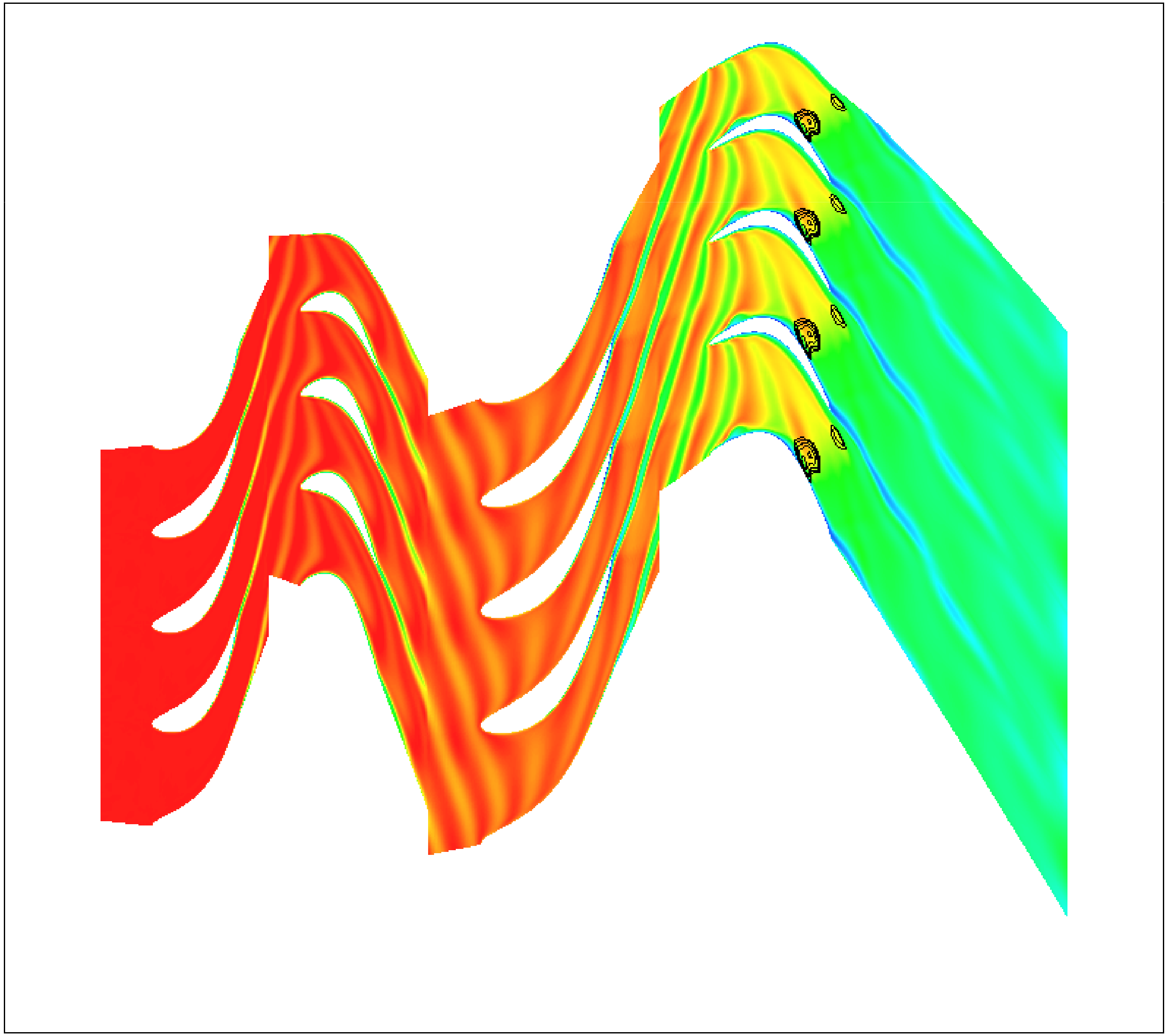
Q3D Results: Wakes

Entropy Contours for a gas calculation

Contours of
exp(-Δs/R)

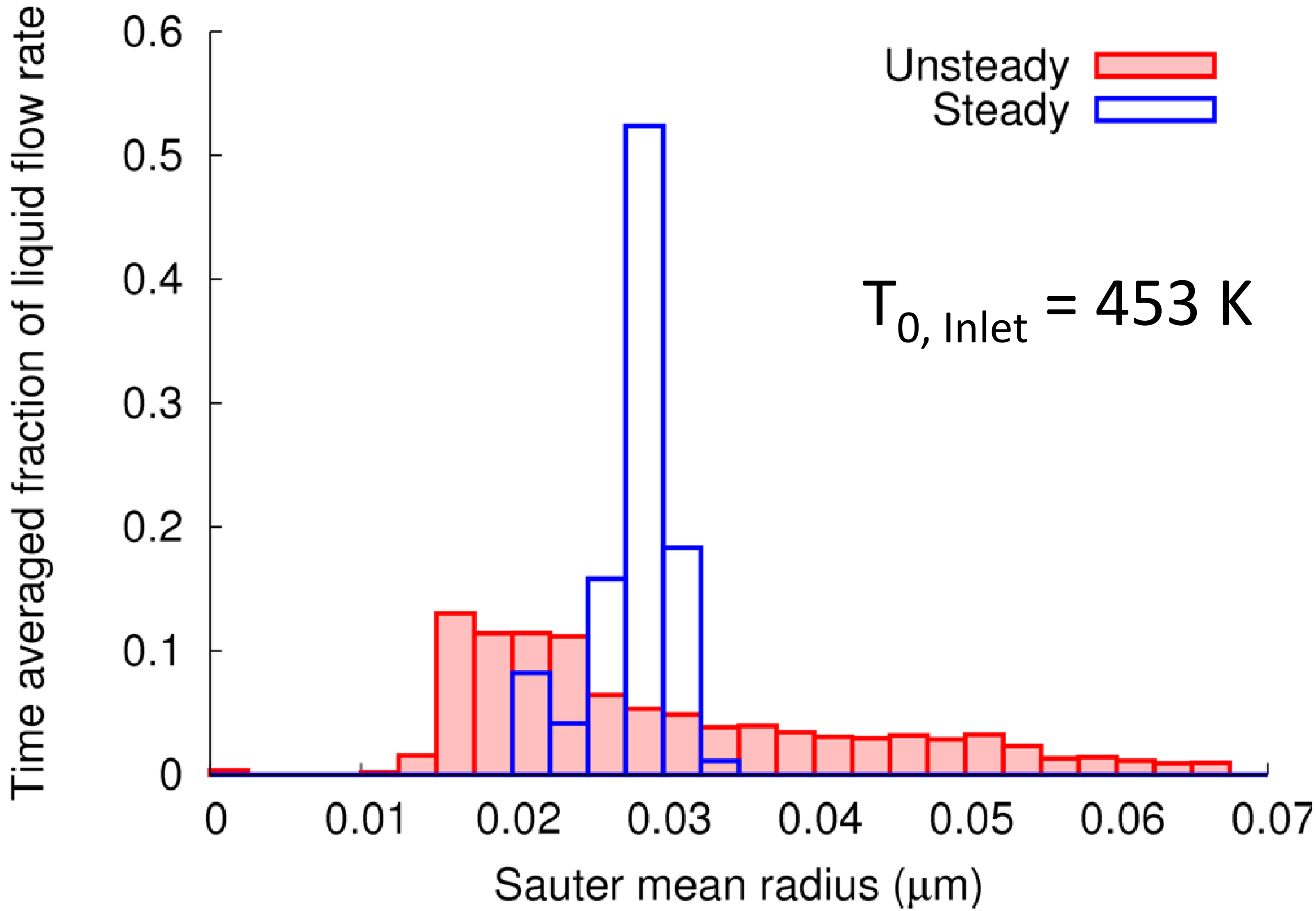


Q3D: Fluctuating Nucleation Rate

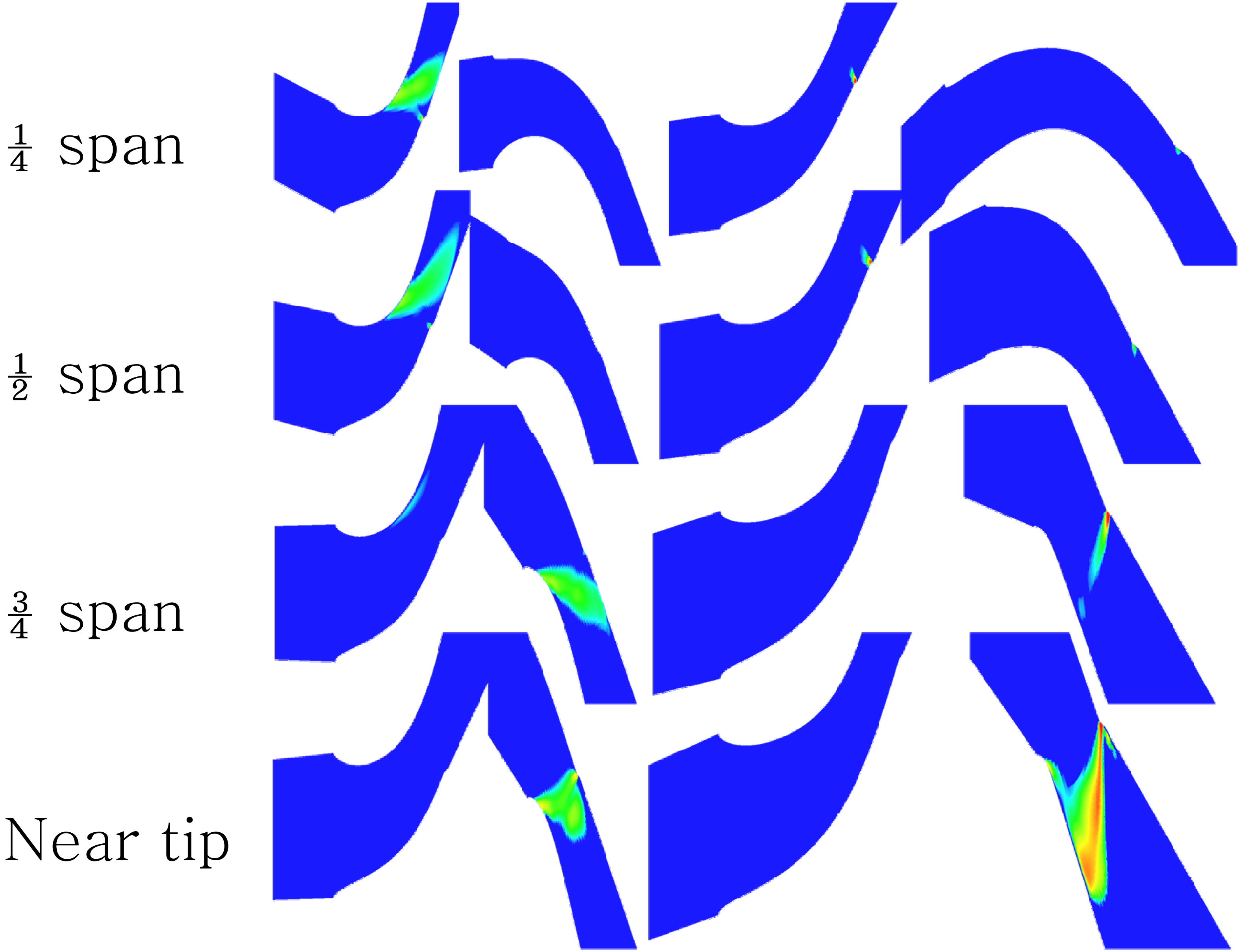


Q3D: Droplet Sizes

Nucleation in Final Row

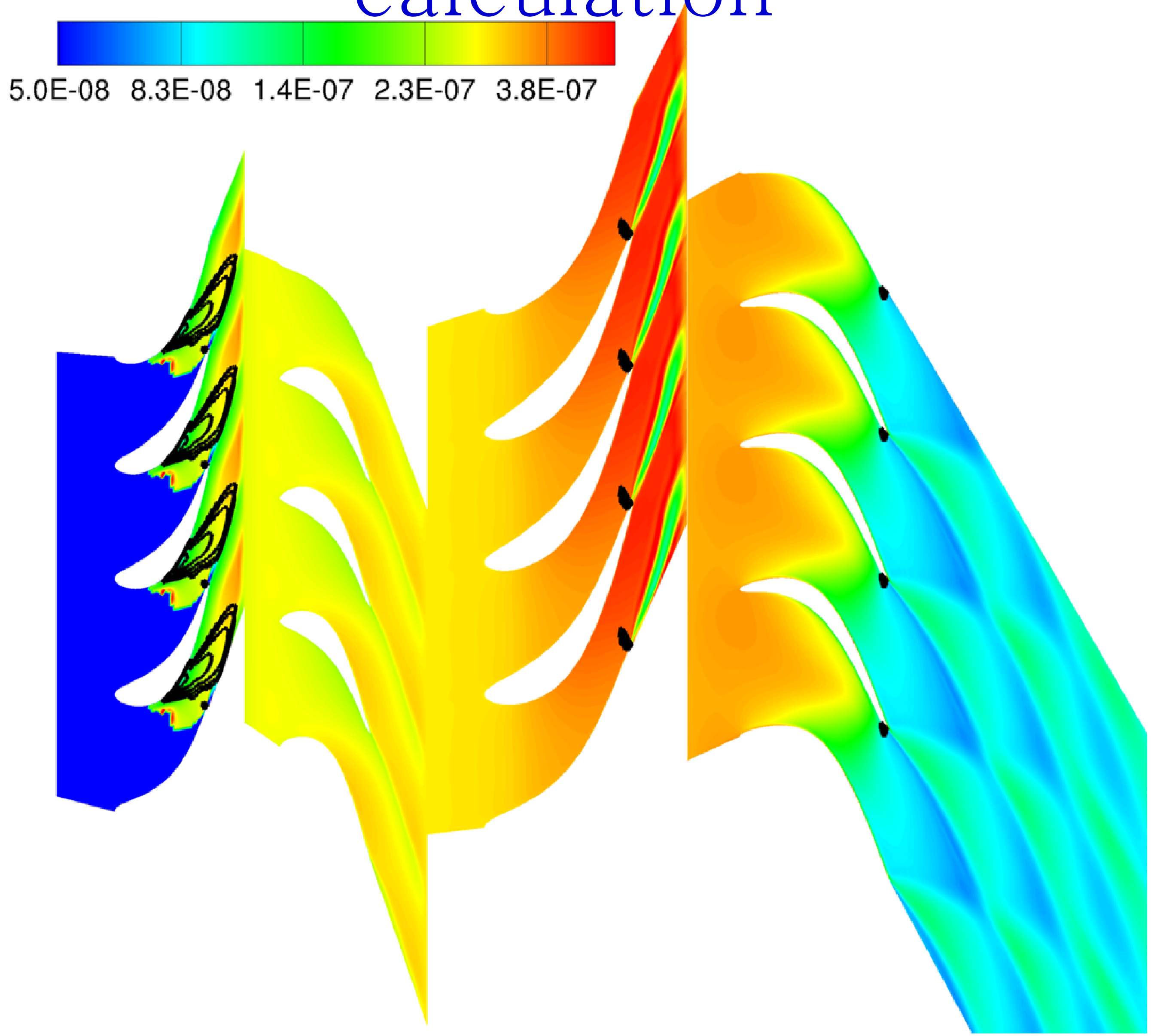


3D Two Stage Turbine: Nucleation



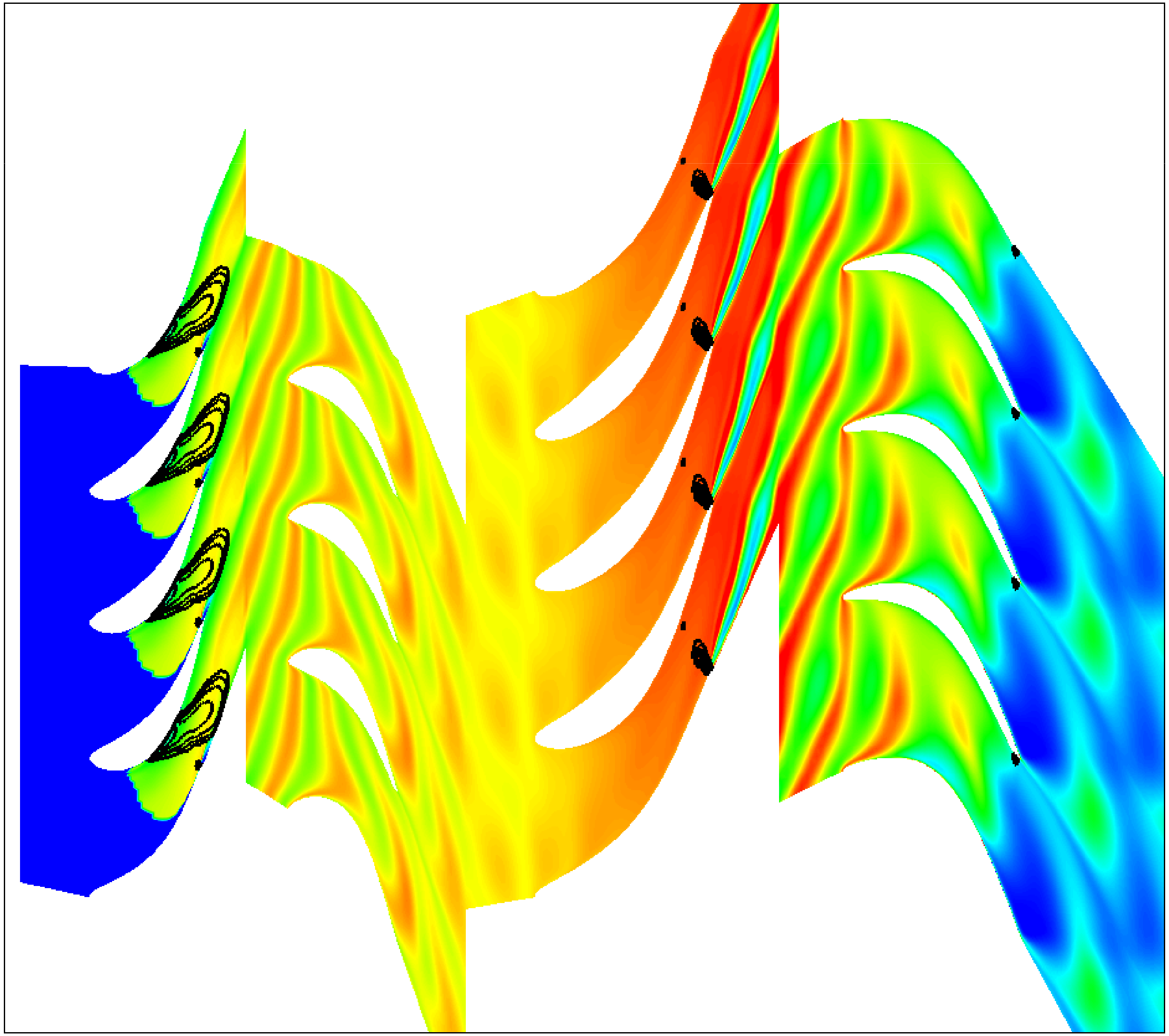
3D: Droplet Sizes at ½ Span

Droplet size contours for steady calculation

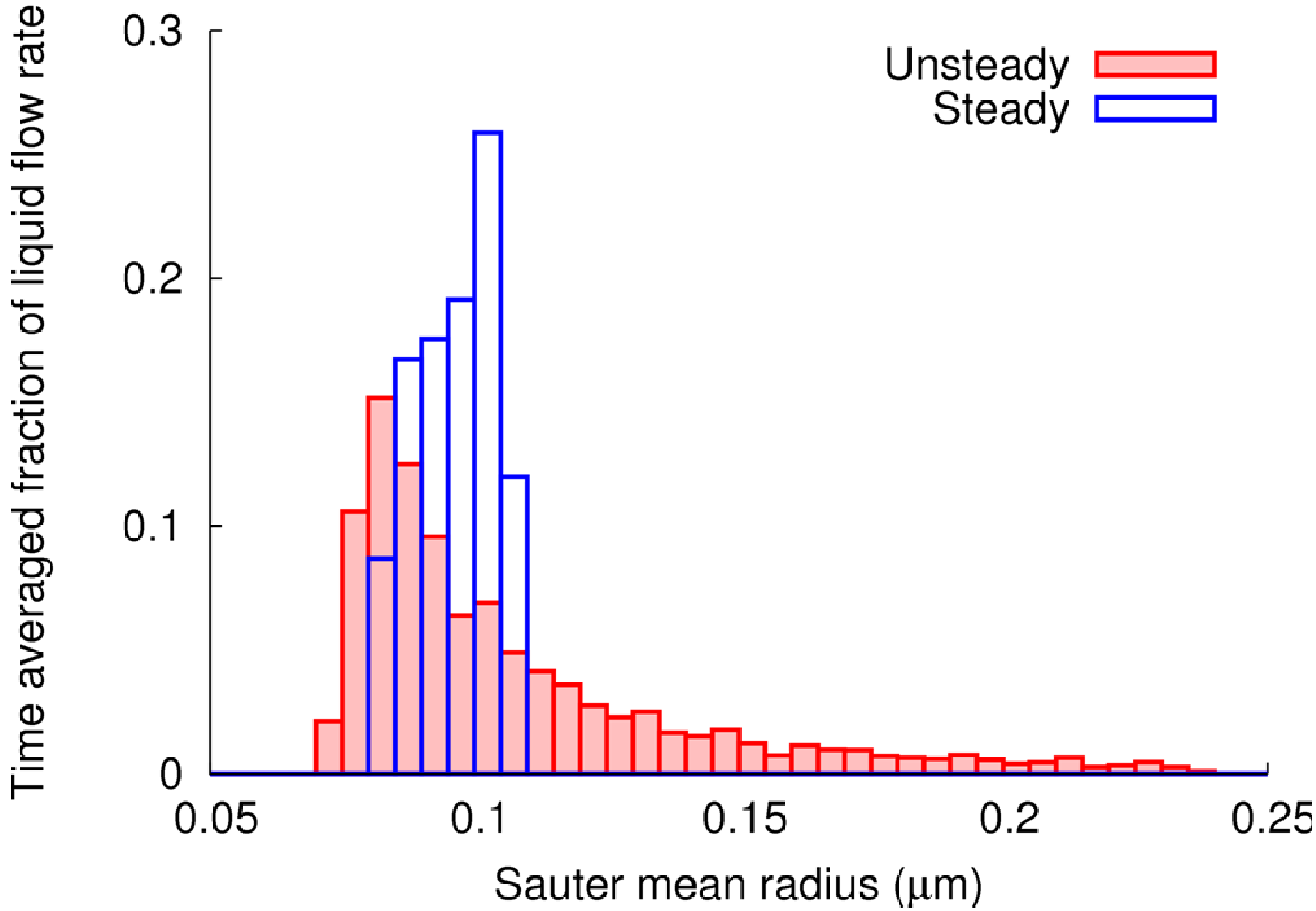


3D: Droplet Sizes at ½ Span

Size contours for unsteady calculation



3D: Droplet Sizes at ½ Span



Summary / Conclusions

- Unsteady wake segmentation clearly has a significant impact on the droplet spectra
- 2-stage Q3D calculations indicate a strong dependence on inlet superheat
- Full turbine calculations, however, might not show the same sensitivity due to unsteadiness generated by upstream blade rows
- 3D unsteady calculations for a 5 stage machine are now within easy reach (anticipated run time: ~8 hrs on 25-core cluster)

3D Contour Plots