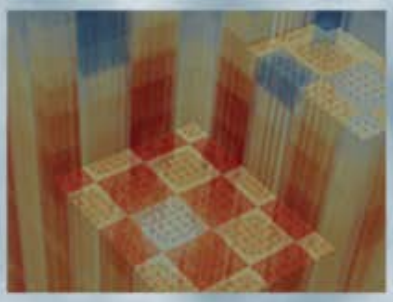
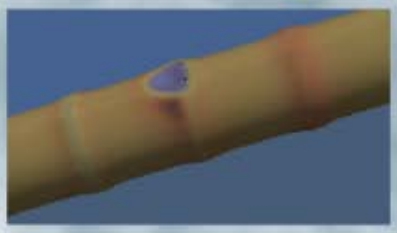
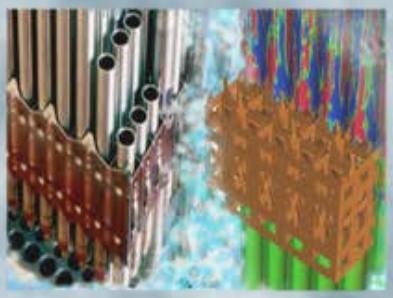
CASL-U-2015-0242-000

Analysis of the Turbulent Kinetic Energy Spectrum in Single and Two-Phase Bubbly Flows in Different Geometries Based on Direct Numerical Simulation Results







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U.S. DEPARTMENT OF ENERGY | Nuclear Energy

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Analysis of the Turbulent Kinetic Energy Spectrum in Single and Two-Phase Bubbly Flows in Different Geometries Based on Direct Numerical Simulation Results

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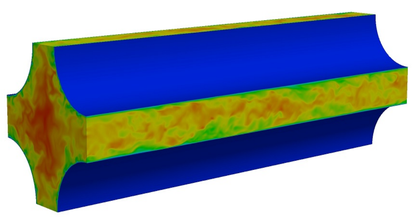
Introduction

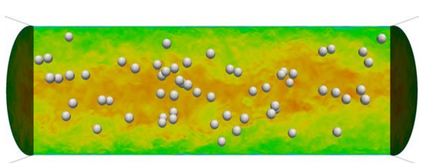
- Understanding the fundamental physics of multiphase flows improves nuclear reactor safety and thermal-hydraulic analysis
- The **turbulent kinetic energy spectrum** provides information about bubble interactions with the liquid turbulence
- The slope of the energy spectrum is well known for single-phase flows (-5/3) but not for multiphase flows
- Direct numerical simulation (DNS) provides data for spectral analysis of turbulent single and two-phase bubbly flows



Snapshot of single-phase DNS of a reactor subchannel

Objectives

- Construct a computational code to spectrally analyze data from DNS performed at NCSU
- Develop and use the **pseudo-void** technique to analyze bubble wake effects on the liquid turbulence
- Spectrally analyze DNS data from different geometries including:
  - i. Flat plane channel[1]
  - ii. Nuclear reactor subchannel[2]
  - iii. Circular pipe (*two-phase DNS snapshot below*)

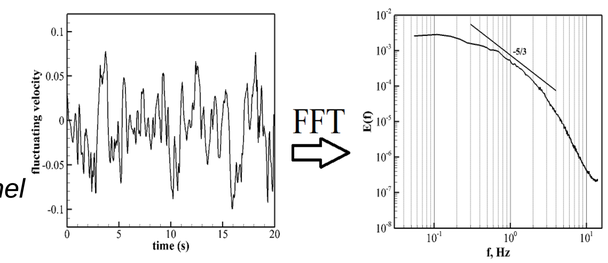


Numerical Method

- Instantaneous flow quantities (i.e. velocity, pressure, etc.) are recorded over the DNS time at numerical probes
- Instantaneous velocity signal is decomposed into mean and fluctuating components
- Velocity fluctuations at each timestep are used to compute the single-point velocity correlation:

$$R_{ii}(t_j) = \frac{1}{2} u_i' u_i'$$

- **Fast Fourier transform (FFT) of the single-point velocity correlation results in a transformation from the time domain to the frequency domain:**

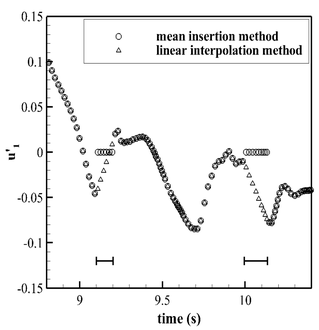


Two-Phase Velocity Signal

Energy spectrum calculations are more difficult in multiphase flows since

- Liquid velocity signal is discontinuous due to bubble passages over the numerical probes
- Handling of the defective portions of the signal can skew the energy spectrum

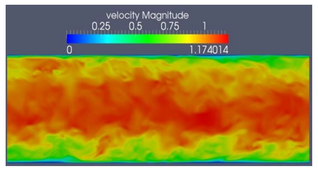
A linear interpolation is chosen to bridge the defective portions of the liquid velocity signal:

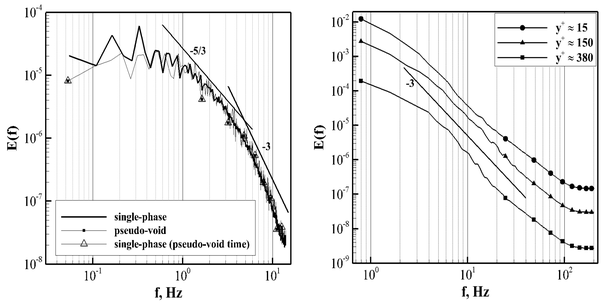


Results

Plane Channel Geometry

Snapshot of single-phase DNS in the plane channel geometry

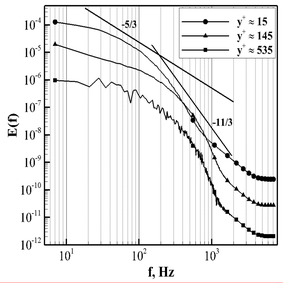




Energy spectra : single-phase and pseudo-void near the channel centerline (left), two-phase (right)

Reactor Subchannel Geometry

Energy spectra: from currently available single-phase data



Pseudo-Void Technique

The wake behind a bubble interacts with the liquid turbulence to alter the slope of the energy spectrum in multiphase flows

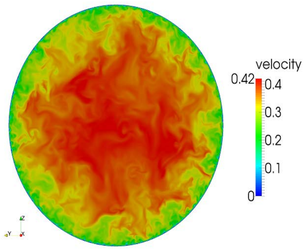
The **pseudo-void** technique overlays the bubble distribution of a two-phase simulation onto single-phase DNS data

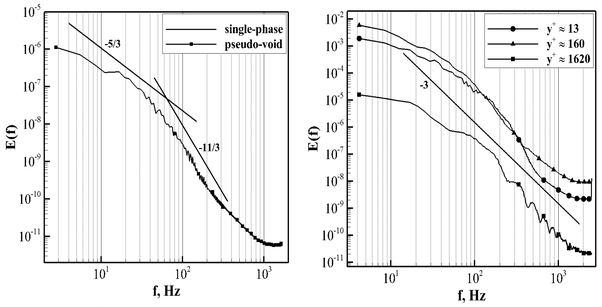
Therefore the velocity signal ***contains the defective bubble locations*** however, the ***bubble wakes are not present***

Results

Circular Pipe Geometry

Snapshot of single-phase DNS in the circular pipe geometry





Energy spectra : single-phase and pseudo-void near the pipe centerline (left), two-phase (right)

Conclusions

- The turbulent kinetic energy spectrum has a power law scaling close to -3 for turbulent two-phase bubbly flow
- The expected -5/3 slope for single-phase flow is shown in all of the considered geometries
- Pseudo-void calculations show that the change of the energy spectrum slope in two-phase flows is due entirely to liquid turbulence interactions with the bubble wakes
- Quantifying and validating the behavior of two-phase flows enhances computational multiphase fluid dynamics (CMFD) modeling capabilities for reactor relevant geometries

References

[1] Bolotnov, I. A. Influence of Bubbles on the Turbulence Anisotropy. *Journal of Fluids Engineering-Transactions of the Asme* **135**, 051301 (2013).

[2] Fang, J., Rasquin, M. & Bolotnov, I. A. *Interface tracking simulations of bubbly flows in the PWR relevant geometries*, NURETH-16, Chicago, IL, USA, 2015

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