Nuclear Science, Technology, and Policy Research at the George Washington University

Philippe M. Bardet

The George Washington University

2013, 04–11 / ANS
DC Section

Outline

1. GW Nuclear Heritage
2. Research and Teaching
   - Research
   - Teaching
3. TFL Research Activities
   - Fluid Structure Interaction
   - Seismic Response of Fuel Assemblies
   - Two-phase flow regime transition
   - New diagnostic Development for two-phase flows

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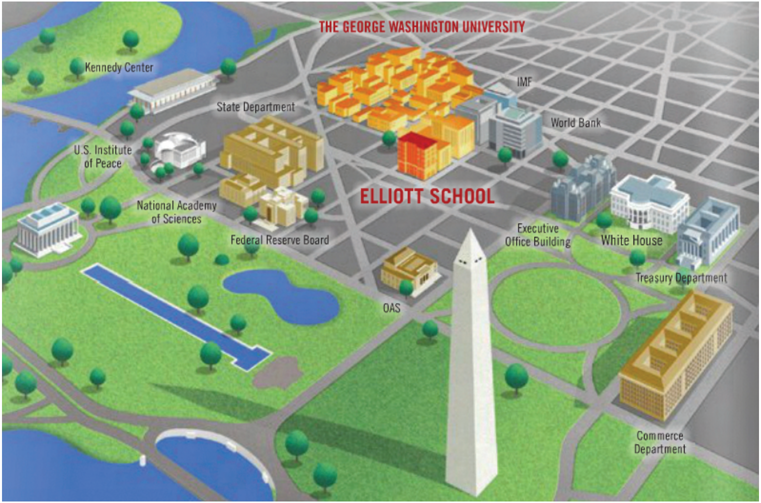
The George Washington University



Science and Engineering Hall

Historical Perspective

The George Washington University has been at the center of the nuclear age from the start.

George Gamow (1934):

- α-decay theory
- Big Bang theory
- Mr Tompkins ...

Edward Teller (1935):

- Gamow-Teller Transition
- Jahn-Teller Effect

January 26, 1939
5^{th} Washington Conference on Theoretical Physics
Neils Bohr and Enrico Fermi reported the first successful fissioning of the Uranium nucleus.

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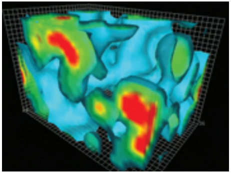
Nuclear Physics

Experimental Nuclear Physics

Theoretical Nuclear Physics

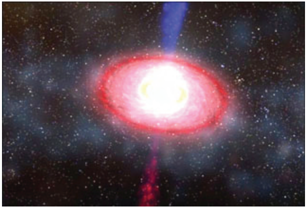


Quantum Chromodynamics simulation

Data Analysis Center

Database of nuclear reactions

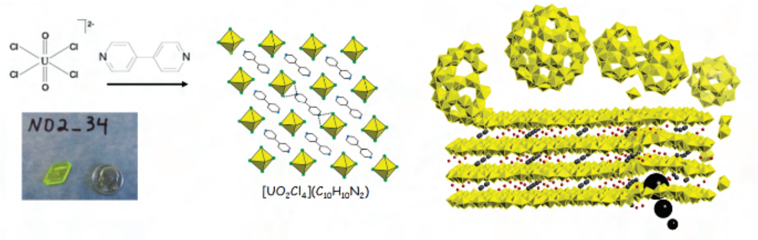
Nuclear Astrophysics



$\sim$ 17 Faculty

Radiochemistry & Nuclear Materials

- From nano to meso
- Actinide coordination chemistry
- Uranium speciation in environmentally relevant media



Prof. C.L. Cahill
Prof. S.R. Daly (radio-pharmaceutical)

Nuclear Policy Studies

Elliott School of International Affairs

- Science and Policy aspect of the Nuclear Fuel Cycle
- Non Proliferation

Alumni

- Acting Under Secretary of State for Nonproliferation and International Security: Rose Gottemoeller (M.A. 81)
- Director of the Office of Treaty Compliance in the Office of the Secretary of Defense: Tom Troyano (M.A. 87)
- U.S. Permanent Representative to NATO: Kurt Volker (M.A. 90)

Faculty $\sim$ 15

GWINS

In 2011, the George Washington Institute for Nuclear Studies was formed from:

Physics

Radiochemistry & Nuclear Materials

Diagnostic Radiology

Elliott School of International Affairs

School of Engineering and Applied Science

Have organized: - University Seminars
- New courses

The Science of Nuclear Materials: A Modular, Laboratory-Based Curriculum

Christopher L. Cahill[1,2], Gerald Feldman[3], William J. Briscoe[3]

[1] Department of Chemistry
[2] Elliott School of International Affairs
[3] Department of Physics

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Background: Needs and Opportunities – GW and beyond

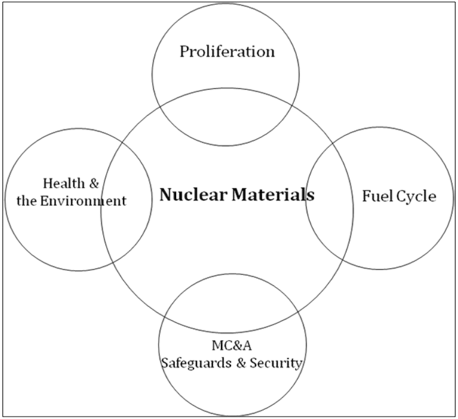
The Elliott School of International Affairs (ESIA)
MA in International Affairs, concentration in Security Policy Studies.

- IAFF 6175: Nuclear Weapons
- IAFF 6186: Proliferation and Non-proliferation
- IAFF 6186: New Proliferation Dynamics

Nowhere is the gap between science and policy greater than in the energy arena; nuclear energy in particular. Moreover, weapons and energy are inherently linked.

Increased demand at GW.

New Courses Overview



Modular, laboratory-based curriculum targeting NON-technical individuals.

Emphasize the fundamentals

Sample lab equipment

Curriculum Overview

Week	Lecture	Lab
1	Radiation- origin etc.	Geiger counters, everyday objects. Measure dose rates.
2	Radiation- structure of the atom	$1/r^2$
3	Half-lives	M & M Statistics
4	Historical treatment: criticality to enrichment	Half-life determination using GM counters
5	Weapons I: Enrichment to weapons	Uranium decay series using MCA
6	More on Fission	No Experiment
7	Exam	Exam
8	Fuel Cycle I- World energy needs, fuel production	Attenuation using GM counters
9	Fuel Cycle II- LWRs	Guest Lecture- Graham Allison
10	Fuel Cycle III- Alternative cycles, breeders.	Criticality calculations.
11	Fuel Cycle IV- Waste	Determination of a long-lived half-life
12	Fuel Cycle V- Reprocessing	Separations demonstrations
13	Fuel Cycle VI- Fukishima	Deay heat calculations exercise- Spent Fuel Pool Temperatures
14	Radioisotope Power systems	None.

Feedback

Who took the 1^{st} class?
21 students total.

- DHS Office of Infrastructure Protection's Nuclear Sector-Specific Agency
- State Department Fellow
- Research Assistant at the US Institute of Peace
- Nonproliferation Graduate Fellow at the NNSA
- Nuclear Research Assistant at the Partnership for Global Security
- National Security Analyst – (SAIC)

Some Term Paper Topics

- SILEX
- Breeder reactors - challenges & opportunities
- SMRs

Student feedback

- Yes, very relevant. As a policy person I've found that the engineers I work with already respect me more due to my increased technical literacy.
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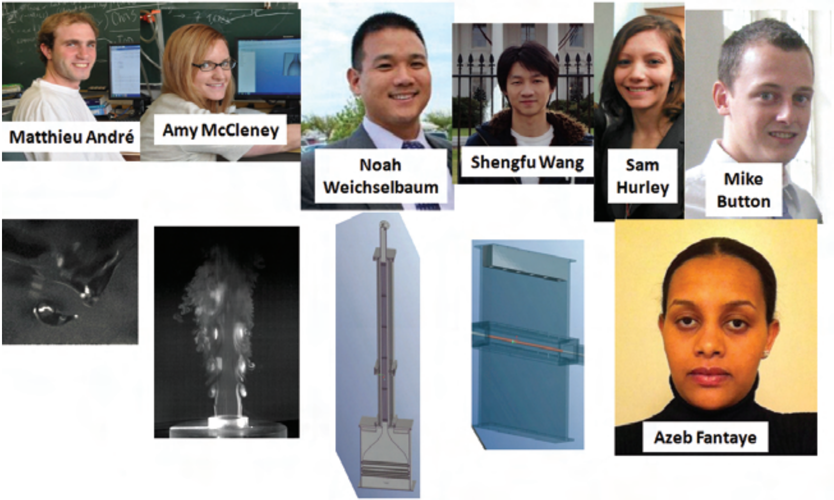
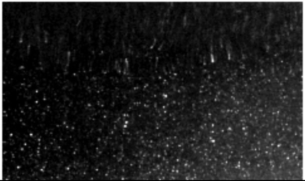
Thermo-Fluids Lab – TFL

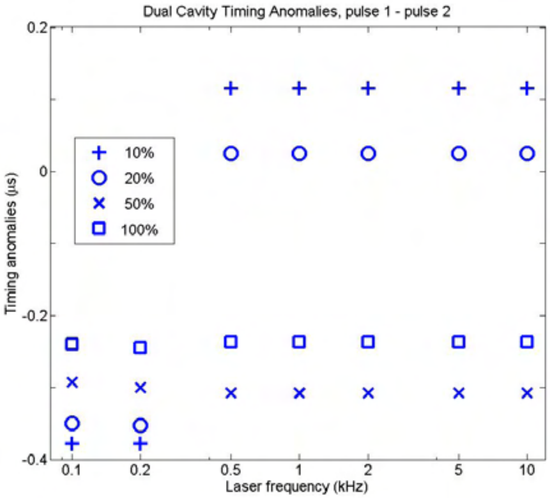


High-speed high-resolution instruments

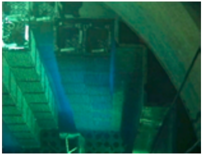


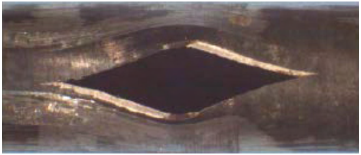
- Custom high-spatio-temporal resolution PIV
  - 4 pulse Nd:YLF laser
    - 527nm
    - up to 60mJ/pulse
    - up to 4 $\times$ 5kHz
    - material acceleration
    - pressure field
    - dual plane PIV
  - High resolution high-speed cameras
    - 7,500 fps at 1MPixel
    - Magnification up to 6

Laser Timing Issues



Need for FSI Validation Data





Applications of FSI:

- Nuclear fuel rods
- Steam generators

Limitations of available datasets

- structural data
- inform structural models

Experiment Objectives

- Gain (new) physical insights into FSI
- High-spatio-temporal resolution fluid velocity & structure vibrations
- Tractable validation data for CFD development

Experimental approach

- Use non-intrusive diagnostics
- Use complimentary diagnostics
- PIV, LIFT

For slender tubes in axial flow, resolve:

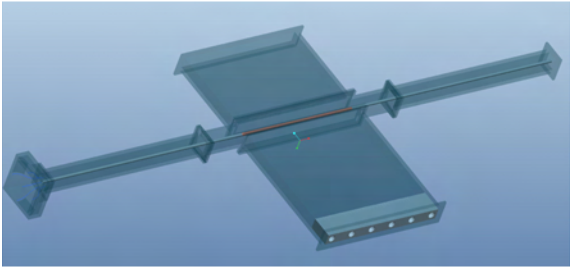
- Tube vibration mode & frequency
- Associated velocity (& pressure) fields

Planned tests

- Influence of inflow conditions
- Extend measurements to 3D

Modular Facility designed for Optical Diagnostics

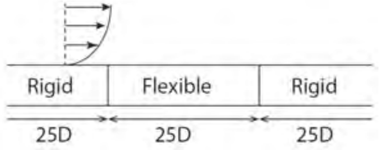
Test Section Design



Experiment Parameters

L	(m)	0.5
OD	(m)	0.0127
ID	(m)	0.0109
ϵ		39.4
EI	(Nm^2)	0.024
U^*	(m/s)	0.87
$\mathcal{U}$		$\sim$ 10
β		0.23
Re_D		1.3×10^5

CFD Validation Facility

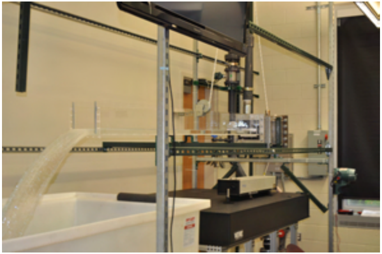


Control of initial conditions:

- Level of turbulence
- Profile of boundary layer
- Location of boundary layer transition to turbulence

Boundary conditions:

- Water tunnel with $W^2 >> \pi d^2/4$

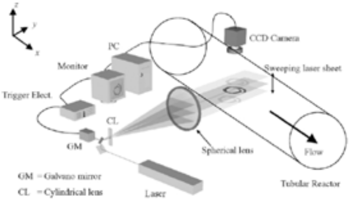


- 50Hp centrifugal pump: 900 gpm : $\sim$ 10m/s
- Variable Frequency Drive: Computer controlled, 0.01 Hz
- Magnetic flowmeter: Can be coupled to VFD with PID 0.5% accuracy

Instrumentation Development: 3D Rod Vibration

Scanning PLIF:

- Galvano Mirror
- Polygonal mirror

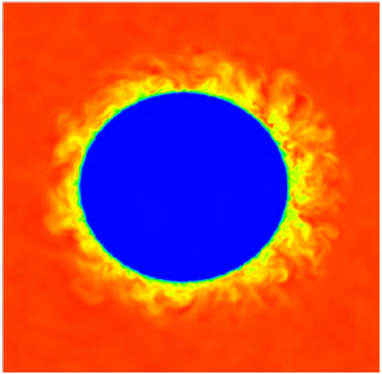


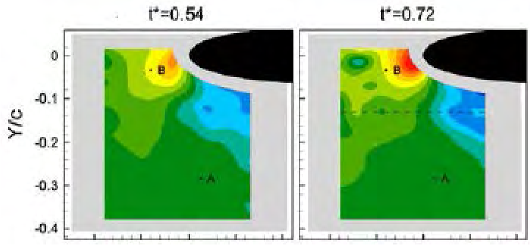
Diagnostics will enable:

- 2D lateral displacement per plane
- One plane per mode minimum
- want about 5 planes

In second phase, we will add velocity measurements in each planes

Time-Resolved Velocity coupled with Vibration





Violato *et al*, 2011

Planar pressure field has been derived from TR-PIV.

Validation data and model development for fuel assembly response to seismic loads

Philippe Bardet, Elias Balaras, Majid Manzari, The George Washington University -- GW
W David Pointer, ORNL
Guillaume Ricciardi, CEA (France)

Project Objectives

- Provide comprehensive data characterizing the dynamics of the fluid and the structure in fuel assemblies under seismic loads, which is a major safety concern in light of recent world events.
- Validate NEAMS Reactor Product Line software.

International contributory campaign

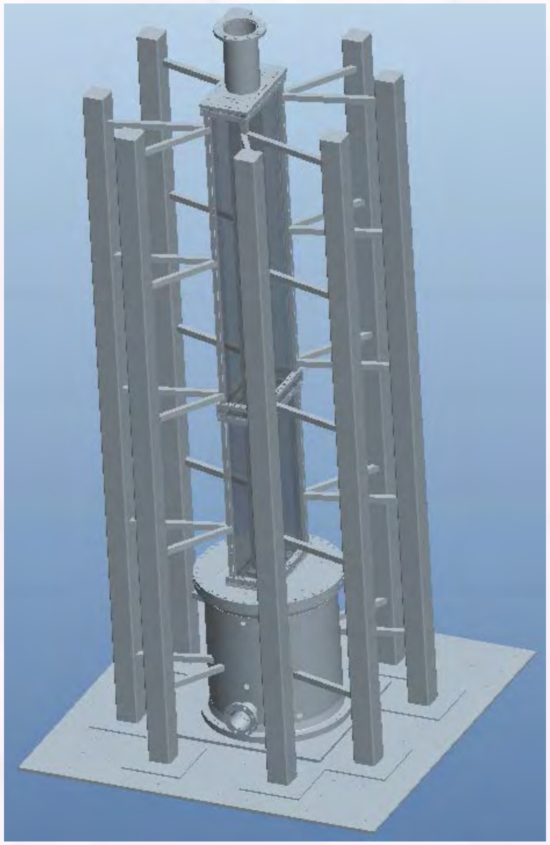
- Meso-scale (GW & ORNL):
  - ➢6 × 6 subassembly
  - ➢Details of coupling between flow and rods vibration during seismic events
- Macro-scale (CEA):
  - ➢4- 8 × 8 subassemblies
  - ➢Effect of axial flow on assembly global deformation

Validation campaign (US)

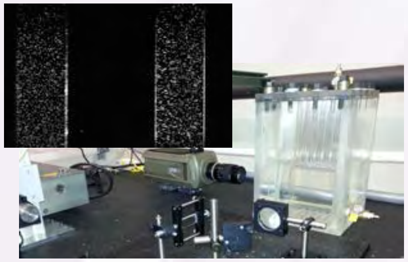
- Close cooperation between experimentalists and numericists at GW.
- Index matched facility to resolve flow and structures simultaneously
- Surrogate fuel rods: acrylic rods (in 1st phase)
- Rod ø increased by 50% to match fuel rods natural frequency
- 6 spacer grids
- Reynolds number: 1.0×10^5

New experimental diagnostics developments

- Suite of high-spatio-temporal resolutions diagnostics will be developed and operated on shake table for first time.
- Time-Resolved Particle Image Velocimetry (TR-PIV)
- Velocity field between the fuel rods with high-spatio-temporal resolution



GW 6 dof shake Table



Sample PIV data confirming index matching methodology

- Time-Resolved Laser Induced Fluorescence Tomography (LIFT)
  - ➢Time-resolved vibration fields of all the 36 surrogate rods.
- Digital Image Correlations (DIC)
  - ➢Oscillation of the spacer grids with sub 10μm resolution

Experiment design is informed by detailed simulations

Validation data and model development for fuel assembly response to seismic loads
Bardet, Balaras, Manzari (GW), Pointer (ORNL), Ricciardi (CEA)

Objectives

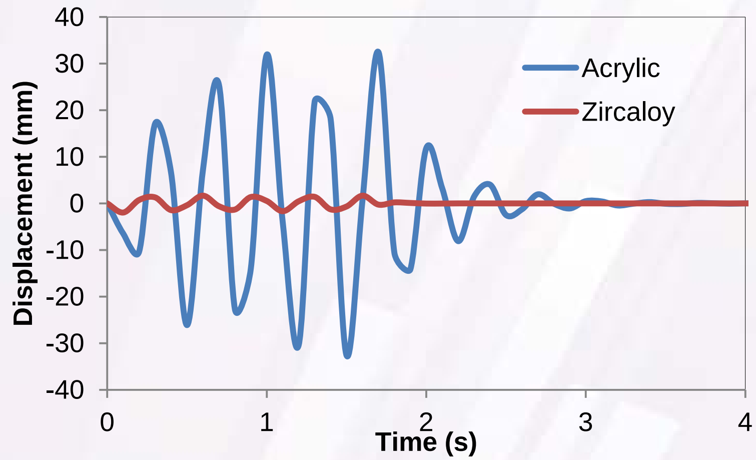
- Inform scaling analysis and surrogate rods materials and size.
    - ➢Derive methodology for scaling base ground motion to materials stiffness of model
    - ➢Confirm overall dimensions of the test section
- Validate Finite Element Analysis code (FEA) that will be implemented with GW CFD code.

Initial Developments

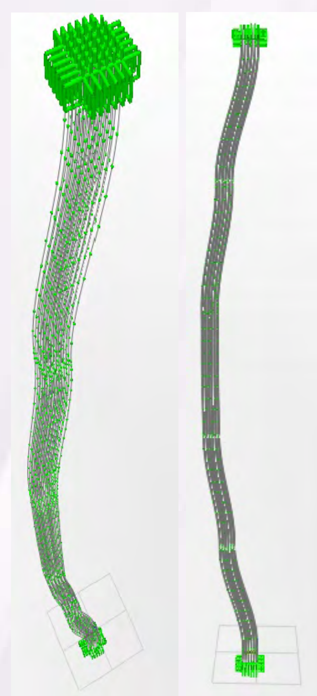
- Built three different finite element models of the fuel assembly (dry condition) with different levels of sophistication. Acrylic and Zircaloy were used as the material of choice for fuel rods.
- Extensive finite element analyses show that the seismic response of the assembly is very sensitive to the choice of the surrogate material used for the fuel rods
- Time history analyses of the dry fuel assembly response to real earthquake loading shows that relative displacements of the fuel rods are small and may be negligible.

Future Developments

- The computational model will be validated by shake table testing of the dry fuel assembly.
- The computational model will be extended to consider the presence of fluid under axial flow



Deformation maximum amplitude for acrylic rods and zircaloy tubes.



Deformed shape of the 6 × 6 subassembly at the time of maximum displacement. Lateral deflections are artificially amplified for display.

THE GEORGE WASHINGTON UNIVERSITY
WASHINGTON, DC

Highly efficient & high-fidelity fully-coupled CFD-FEA codes are under validation

NEUP Nuclear Energy University Programs
U.S. Department of Energy

Validation data and model development for fuel assembly response to seismic loads
Bardet, Balaras, Manzari (GW), Pointer (ORNL), Ricciardi (CEA)

Objectives

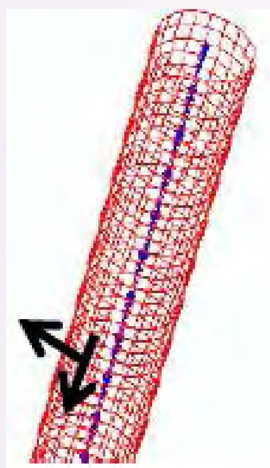
- Perform well resolved large-eddy simulations (LES) of fuel rod assemblies matching the conditions of the experiments at GW.
- We will consider:
  - ➢ Variety of geometrical configurations
  - ➢ Modeling approximations of increasing complexity.
- We will use NEAMS RPL and GW codes.

NEAMS Reactor Product Line approach

- High-fidelity CFD code (SHARP) fully coupled to FEA code (Diablo)
- Coupling performed through MOAB

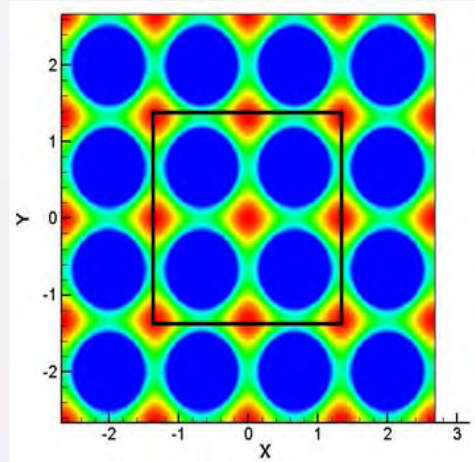
Initial developments at GW

- Focused on LES of small clusters of flexible rods clamped at both ends.
- Coupled solution of NS equations for incompressible flow with beam model representing the rod. An hydrodynamic shell model represents its surface.

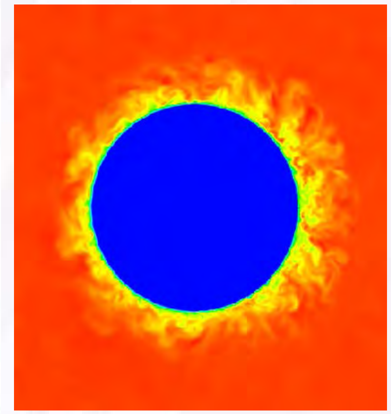


Representation of a fuel rod: hydrodynamic shell and beam model

- Laminar and turbulent axial flow around a rod cluster.

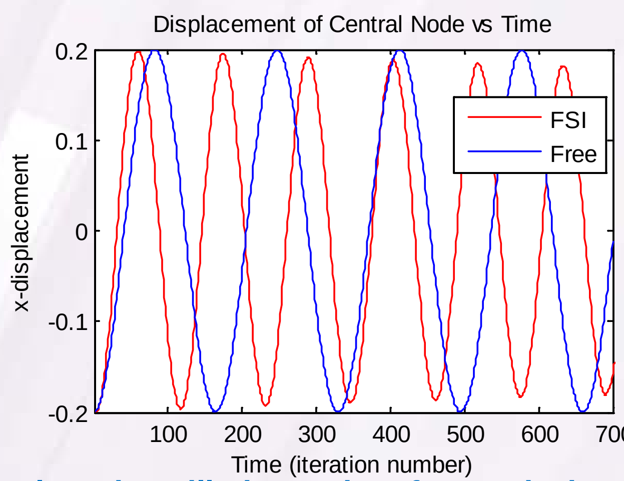


Isolines of axial velocity in a 4 × 4 periodic array



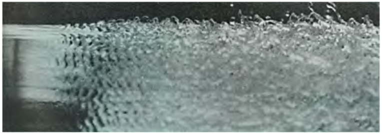
Isolines of turbulent kinetic energy at a cross section

- Axial flow significantly affect oscillations of a single rod



Single rod oscillations when free and when fully coupled with axial flow

Surface Renewal Characterization



Taylor & Hoyt, 1977

No detailed understanding of surface renewal on turbulent surfaces.
Relevant to:

- Uchida Correlation
- Condensation
- Containment analysis
- Interface shear
- Validate multiphase CFD codes

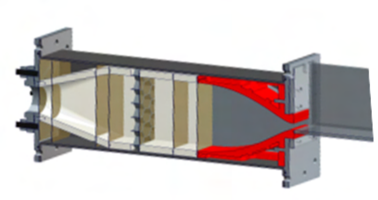
Experiment Objectives

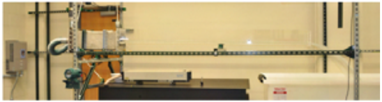
- Gain (new) physical insights into micro-scale effects of surface turbulence
- Provide high-spatio-temporal resolution and tractable validation data
- Need canonical flow with access to bulk of the flow

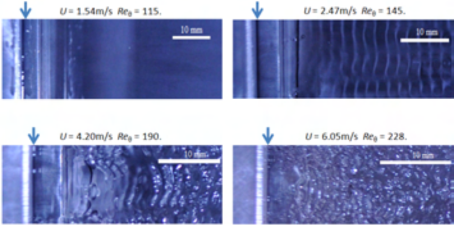
Experimental approach:
In Boundary Layer Instabilities, resolve:

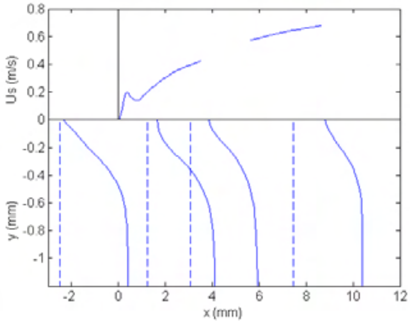
- gas and liquid velocity fields
- surface profiles
- effect of shear below an interface
- surface renewal rate

Facility Design

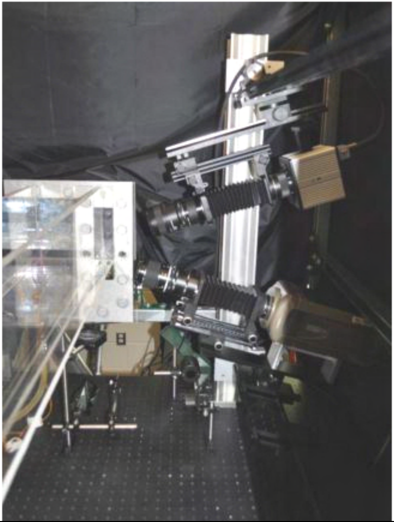


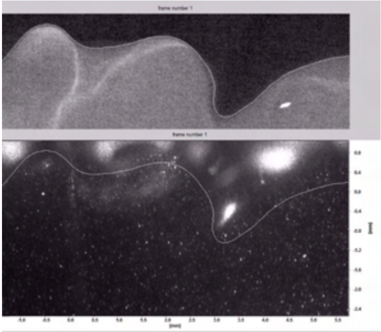






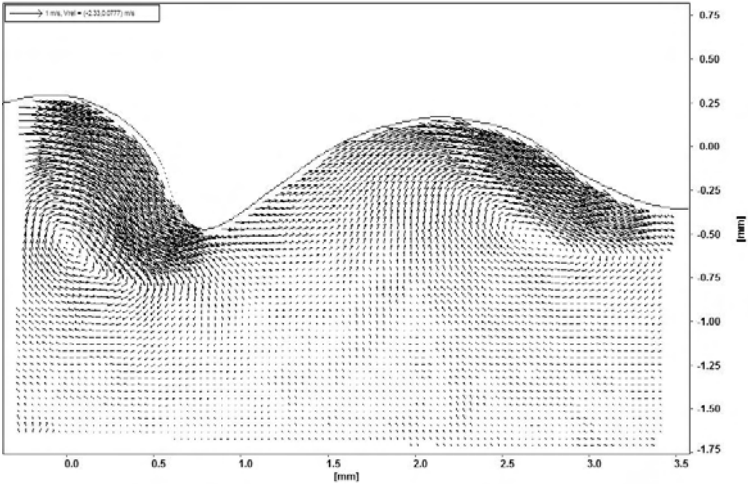
Combined PLIF/PIV Optial Setup





- High-spatiotemporal resolution PLIF
  - use PIV Nd:YLF laser with dedicated camera
  - High resolution high-speed camera
  - Interface location based on gradient

μ-PIV Resolution

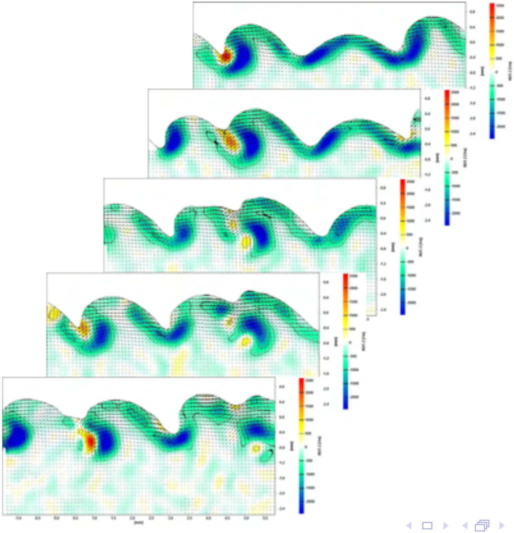


$$U = 2.36 m/s, \quad Re_\theta = 177, \quad 5mm$$

Vorticity Injection – PLIF

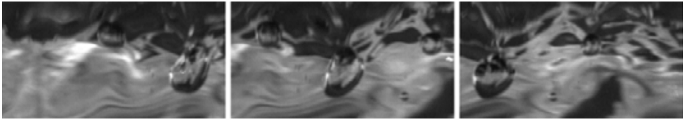
$$U = 4.51 m/s, \quad Re_\theta = 195$$

Vorticity Injection – PIV

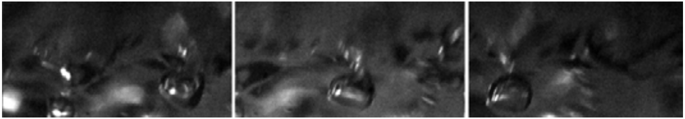


Air entrainment – Mechanisms

$U = 4.89 m/s$
$Re_\theta = 204$
$1 mm - \varnothing$ bubble



$U = 5.89 m/s$
$Re_\theta = 224$
$1.6 mm - \varnothing$ bubble



$U = 6.77 m/s$
$Re_\theta = 240$
$1.5 mm - \varnothing$ bubble

Summary

- GW is expanding its research on nuclear science, technology, and policies
- US NRC grant has been a tremendous catalyst to developing new curriculum
- New Science and Engineering Hall will contribute to expansion of courses and research
- Thermo-Fluids Lab is developing:
  - New non-intrusive diagnostics
  - New understanding of Fluid-Structure Interactions
  - New correlations for steam condensation in presence of non-condensable gases