CFD Modeling of Macro Scale Ultrasonic Separator

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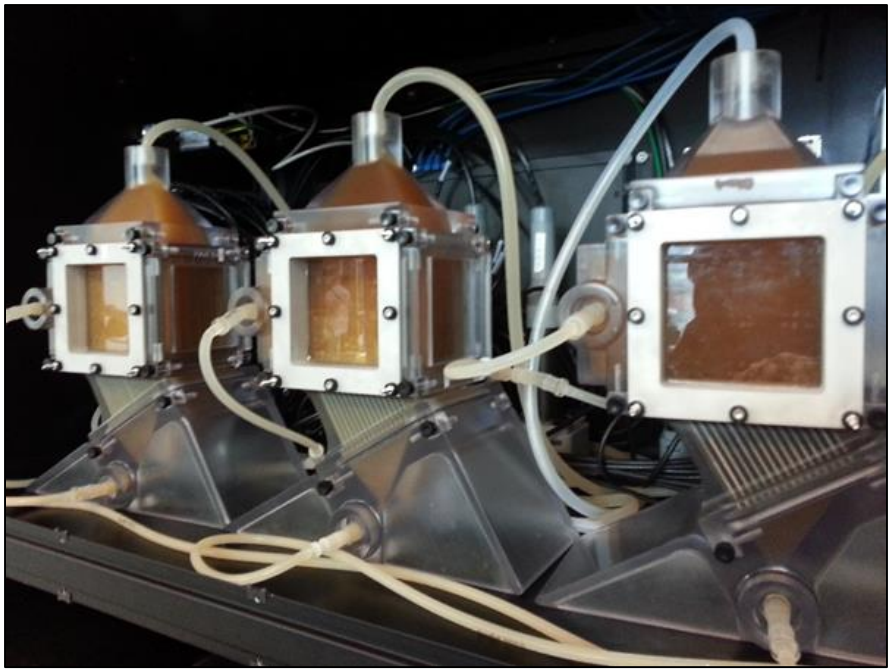
FloDesign Sonics

FloDesign Sonics

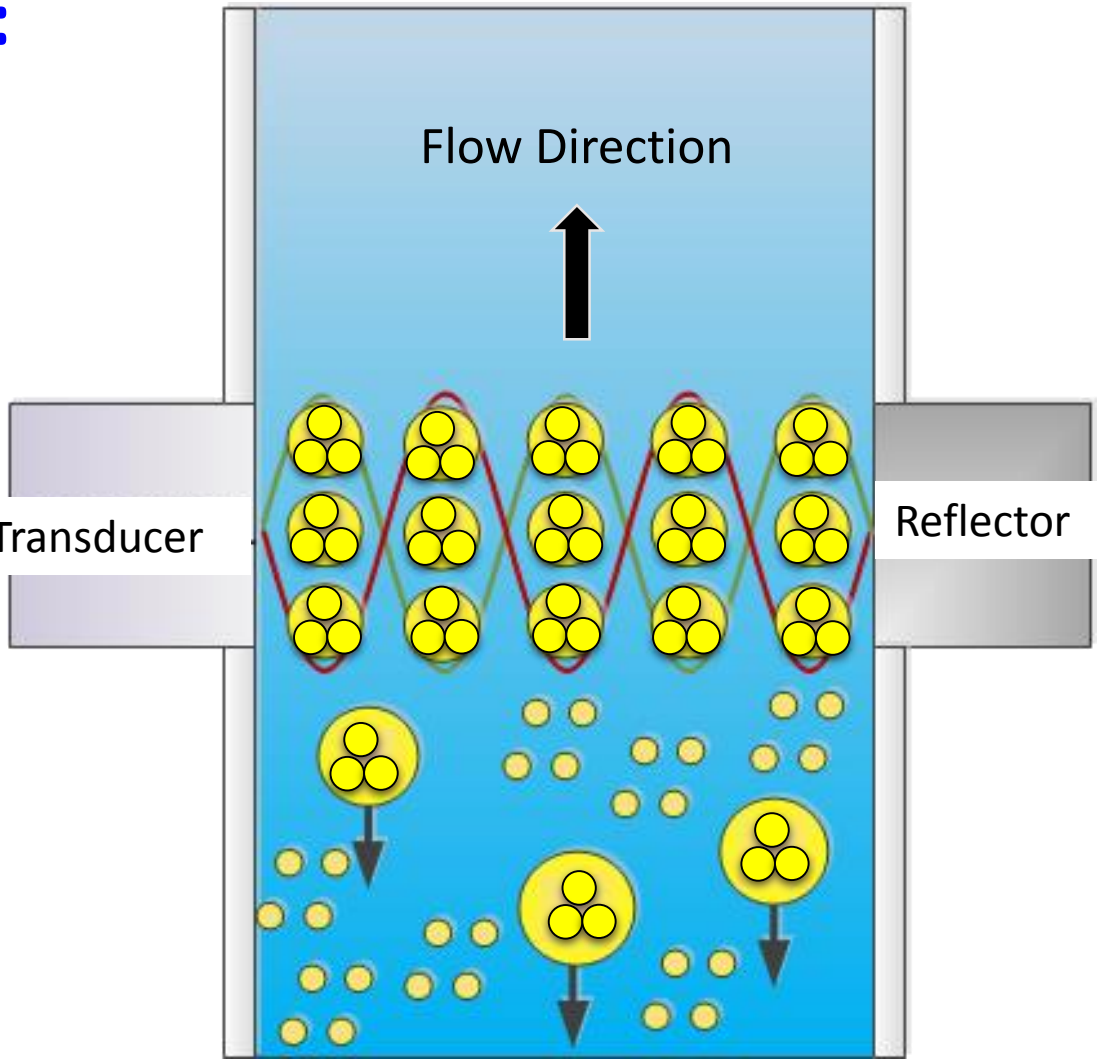
- Based in Wilbraham, MA
- Using acoustics to separate particles from fluid
- Applications
  - Bio-pharma: Purification
  - Industrial: Oil-water
  - Life Sciences:
    - Blood-lipid
    - Cell concentration and washing
    - Fractionation
- Advantages
  - Continuous & Single Use
  - No clogging or fouling
  - No shear
  - Scalable
  - It's cool!



Macro Acoustics Separator

Acoustophoretic Separation:

- Generation of multi dimensional standing wave
- Cells enter flow channel
- Acoustic forces trap cells from flow
- Acoustic forces cause cell clumping
- Increased buoyancy causes cells to drop



Particle Forces

- Acoustic radiation force[1]

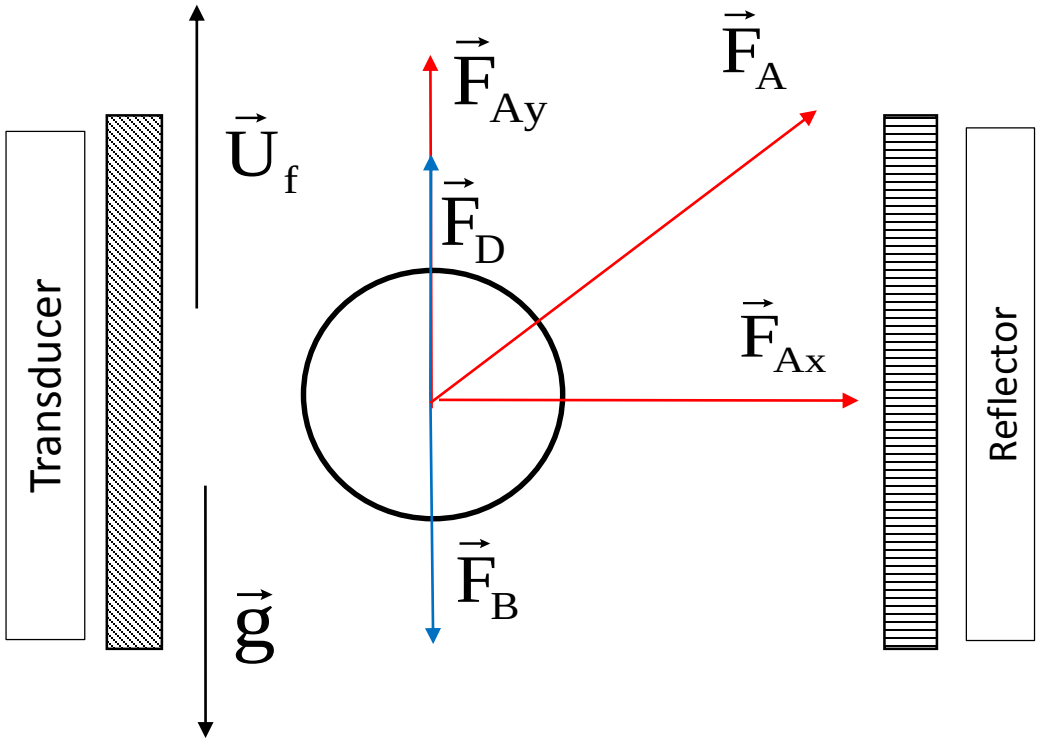
$$\vec{F}_{Az} = i\pi K k^2 \sum_{n=0}^{n_{\max}} \sum_{m=-n}^{n} \frac{(n+m+1)(n+m)!}{(2n+1)(2n+3)(n+m)!} \left[A_n^* + A_{n+1} + 2A_n^* A_{n+1} \right] a_n^{m*} a_{n+1}^{m} + c.c.$$

- Viscous drag force

$$\vec{F}_D = 6\pi\mu_f R_P \left(\vec{U}_f - \vec{U}_P \right)$$

- Gravity/Buoyancy force

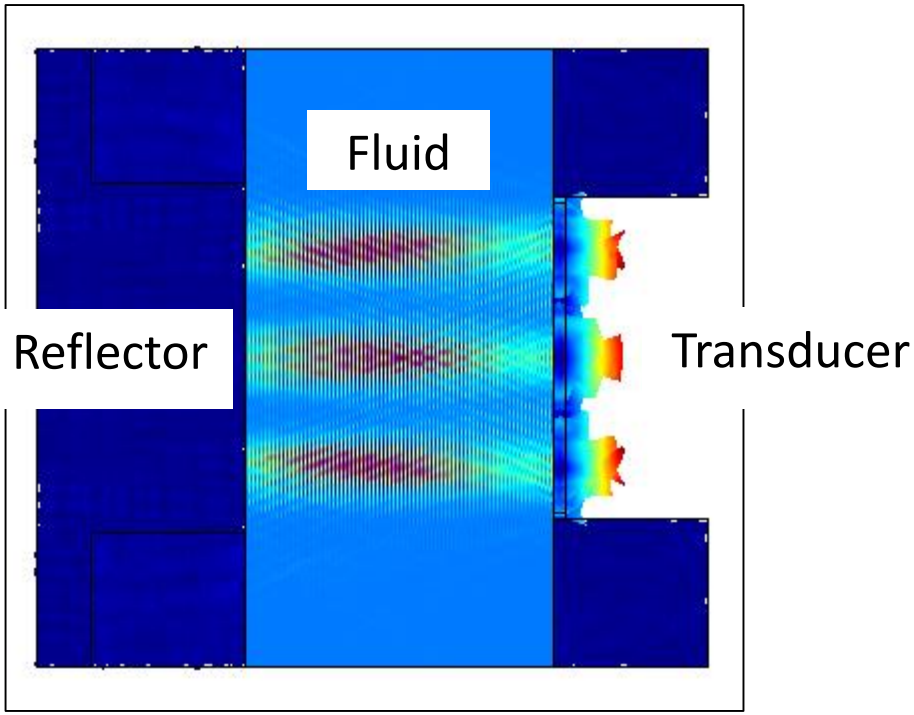
$$\vec{F}_B = \frac{4}{3}\pi R_P^3 \left(\rho_p - \rho_f \right) \vec{g}$$



1. Y. A. Ilinskii, E. A. Zabolotskaya, M. F. Hamilton, "Acoustic radiation force on a sphere in tissue", *AIP Conference Proceedings*, Vol. 1474 1, p. 255-258, (2012).

Cluster Dropout

- Cylindrical shaped clusters

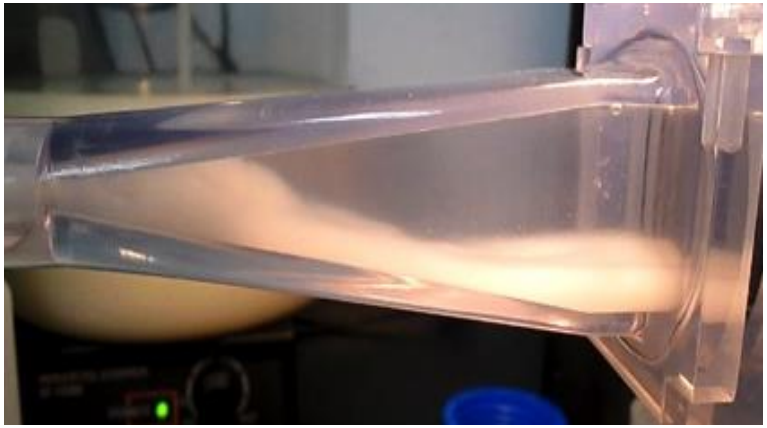


Macro Scale Fluid Phenomena

- Reynolds number effects
  - Chamber Re = 5-20
  - Particle Re = 0.001-1
- Multiphase effects:
  - Suspensions of 0.1-10% volume concentrations
- Gravity driven flows
- Particle size: 1-20um
- Local high concentrations
- Fluid dynamics and interaction with acoustics

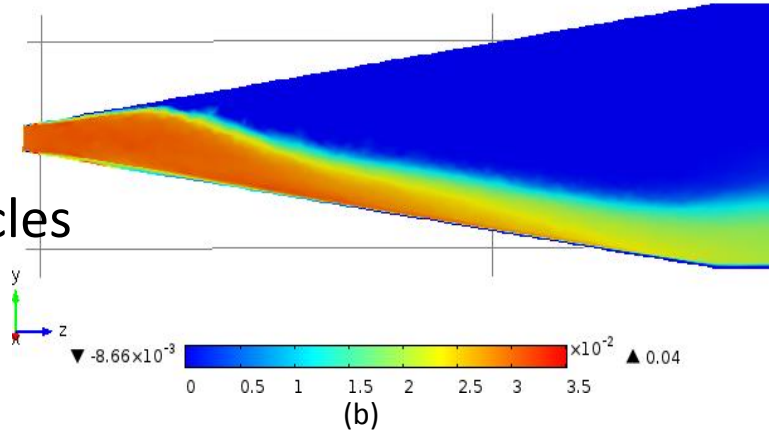
Flow Modeling

- Multiphase Flow: Mixture Model
- Gravity effects dominant

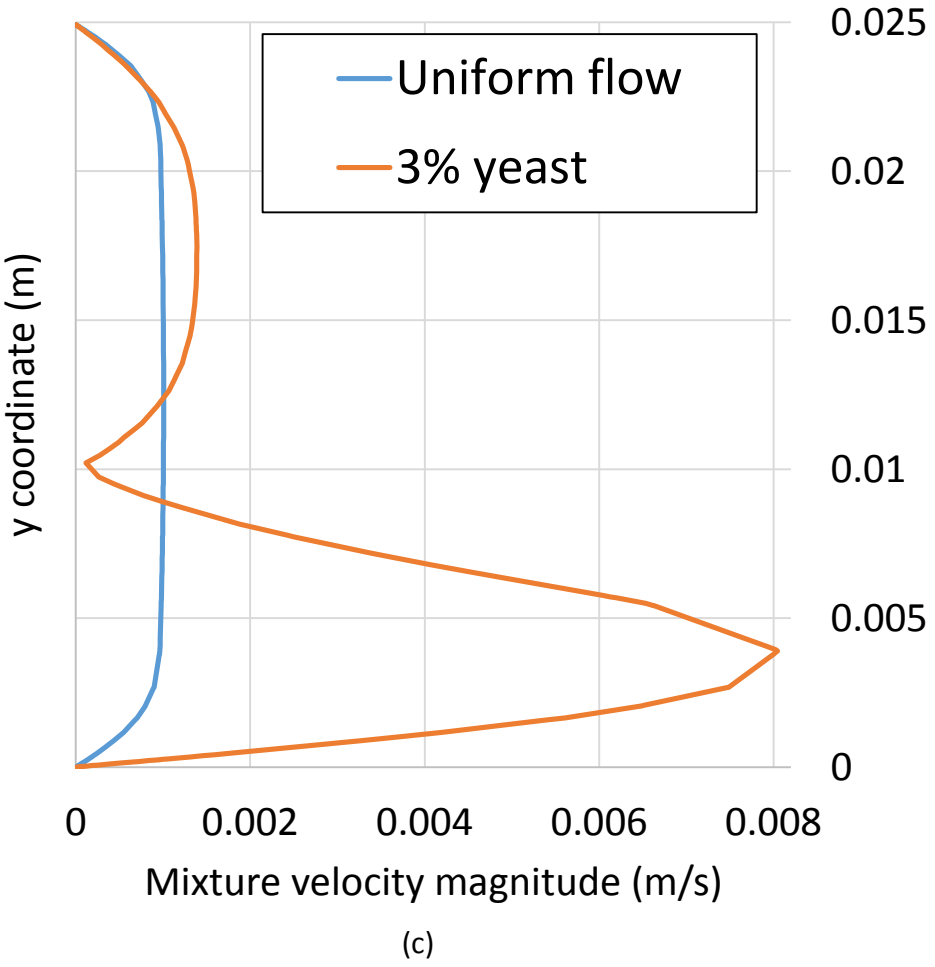


(a)

Volume Fraction of particles



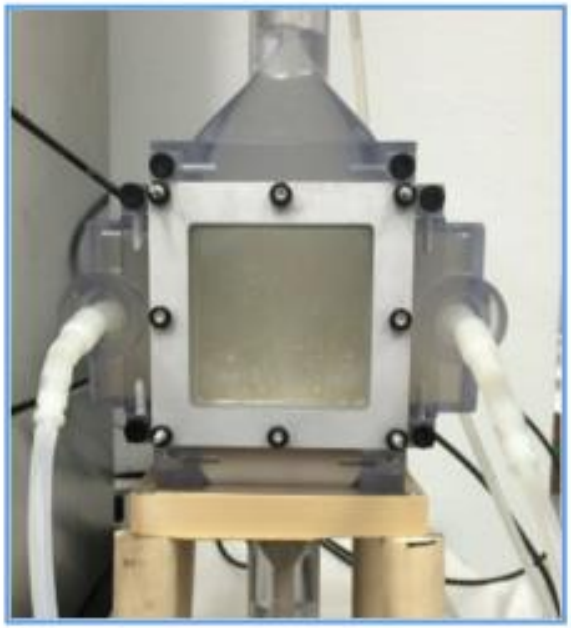
(b)



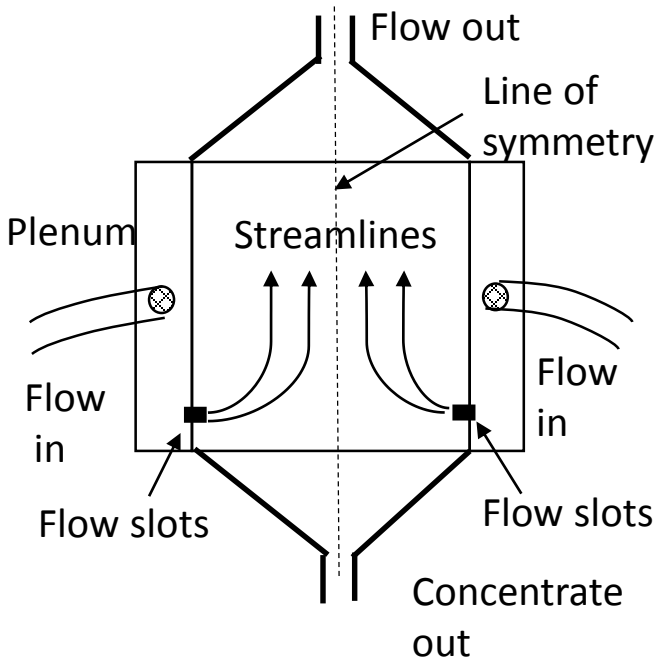
(c)

Flow Modeling

- Scaled up vertical idea for higher throughput



(a)



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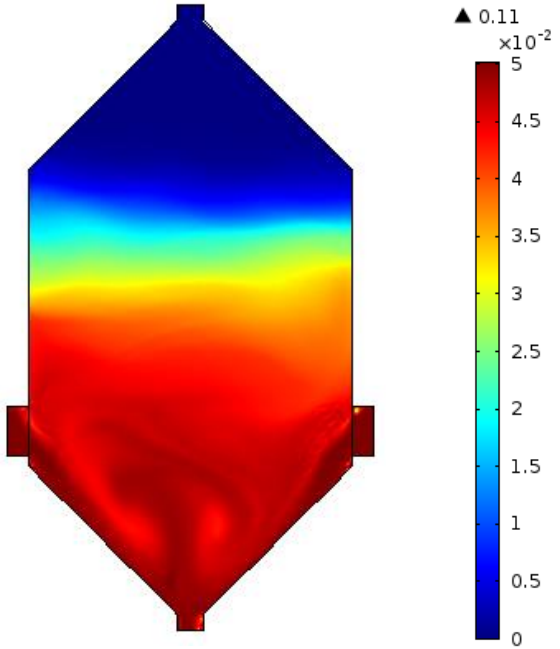
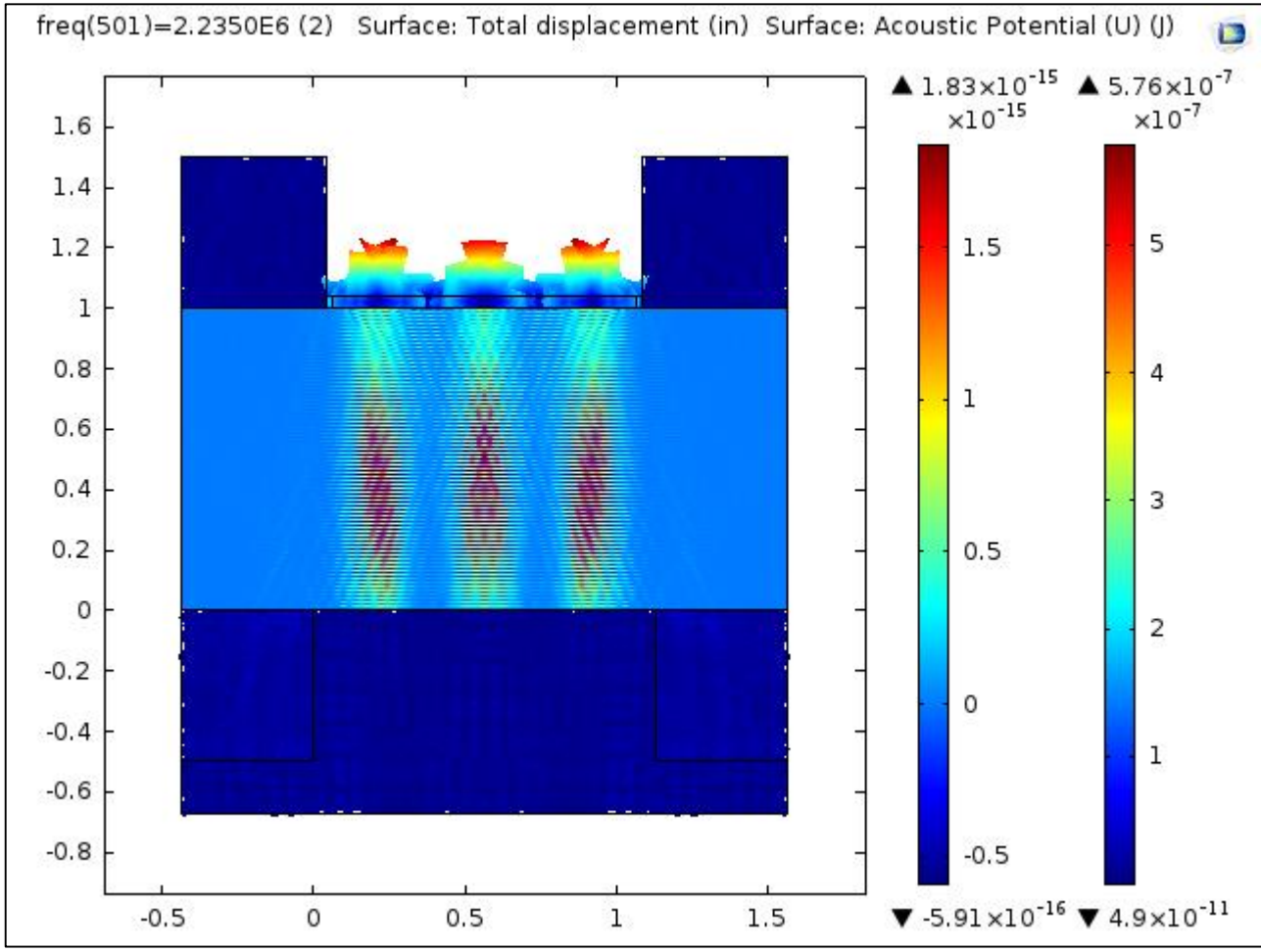


(c)

(a) Experimental setup, (b) Sketch of concept, (c) CFD predictions of volume fraction

Acoustics Modeling

- 2D and 3D COMSOL Models
  - Piezo-electric-acoustic interface with electric circuit
  - Viscous fluid model
  - Frequency domain
  - Calculation of lateral and axial forces



Crystal Vibration

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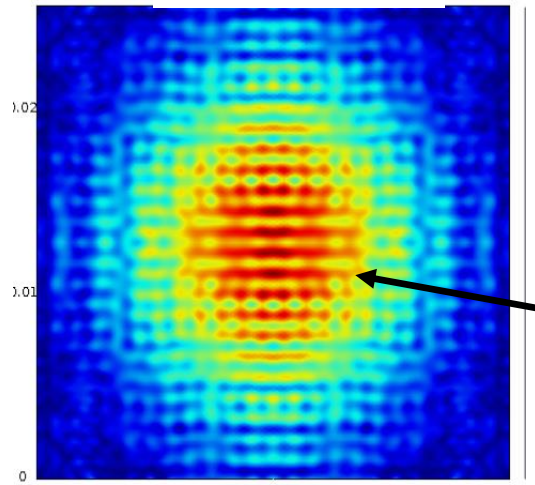
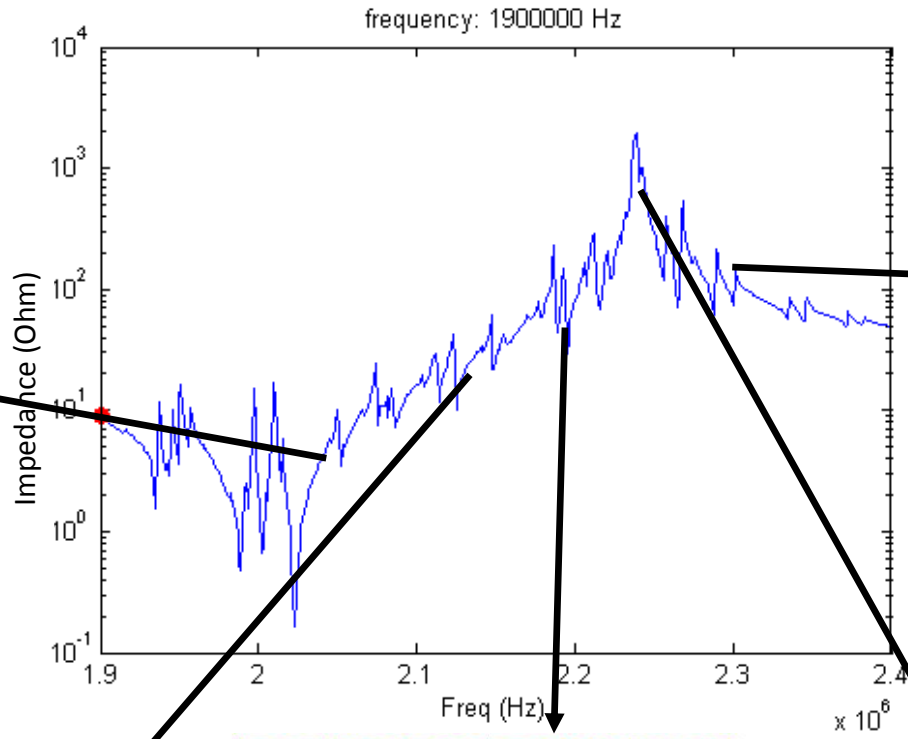
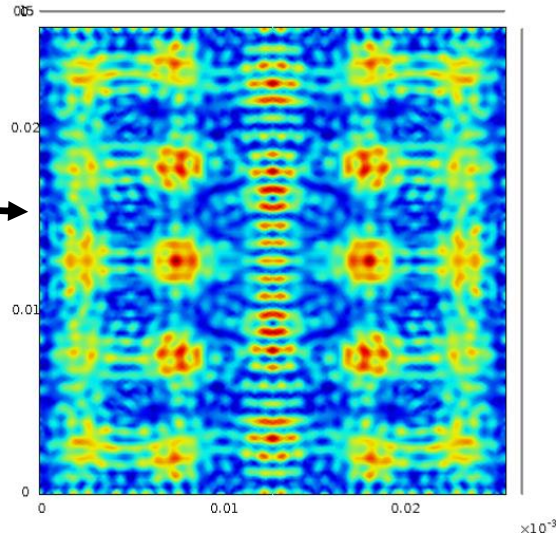
3D Piezoelectric Model, 1”x1” Crystal, 2MHz PZT-8

1x1 Mode

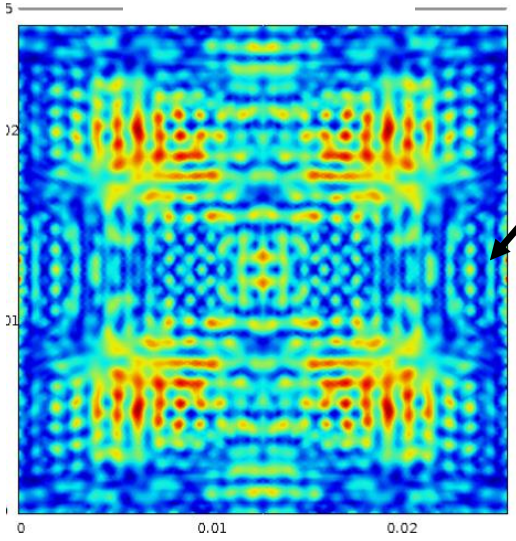


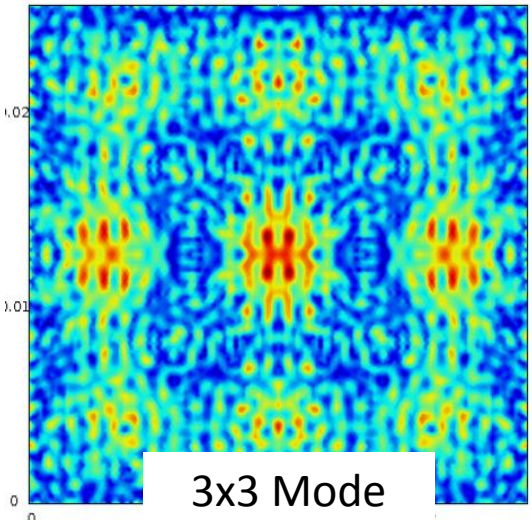


5x5 Mode



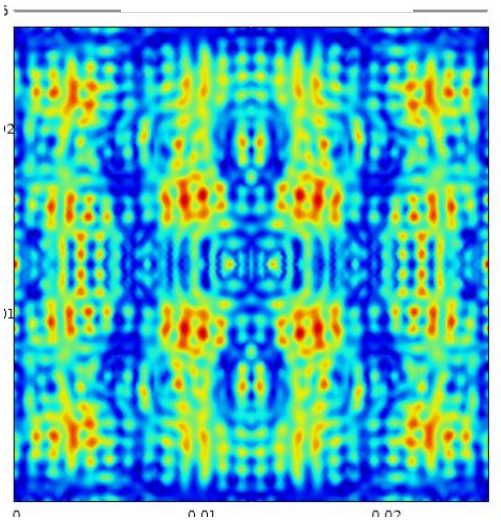
2x2 Mode





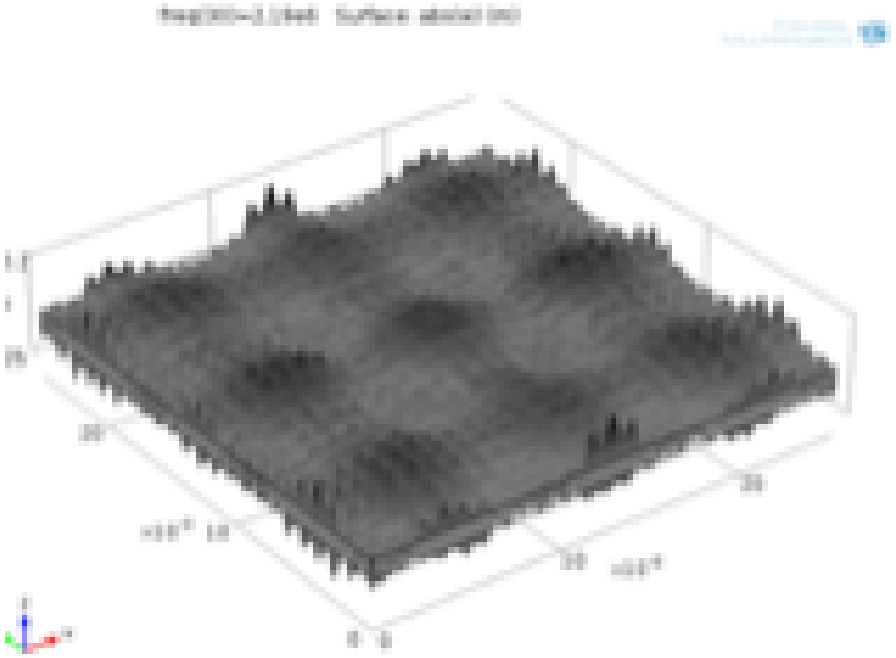
3x3 Mode

4x4 Mode



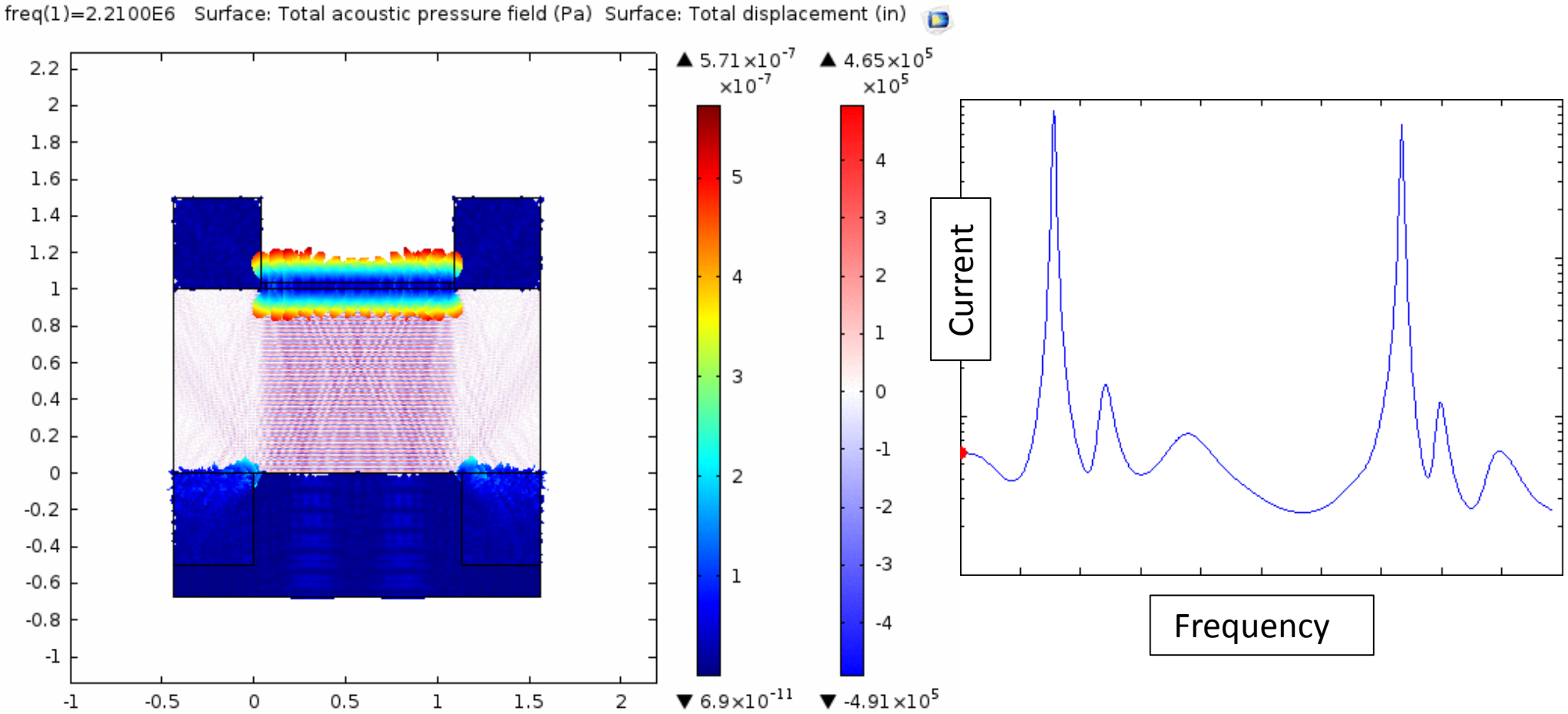
Multi-Dimensional Wave

- 3D mode of vibration generates a multi-dimensional standing wave
- PZT-8 transducers excitation near eigenfrequency



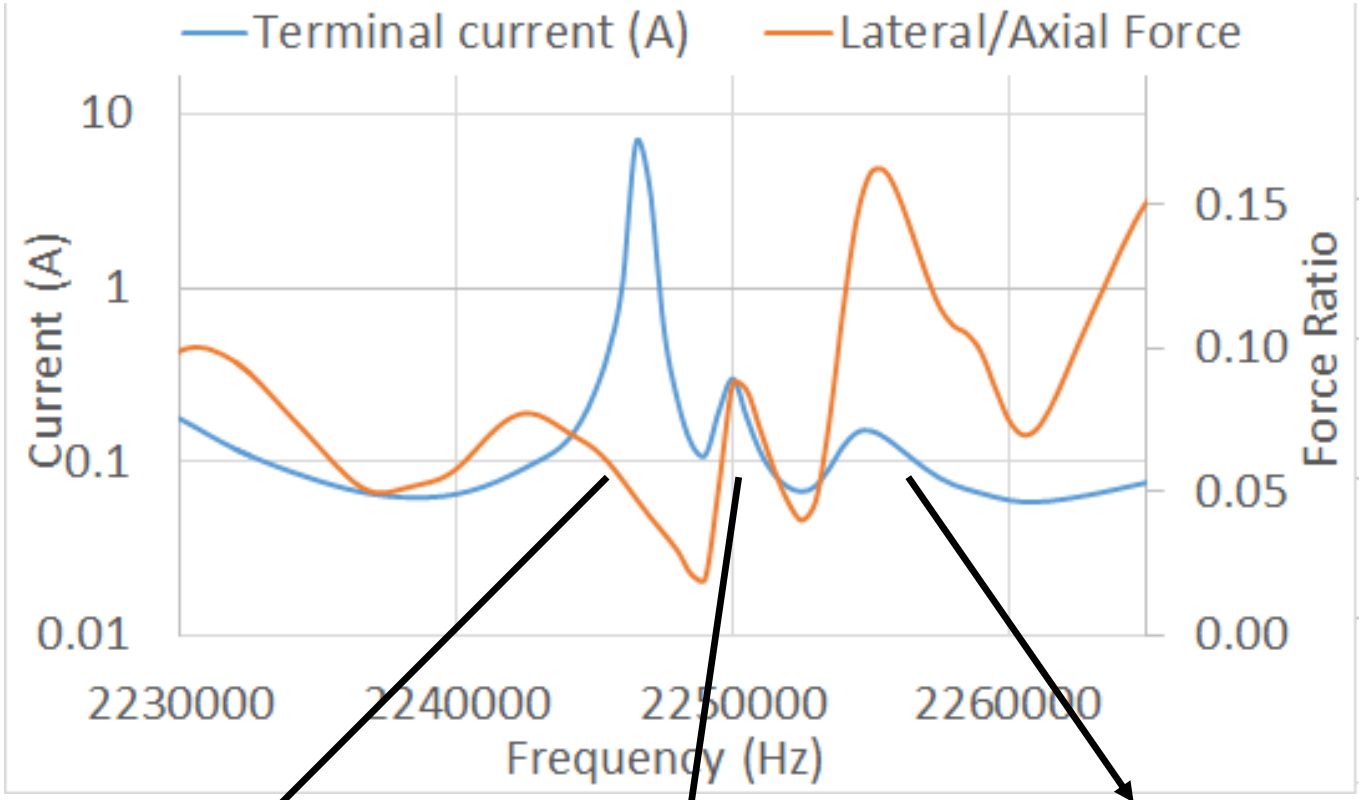
Multi-Dimensional Wave

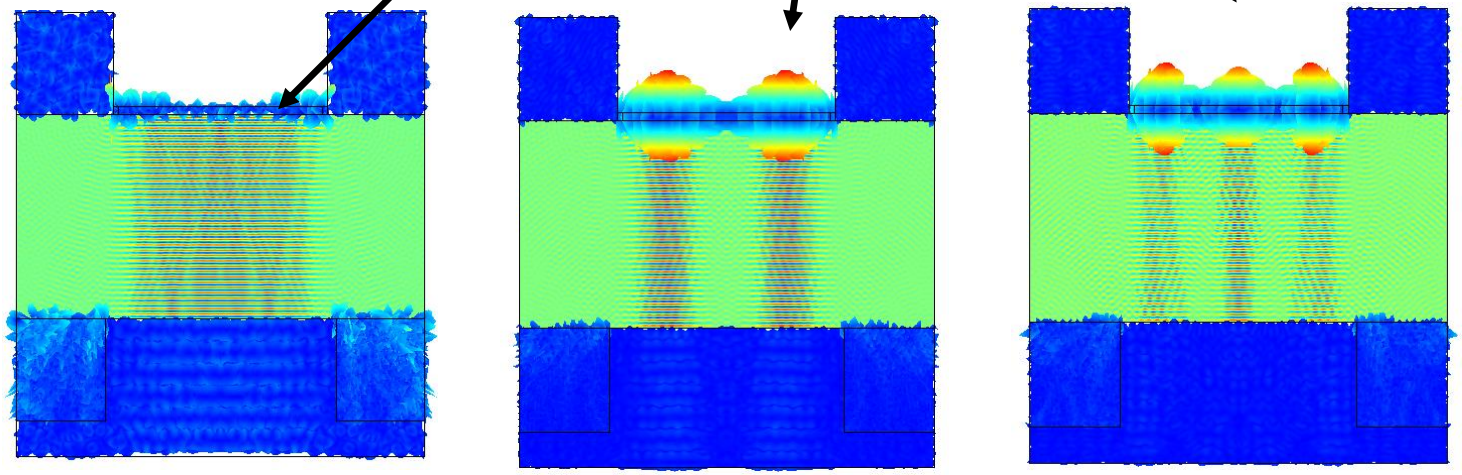
2D Piezoelectric-acoustics interaction Model, 1”x1” Crystal, 2MHz PZT-8



Multi-Dimensional Wave

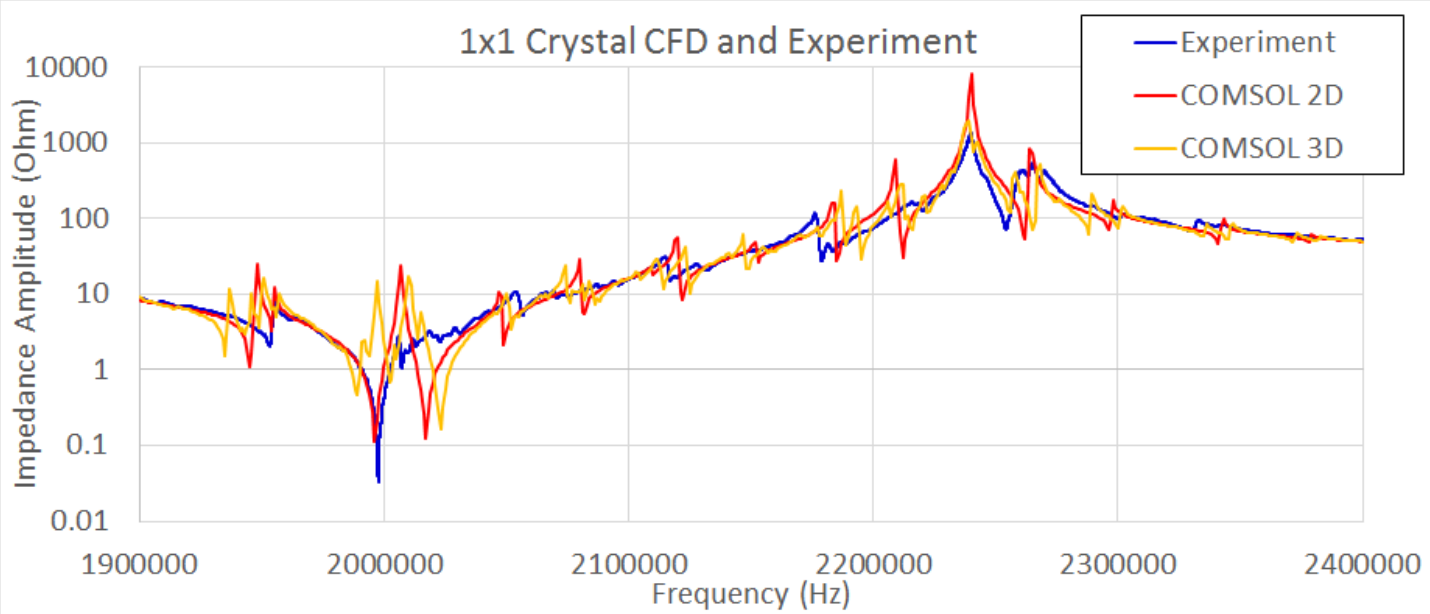
- Larger Lateral to Axial force ratio at multi-modal operation
- Higher trapping of particles results in greater efficiencies



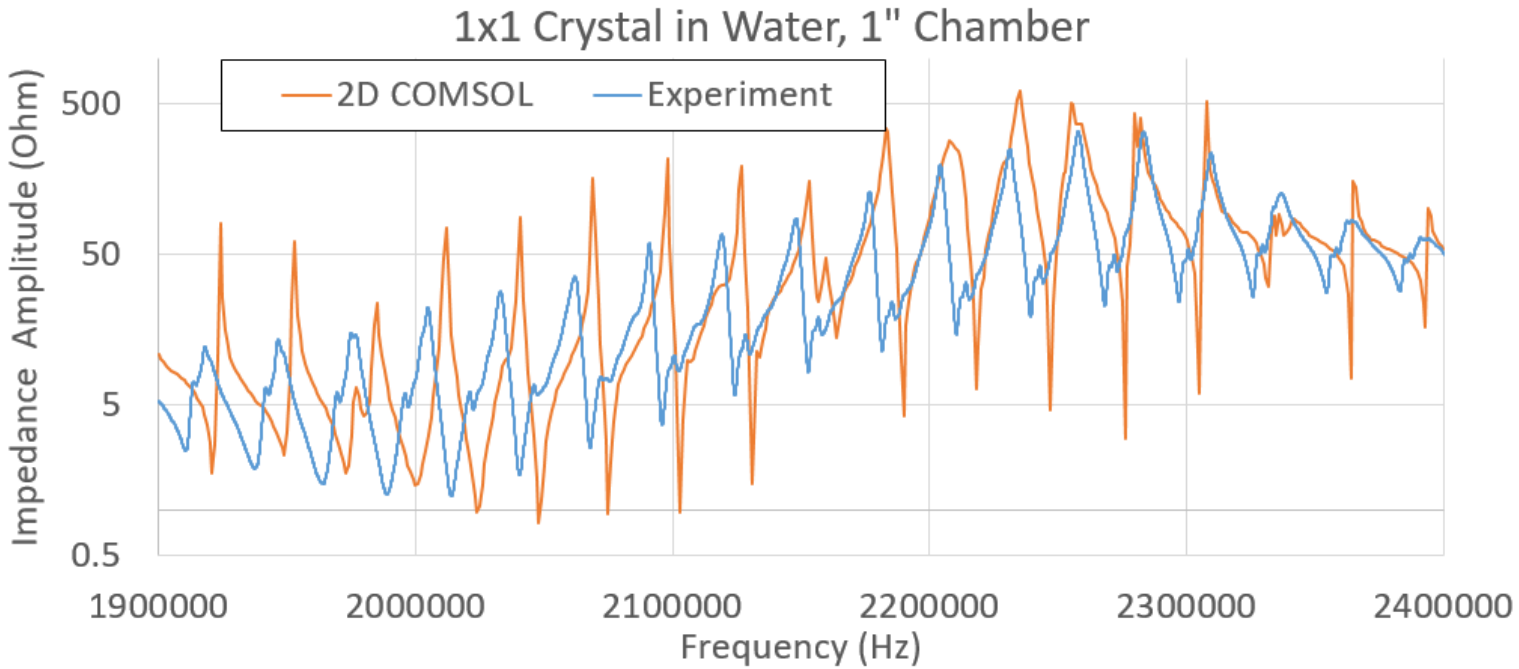


Comparison with Experiments

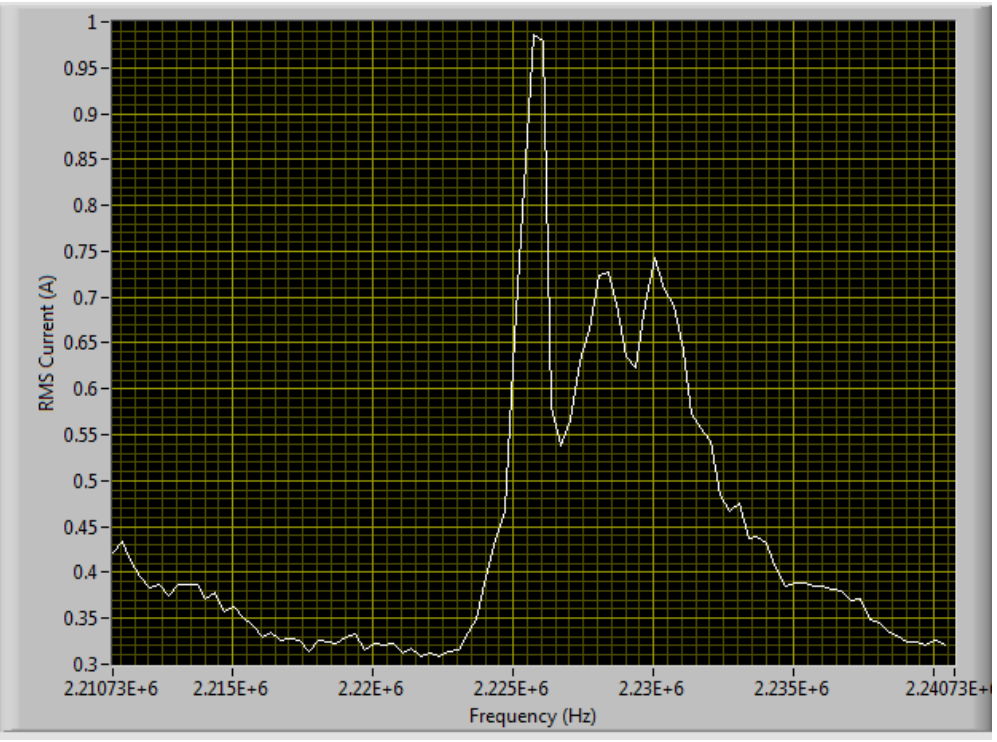
Response of a 2MHz PZT-8 crystal (3D)



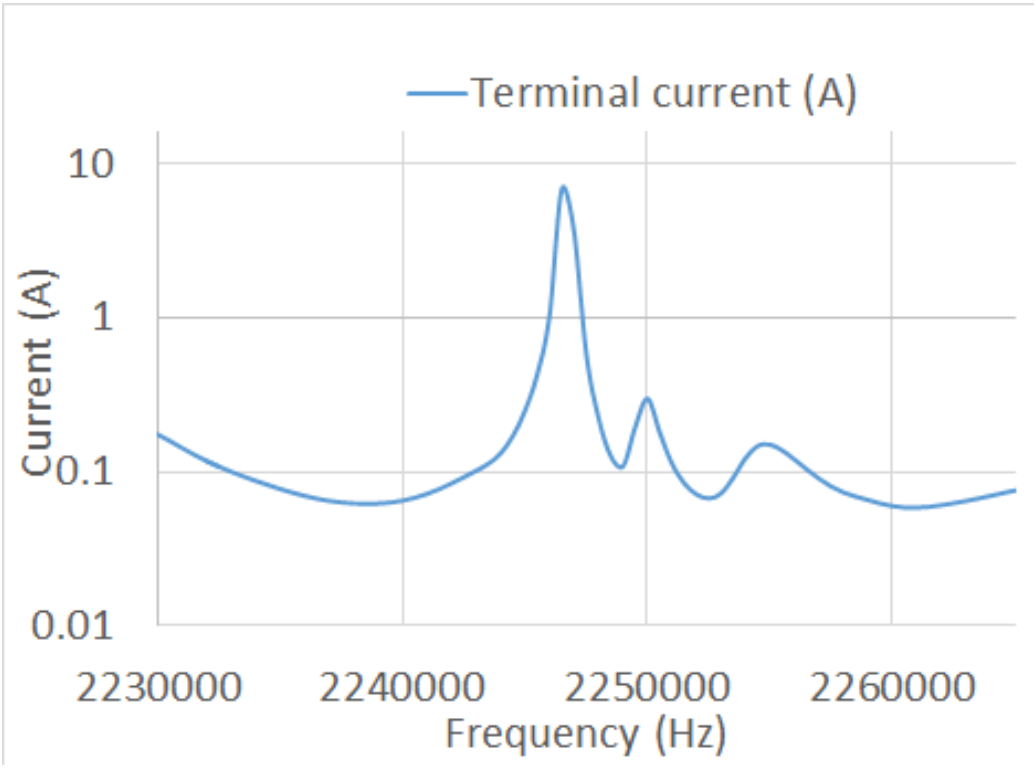
Response of a 2MHz PZT-8 crystal in water (2D)



Comparison with Experiments



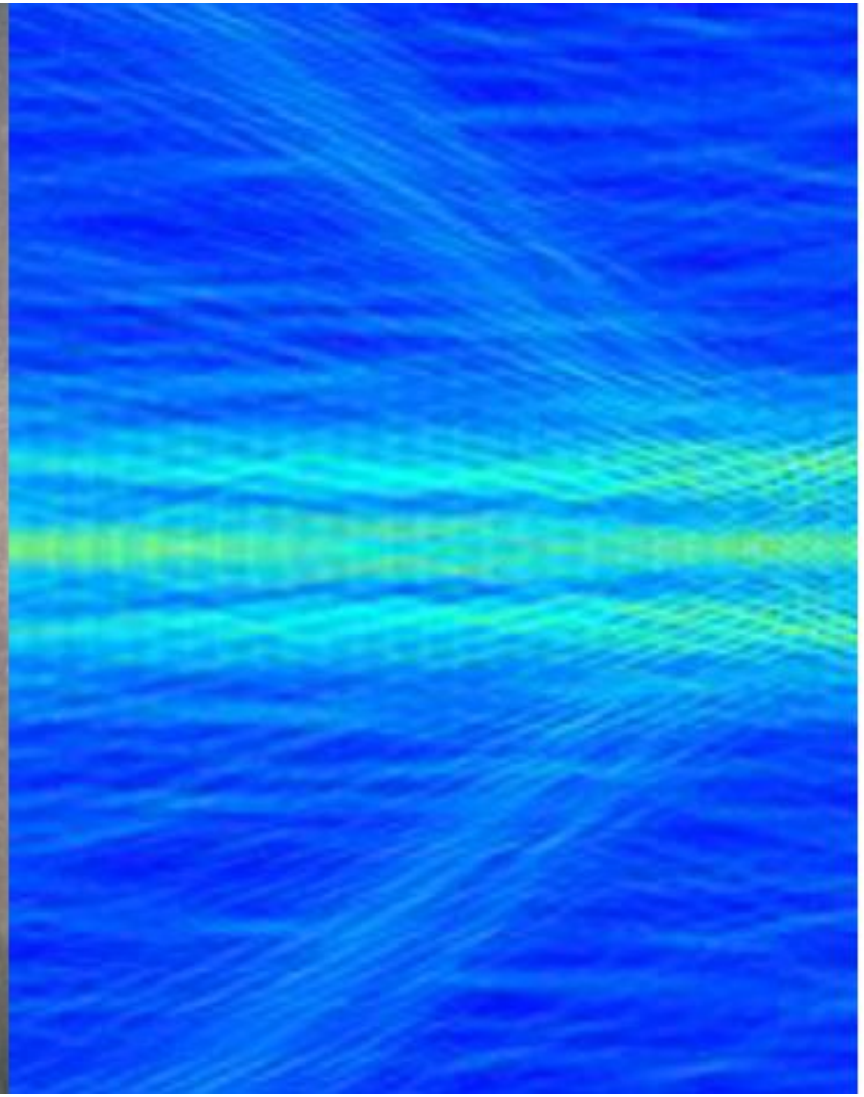
Experimental current response with frequency



Simulated current response with frequency

Comparison with Experiments

Experimental trapping of oil particles



Simulated forces in COMSOL

Advanced CFD Modeling

- Particles move to nodal planes as soon as they enter
- Particles trap and eventually form clusters

Summary

- Vertical systems have a fluidic advantage
- Multi-dimensional acoustic standing wave critical
  - Particle trapping
  - Cluster growth
  - Continuous gravity/buoyancy separation
- COMSOL a great resource for optimizing the system
- Need advanced modeling to get full picture

THANK YOU!

Questions?