Near-wall dynamics of microbubbles in an acoustical trap

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Microbubbles

- Micron-scale radius bubbles, typically of inert gas with a thin polymer or lipid shell
- Used as ultrasound contrast agents and as a drug delivery mechanism via sonication
- Potential to work as microscale sensors
    - Move & excite acoustically, analyse reradiated signal to understand environment bubble is in.
- Understanding interaction between microbubbles, acoustic fields, and walls is key to future developments

Existing models

- Analytical models exist that assume radial symmetry
  - Predict radius change over time: bubble pulses
  - Can include bubble translation
  - Can include interaction with walls or other bubbles
  - Can simulate complicated shell behaviour
- Simplest model: Rayleigh-Plesset equation
  - Spherical bubble with no shell in the middle of an infinite sphere of liquid

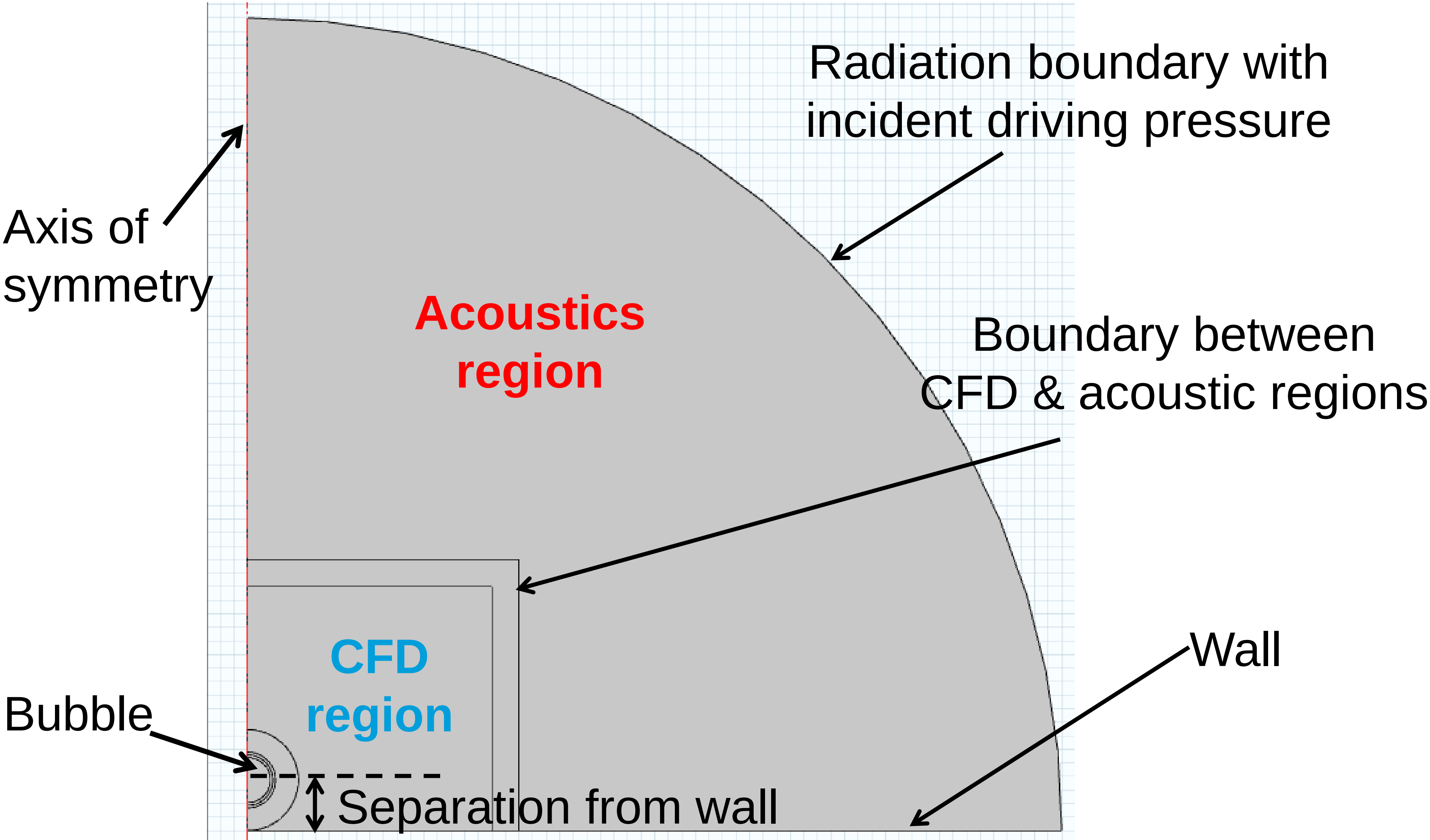
Need for finite element model

- Analytical models assume spherical bubble
  - Less likely when bubble is excited at near-resonance
  - Less likely when bubble is near a wall
  - Both of these conditions are likely to occur for the applications of interest
- Use FE to predict shape changes under acoustic excitation
  - Drive for developing & validating new analytical models?

FE model requirements

- Need to simulate a transient two-phase compressible flow with no mixing
  - Comsol CFD module: level-set method with compressible flow and surface tension
- Need to simulate domains much larger than the bubbles where little of interest is happening
  - Comsol Acoustics module: radiation boundary conditions allow scattered signal to leave, incident field capability allows excitation field to be included
- Couple via pressure & normal stress conditions

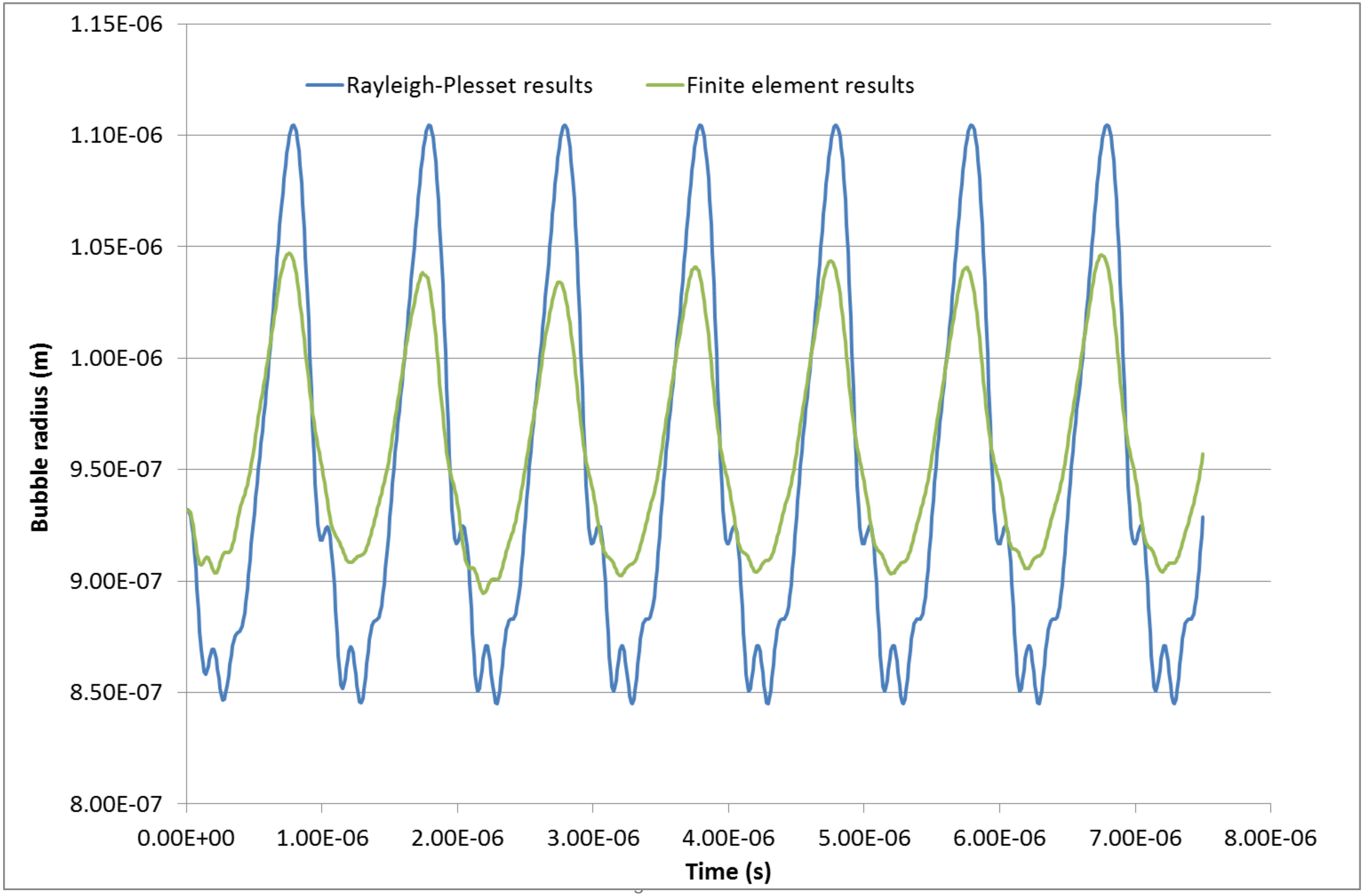
Axisymmetric model of a bubble near a wall



Initial development

- 0.932 micron radius bubble of compressible polytropic air in compressible water: neglect shell properties
- Driven by an incident pressure of 95 kPa at a single frequency over 7.5 microseconds.
- Start with a centred bubble (no translational motion)
  - Compare with Rayleigh-Plesset equation
- Place bubbles at various distances from the wall
  - Look at sphericity
- Test one frequency far from resonance (1 MHz) and one closer to resonance (2 MHz)
  - Linearised estimate of resonanace is 3.5 MHz

Comparison with Rayleigh-Plesset



Sphericity?

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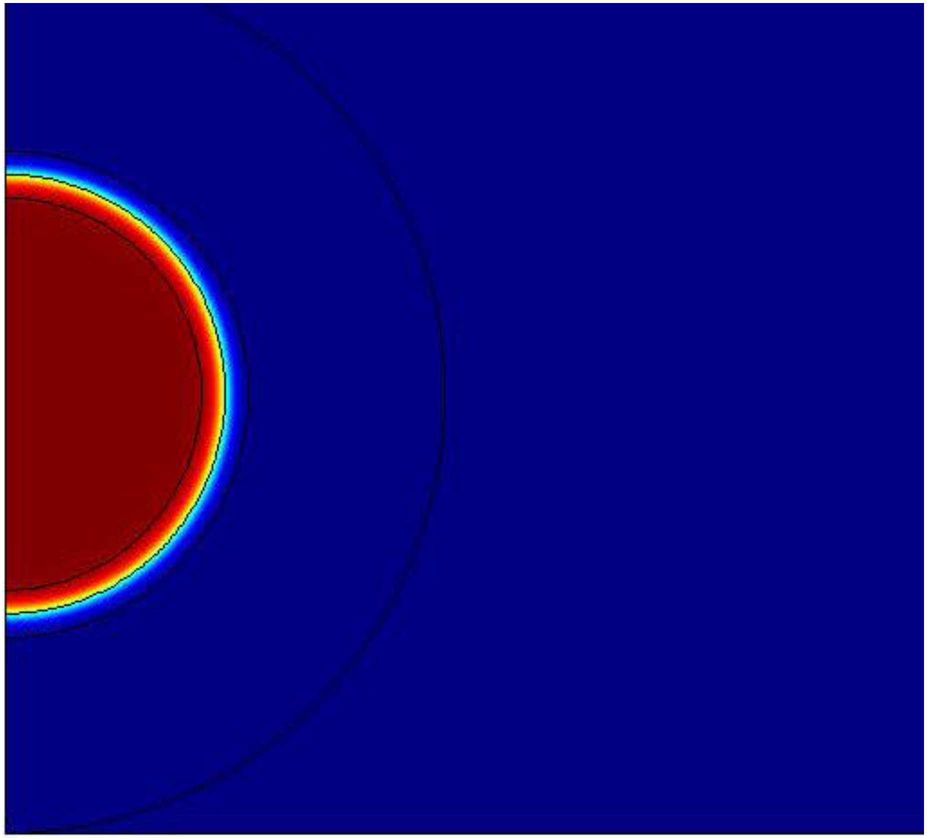
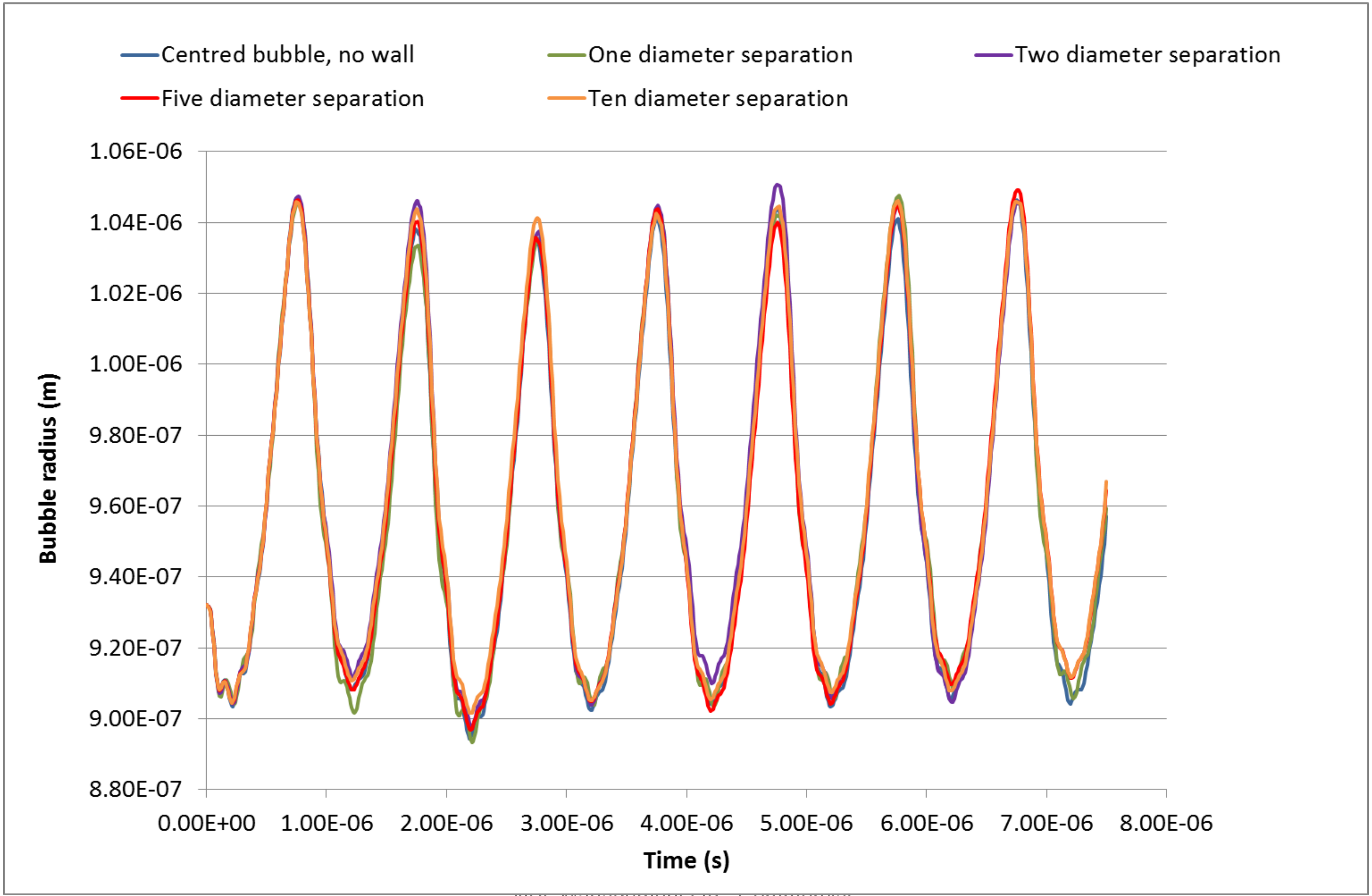
- All of the bubbles at 1MHz stayed spherical:
  - Ellipsoids fitted to isosurfaces showed less than 0.5% difference between semi-axes throughout
  - Separation from wall did not affect sphericity
- Bubbles at 2 MHz did not complete run
  - Still working on why: high fluid velocity near the interface seems to cause a problem
  - Tried changing interface resolution parameter
  - Any advice gratefully received…

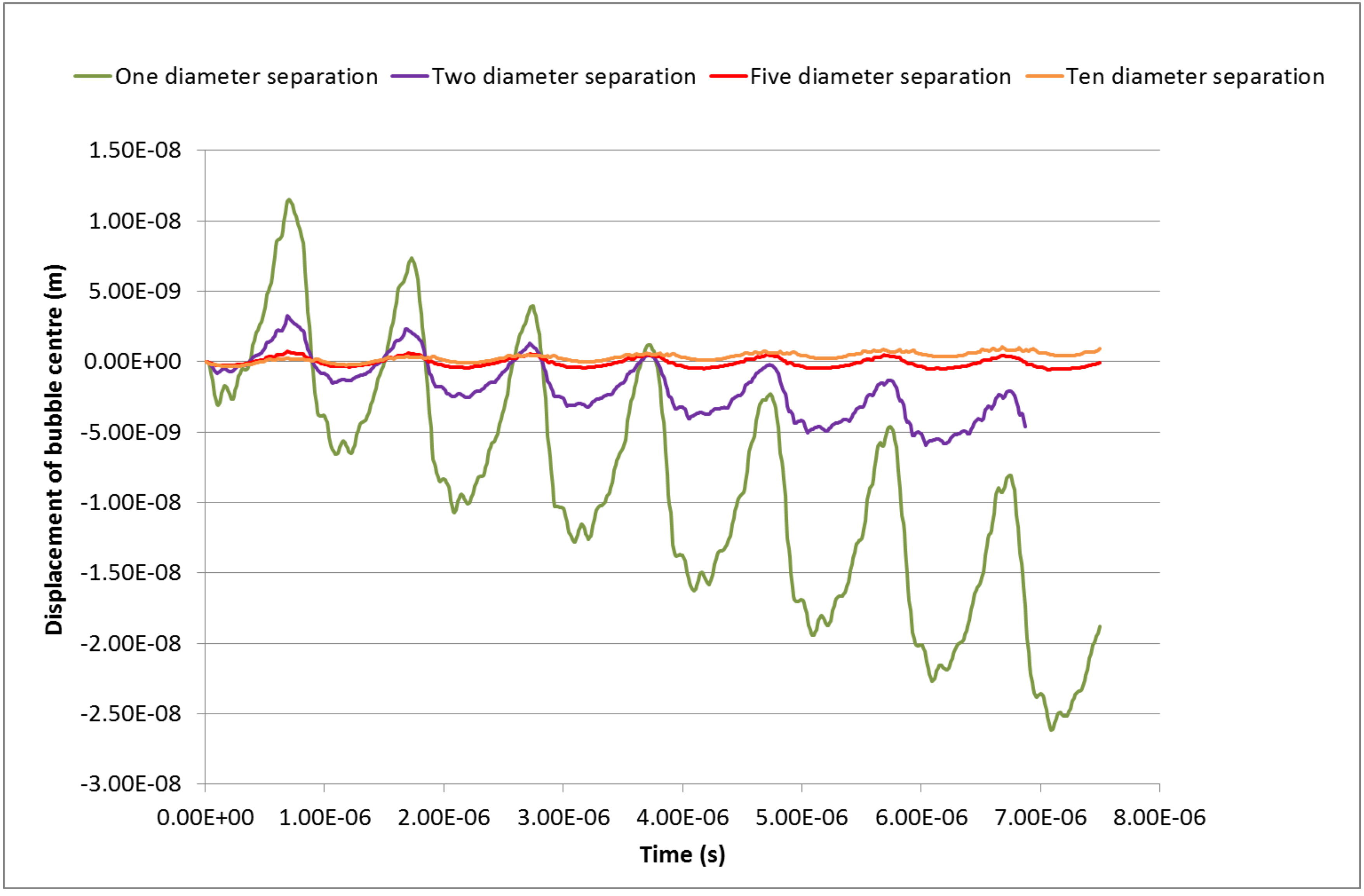
Typical behaviour



Effects of wall on radial oscillation



Effects of wall on centre motion



Why?

- Radial oscillation is largely driven by the time-dependence of the pressure amplitude
  - Pressure gradient across the bubble has little effect for this example
- Centre motion is largely driven by the pressure gradient across the bubble
- Analytical model for this behaviour is available
  - Requires proper characterisation of pressure to get reliable results

Conclusions and next work

- Comsol enables us to simulate the detailed shape of an acoustically excited microbubble by coupling modules
- Bubbles away from resonance stay spherical when excited
- Characterise pressure then compare FE model to analytical solution
- Extend to multiple frequencies to simulate experimental situation

Thankyou! Questions?