IB, IBARM and mitral valves

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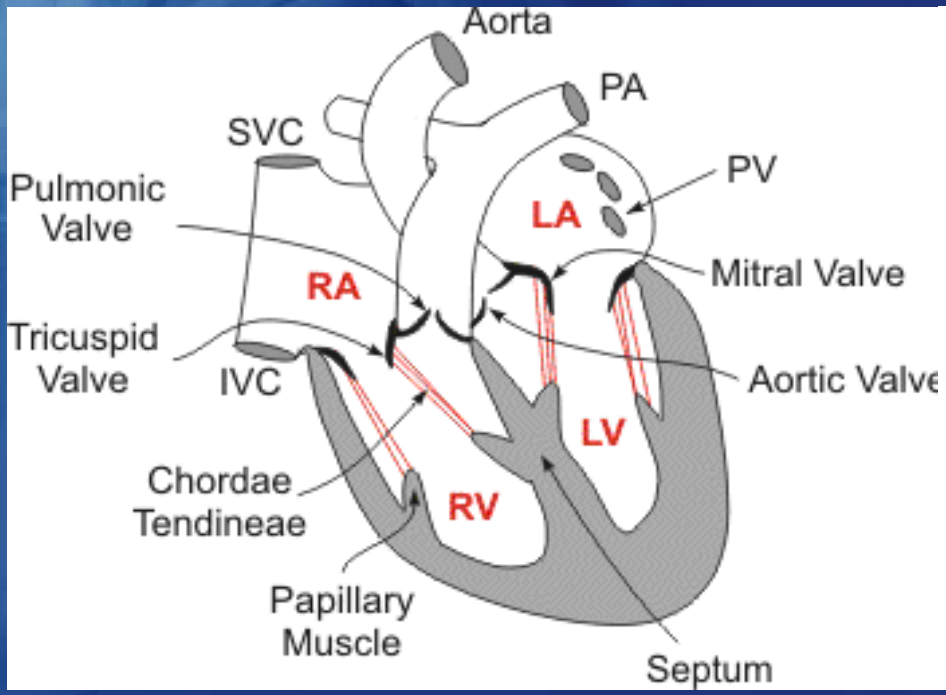
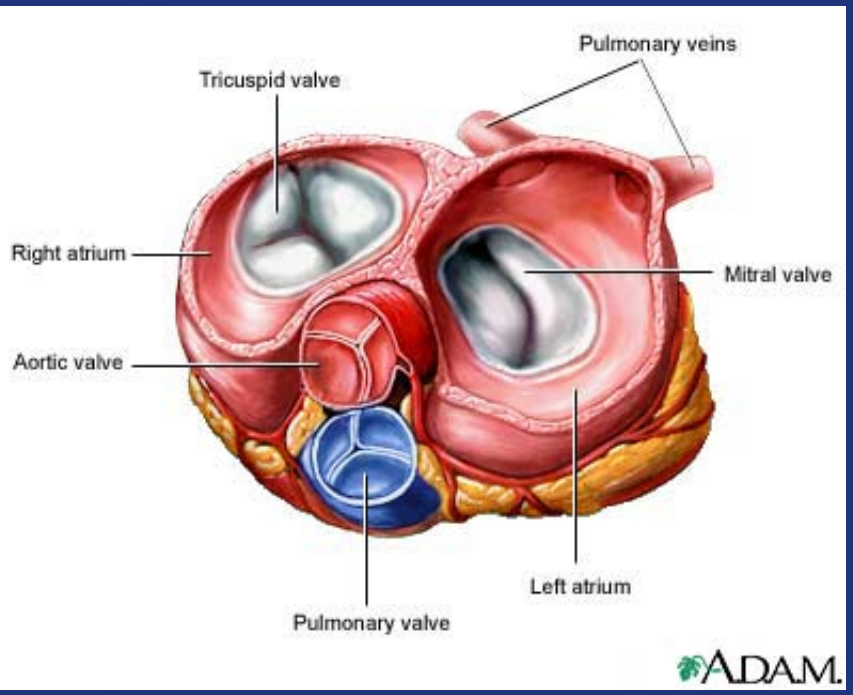
Mitral valve



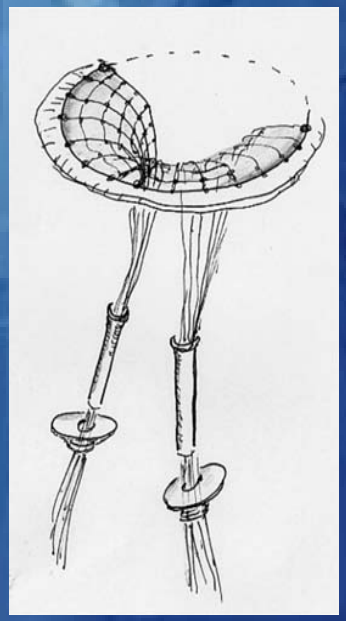


Typical diseases of MV: Mitral stenosis & mitral regurgitation.

Need to be repaired or replaced when damaged (225,000 replaced yearly world wide).

A New Bioprosthetic Mitral Valve

A new bioprosthesis (polyurethane) design developed by Dept. of Cardiac Surgery, University of Glasgow



D.J. Wheatley (2002), Mitral valve prosthesis Pat. no. WO03037227.

Benefits:

- durable
- no need for anticoagulation therapy,
- biostable (tested on sheep)
- based on real MV geometry, “similar” mechanical properties
- with chordae !

Immersed Boundary (IB) Methods-1

Old version: IB

Uniform Eulerian grid, 1st order approximation, no bending, solved with FFT, periodic BCs, Fortran code

Key results: reasonable agreement with experiments.
Highlighted problems in design (over-stretched posterior leaflet with chordae).
Modelling issues: Predicted opening pressure too high, valve over-opening, and not closing.

(Watton, Luo, Wang, Bernacca, Molloy & Wheatley JBM, 2007, Watton, Luo, Yin, Bernacca & Wheatley, JFS, 2008)

The IB valve modelling

GAMBIT

FEM model

→

FIBRE GENERATOR

→

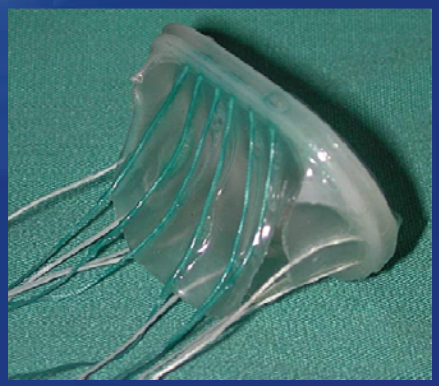
IB Solver

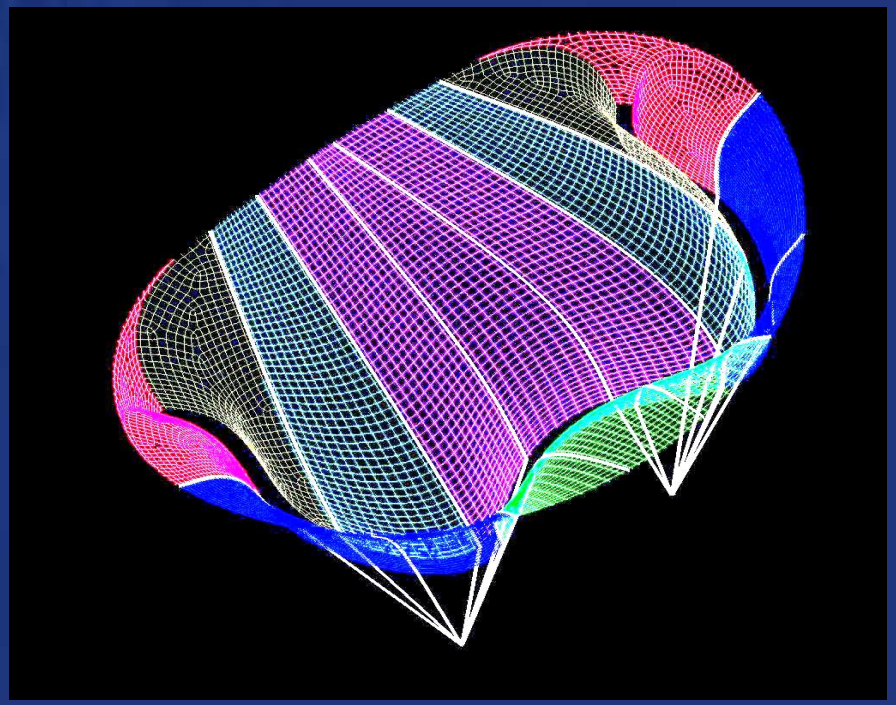
↓

Tecplot (graphics)

SOLIDWORKS (Valve Design) IGES file

↑

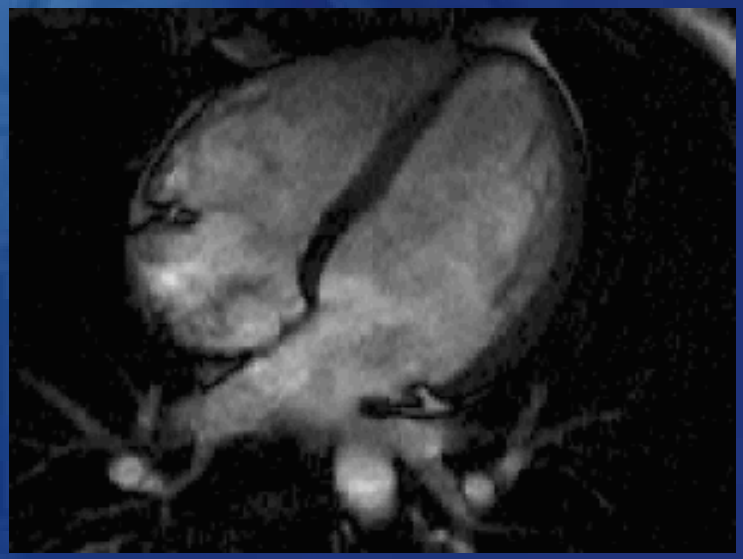


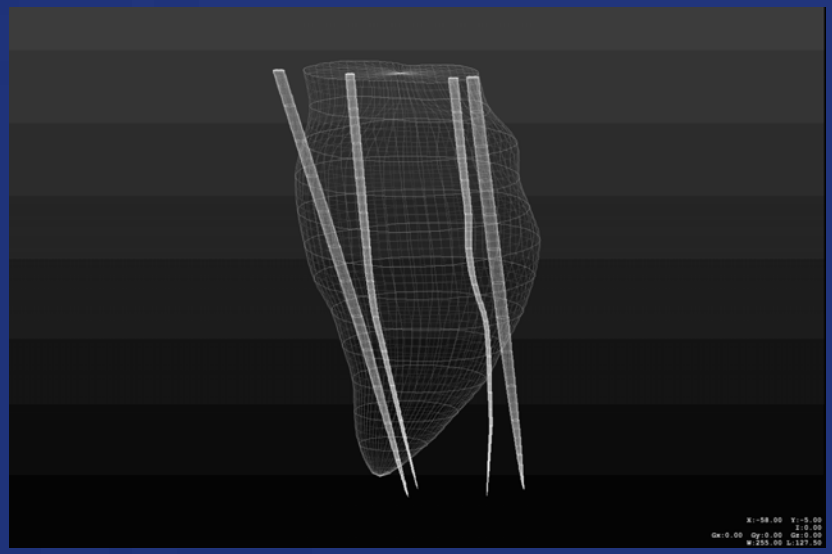


The mitral valve mesh

Polyurethane leaflets:
E = 5MPa,
h = 0.125mm
Chordae: E =30MPa,
Area = 0.4mm^2

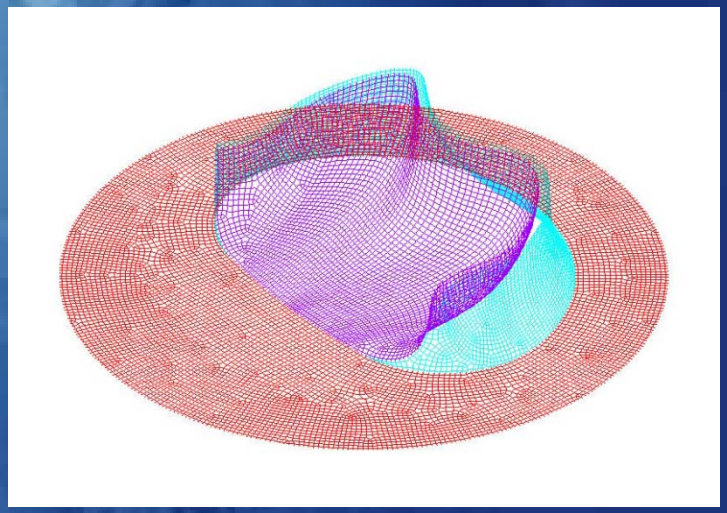
LV effects: modelled with IB
(with 1st order, no bending, and uniform mesh)

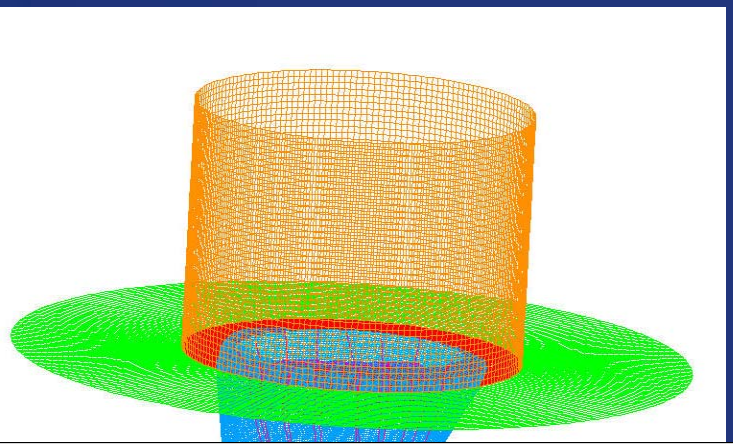


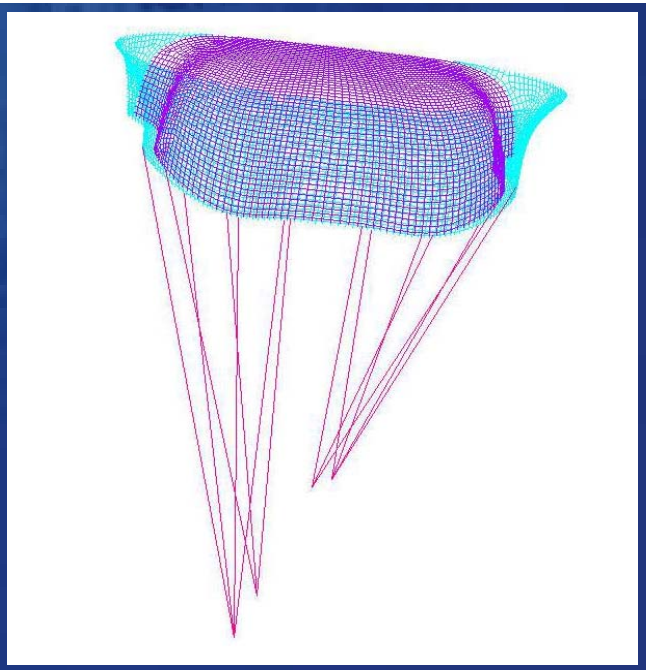


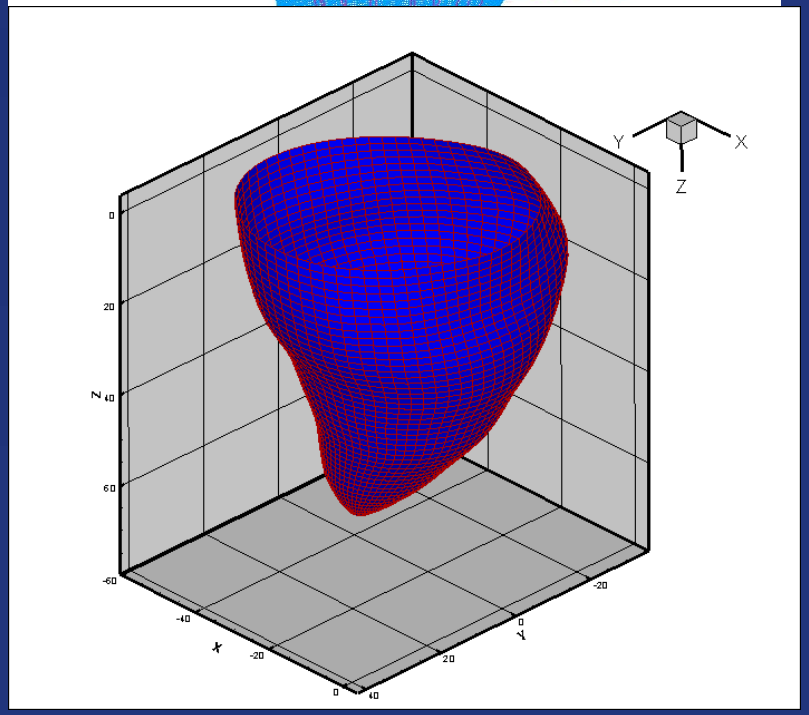
- Analyse Human MRI data with CMRTOOLS - software package for analysing Cardiovascular Magnetic Resonance (CMR) images (IC: www.cmrtools.com)
- Determine dynamic geometry of ventricle and papillary muscle axes.

The MV model is placed inside the moving LV

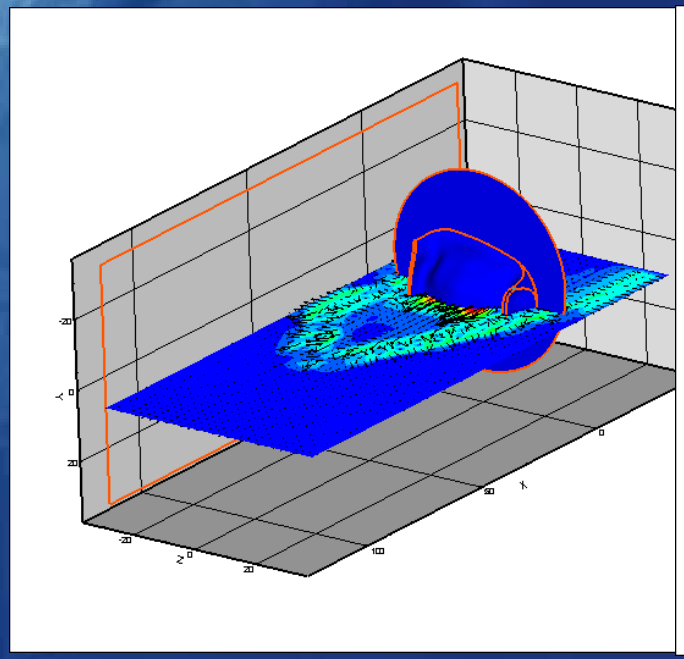




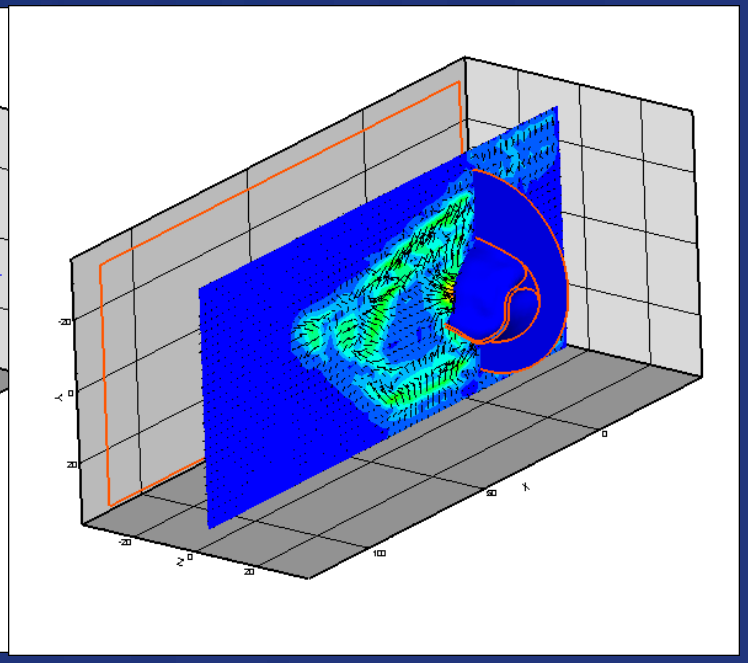




Flow vertex in the left ventricle



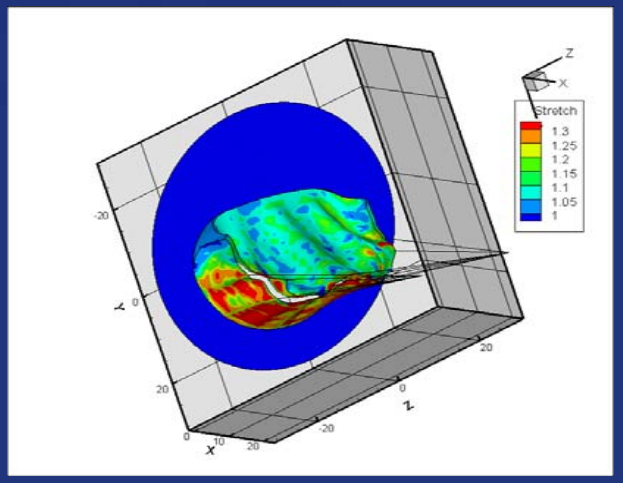
Horizontal mid-plane view of the flow



Vertical mid-plane view of the flow

Clock-wise vortex is observed, the system becomes more asymmetric. However, the flow vortex does help with the valve closure.

(Yin, Luo, Wang & Watton, CMN, 2009).



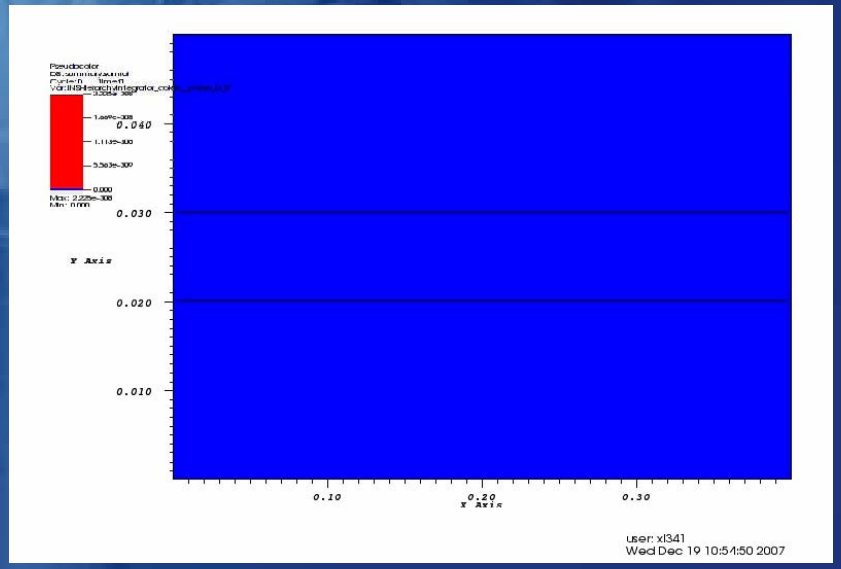
Immersed Boundary (IB) Methods-2

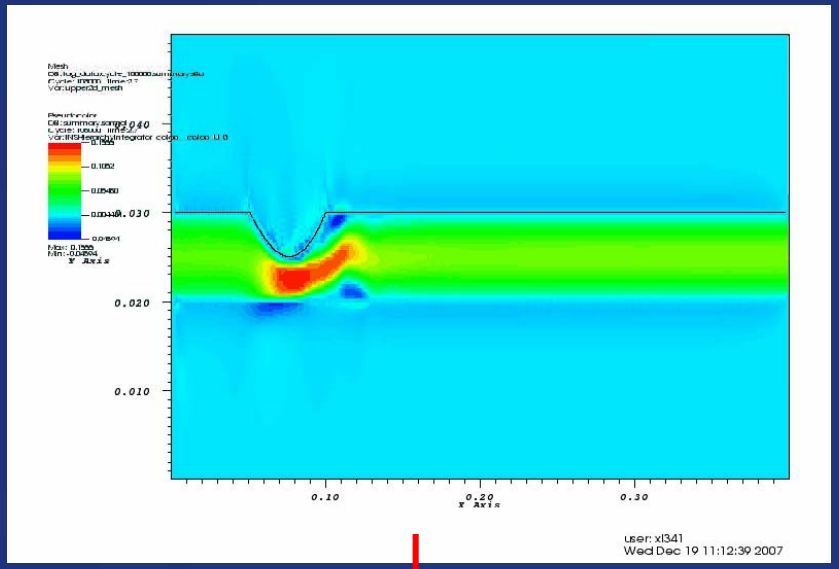
New version: IBAMR

Adaptive grid, formally 2nd order in time & space, can add bending force, coded in C++, solved with libraries: SAMRAI (adaptive mesh refinement), HYPRE (parallel multigrid solvers, PETSC (linear/nonlinear solvers), and VisIT (post-processing), physiological BCs.

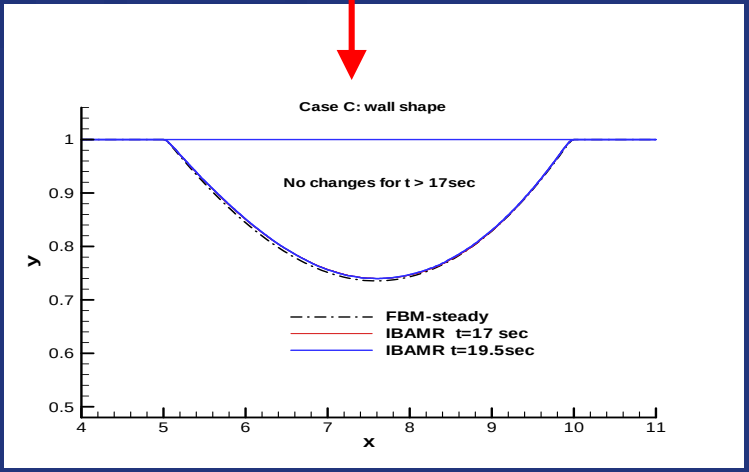
(Griffith et al. Journal of Computational Physics, 2007, Griffith, Luo, McQueen & Peskin, IJAM, 2009)

IB validation: collapsible channel flows

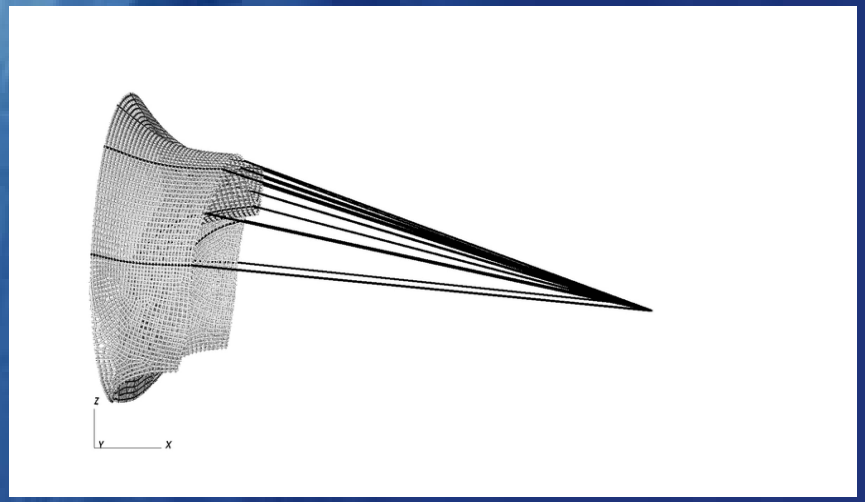




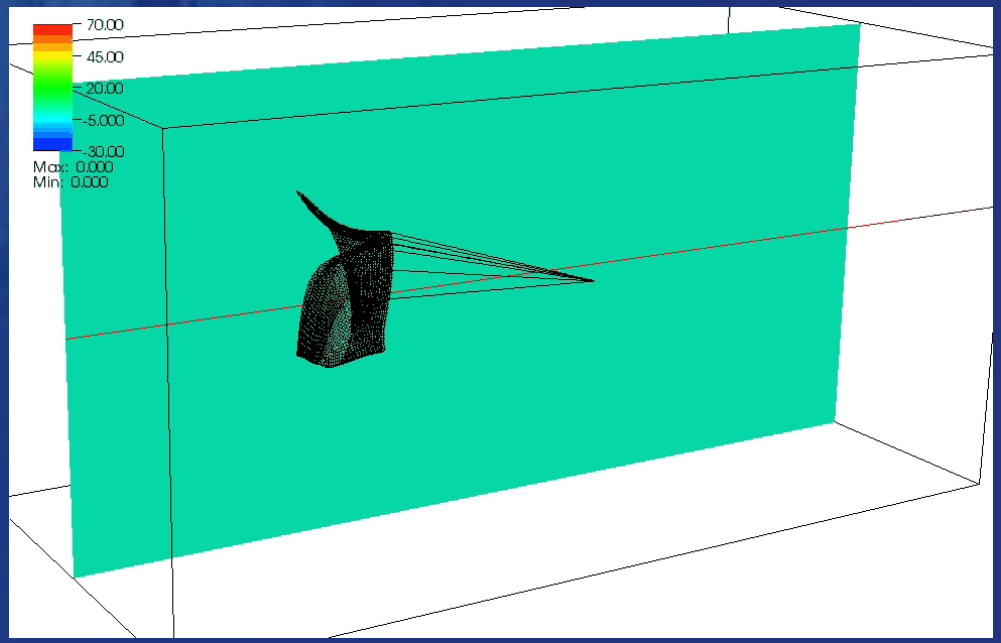
IBAMR reaches the steady solution computed using our ALE in-house code.



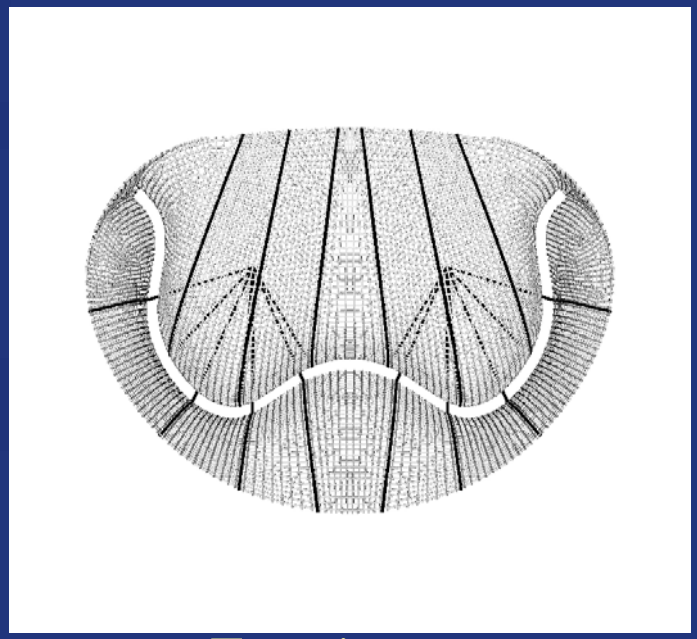
IBAMR: Valve closure



No valve bending: better closing, poor opening



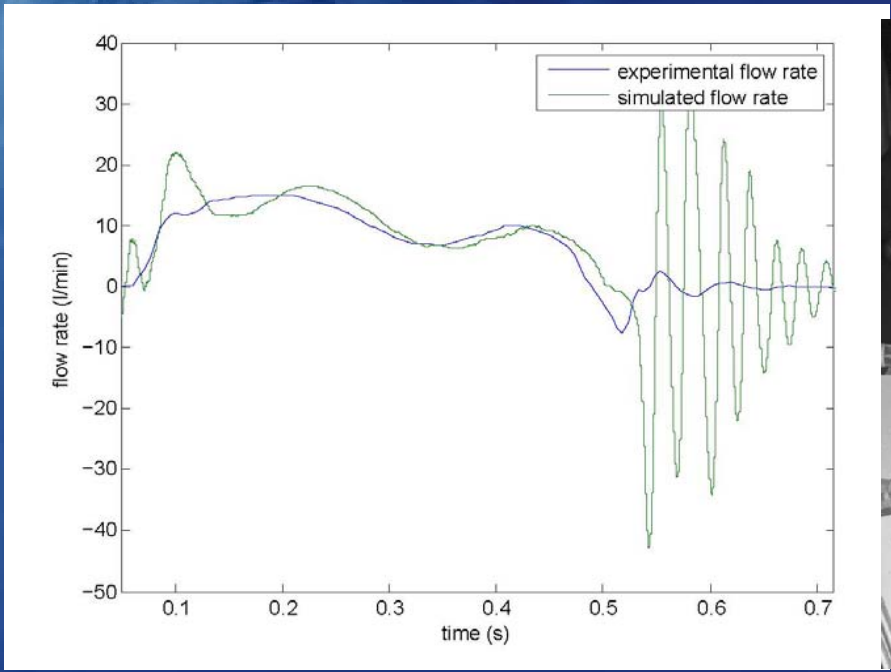
with valve bending

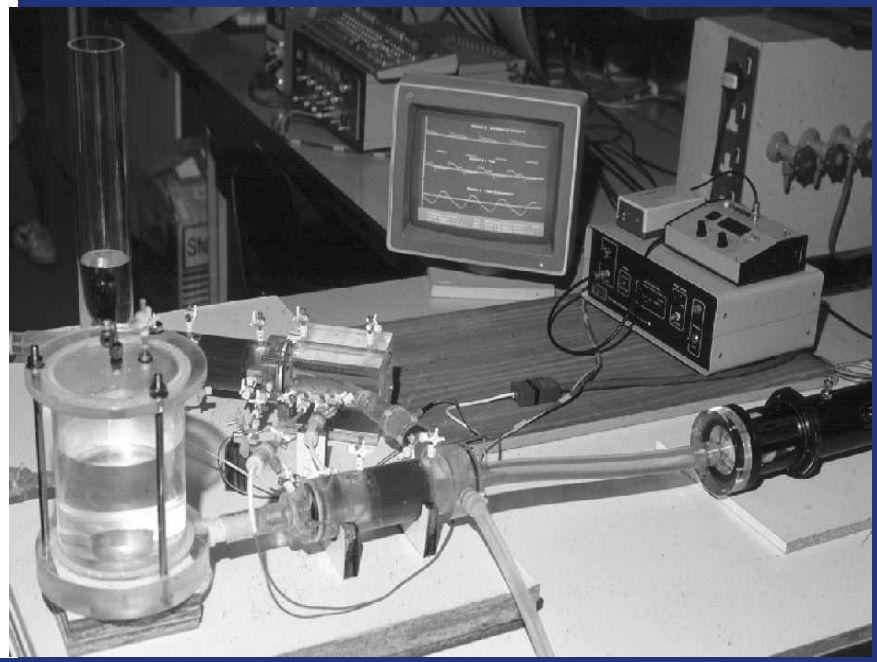


Top view

Experiments

Computed flow rate agrees well with experiments





Better agreement can be achieved by using a lumped parameter model downstream.

Conclusion

IBAMR is successfully used to simulate dynamic mitral valves.

It is a promising tool for studying fluid-structure interactions of more complicated 3D model (i.e. heart).

Acknowledgement

British Heart Foundation
Royal Academy of Engineering
The Royal Society
Royal Society of Edinburgh
Edinburgh Mathematics Society