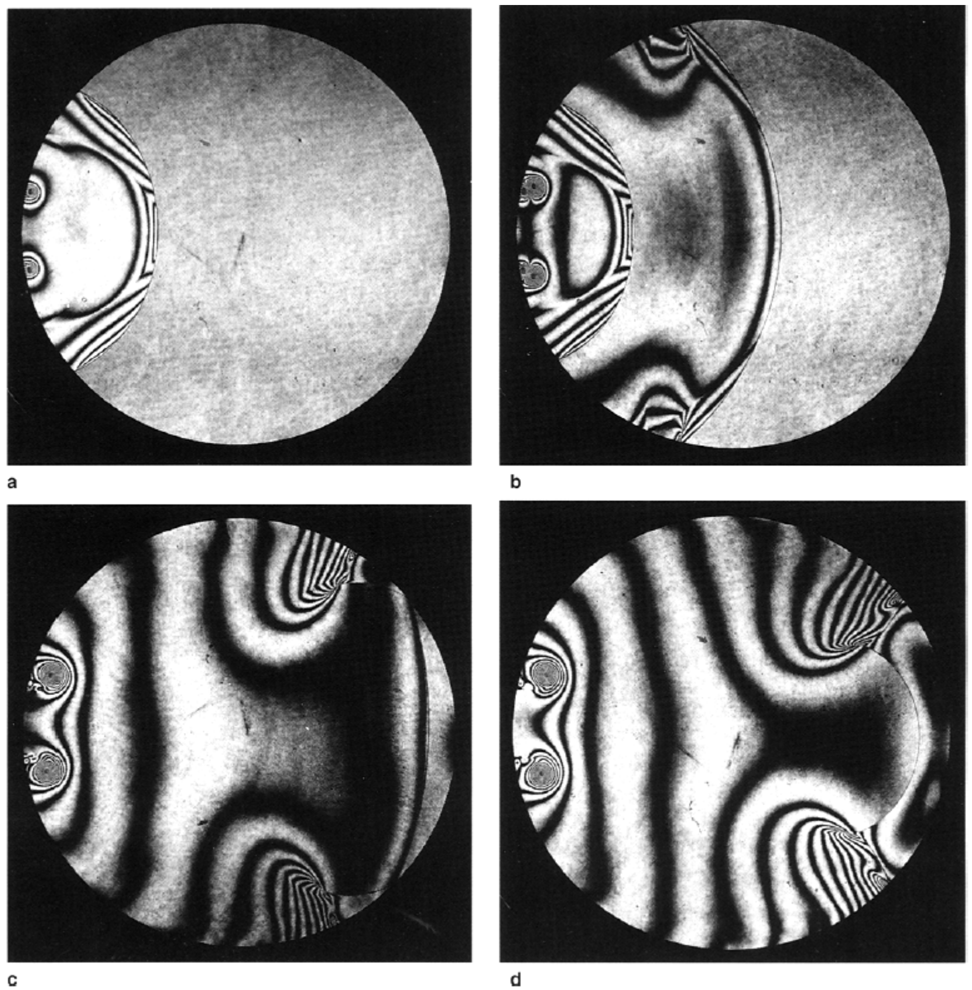
Wave phenomena in fluid-structure interaction

Serguei Iakovlev

Department of Engineering Mathematics and Internetworking,
Dalhousie University, Canada

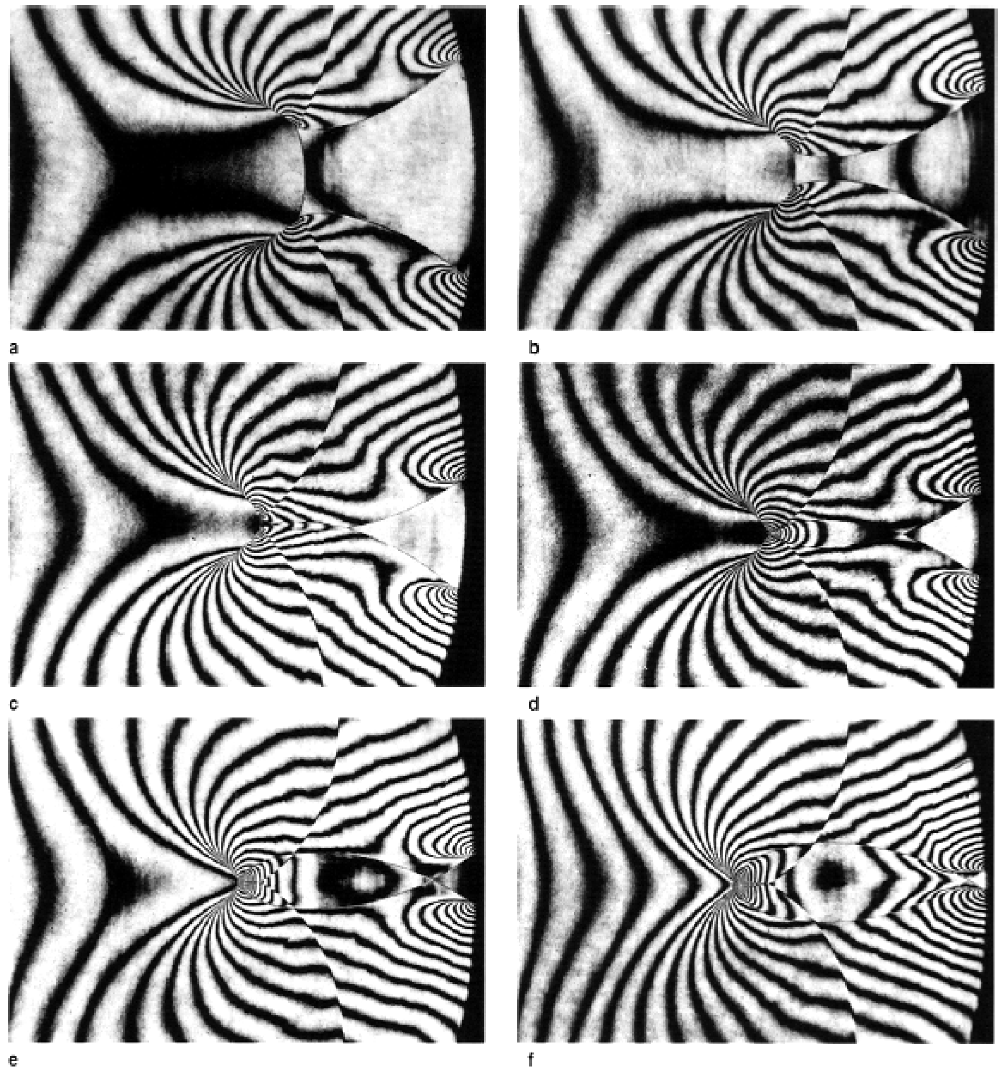
Department of Structural Mechanics, University of Pavia, Italy

Wave propagation in a cylindrical cavity

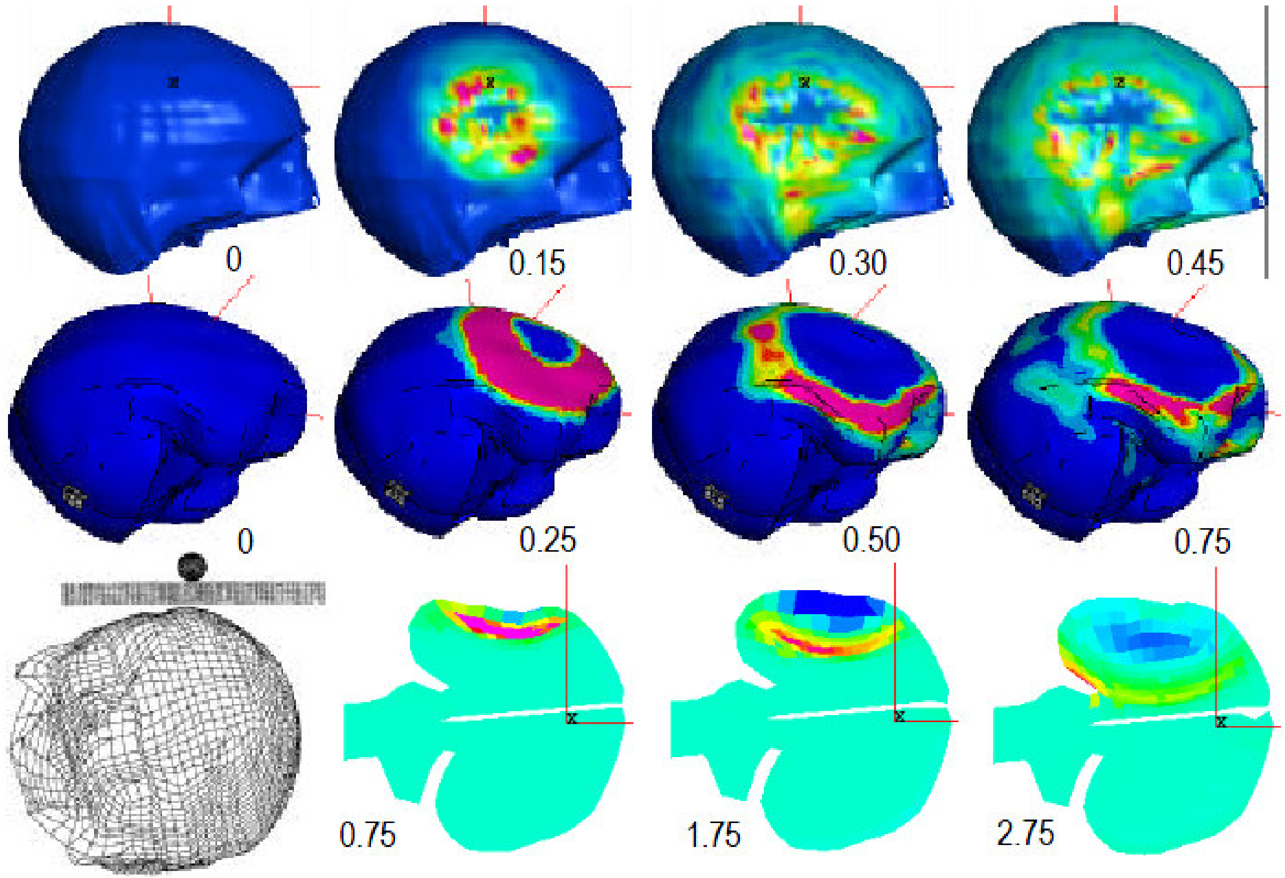


Sun, M. & Takayama, K. 1996 A holographic interferometric study of shock wave focusing in a circular reflector. Shock Waves 6, 323-336.

Wave focusing in a cylindrical cavity (detail)



Human skull subjected to a projectile impact



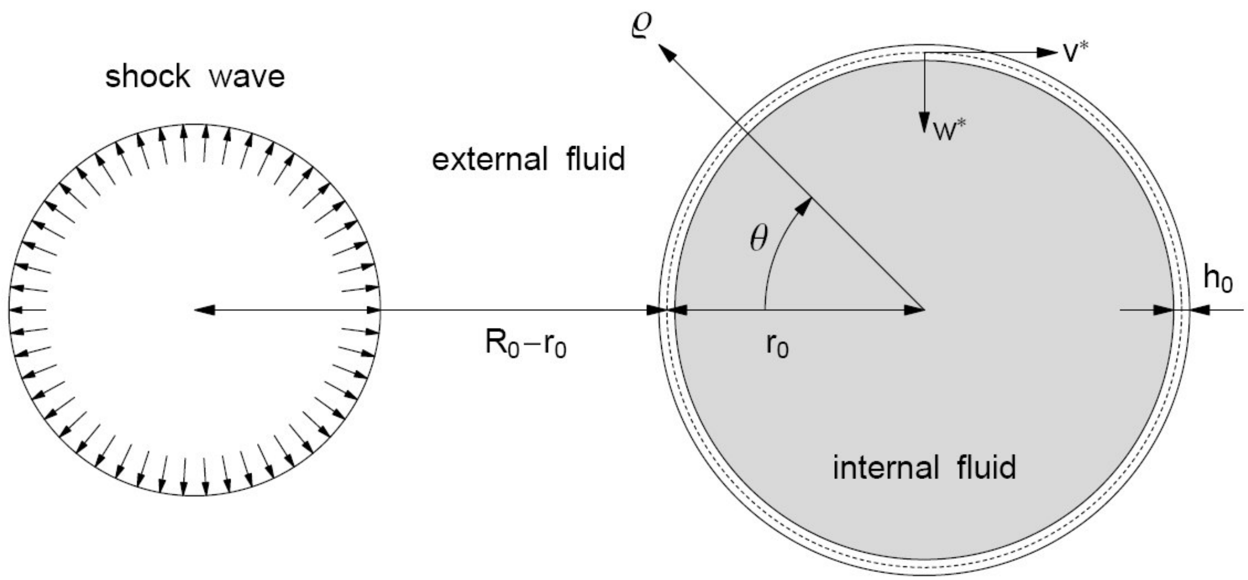
Trameçon, A., Allain, J.-C., Haug, E., Montmayeur, N., Beaugonin, M. Design of Soldier's Protection Equipment: Recent Trends in Biomechanical Models and Comfort, Proceedings of the 76th Shock and Vibration Symposium, 2005.

Biomechanical significance:

impulse loads are quite common and are not limited to accidents (e.g. working with power tools and sport-related activities).

How do such loads affect the overall performance of biomedical devices?

Overview of the main aspects of the problem for a typical, relatively simple FSI setup



Solution:

Fluid dynamics (wave equations):

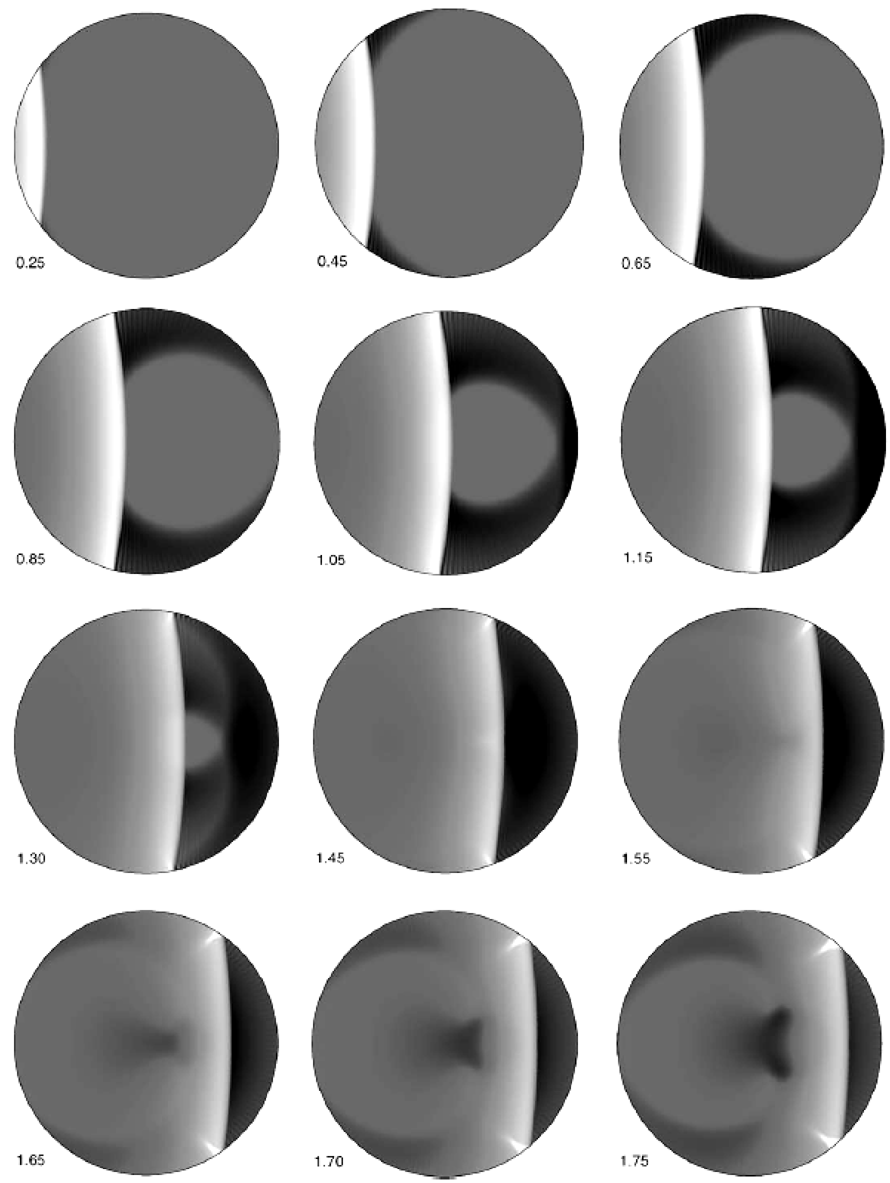
Laplace transform in time, separation of variables in space, series solution for the pressure

Structural dynamics (linear shell equations):

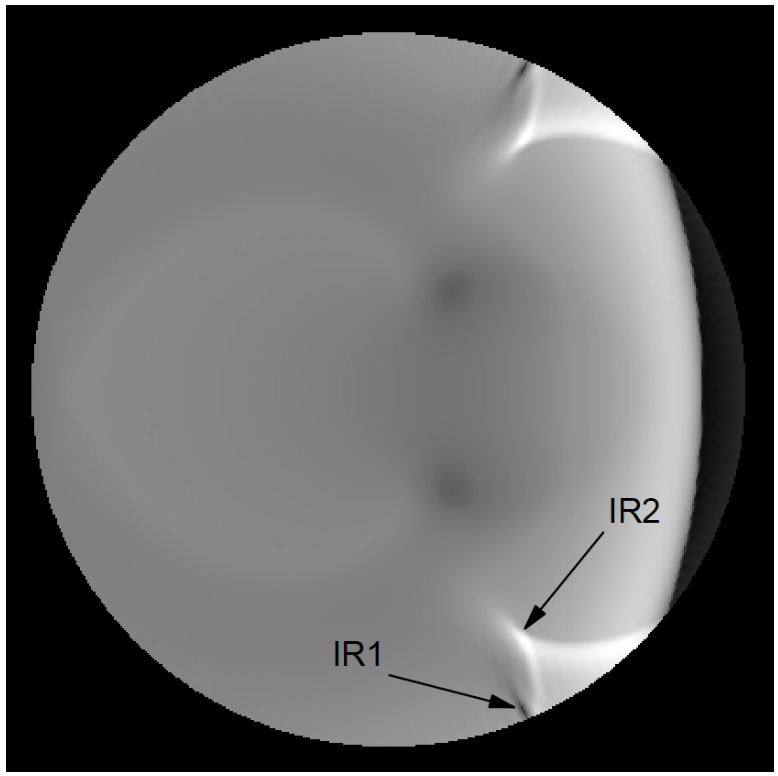
modal decomposition using eigenfunctions of the hydrodynamic part, set of systems of ordinary integro-differential equations

Numerical coupling of the two parts (finite differences)

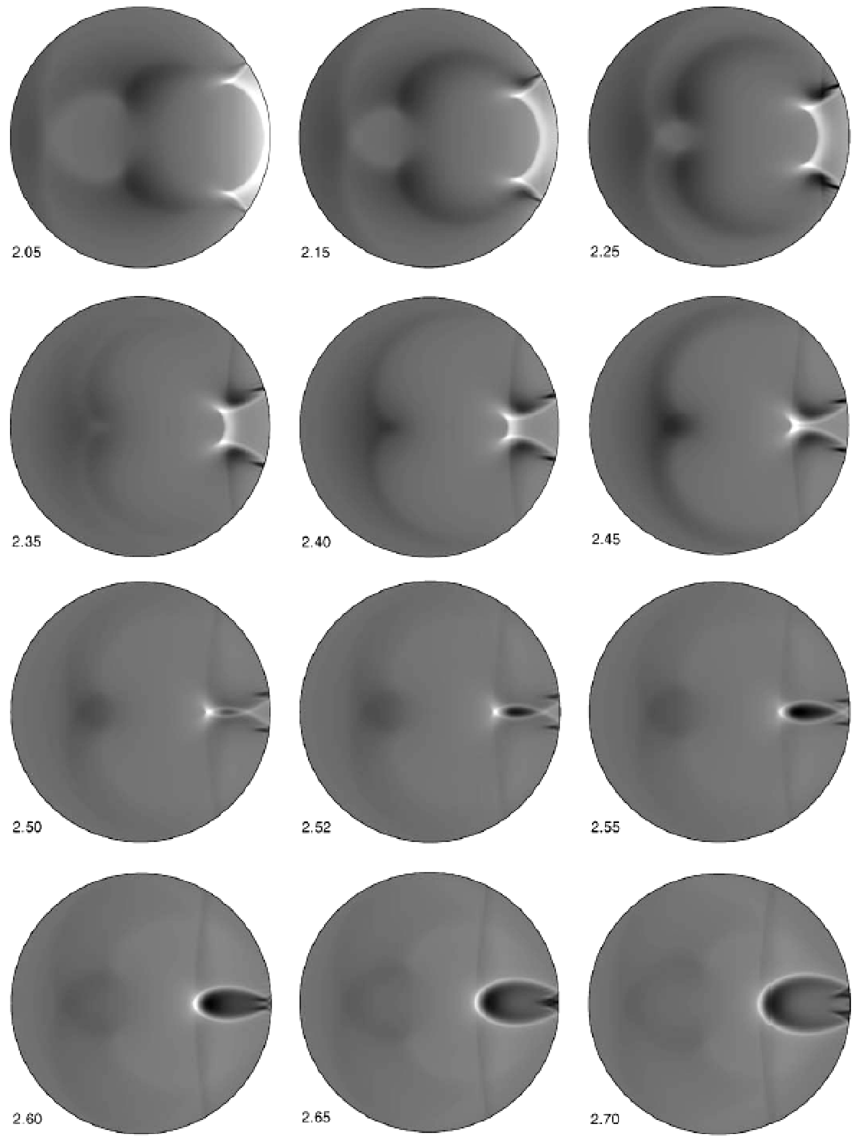
Early interaction



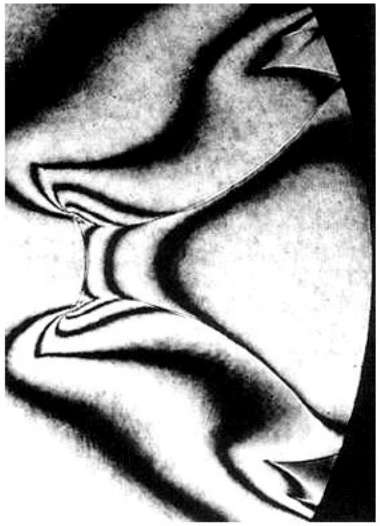
Primary reflection



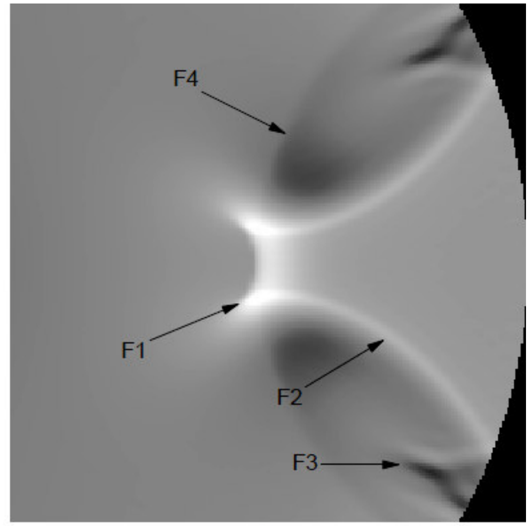
Mid-interaction



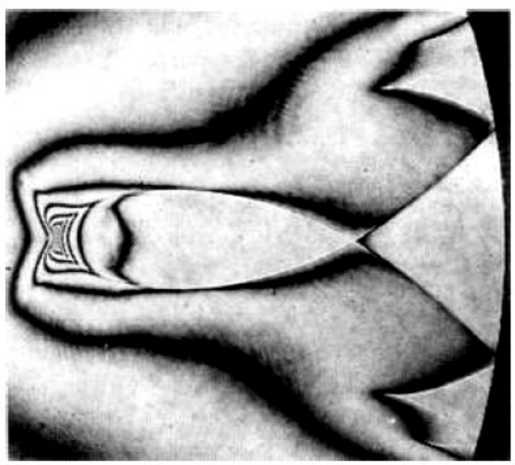
Reflection and focusing



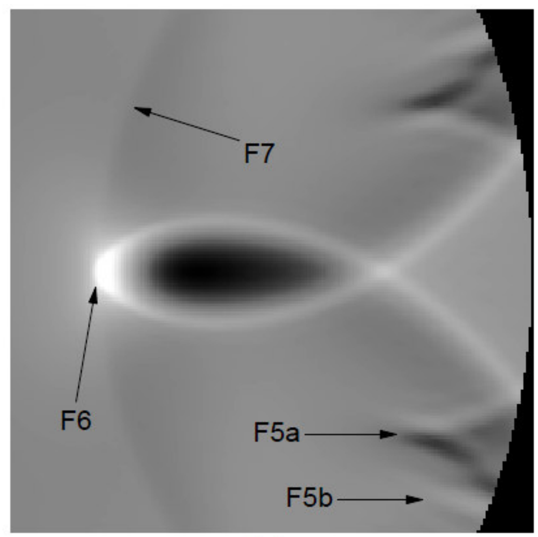
(a)



(b)

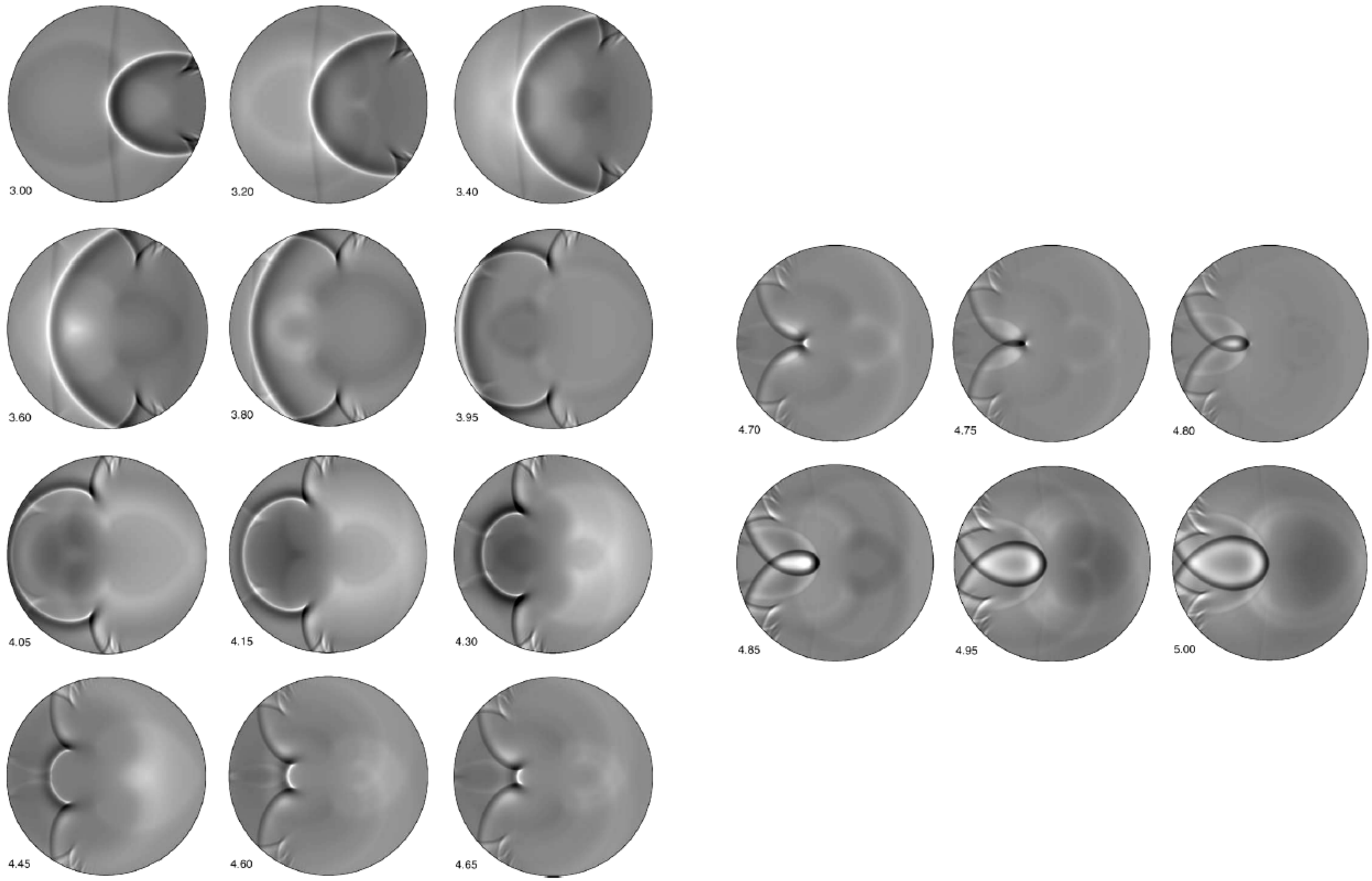


(c)

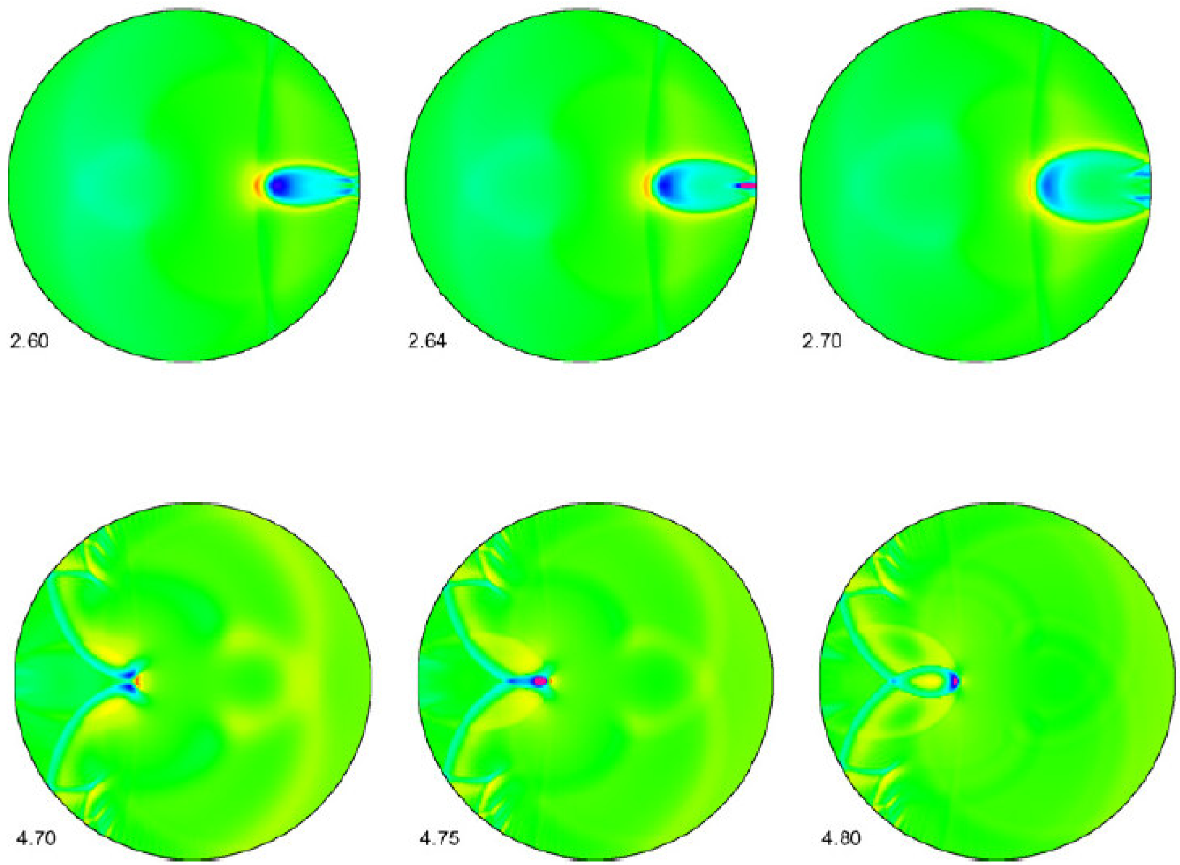


(d)

Late interaction

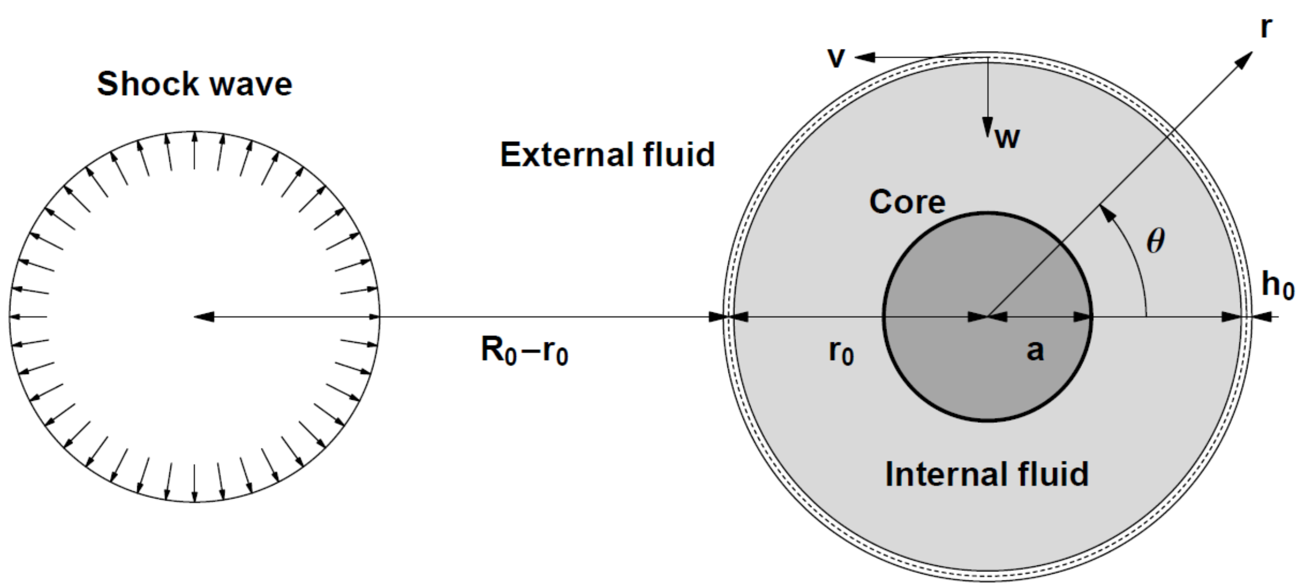


Possibility of cavitation due to reflection and focusing

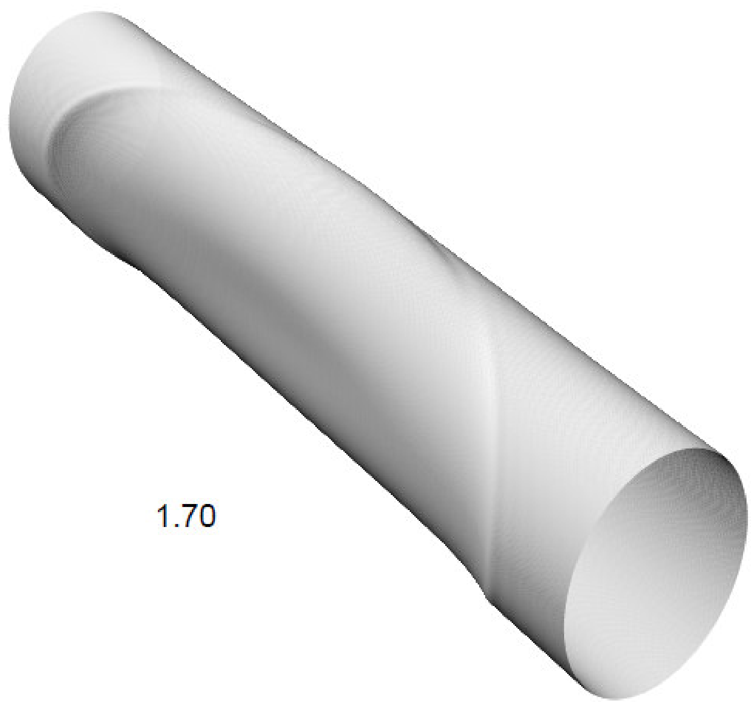


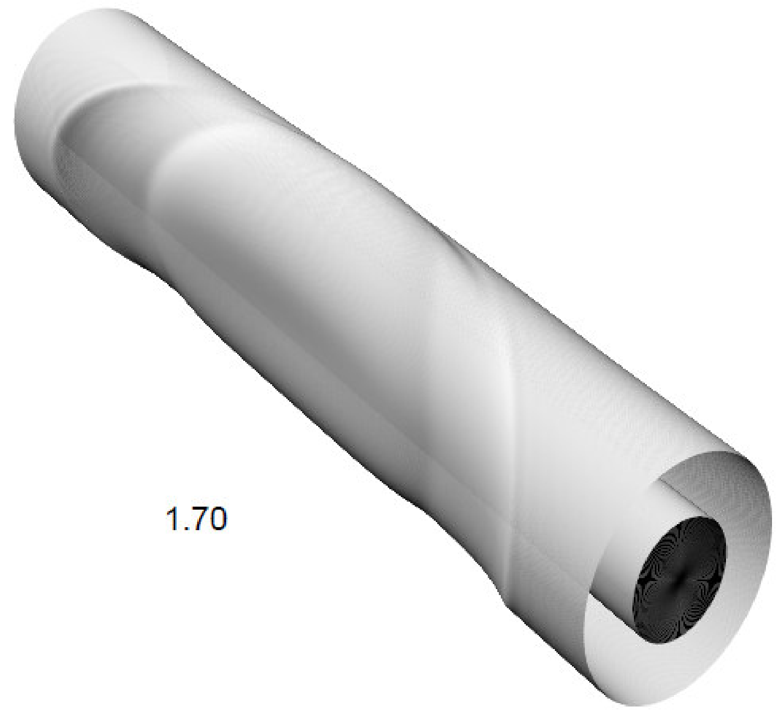
What happens if the reflection-focusing pattern is altered, for example by means of adding smaller internal structures?

A co-axial core idea: a starting point for modeling a double-wall tubular structure. Such a system holds a significant promise of providing a better structural performance, and is of interest to many industries. Development of biomedical devices could possibly benefit from using its stress-reduction properties as well.

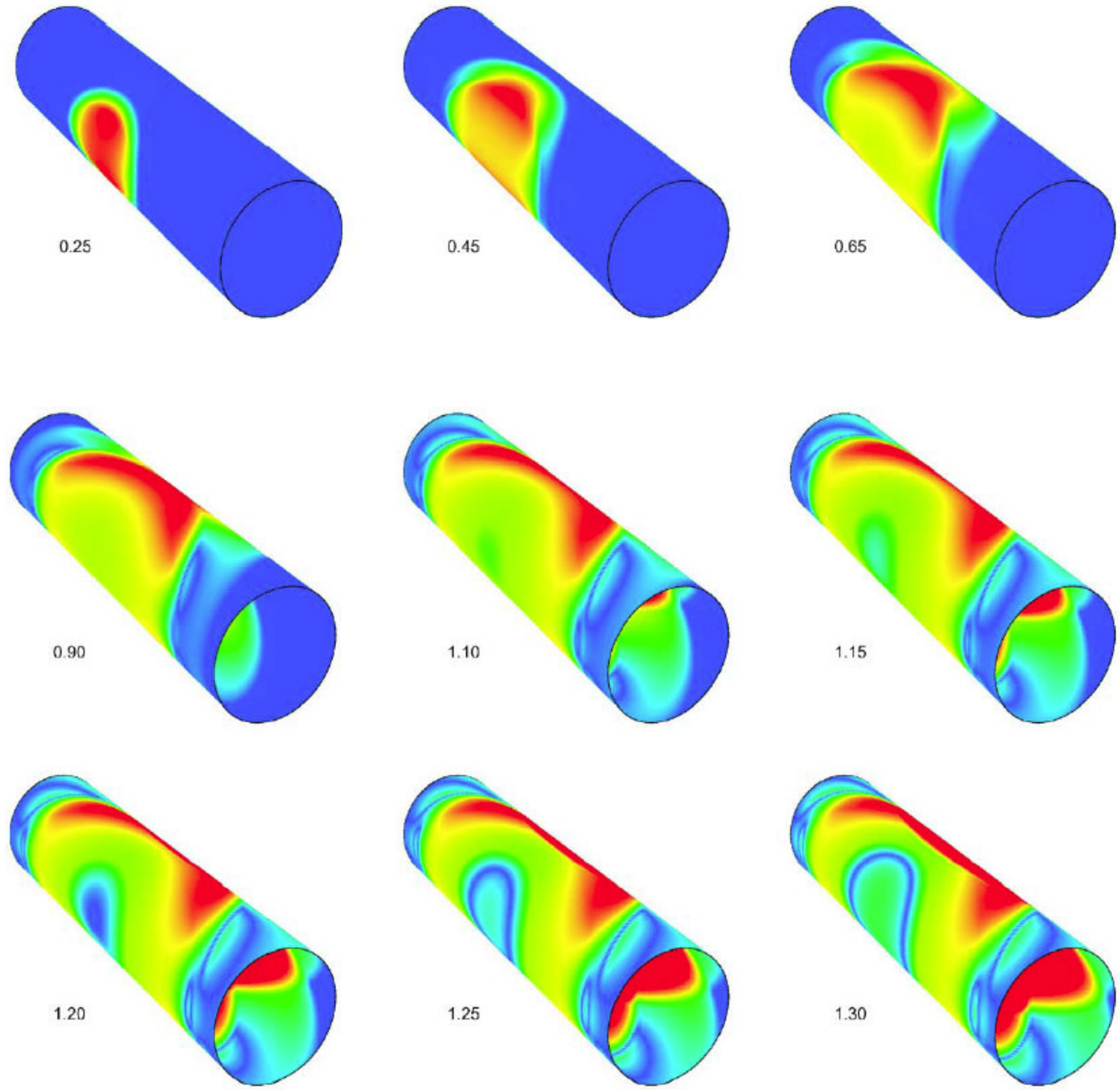


Structural deformations

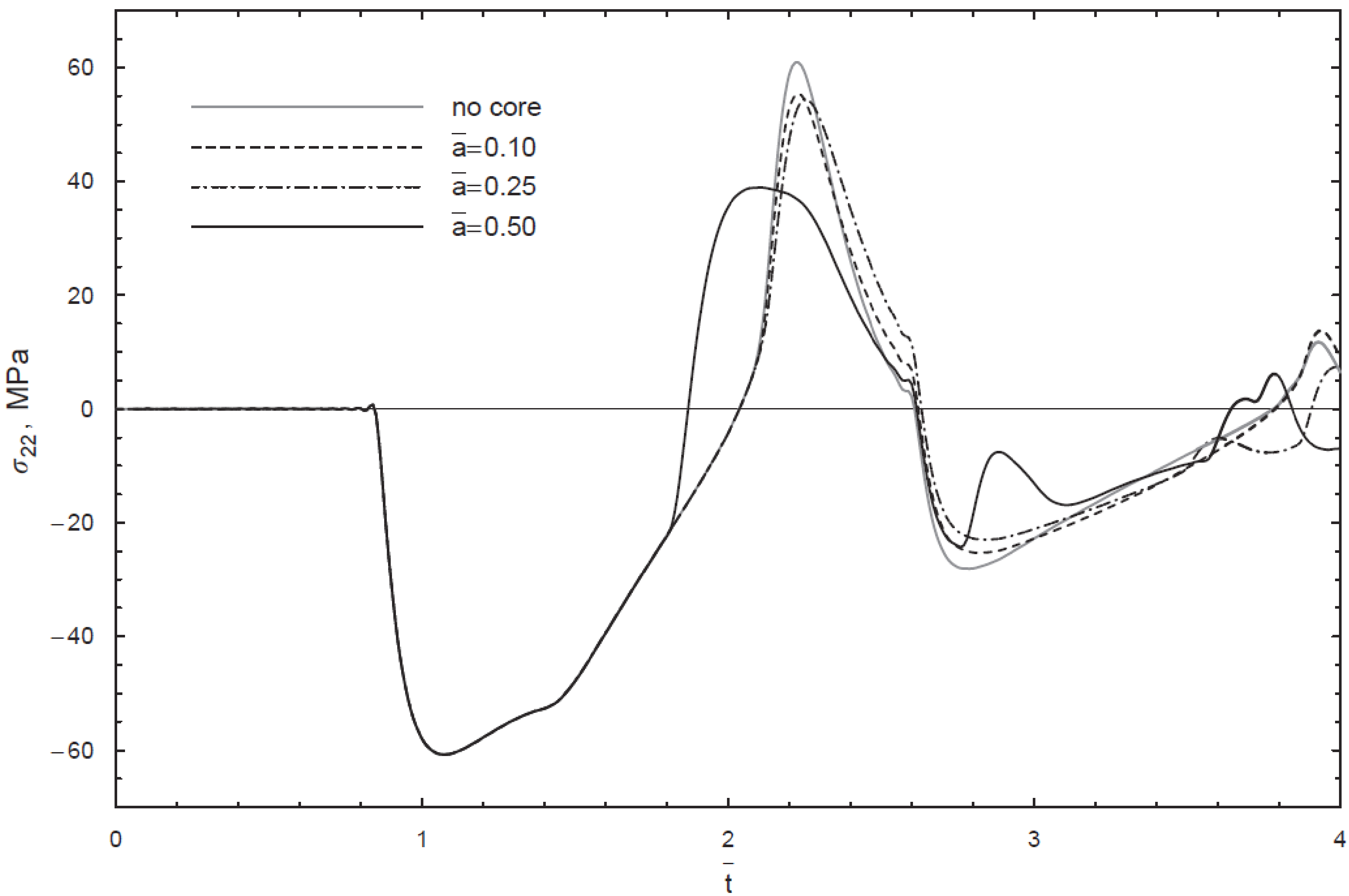




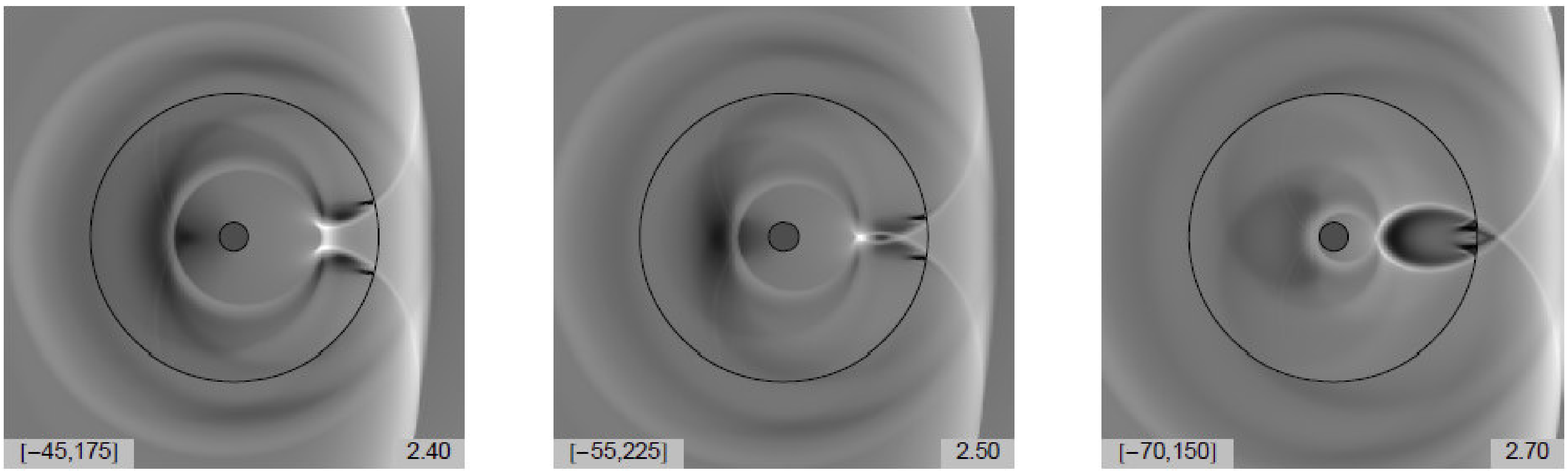
Dynamics of the stress state



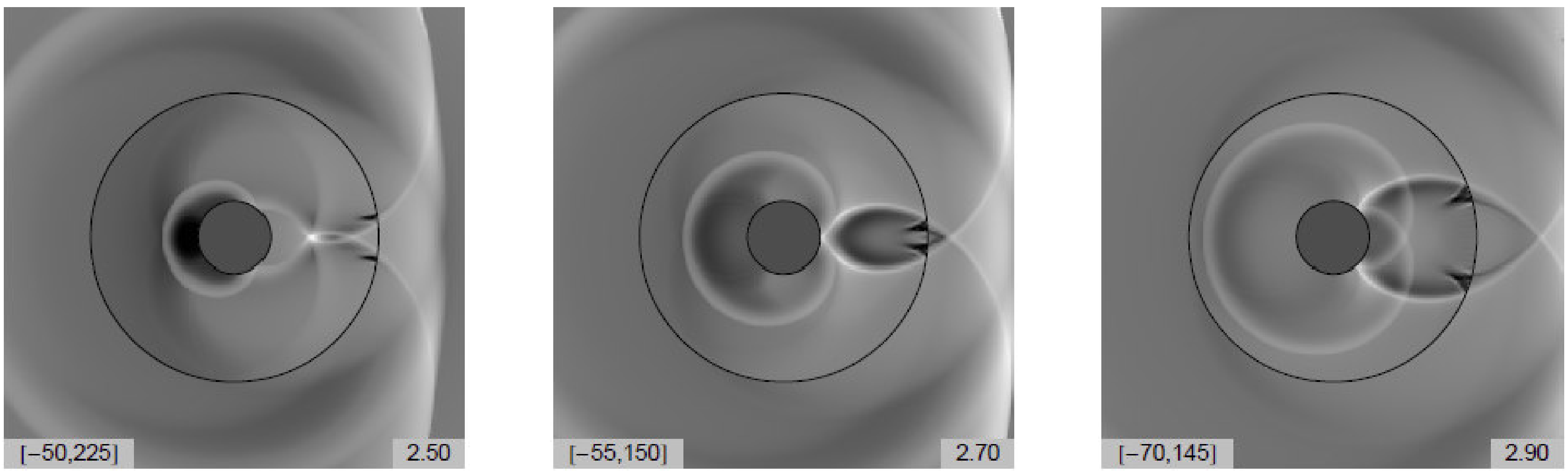
Considerable reduction of the tensile stress at the tail point



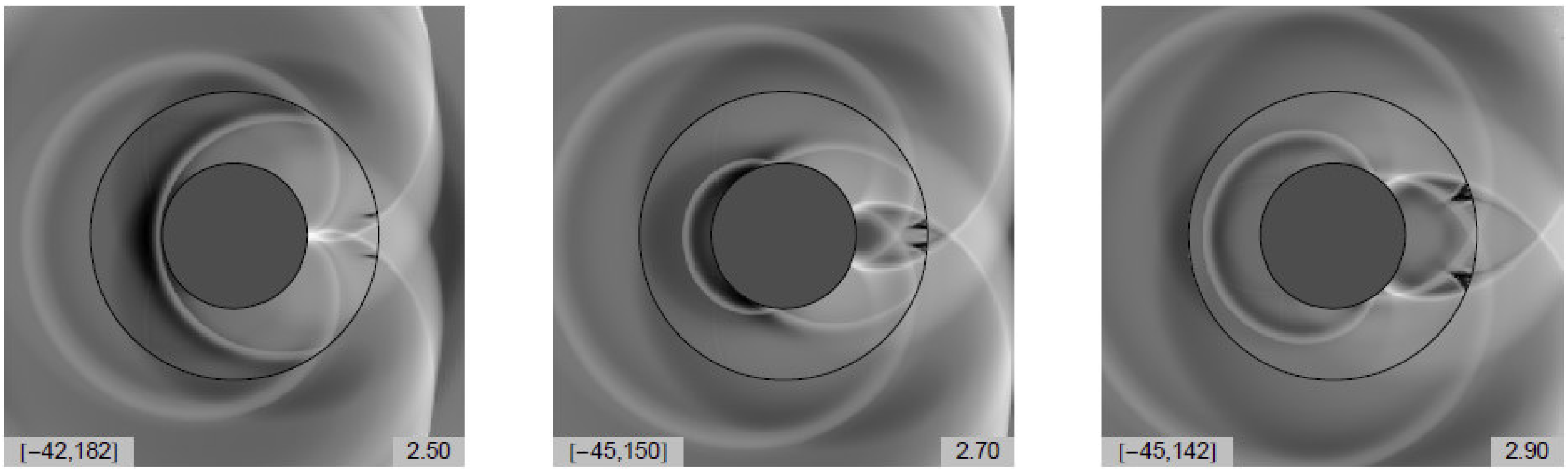
Primary focusing, small-radius core



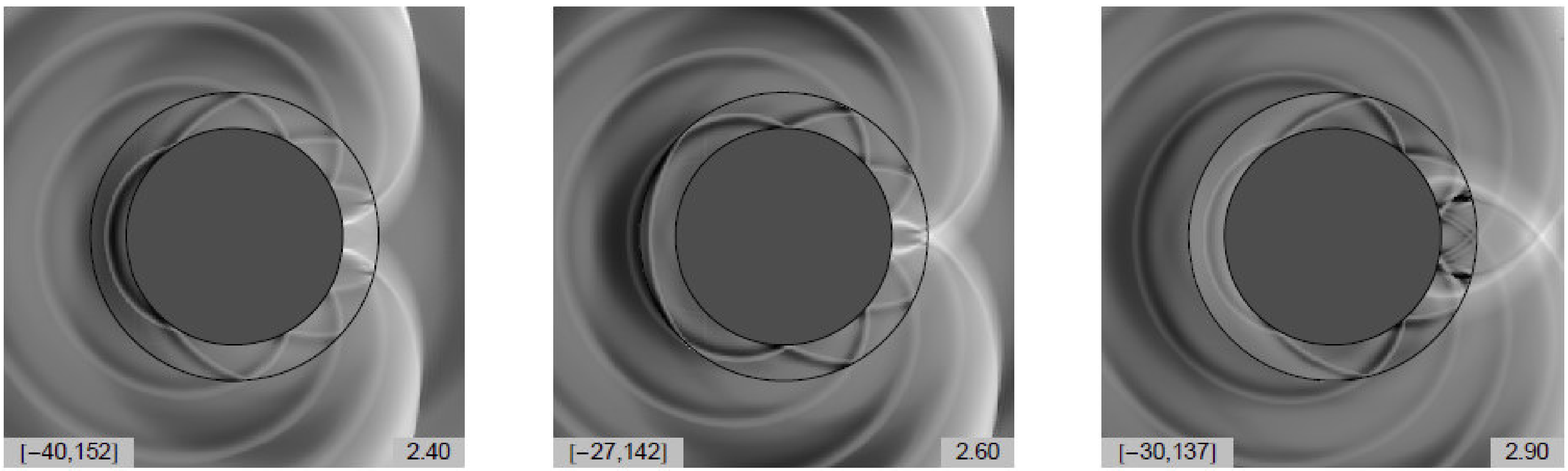
Primary focusing, medium-radius core



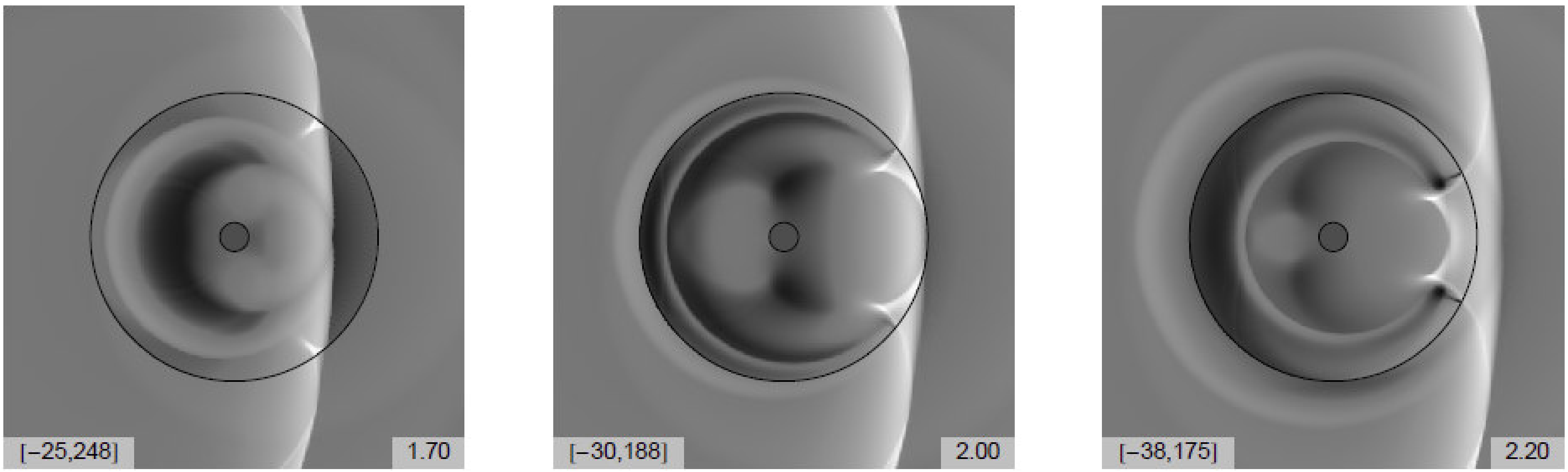
Primary focusing, large-radius core



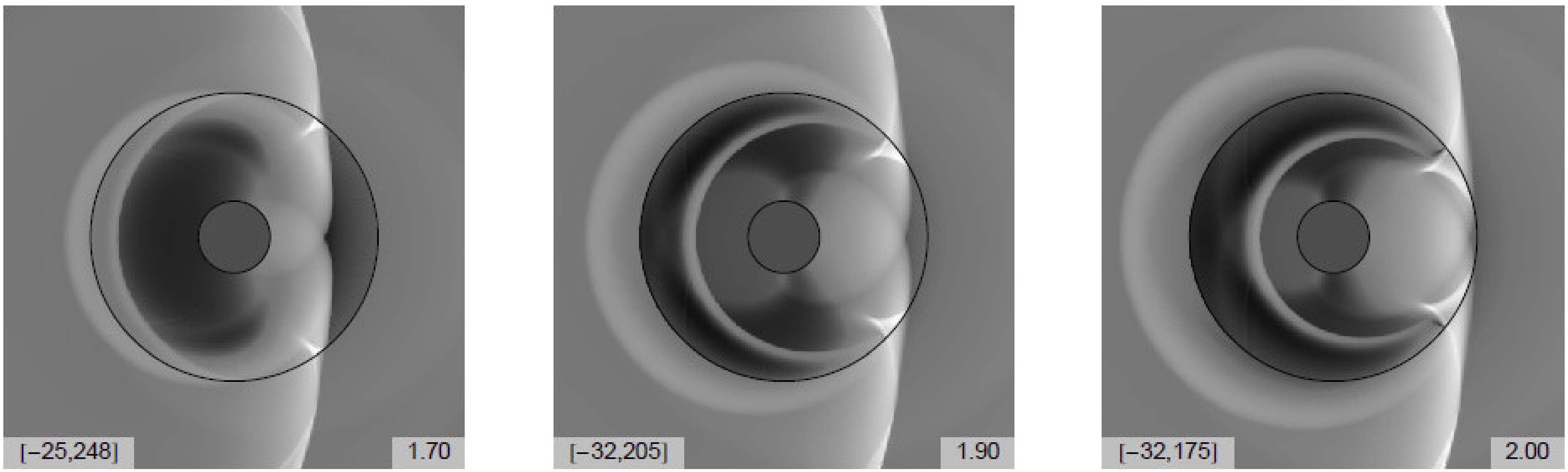
Primary focusing, very large-radius core



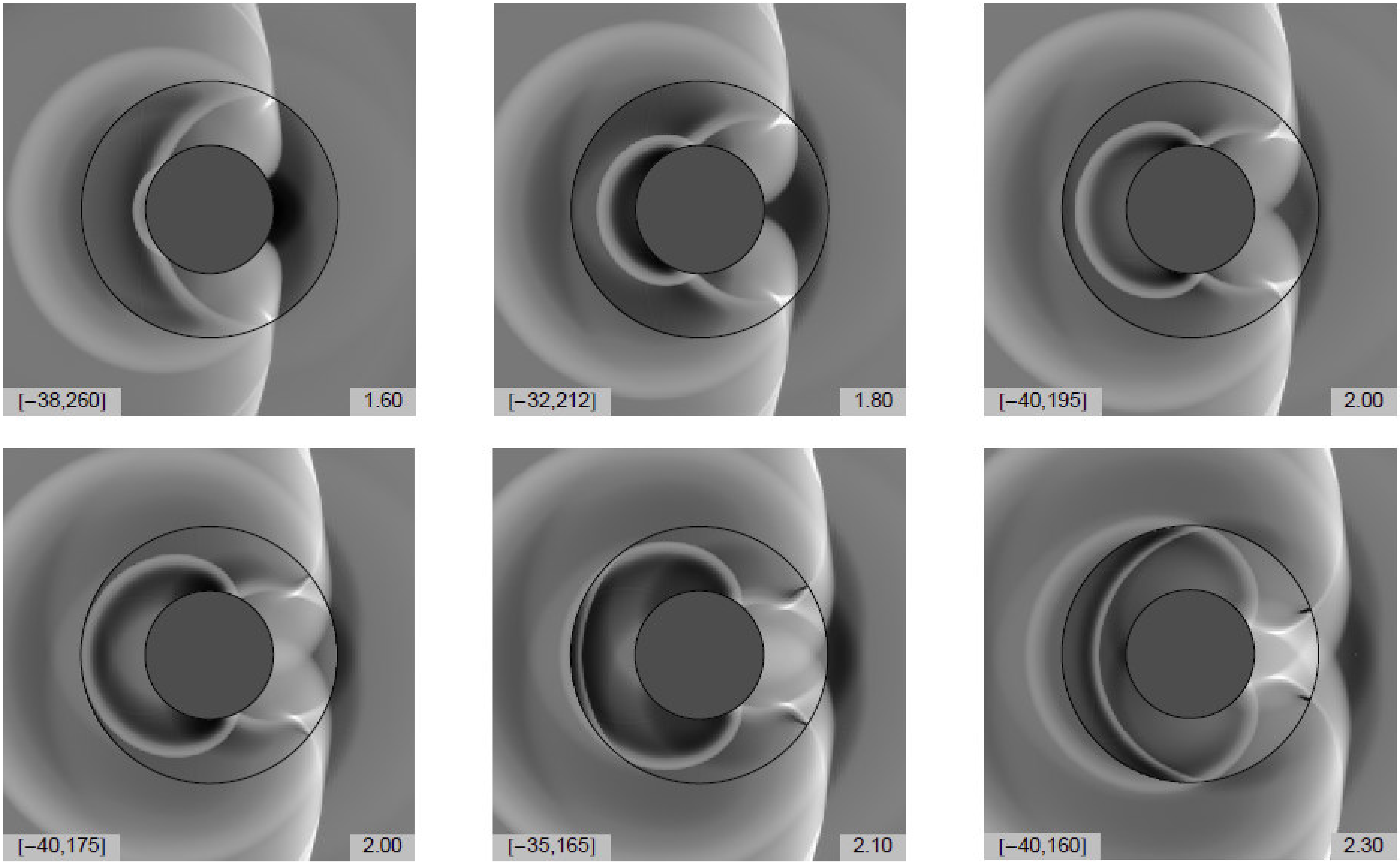
Primary reflection, small-radius core



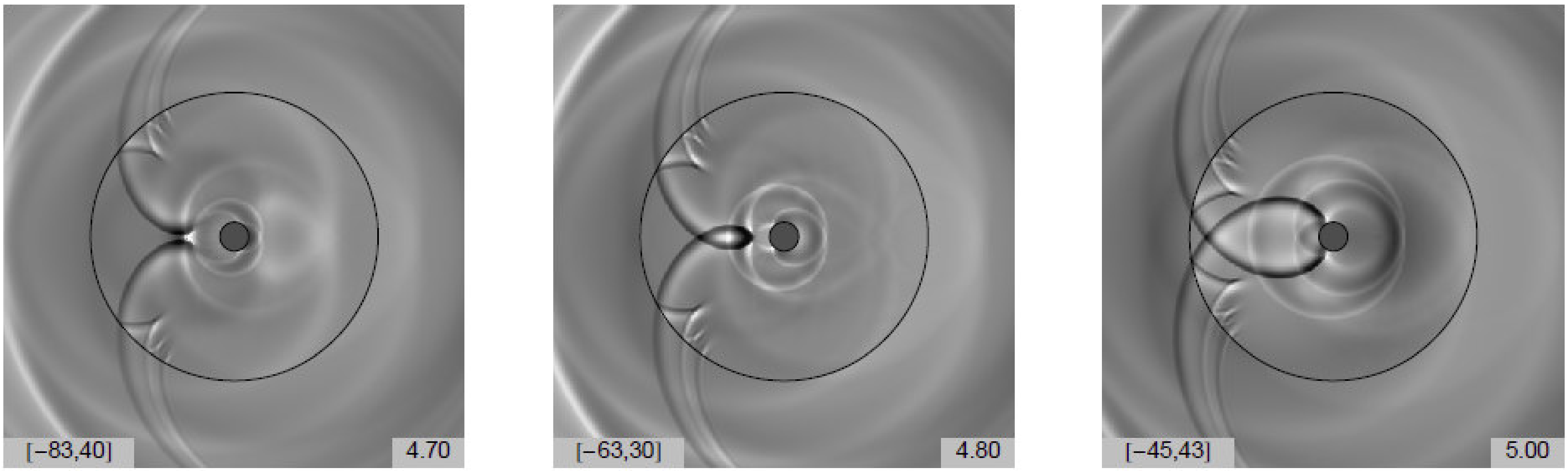
Primary reflection, medium-radius core



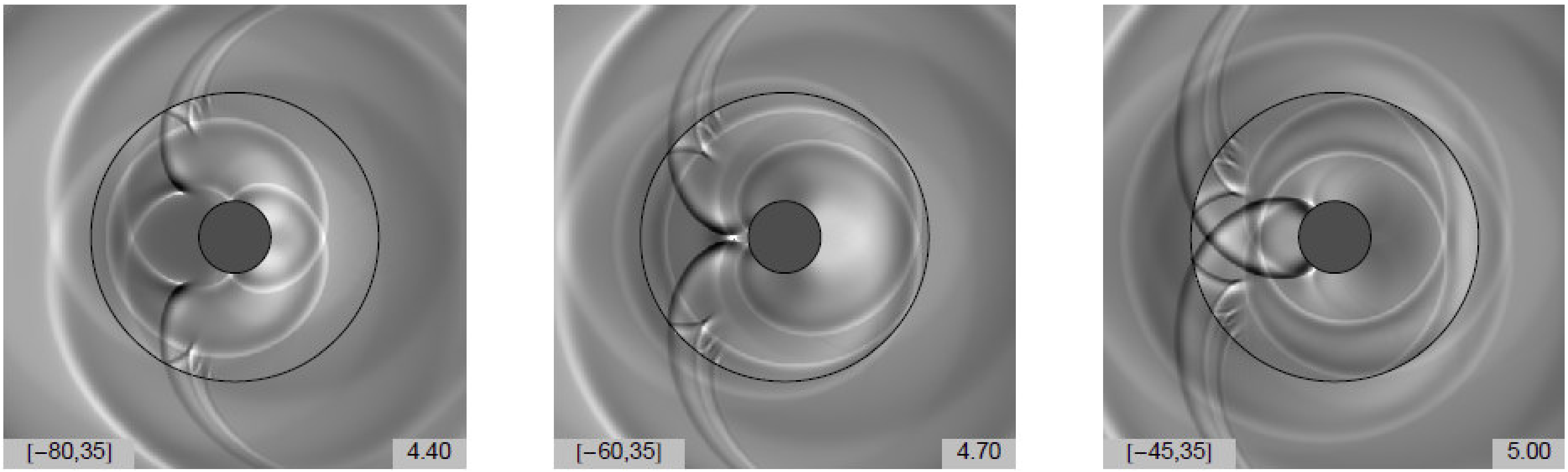
Primary reflection, large-radius core



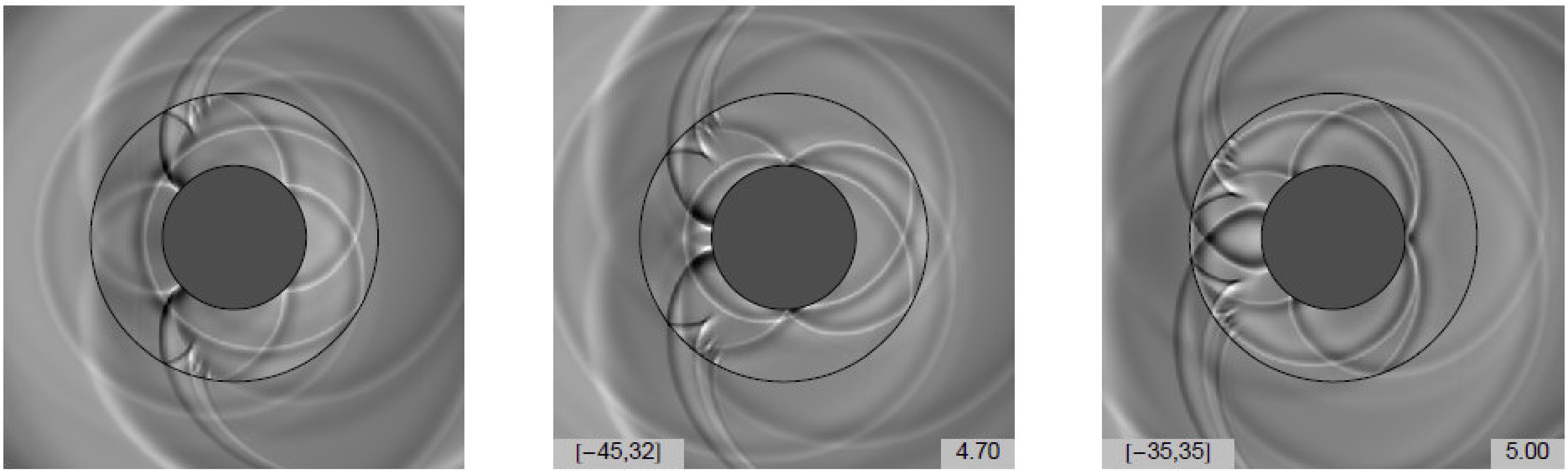
Secondary focusing, small-radius core



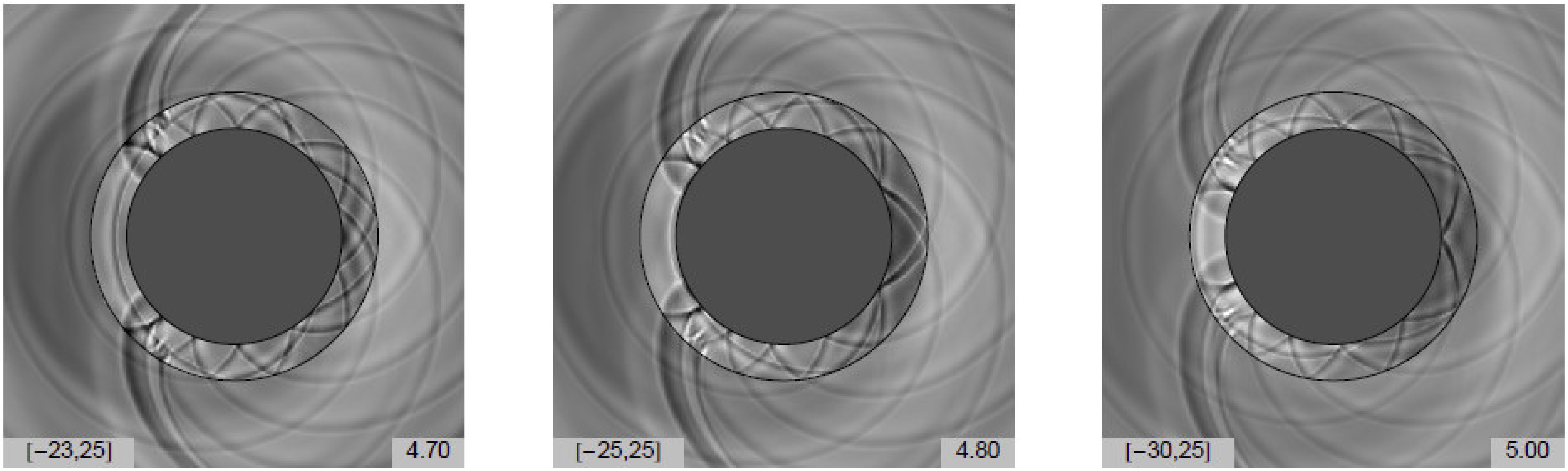
Secondary focusing, medium-radius core



Secondary focusing, large-radius core



Secondary focusing, very large-radius core



Conclusions:

reflection and focusing phenomena are responsible for a very high pressure experienced by the fluid, often the highest during the entire interaction; they, therefore, could be responsible for negative effects in the fluid when it is sensitive to high pressure (e.g., blood cell damage);

controlling the reflection and focusing holds a great promise of both optimizing the structural performance and reducing the negative impact on the fluid contained by, and in some cases surrounding, the structure.

Acknowledgements

This project was financially supported by the Natural Sciences and Engineering Research Council (NSERC) of Canada, the Killam Trusts, the Office of Cooperative Education at Dalhousie University and the Faculty of Engineering at Dalhousie University.

The following students have contributed to the results that were reported here:

Mathew Bligh (Mechanical Engineering, Dalhousie)
Bryan MacDonald (Mechanical Engineering , Dalhousie)
Garrett Dooley (Mechanical Engineering , Dalhousie)
Martin Mitchell (Mechanical Engineering , Dalhousie)
Robynne Murray (Mechanical Engineering , Dalhousie)
Jonathan Gaudet (Proc. Eng. and Applied Science)
Kyle Willsiton (Environmental Engineering, Dalhousie)

Thank you for inviting me
to join your research group!