

Structure-induced hydrodynamic waves

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hydrodynamic loading → structural response

(the load is known,
the stress-strain state is assessed)

structural response → hydrodynamic fields

(structural deformations are known,
the hydrodynamic response is assessed)

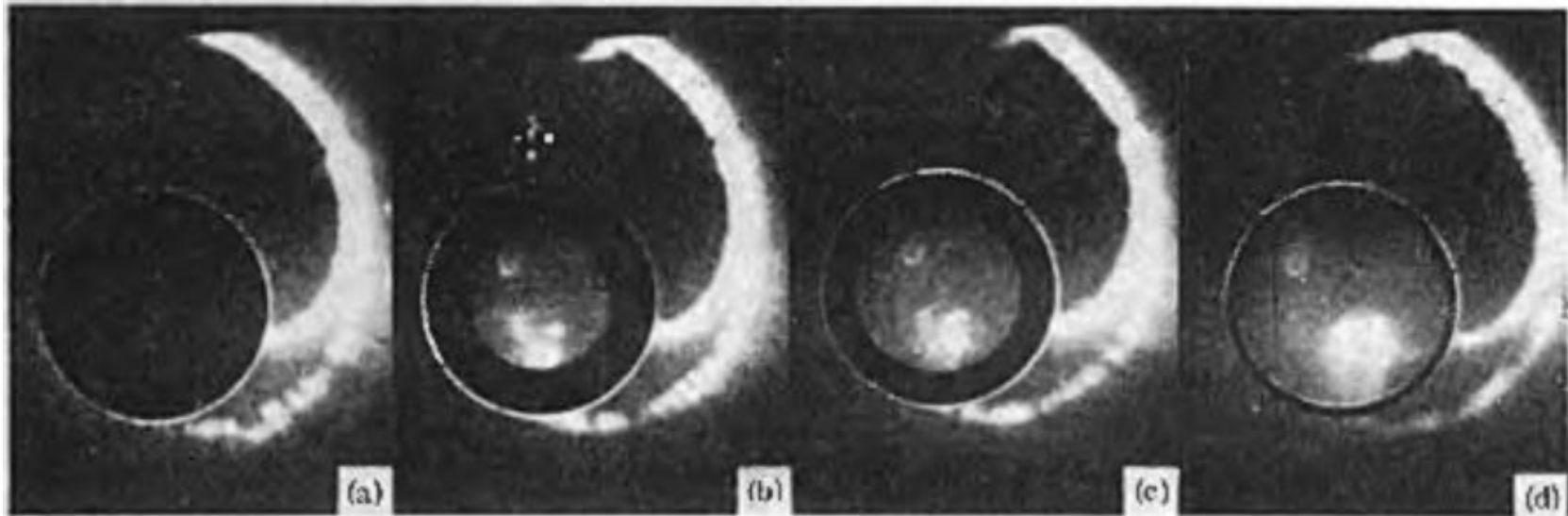
We will focus is on the so-called “hydroelastic” response,
i.e. the hydrodynamic waves induced by
the radiation of the elastic waves propagating in the structure;

the respective time scale is

$$O \left(\frac{a_0}{c_0} \right)$$

where a_0 is the characteristic dimension of the structure and
 c_0 is the elastic wavespeed in the structure’s material.

Brief history

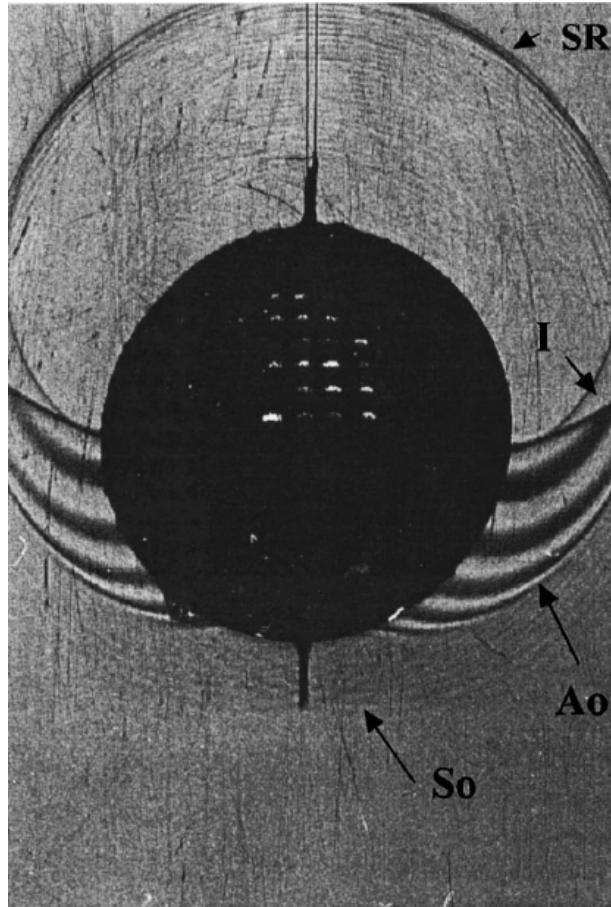


Neubauer, W. G. & Dragonette, L. R. 1970 Observation of waves radiated from circular cylinders caused by an incident pulse. *Journal of the Acoustical Society of America* 48, 1135-1149.

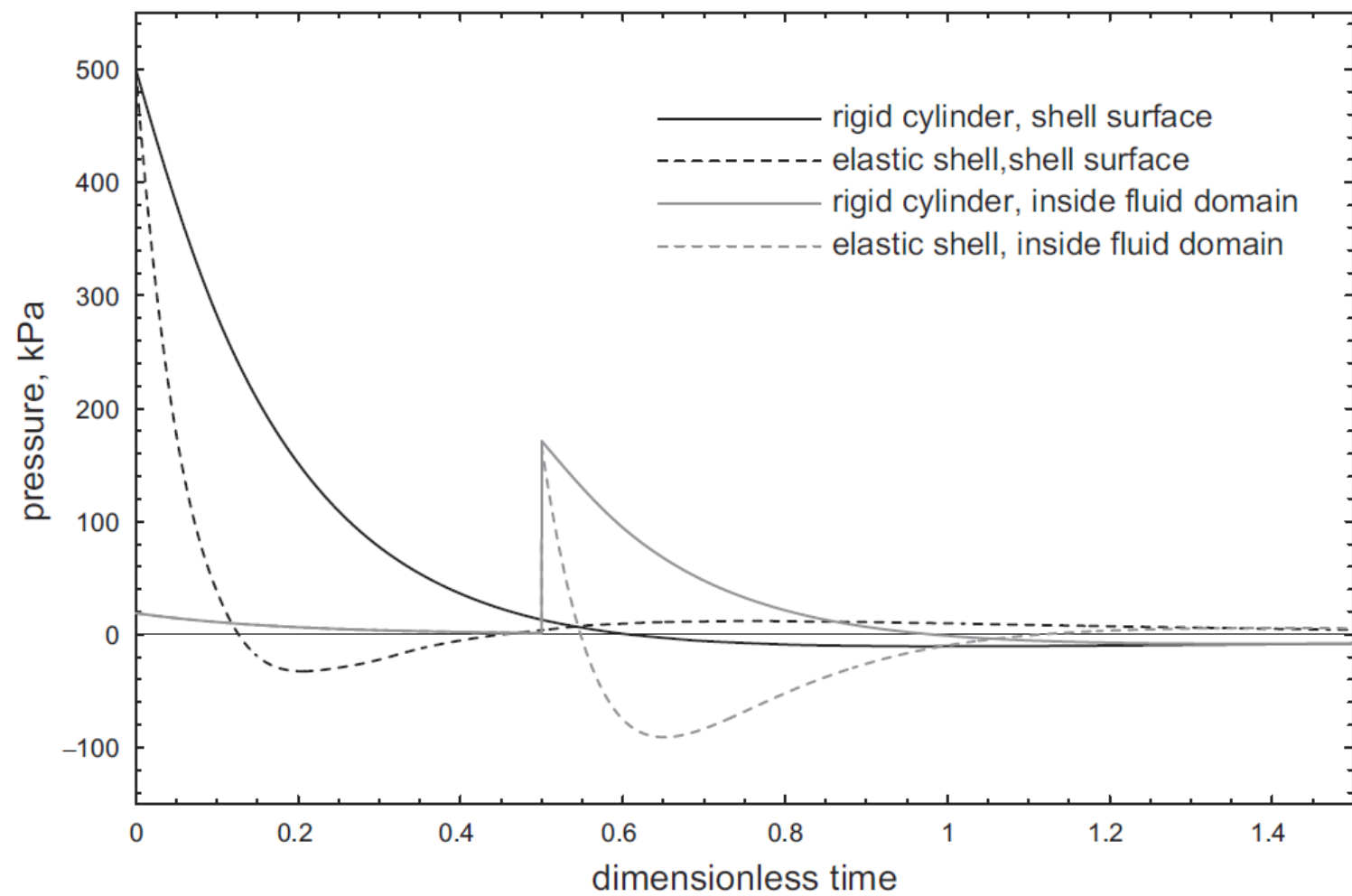
Complex field observed but
the resolution is not high enough (1970)



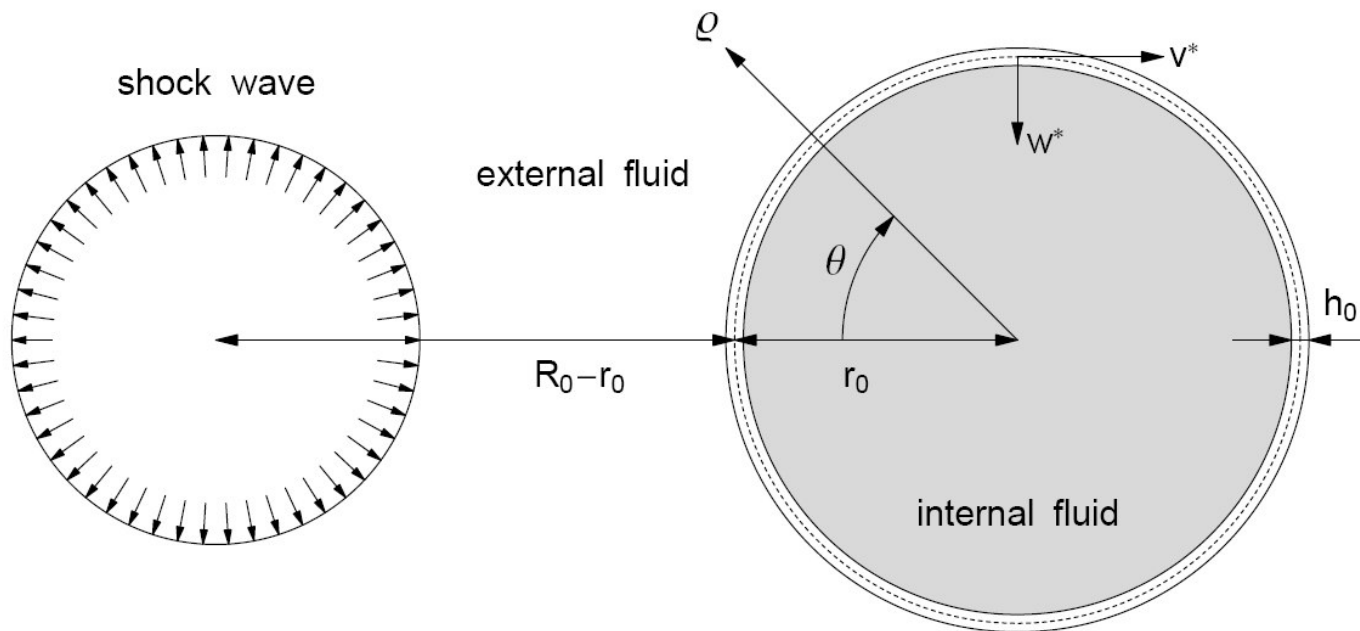
High-resolution images (1998)



Ahyi, A. C., Pernod, P., Gatti, O., Latard, V., Merlen, A., and Uberall, H. 1998 Experimental demonstration of the pseudo-Rayleigh (A_0) wave. *Journal of the Acoustical Society of America* 104, 2727-2732.



Geometry of the problem



Solution:

Fluid dynamics (wave equations):

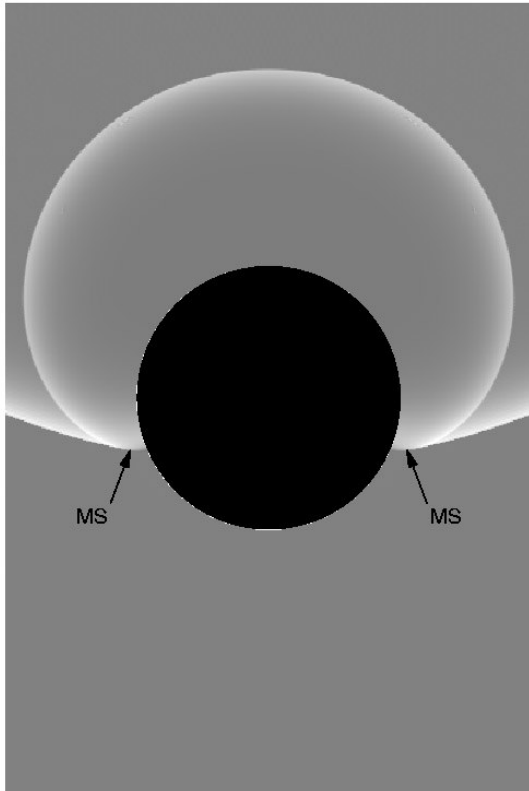
Laplace transform in time, separation of variables in space, series solution for the pressure

Structural dynamics (linear shell equations):

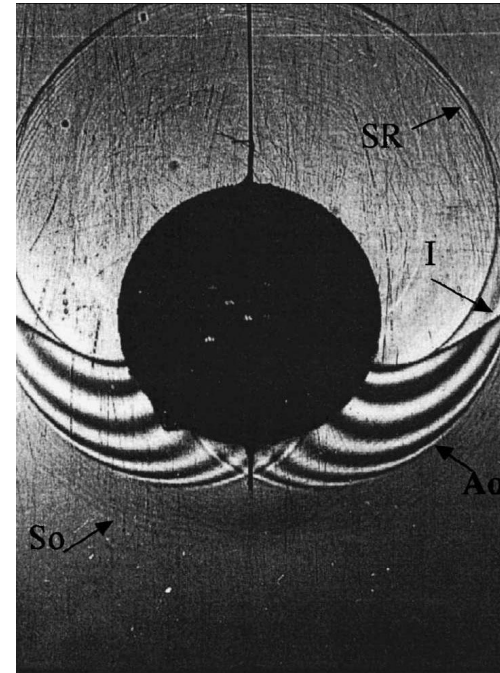
modal decomposition using eigenfunctions of the hydrodynamic part,
set of systems of ordinary integro-differential equations

Numerical coupling of the two parts (finite differences)

Model 0 – absolutely rigid cylinder

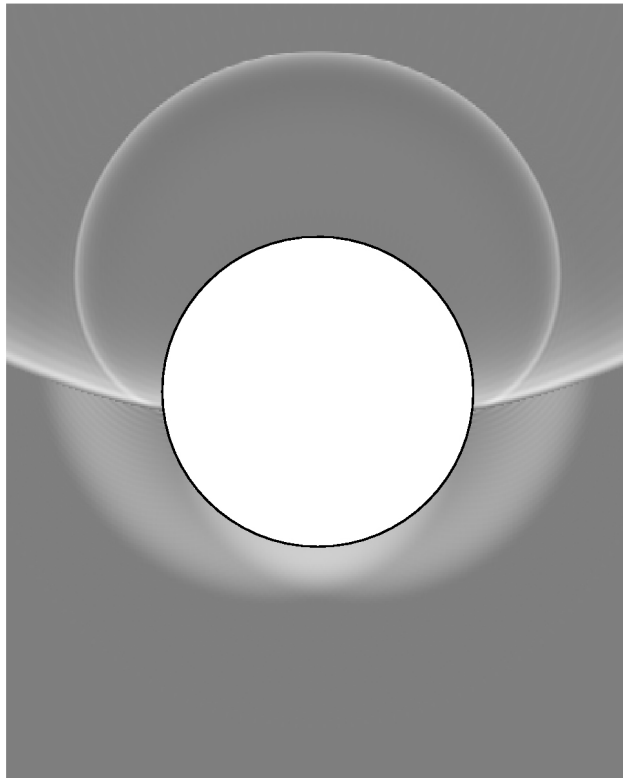


Numerically simulated pressure pattern

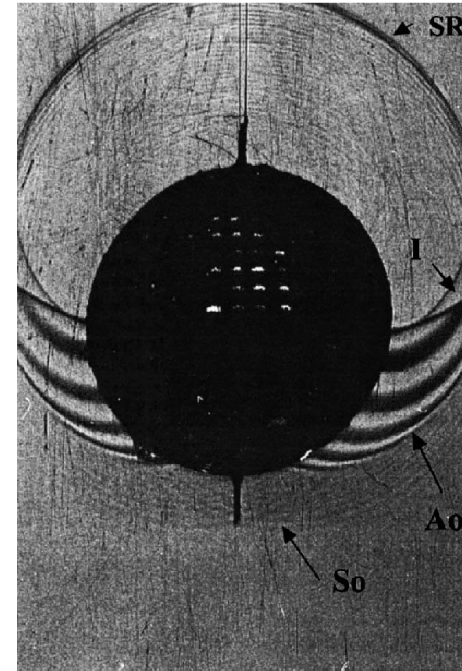


Ahyi, A. C., Pernod, P., Gatti, O., Latard, V., Merlen, A. and Uberall, H. Experimental demonstration of the pseudo-Rayleigh A0 wave. *Journal of the Acoustical Society of America* 104, 1998, 2727-2732. © American Institute of Physics.

Model I – membrane thin shell theory (no bending stiffness)

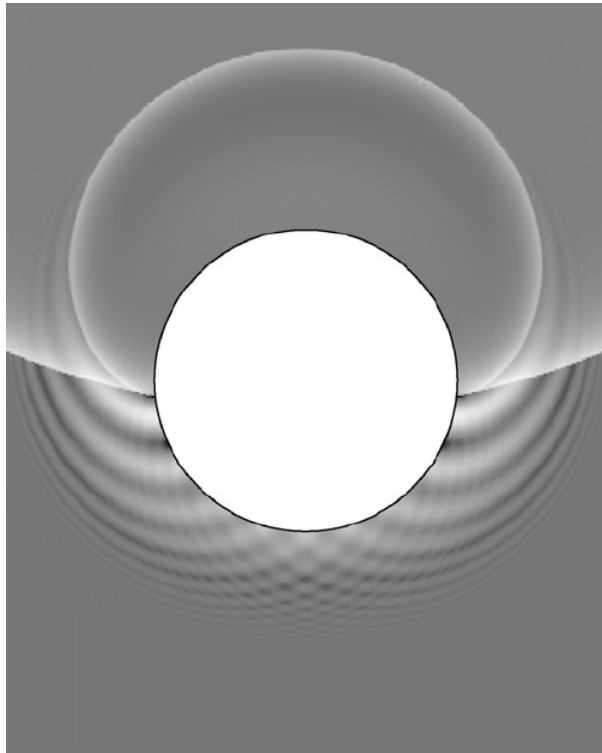


Numerically simulated pressure pattern

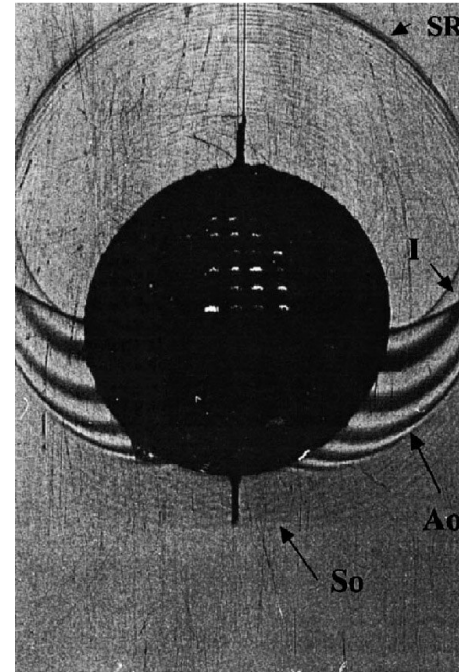


Ahyi, A. C., Pernod, P., Gatti, O., Latard, V., Merlen, A. and Uberall, H. Experimental demonstration of the pseudo-Rayleigh A0 wave. *Journal of the Acoustical Society of America* 104, 1998, 2727-2732. © American Institute of Physics.

Model II – full thin shell theory (with bending stiffness)

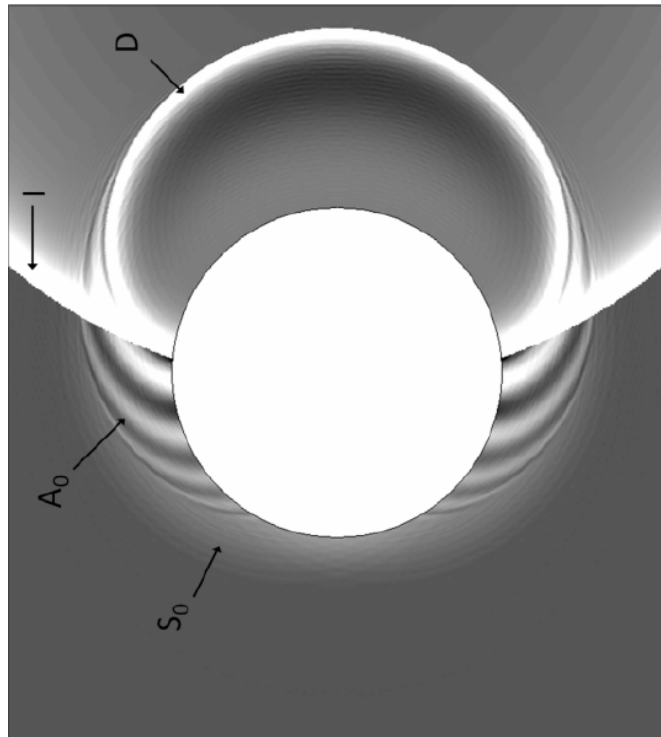


Numerically simulated pressure pattern

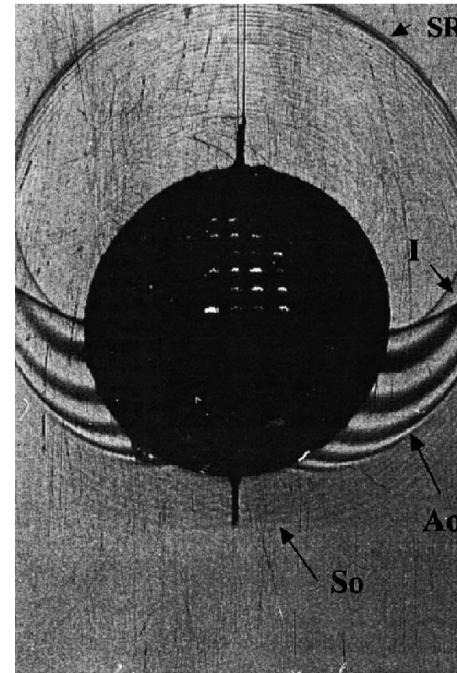


Ahyi, A. C., Pernod, P., Gatti, O., Latard, V., Merlen, A. and Uberall, H. Experimental demonstration of the pseudo-Rayleigh A0 wave. *Journal of the Acoustical Society of America* 104, 1998, 2727-2732. © American Institute of Physics.

Model III – fully elastic model (shell as an elastic body of finite thickness)

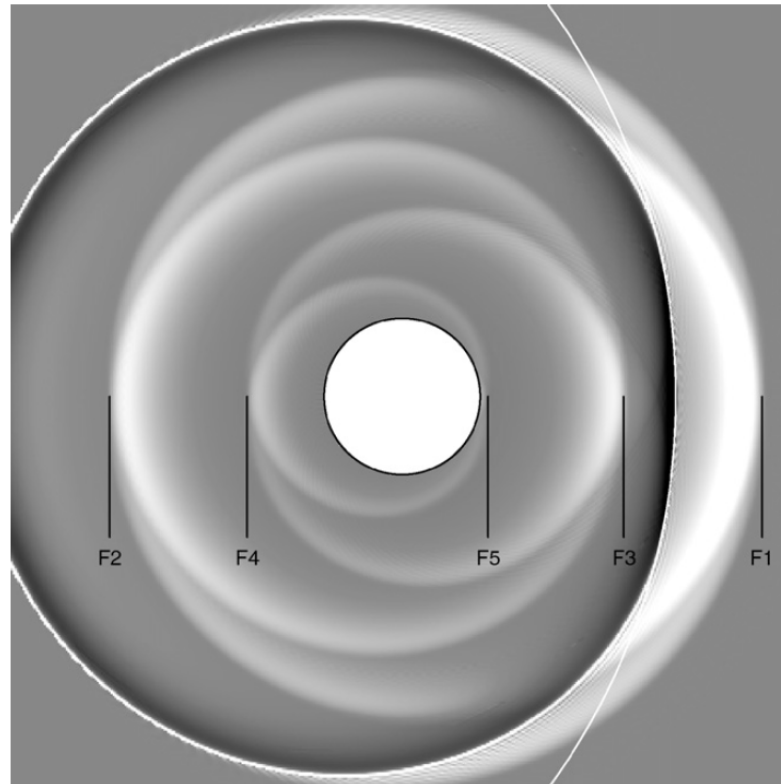


Numerically simulated pressure field
(in collaboration with JF Sigrist and C Leblond)



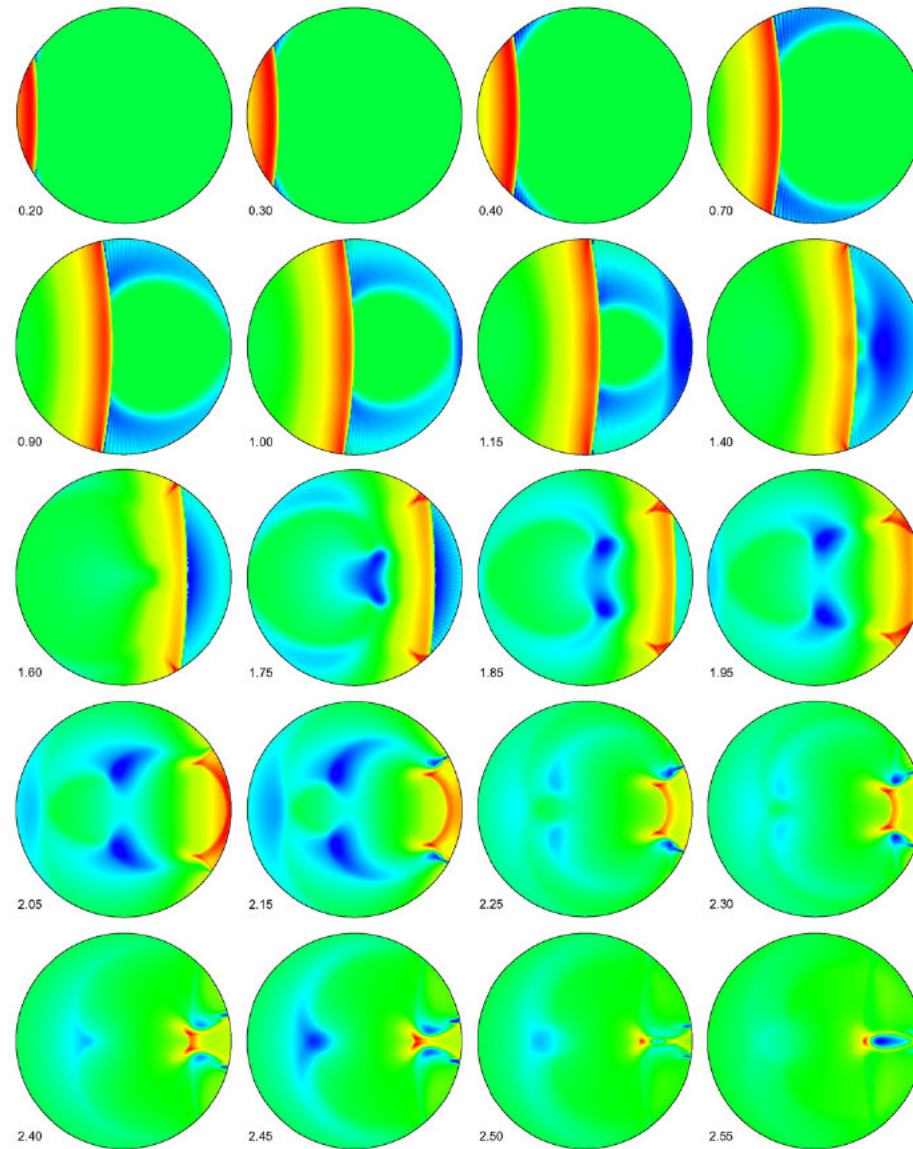
Ahyi, A. C., Pernod, P., Gatti, O., Latard, V., Merlen, A. and Uberall, H. Experimental demonstration of the pseudo-Rayleigh A₀ wave. *Journal of the Acoustical Society of America* 104, 1998, 2727-2732. © American Institute of Physics.

Late-interaction radiation pattern

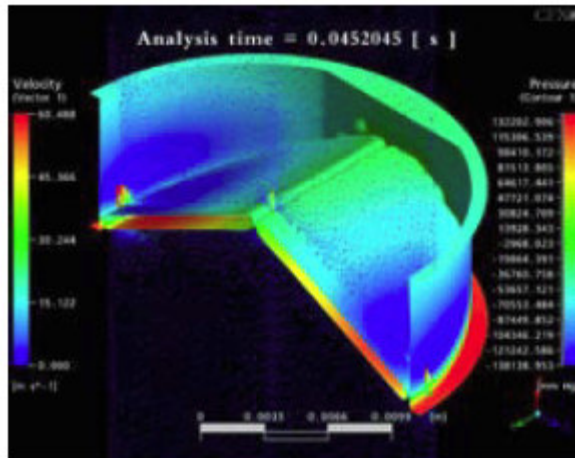


We will focus on the internal fields
because they are most relevant to
the cardiological applications

Overall dynamics of the early and mid-interaction



Cavitation in the aortic root system



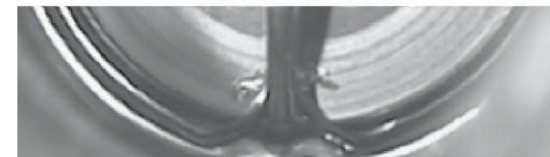
from Rafiroiu D, Diaz-Zuccarini V, Narracott A, Lawford PV and Hose DR (2008) Multi-physics and multi-scale modelling: closure dynamics of a bileaflet prosthetic heart valve. *Journal of Biomechanics* 41, Supplement 1: S241.



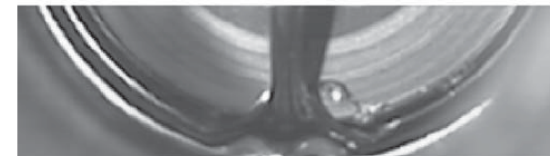
(a)



(b)



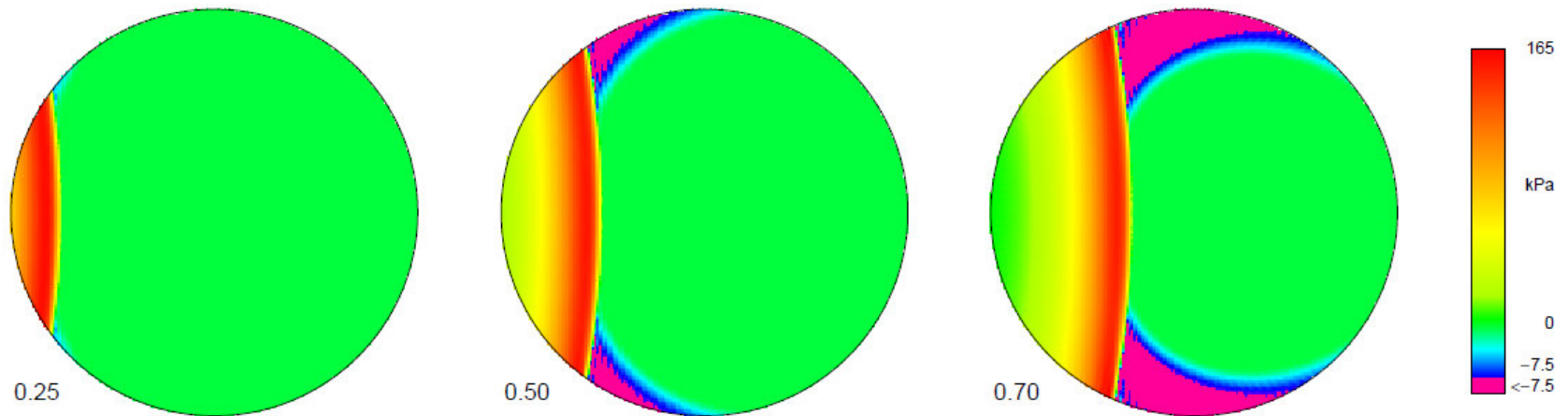
(c)



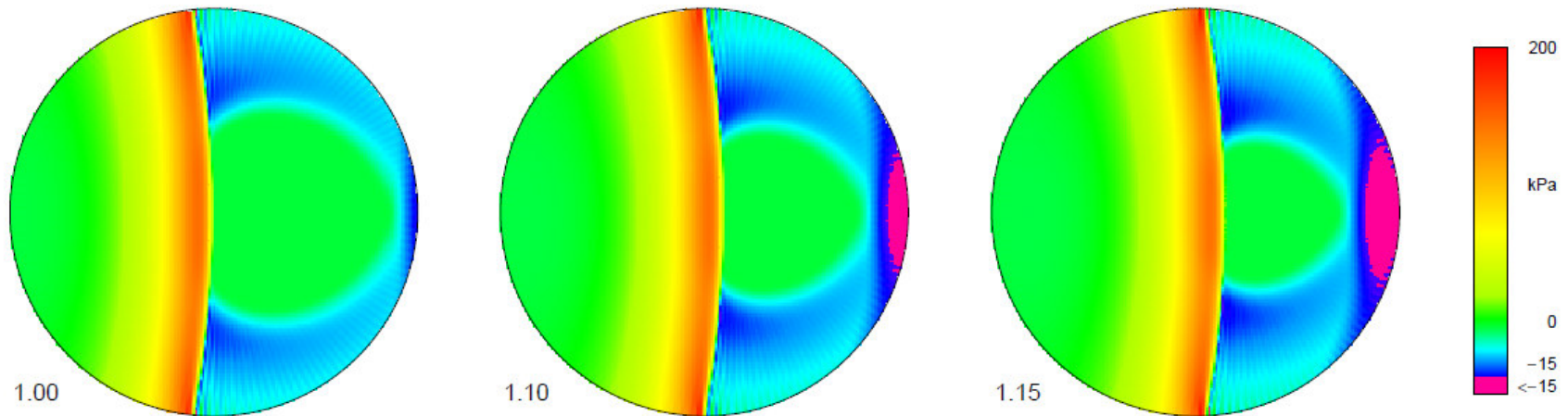
(d)

from Lee, H., Homma, A., Tatsumi, E. and Taenaka, Y., 2007 Estimation of mechanical heart valve cavitation in a pneumatic ventricular assist device, *Journal of Artificial Organs* 10, 181–185. The formation of cavitation bubbles is clearly visible.

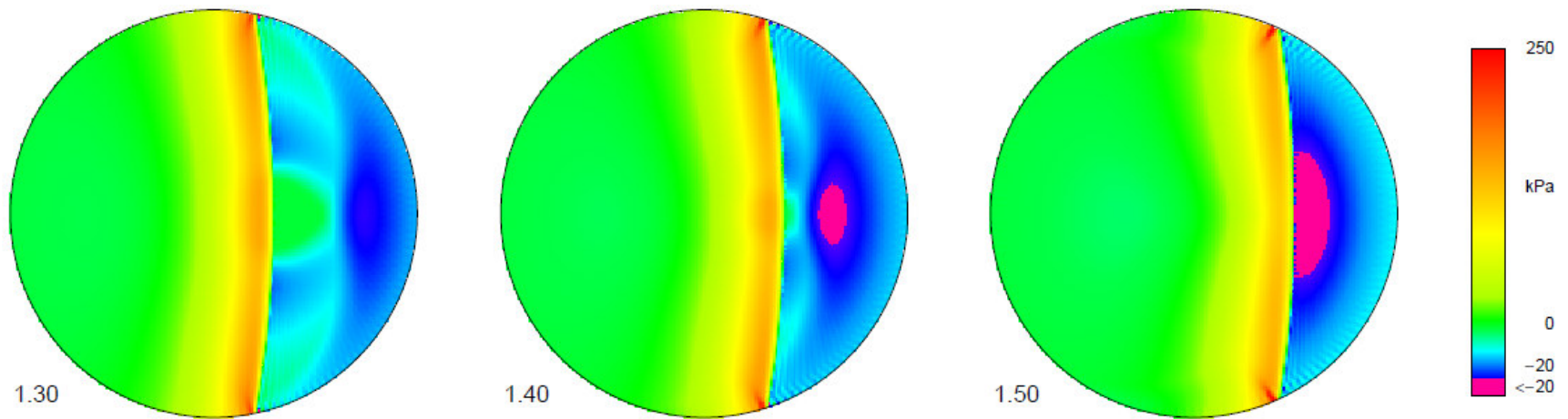
Possibility of cavitation – Scenario I



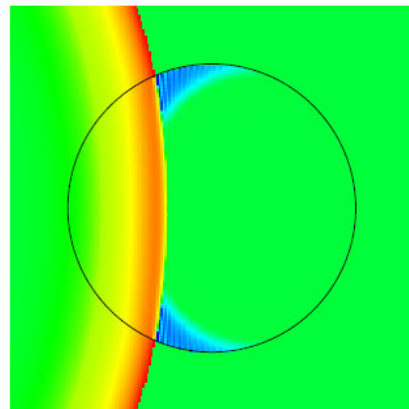
Possibility of cavitation – Scenario II



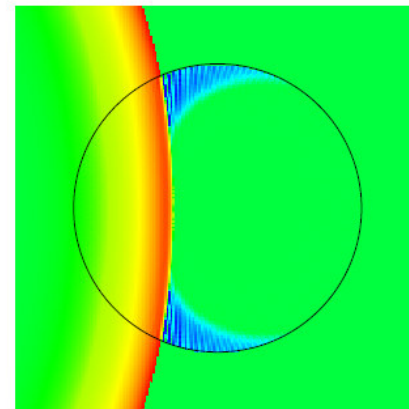
Possibility of cavitation – Scenario III



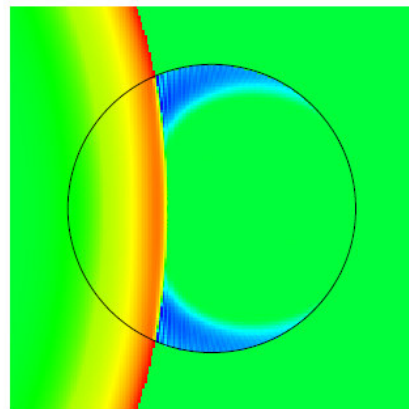
Different materials



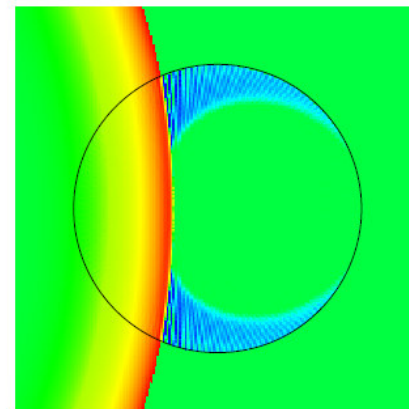
(a)



(b)



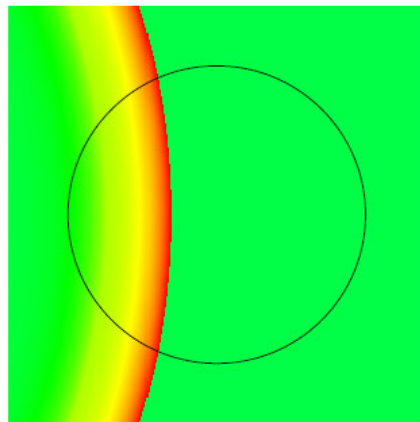
(c)



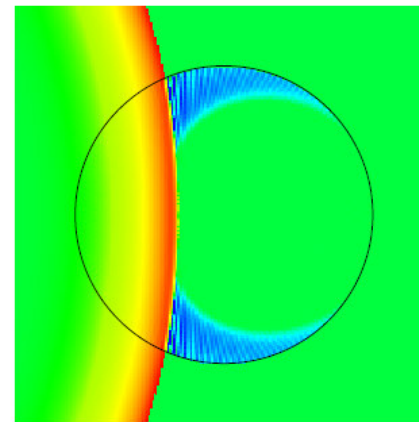
(d)

(a) copper; (b) titanium; (c) steel; (d) aluminum

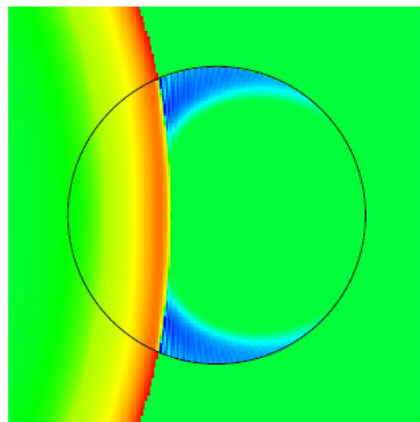
Different thicknesses



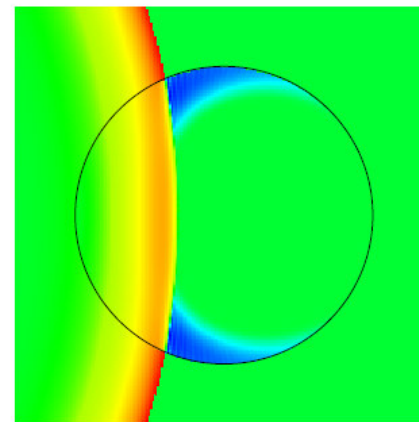
(a)



(b)



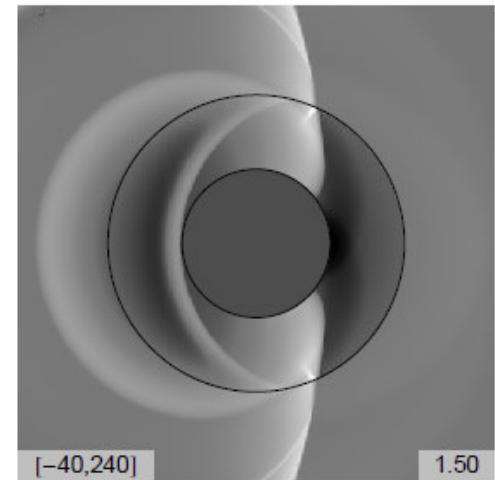
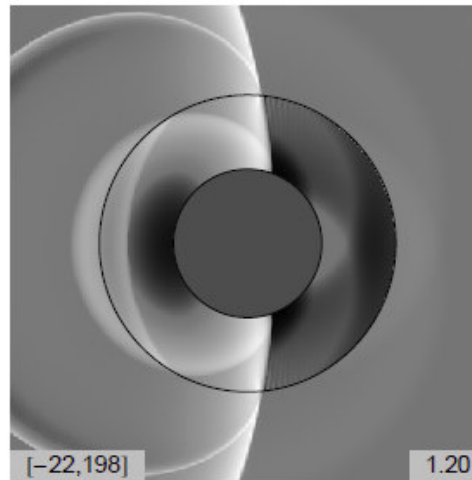
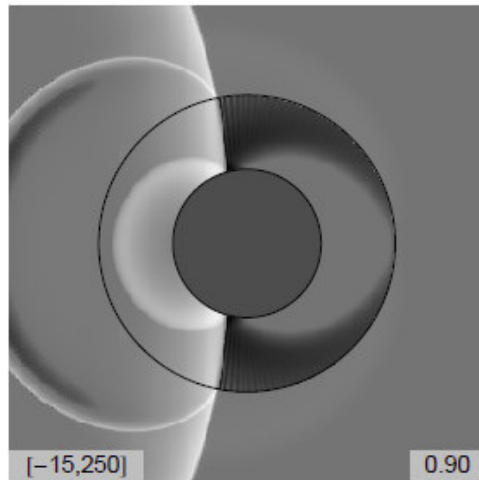
(c)



(d)

(a) shell is absent; (b) thickness-to-radius ratio=0.005; (c) 0.01; (d) 0.02

Structurally enhanced systems are even more interesting:



Conclusions:

structure-induced waves are responsible for a wide variety of FSI phenomena, and could often result in effects that negatively (sometimes to a significant degree) impact both the structure and fluid(s); thus, integrating the analysis of the structure-induced waves in the design process is necessary;

controlling (and, hopefully, beneficially using) the structure-induced waves is a promising direction for the FSI research – not only it could result in the reduction of the possible negative effects that the waves have on the fluids, it could also be used to improve the overall performance of structures under impulse and shock loading;

Acknowledgements

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Bryan MacDonald (Mechanical Engineering , Dalhousie)
Garrett Dooley (Mechanical Engineering , Dalhousie)
Martin Mitchell (Mechanical Engineering , Dalhousie)

Thank you for inviting me
to join your research group!