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The significance of elasticity for a sinking cylinder in a fluid with an Earth-like compressible rheology

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Although it is generally accepted that the Earth has a compressible rheology, this parameter is neglected in most numerical models. However, the validity of this assumption is poorly understood. Therefore, the effect of elastic compressibility on the settling velocity of a gravity driven cylinder is examined with a finite element code that solves the mechanical equilibrium equation for a Maxwell viscoelastic rheology. The fluid is homogeneous and bounded by no-slip conditions. The only differences with the semi-analytical benchmark are the closed boundaries at the top and bottom and the compressible viscoelastic rheology. For large Poisson ratios ($\nu = 0.4$), a discrepancy with the steady state incompressible solution of 17% is found. This is caused by the downward motion of the cylinder, which compresses the fluid in the region below the cylinder, so that the resistance on the cylinder is decreased. The downward velocity associated with this compression depends on the distance between the cylinder and the bottom boundary, therefore the cylinder decelerates as it approaches the bottom and true steady state solutions are only achieved in very long tubes (i.e. at least 100 times the radius of the cylinder for the reference model).

Another effect which is not observed in the incompressible case is that in the region above the cylinder, the fluid motion is directed upward. This flow, resulting from the return flow, acts as an extra resistance to the motion of the cylinder and decreases with distance from the top boundary. It can be used to damp the initially large elastic effects so that the convergence towards the steady state solution is faster.

This model shows that elastic compressibility influences the velocity of a sinking cylinder significantly. The benchmark can only be reproduced if the position of the boundaries are carefully selected and in limiting cases of the Poisson ratio. In Earth-like model setups, one does not have the same degree of freedom to choose the initial situation. Hence, this idealization of incompressibility is not always justified. Elastic compressibility probably affects the results in confined flow, such as mantle wedge flow, channel flow or subducting plates interacting with material boundaries such as the discontinuity between the upper and lower mantle.