Nonlinear hydrodynamic damping of elastic vibrations of beams near a plane boundary

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Abstract. The paper is devoted to the study of hydrodynamics around long cantilever beams that perform flexural vibrations in a viscous incompressible fluid near a plane boundary. The study is based on the numerical three-dimensional and two-dimensional simulations of flows induced by vibrations. The fluid motion is described by the full non-stationary system of Navier-Stokes equations and the oscillation profile of the beam is determined according to the Euler-Bernoulli theory. In the framework of the research the analysis of the changes of hydrodynamics around the beams occurring with an increase of the relative length, the gap-to-width ratio, the dimensionless frequency and amplitude of vibrations is made.

Introduction

Studies of aero-hydrodynamic effects acting on elongated small beam structures undergoing elastic vibrations have been actively developed in the last two decades in connection with the emergence of a number of innovative technological solutions based on piezoelectric bending actuators. Due to their energy efficiency and mobility, piezoelectric actuators are being successfully introduced in the field of robotics, as a part of propulsion systems of autonomous underwater and aircraft vehicles, as cooling systems and energy harvesters in microelectronics, as pump systems in microfluidic devices, etc. In recent years, an extensive theory has been created that describes the aerodynamic influence on a single beam-type actuator that vibrates in an infinite volume of viscous fluid (see, for example, [1-2]). However, the design of most devices suggest the presence of surfaces close to the actuator, in this case the application of this theory is limited. The present work is devoted to the study of hydrodynamics around beams that perform bending vibrations near a plane boundary.

Results and discussion

A beam-fluid model of interaction was considered, according to which flexural vibrations of a beam was described according to the Euler-Bernoulli theory, and the fluid motion around the beam was governed by the Navier-Stokes equations. The solution of the problem was carried out numerically in the range $1 \leq KC \leq 7$ (where KC is the Keulegan-Carpenter parameter calculated by the amplitude of oscillations of the free end), $50 \leq \beta \leq 1000$ (where β is the Stokes number), $3 \leq L \leq 20$ (where L is dimensionless length of the beam), $0.1 \leq S < \infty$ (where S is the dimensionless gap distance between the plane boundary and the beam). The numerical models were realized on the basis of the OpenFOAM package.

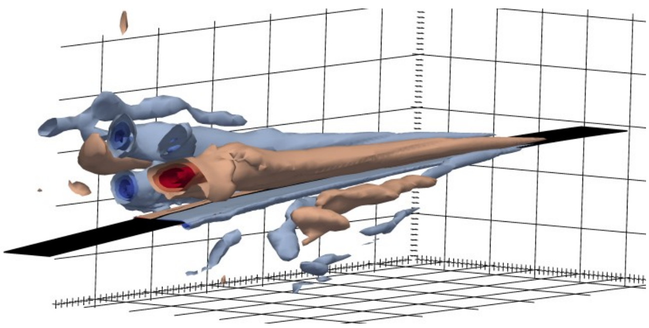

Figure 1: Three-dimensional visualization of the flow formed near the vibrating beam. Isosurfaces of the z-component of the vorticity.

According to the results of the study the primary unsteady and secondary steady fluid flows in cross-sections parallel and perpendicular to the axis of the beam were described, the map of observed flow regimes was constructed and analysis of the dependence of hydrodynamic forces on the vibration parameters was carried out. The collected data indicates a significant influence of the plane boundary for $S \leq 0.5$ on the structure of primary and secondary flows forming around the beams and on the added mass and damping forces acting on the beams. For example, in the range $0.05 \leq S \leq 0.5$, with a decrease in the distance to the wall, the damping force can increase by 200% and the added mass force can increase by 50%.

References

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