Flutter of an infinite-chord Nemtsov membrane induced by radiation of surface gravity waves on a uniform flow

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Flutter of membranes has been a classical subject for at least seven decades.Membranes submerged in a compressible gas flow occupying a space or a semi-space and their flutter at supersonic speeds have been considered already in the works by Miles (1947, 1956), Goland and Luke (1954), Benjamin (1963) and Bolotin (1963), see [2] and references therein. Recent works on membrane flutter are motivated by such diverse applications as stability of membrane roofs in civil engineering, flutter of travelling paper webs, aerodynamics of sails and membrane wings of natural flyers, as well as the design of piezoaeroelastic systems for energy harvesting [2, 3].

Surface gravity waves on a motionless fluid of finite depth are a classical subject as well, going back to the seminal studies of Russell and Kelvin. Nemtsov (1985) was the first who considered flutter of an elastic membrane resting at the bottom of a uniform horizontal flow of an inviscid and incompressible fluid as an anomalous Doppler effect due to emission of long surface gravity waves [1]. In the shallow water approximation, he investigated both the case of a membrane that spreads infinitely far in both horizontal directions and the case when the length of the membrane in the direction of the flow (or the chord length) is finite whereas the span in the perpendicular direction is infinite. Nevertheless, the case of flow of arbitrary depth has not been studied in Nemtsov (1985), and no numerical computation supporting the asymptotic results has been performed. Another issue that has not been addressed in Nemtsov (1985) is the relation of stability domains for the membrane of finite length to those for the membrane of infinite length.

In the present work we reconsider the setting of Nemtsov in order to address the finite depth of the fluid layer, find flutter domains in the parameter space, analyse them using perturbation of multiple roots of the dispersion relation and investigate the flutter onset for the membrane of infinite chord length. We will explain the radiative instabilities via the interaction of positive and negative energy waves using an explicit expression for the averaged total energy derived rigorously from physical considerations and relate them to the anomalous Doppler effect. We believe that the Nemtsov membrane is as important for understanding the phenomenon of radiation-induced instabilities as the famous Lamb oscillator coupled to a semi-infinite string was for understanding the radiative damping.

References

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