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Surface Hydrodynamics of Viscoelastic Fluids and Soft Solids: Surfing Bulk Rheology on Capillary and Rayleigh Waves.

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ABSTRACT

From the recent advent of the new soft-micro technologies, the hydrodynamic theory of surface modes propagating on viscoelastic bodies has reinvigorated this field of technology with interesting predictions and new possible applications, so recovering its scientific interest very limited at birth to the academic scope. Today, a myriad of soft small objects, deformable meso- and micro-structures, and macroscopically viscoelastic bodies fabricated from colloids and polymers are already available in the materials catalogue. Thus, one can envisage a constellation of new soft objects fabricated by-design with a functional dynamics based on the mechanical interplay of the viscoelastic material with the medium through their interfaces. In this review, we recapitulate the field from its birth and theoretical foundation in the latest 1980's up today, through its flourishing in the 90's from the prediction of extraordinary Rayleigh modes in coexistence with ordinary capillary waves on the surface of viscoelastic fluids, a fact first confirmed in experiments by Dominique Langevin and me with soft gels [Monroy and Langevin, Phys. Rev. Lett. 81, 3167 (1998)]. With this observational discovery at sight, we not only settled the theory previously formulated a few years before, but mainly opened a new field of applications with soft materials where the mechanical interplay between surface and bulk motions matters. Also, new unpublished results from surface wave experiments performed with soft colloids are reported in this contribution, in which the analytic methods of wave surfing synthetized together with the concept of coexisting capillary-shear modes are claimed as an integrated tool to insightfully scrutinize the bulk rheology of soft solids and viscoelastic fluids. This dedicatory to the figure of Dominique Langevin includes an appraisal of the relevant theoretical aspects of the surface hydrodynamics of viscoelastic fluids, and the coverage of the most important experimental results obtained during the three decades of research on this field.

1. Introduction

Surface waves at a glance. Examples of surface waves are abundant in nature. For instance, the waves created on the free surface of water, the wind waves, tidal waves and tsunamis existing in ocean, the seismic waves appeared on the Earth surface from tectonic activity, are typical examples that illustrate how ancestral is the interest on surface waves created by natural forces. Surface waves are ubiquitous not only at fluid interfaces but also on the surface of solids, where surface motion occurs after the mechanical interplay between excitation and restoring forces in the bulk phases [1,2,3]. Indeed, such a

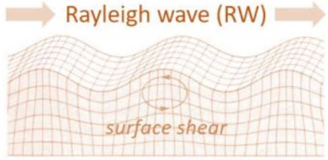

FIG. 1. A surface Rayleigh wave (RW) propagating as an acoustic wave on the surface of a deformable solid. Surface RWs supported by shear rigidity do not penetrate deeply the bulk, decaying over distances comparatively shorter than bulky shear waves, which spread in the three dimensions. Surface RWs propagate over long distances with a constant phase velocity (at lesser friction as compared to bulk waves). Due to the longitudinal and transverse restoring forces imposed by shear rigidity, shear-like RWs cause the surface elements to rotate in counter-clockwise motion as elliptical orbits in the planes parallel to the direction of propagation. This kinematic signature is specific of the "extraordinary" (solid-like) RWs in viscoelastic fluids, by opposite to the "ordinary" (liquid-like) waves, which make fluid surfaces to move clockwise, as capillary ripples do on the surface of liquid water. These surfing motions may be exploited to infer bulk rheology in soft solids and viscoelastic materials.