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Leaking inflatables: from defects to functionalities

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Inflatable structures offer promising solutions for lightweight, deployable systems in medicine, architecture, and engineering. However, leakage often compromises their functionality, potentially leading to catastrophic outcomes. A comprehensive understanding of leak dynamics in deformable inflatables is therefore critical for designing next-generation, leak-resistant structures. In this study, we systematically investigate the dynamics of leaks in highly deformable inflatables with standard geometries, including spheres, cylindrical tubes, and flat membranes. The inflatables were fabricated using commercially available elastomers such as Ecoflex, VPS, and silicone rubber, with controlled defects of varying sizes introduced into the membranes. Air and water were selected as the injection media. Through controlled-injection rate experiments, we identified a steady-state leaking pressure that depends on the inflation rate, the viscosity of the injection medium, and the large deformation behavior of the inflatables. We formulate a theory to reveal a coupling between elasticity and fluid mechanics that governs the dynamics and equilibrium deformation of these structures. Lastly, we demonstrate that the leaking process can be exploited to develop inflatables with tunable elastic and hysteretic mechanical responses, which could serve as building blocks for energy-absorbing structures, autonomous soft robots, and mechanical logics.