Harnessing stiffness asymmetry in thin sheets inflatables for high deformation shape morphing

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Inflatables are particularly popular in the field of shape morphing materials. Their simple, purely mechanical actuation allows for fast deployment and high reusability. Moreover, just as the overall shape and stiffness of a party balloon are directly linked to its internal pressure, inflatable objects offer an elegant example of the coupling of elasticity and geometry.

We study networks of parallel inflatable tubes obtained through the planar welding of two plastic sheets. Composite tubes presenting two sides of distinct stiffness can be made by using two sheets of different thicknesses. Upon inflation of such tubes, a mismatch of curvature between the two walls rotates the seam line connecting them. Those local displacements allow for enormous deformations when integrated across large networks. We present experimental results on the mechanics of inflation of either one or several connected tubes.

The shapes of the tubes can be predicted throughout inflation using a simple Kirchhoff beam model, for which analytical solutions are determined for the limit cases of low and high pressures. In the latter case, a boundary layer at the edge of the seam line fully determines the rotation between two connected tubes. We highlight as well how contact between neighboring tubes limits in practice the overall motion of our inflatables. Afterwards we formulate and solve an inverse problem to design a wide variety of objects that can be described as a two-dimensional curve perpendicularly to the direction of the tubes. The question of the stiffness of such structures is discussed as well. We finally present several applications of asymmetric tubular inflatables to more complex geometries: axisymmetric surfaces, kirigami, and curved folding.

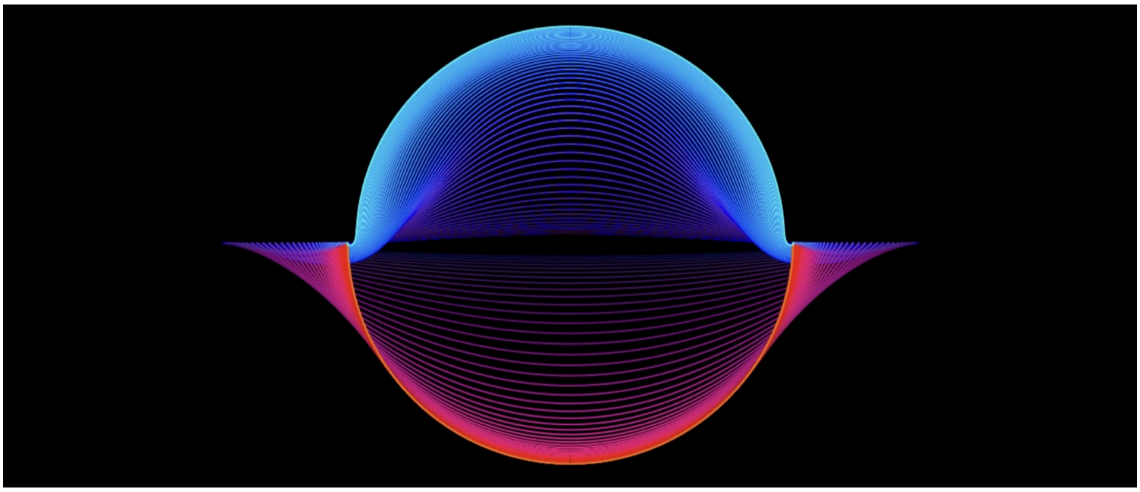

Figure 1: Cross-section of a tube with various levels of pressurization.