Dielectric-elastomer-driven airship uses fish-like propulsion

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A biomimetic approach that bends a helium-filled body may optimize thrust.

The propulsion of fish in water is very efficient and optimized for speed, acceleration, and maneuverability. By contrast, the movement of conventional airships driven by propellers is only of limited efficiency.¹ A biomimetic approach conveying fish-like movement to airships is expected to optimize their propulsion. Large-scale, planar dielectric-elastomer (DE) actuators that bend the helium-filled body of the airship are ideal for such applications because of the large deformations that are possible and their light weight.

DE actuators are compliant capacitors that are unique for their soft-membrane structure and, therefore, ideal for use in inflatable or lightweight objects. DEs are coated on either side with a compliant electrode and squeezed in the thickness direction when voltage is applied. Because of their incompressibility, the membrane actuators expand in-plane (see Figure 1). On the airship, the actuators are placed in an agonist-antagonist configuration. The ship is propelled in a fish-like manner by sinusoidal bending of the body and tail fin that is driven by a number of large, planar DEs on either side of the ship.² The shape and movement is adapted from the rainbow trout, whose propulsion is very efficient and versatile.³

For this interdisciplinary project we had to combine many different fields, including DE actuation, aerostatics, aerodynamics, biomimetics, ultralightweight structural design, electronics, and control of high-voltage power supplies, and also develop new technologies. Two functional model airships with different DE actuator types increased our knowledge of actuator technology and airship design. We built a ‘flying fish’ with servo motors to study fish-like movement in air. Collaborations with the Swiss Federal Institute of Technology for wind-tunnel testing of different tail-fin types and numerical simulations improved our experimental and theoretical expertise on fish-like propulsion (see Figure 2). We developed a power-supply and control unit that allows computer manipulation of movement. Data is transmitted to the airship via a wireless local-area network, and sensor information can be returned in-flight. The optimal fish-like movement can be adjusted by tuning the activation frequency and amplitude as well as a phase shift between body

Figure 1. Working principle of biomimetic airship and dielectric-elastomer (DE) actuators, which create fish-like sinusoidal bending of the ship’s helium-filled body.

Continued on next page
and tail-fin undulation. Turns can be implemented by asymmetric activation of the left- and right-hand actuators. Finally, we successfully integrated the different technologies, resulting in an 8m-long airship model. That ‘fish’ is filled with helium, has a volume of 11m$^3$, and a lift of 9.7kg. Its body and tail fin execute an undulatory movement demonstrating fish-like propulsion and maneuverability in air (see Figure 3).

Many studies have investigated fish-like propulsion in water. But few attempts have been made to transfer this movement to propulsion in air. Our model airship is the first built for DE-actuator research and, to date, the first and only example with DE-actuator propulsion. For large DE-membrane actuators, novel designs and manufacturing tools (including knowhow for maintaining large prestrains when applying the membranes) had to be developed in our laboratory. The actuators are internally reinforced with carbon rods and polyamide strings. For body deflection we applied a total area of 6.5m$^2$ with two-layered actuators, and at the tail fin a total area of 2.7m$^2$ with four-layered actuators. Upon activation with 3kV over 5s, we achieved a linear strain of 16%, a blocking-force difference between active and passive states of 10N, and an efficiency of 6.3% for the tail-fin actuators. For the airship, maximal velocity of 0.57m/s was reached at 0.15Hz, and there was a phase shift between body and fin movement of 72°.

Because of their unique features, DE actuators seem ideal for a wide range of applications, including in the biomedical, optical, and automotive industries. We used an acrylic elastomer as dielectric for our project. Future investigations will concentrate on different materials that allow lower activation voltages, less viscous losses, and better temperature stability. Our airship serves as research platform, simultaneously demonstrating the potential of membrane-type DE actuators for many applications, including peristaltic pumps for sensitive liquids.

Figure 2. Computational fluid-dynamics simulation of a fish resembling an airship in 3D.

Figure 3. Biomimetic model airship driven by DE actuators.

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Christa Jordi graduated in mechanical engineering from the Swiss Federal Institute of Technology (ETH) in 2007, and subsequently started her PhD research in mechanical engineering at EMPA Dübendorf. Her dissertation’s research goal is development and characterization of a biomimetic airship driven by dielectric elastomers.

Christian Dürager worked for 13 years as an electrical engineer and two years as test engineer in hardware-in-the-loop systems. He graduated in electrical engineering from Graz University of Technology (Austria) in 2003. He started his PhD at EMPA in 2008, focusing on structural-health monitoring with active-fiber composites.

Silvain Michel graduated in mechanical engineering from ETH in 1989. After 10 years as a fatigue- and damage-tolerant specialist in the aerospace industry, he joined EMPA in 2000. From 2003 to 2008 he headed the research group for electroactive polymers within the Laboratory for Mechanical Systems Engineering. Since 2009, he has been a senior scientist, responsible for various projects on DE actuators and devices.

References