# Electriflow: Augmenting Books With Tangible Animation Using Soft Electrohydraulic Actuators


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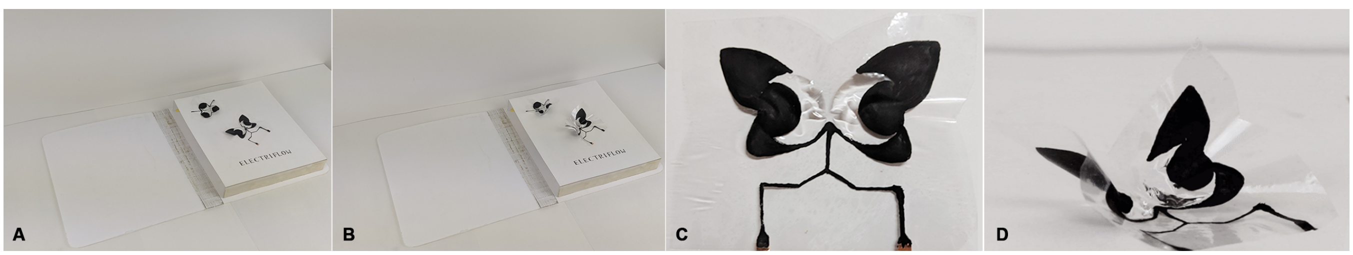


**Figure 1: A book augmented with tangible animation employing soft electrohydraulic actuators. (A) Shows the book with voltage OFF, (B) shows the book with voltage ON state. (C) Shows the close up of an artificial butterfly that can be animated, (D) shows the same butterfly with voltage ON.**


## ABSTRACT

We present Electriflow: a method of augmenting books with tangible animation employing soft electrohydraulic actuators. These actuators are compact, silent and fast in operation, and can be fabricated with commodity materials. They generate an immediate hydraulic force upon electrostatic activation without an external fluid supply source, enabling a simple and self-contained design. Electriflow actuators produce an immediate shape transition from flat to folded state which enabled their seamless integration into books. For the Emerging Technologies exhibit, we will demonstrate the prototype of a book augmented with the capability of tangible animation.




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## CCS CONCEPTS

• **Human-centered computing → User interface toolkits**; **Human computer interaction (HCI)**.

## KEYWORDS

Books, tangible animation, electrohydraulic actuator

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## 1 INTRODUCTION

Traditionally books are composed of static text and graphics. However, in recent years, there has been an emphasis on developing life-like animation for objects and graphics in books, especially in the field of Human-Computer Interaction (HCI) and design. Previous

works in this direction often combine paper with a variety of hardware to produce physical animation in a book, like shape memory alloys [Qi and Buechley 2010] or thermoreponsive polymers [Wang et al. 2018]. These actuation mechanisms are slow in operation. Instead, a better prototyping technology for a dynamic book would enable immediate actuation, noiseless operation and compact integration. In this work, we present Electriflow: soft electrohydraulic actuators for augmenting books with tangible animation. Electriflow offers numerous advantages as a silent, fast, soft, and self-contained technology.

## 2 ELECTRIFLOW ACTUATORS

Electriflow utilizes a combination of electrostatic and hydraulic phenomena to constrain the flow of a working fluid contained in flexible pouches [Purnendu et al. 2021b]. Based on this working mechanism, we present a novel **Crescent Moon actuator** as a building block for tangible animation (shown in figure 2). These compact, silent actuators produce immediate shape transitions between flat and folded states upon electric stimulation. As in the previous work on electrohydraulic actuators [Acome et al. 2018; Purnendu et al. 2021a], the Crescent Moon actuator consists of two main parts:

- a **pouch** that is non-stretchable and compliant (figure 2)
- flexible **electrodes** covering parts of the pouch (figure 2A)

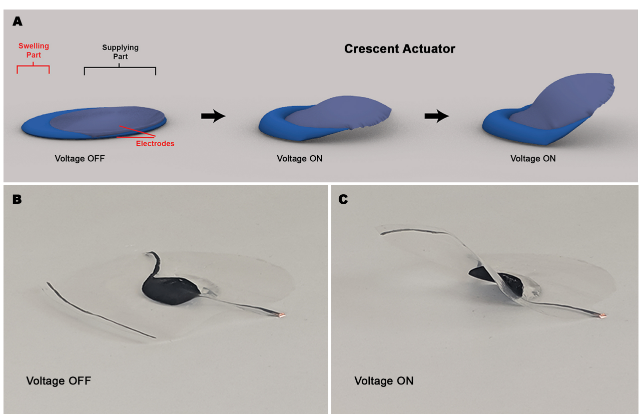


**Figure 2: (A) Shows the main components of the Crescent Moon actuator and its actuation states as the voltage is applied. (B) Shows the actuator when the voltage is OFF while (C) shows the actuator with voltage ON.**

The pouch is filled with a dielectric liquid (silicone oil in this case) and is divided into two regions: a supply region (purple in figure 2A), and a swelling region (blue in figure 2A). The supply region is covered with opposing flexible electrodes on both sides. The operation principle of these Crescent Moon actuators is similar to other soft electrohydraulic actuators reported earlier [Acome et al. 2018]. The **Crescent Moon actuator** has a circular fluid-filled region and a non-concentric elliptical electrode, resulting in an asymmetric swelling region that drives a smooth-curve bending behavior (figure 2). An actuator in OFF and ON states is illustrated in figure 2B and figure 2C respectively. These actuators produce a maximal bending angle of $60^o$ and a maximum actuation frequency of 25 Hz.

## 3 TANGIBLE ANIMATION IN A BOOK

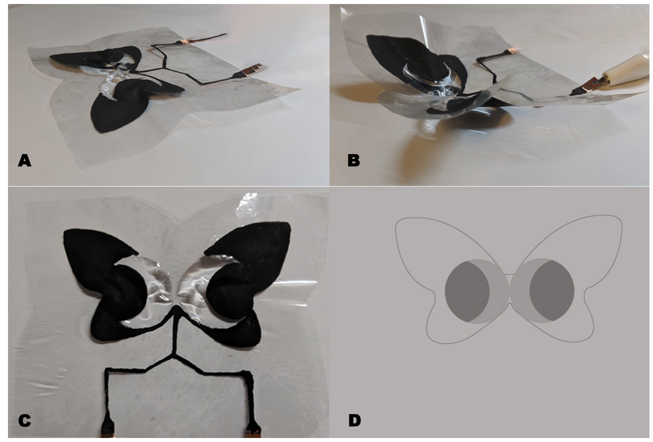


**Figure 3: An actuating butterfly for tangible animation. (A) State when the voltage is OFF, (B) state when the voltage is ON, (C) the top view and (D) the actuator layout consisting of two Crescent Moon actuators facing opposite to each other.**

The **Crescent Moon actuator** can transition from a flat state to smooth curve-like folded state which makes it suitable for embedding in a book (see figure 1). In figure 3, we show the prototype of a butterfly, composed of two Crescent Moon actuators embedded in the wings. At an activation voltage of 10 kV, the wing fluid is displaced toward the body of the butterfly, constraining the fluid in a crescent shape. This redistribution of fluid results in a flapping motion (see figure 3) which can actuate up to a frequency of 25 Hz.

Crescent Moon actuators can also be embedded on thin-film sheets for character animation or form the basis of a flower that blooms (see demo video). For the SIGGRAPH Labs exhibition, we will demonstrate the prototype of a book capable of tangible animation using our soft electrohydraulic actuators.

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