Developing morphing wing and tail elements

Fly Like a Bird

New knowledge in materials sciences and the continuous improvement of sensor networks open up new possibilities for adaptive aircraft technologies. At the University of Michigan, MicroLabBox plays a crucial role in testing these new designs with regard to data recording, actuator control, and the coordination of the experiments.

Giving airplanes the same maneuverability as birds is the dream of aircraft designers (pictured is a hunting falcon).

When developing morphing aircraft technologies, the Adaptive, Intelligent, Multifunctional Structures (AIMS) Lab at the University of Michigan frequently takes its inspiration from nature. Contrary to modern-day aircraft with their mostly stiff structures, birds can make more targeted use of their wings and tails to flexibly react to atmospheric conditions or changing air currents. This adaptability can be particularly useful for smaller aircraft, which, like birds, are influenced more by wind and weather than larger ones. The research at the AIMS Lab focuses on the development of aircraft that can actively and directly react to the surrounding air currents by adjusting their geometry, specifically the shape of their wings and tail. The AIMS Lab investigates these adjustment options to be able to develop an aircraft that uses nature as a model to adapt to the atmospheric conditions.

Morphing Wings – The Bird Flight Model

The ailerons at the wings play a central role in the aerodynamic control of aircraft, which makes them an important research topic in the field of adaptive aircraft technology. The AIMS Lab is investigating the effects of changing the shape along the complete wing surface with the help of Macro-Fiber Composite (MFC) actuators that are connected by elastomeric honeycomb structures (figure 1). This way, certain areas of the wings can be adjusted to minimize unwanted effects from air currents. This method is particularly suitable should the wing experience a sudden stall, a phenomenon where part of the wing significantly loses lift. By modeling the nonlinear aerodynamic behavior during a stall, the AIMS Lab can predict each actuator deflection required to optimize the wing shape in such a way that it compensates

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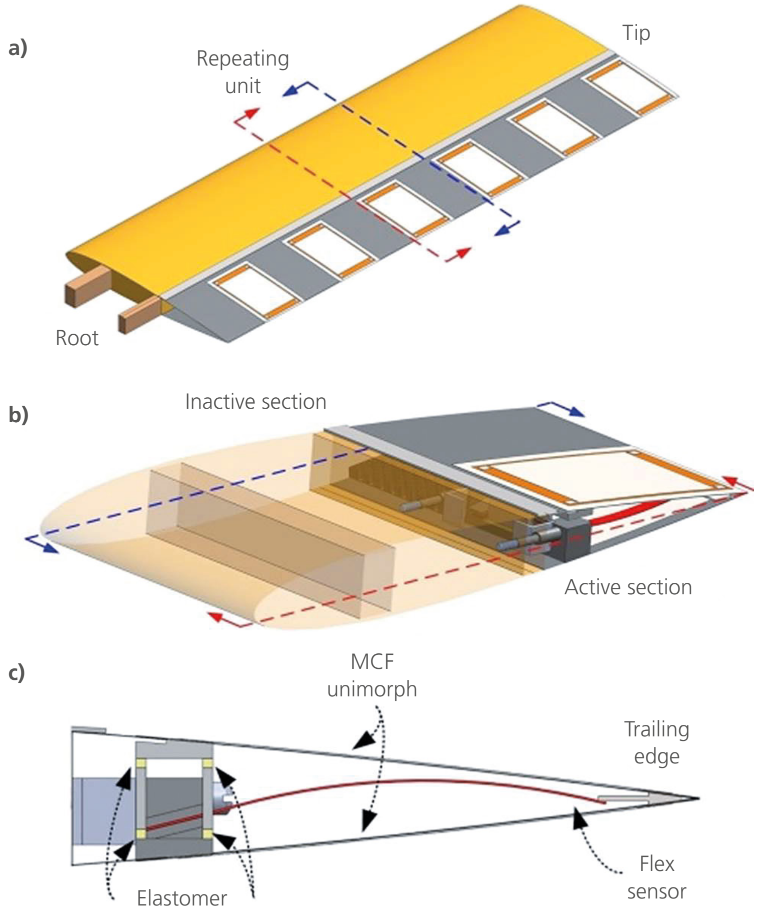

Figure 1: a) Configuration of the morphing wing b) Morphing unit section c) Active morphing mechanism. The MFCs change shape when actuated, deflect the tip of the trailing edge, and produce a cambered shape.

for the unwanted air current effects and re-establishes a stable flight without turbulence. This concept was inspired by biologists who observed that steppe eagles (Aquila nipalensis) intentionally trigger a stall to make rapid banked turns.

Adaptive Tail

Aside from morphing wings, the researchers at the AIMS Lab have also analyzed the air resistance of a moveable, horizontally aligned tail (figure 2). Its actuation mechanism is based on observations of the finely tuned quick movements that a bird makes with its tail while it keeps its head and body steady to watch its prey before launching a rapid and carefully targeted attack. This is the difference to a standard aircraft, where the tail merely ensures directional stability and control. An active tail is significant because it additionally allows pitch and yaw movements and can also work as an aerodynamic brake. An aircraft with an active tail would be highly maneuverable and nearly as versatile as a bird.

Crucial: Flexibly Changing Surface Shapes

A substantial challenge for adaptive aircraft is the development of methods to change the shapes of a surface (e.g., the wings and tail) so that they can seamlessly transition into one another. This is exactly what MFCs do. They consist of a thin, flexible structure that changes shape when high voltages are applied. This way, the MFCs can act both as a surface and as an actuator and are a lightweight alternative to conventional servo or hydraulics mechanisms in small unmanned aerial vehicles (UAVs). The integration of suitable honeycomb structures ensures a continuous changing of shape between the actuators, which reduces the formation of vortices and drag.

> "The ability of dSPACE MicroLabBox to record dozens of sensor channels and control multiple actuators with high precision helped monitor the complex structural and aerodynamic properties of morphing wings during wind tunnel testing."

Lawren Gamble, University of Michigan

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Another challenge is to set the ideal combination of actuator deflection for changing flight conditions. This is where the simulation of aerodynamics comes into play. Simply said, optimized simulation answers the question of which shape a wing needs to have to adjust to the current flow conditions. The result of the optimization determines the shape of each actuator and essentially predetermines the surface geometry of the entire wing span. The challenge then is to monitor the state of the wing geometry via internal sensors, control the suitable deflection for aerodynamic loads and record real-time data of aerodynamic forces and torques.

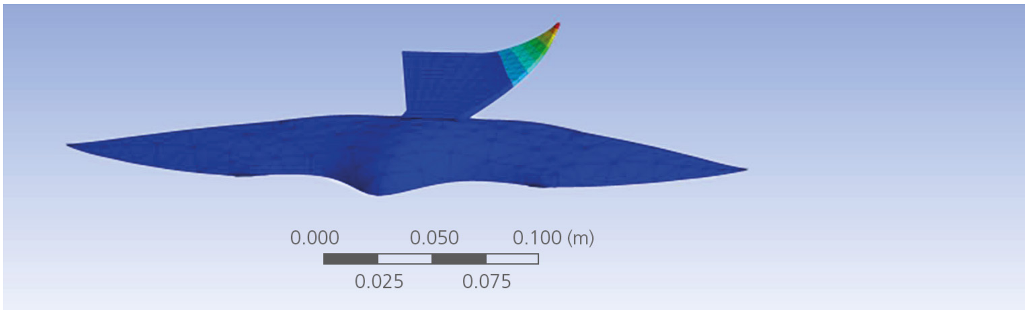

Figure 2: The results of the finite element method of a biomechanically inspired active tail demonstrate the resulting deflection when actuating the right half of the tail.

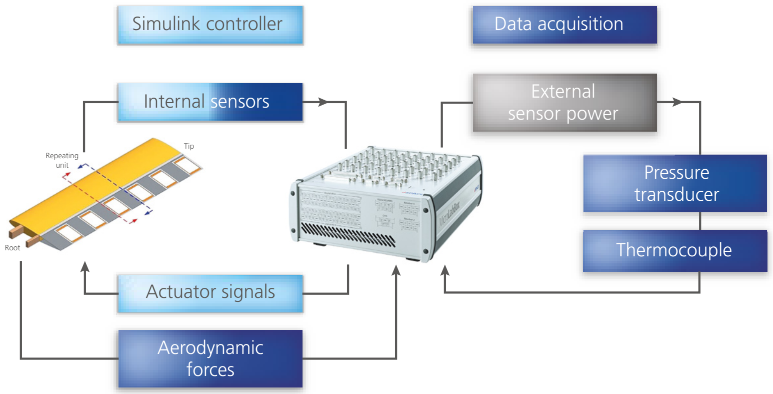

Figure 3: Schematic of the experiment setup and control system. MicroLabBox is the key instrument for controlling the actuator and recording data during wind tunnel tests.

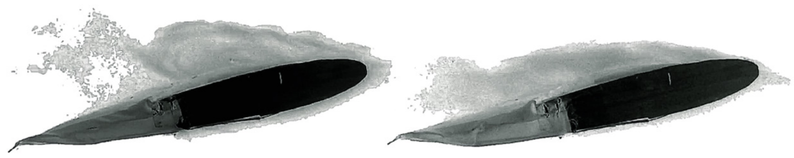

Figure 4: The visualization of the airflow shows the effect of adjusting the wing shape to stall conditions. Left: Strong formation of vortices due to no adjustment. Right: Wing adjustment almost completely suppresses vortex formation.

Wind Tunnel Tests with MicroLabBox

The aircraft constructions inspired by biology require extensive tests in the wind tunnel to measure aerodynamic forces and torques. This is where dSPACE MicroLabBox can demonstrate its performance power, because during these tests large amounts of data must be captured and actuators must be controlled with high precision. During the wind tunnel tests, the aerodynamic and structural properties of a scaled wing or even the entire aircraft must be captured and recorded for data processing and data comparison. Because these comparisons are usually intended to determine how well the adaptive structures are able to adjust to adverse flight conditions, the focus is put on precision and timing. Moreover, the MATLAB®/Simulink®-based work process with MicroLabBox also helps control and coordinate the complex experiments with the varied equipment.

Aiming for a “Fly-by-Feel” Adaptive Aircraft

MicroLabBox helped the researchers of the AIMS Lab come to three important conclusions. Firstly, in comparison to conventional rigid wings, the morphing wings significantly reduce air resistance. Secondly, the morphing wing handles a stall very well. This is clearly demonstrated by a reduction in vortex formation (figure 4). Thirdly, the adaptive tail can control the aircraft’s direction and increases directional stability.

Based on these insights, the overall aim of this research is the development of a fully integrated fly-by-feel adaptive aircraft that has both a distributed sensor network and a tail and wings that adapt to the flight situation. ■

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