Morphing Aircrafts and Wings enable optimal performance in all flight conditions and missions, now started being outfitted on commercial aircraft

The design of aerodynamic airfoils is optimized for certain conditions. For instance, the shape of the wings of fixed-wing aircrafts are designed and optimized for a certain flight condition (in terms of altitude, speed, aircraft weight, etc.). However, these flight conditions vary significantly during the flight. Currently, aircraft are provided with control surfaces such as flaps, slat and ailerons, normally governed by powerful but heavy hydraulic mechanisms. These moving parts allow the aircraft to fly under many different flight conditions, although usually with non-optimal performance. Moreover, these mechanisms introduce hinges and surface discontinuities between parts which cause undesirable effects such as turbulences and noise or a decrease of the lift-to-drag ratio. In contrast, the wings of a bird can be reshaped to provide optimal performance at all flight conditions.

A multi-mission aircraft can be designed for good performance in multiple flight conditions. For example, a fighter with folding wings or variable-sweep wings can have good performance at both high speed and low speeds, which can reduce fuel consumption and improve the flight envelope dramatically.

This issue motivates the research and development of the so-called ‘morphing aircraft’ or ‘morphing wings’. “Shape morphing” has been used to identify those aircraft that undergo certain geometrical changes to enhance or adapt to their mission profiles. Ideally, a morphing aircraft is able to modify quickly the shape of its wings in-flight, thus reaching optimum aerodynamic performance under any flight condition. Morphing technologies offer aerodynamic benefits for an aircraft over a wide range of flight conditions. The advantages of a morphing aircraft are based on an assumption that the additional weight of the morphing components is acceptable.

Military have large demand for smart materials and devices including smart self-repair, smart clothing such as cloaking suits, and adaptive hull structures for ships. In aerospace, smart materials could find applications in ‘smart wings’, winglets in aeroplanes that adapt automatically to changing flight conditions health and usage monitoring systems (HUMS), and active vibration control in helicopter blades.

The ability to change aircraft form and function was the goal of DARPA’s Morphing Aircraft Structures (MAS) program, managed by DARPA’s Defense Sciences Office (DSO). U.S. military aircraft may one day mimic the Hollywood special effects of Batman Begins with wings that change from pliable to rigid and back again or that expand and contract on demand. Two approaches for morphing aircraft structures are being considered that would give the armed forces the ability to use the same airplane in multiple roles, from slow-flying reconnaissance missions to high-speed target takedowns. Several enabling technologies are facilitating the development of this capability; however, determining how such aircraft would meet military requirements still remains to be done, said Dr. Terrence A. Weisshaar , the program manager of MAS.

This idea is applicable to any other aerospace applications such as rotorcraft or wind turbines. Morphing applied to aerodynamic airfoils brings along interesting benefits:

reduction of mechanical fatigue which has a special importance in wind turbines and rotorcrafts (by minimizing vibrations on the structure), reduction of the wing root bending moment, reduction of fuel consumption of flying machines and increase of the performance of wind turbines by increasing the lift-to-drag ratio of the wings or blades, and the reduction of generated noise.

Smart Materials

Smart materials have the potential in developing morphing aircrafts. Smart materials or Active materials or Functional materials are designed materials that have diverse, dynamic features that enable them to adapt to the environment. They have one or more properties that can be significantly changed in a controlled fashion by external stimuli, the stimulus and response may be mechanical, electrical, magnetic, optical, thermal, or chemical.

“Smart” materials and structures have the advantages of high energy density, ease of control, variable stiffness, and the ability to tolerate large amounts of strain. These characteristics offer researchers and designers new possibilities for designing morphing aircraft.

Several types of smart materials and structures were investigated, including piezoelectric materials, electrostrictive materials, magnetostrictive materials, shape memory alloys, and fiber optic sensors

Shape memory alloys have attracted a great interest by many researchers as a promising morphing wing material because of its shape recovery upon application of voltage. Shape memory concept refers the property of a material or an alloy which regains its original shape when external load or electrical energy is applied. The design possibilities in the field of aerospace engineering are advanced by the unique thermal and mechanical properties of shape memory alloys now a day to improve the aerodynamic efficiency.

Morphing Wings

The degree of morphing in a wing can be classified as large, medium, or small (Gomez and Garcia, 2011; Jacob and Smith, 2009; Sofla et al., 2010) depending on the dimension that varies. Folding wings, variable sweep wings, variable-span (telescoping) wings, and deployable wings comprise the large category. Twisting wing, flexible winglets, variable-chord (telescoping) wings, and variable-camber wings comprise the medium category. Variable-airfoil wings and bulging wings comprise the small category. Different levels of morphing require diverse types of materials and structures to meet its various demands.

However wing of production aircraft travelling from 400mph to over 1,000mph is subjected to large structural and skin stresses, therefore designing Morphing wing that is 9g compliant, resists flutter, resists fatigue, support hard points (pylons and stresses generated in flight by stores/engines) and still maintain all of the subsystems within the wing is not easy

Reich and Sanders listed the major challenges of shape morphing aircraft design to be: the requirement for distributed high-power density actuation, structural mechanization, flexible skins, and control law development.

Flexible Composite Wings Morph Into Different Shapes

Composite materials, many built around atomic carbon structures like graphene, are revolutionizing manufacturing industries from car frames to robotics to building infrastructure. Thanks to a combination of high strength, heat resistance, and low weight, composites are particularly useful in the aerospace industry. Aviation Partners Inc. (API) in partnership with FlexSys have developed "flexfoil" wings from composite material

Flexfoil is a uniform, jointless mechanism that equally distributes load-bearing to all parts of the structure as each section bends and contributes to the wing morphing. It's incredibly flexible while retaining its strength and other structural advantages. API and FlexSys claim this seamless alternative to conventional wing modification mechanisms results in low stress across the flexfoil component and provides long service life with low maintenance.

Aviation Week reports that API and FlexSys and working with an undisclosed customer to outfit the first commercial aircraft with flexfoil morphing wings. NASA is also working on adaptive wings, specifically winglets that use actuators to fold up or down mid-flight.

Smart Airfoil, a Collaborative Highly Interdisciplinary Research Project (CHIRP) at ETH:

The CHIRP "Smart Airfoil" project focused on the creation of adaptive structural systems, and successfully led to the design, wind tunnel test, and flight demonstration of a variable camber morphing UAV wing.

This interdisciplinary research project focuses on assessing the potential of wing morphing in improving the characteristics of airplanes. Conventional rigid-wing airplane designs are the result of a tradeoff between different requirements arising from diverse operating points within their typical mission. Morphing wings have the potential of adapting to different flight conditions in an optimal way (e.g. minimal drag at each operating point). The research carried out at the Automatic Control Lab as part of this project consists of parameter identification from free flight data, closed-loop control of Macro Fiber Piezo actuators, attitude stabilization for a flying wing and aims at showcasing closed-loop control of the span-wise lift-distribution on a 3m-span flying wing prototype with smart actuators integrated in a selectively compliant lifting surface.

NASA and MIT Are Making Flexible, Morphing Plane Wings using digital materials

Modern aircrafts rely on flaps to boost lift, and on ailerons to change direction. However these actuators require complex hydraulic mechanisms that add weight and reliability problems in addition to loss in efficiency and noise caused by due to generation of turbulent airflow through gaps in the edge of wings. Therefore Researchers have been trying for many years to achieve a reliable way of deforming wings as a substitute for the conventional, separate, moving surfaces, but all those efforts “have had little practical impact,” Gershenfeld says.

The new wing architecture, which could greatly simplify the manufacturing process and reduce fuel consumption by improving the wing’s aerodynamics, as well as improving its agility, is based on a system of just eight tiny, lightweight subunits made of carbon fiber. The wing would be covered by a “skin” made of overlapping pieces that might resemble scales or feathers and ultimately could be used to build the entire airframe.

The basic principle behind the new concept is the use of an array of tiny, lightweight structural pieces, which Gershenfeld calls “digital materials,” that can be assembled into a virtually infinite variety of shapes, much like assembling a structure from Lego blocks. The assembly, performed by hand for this initial experiment, could be done by simple miniature robots that would crawl along or inside the structure as it took shape. The team has already developed prototypes of such robots.

“One of the things that we’ve been able to show is that this building block approach can actually achieve better strength and stiffness, at very low weights, than any other material that we build with,” says NASA’S Kenny Cheung, one of the leaders of the project.

The new concept is described in the journal *Soft Robotics,* in a paper by Neil Gershenfeld, director of MIT’s Center for Bits and Atoms (CBA); Benjamin Jenett, a CBA graduate student; Kenneth Cheung PhD ’12, a CBA alumnus and NASA research scientist; and four others.

After their success in the wind tunnel, Cheung and the MIT team pushed their solution further, bolting the wings onto a remote controlled plane. The twist of the wing was almost imperceptible from the ground, making the mechanical system seem more organic. These new building methods would likely get their start on small drones and unmanned aircraft. “It’s hard to make a wing that’s morphable and deformable, and still have the stiffness you need to carry a lot of weight,” says Sensmeier.

“Ultralight, tunable, aeroelastic structures and flight controls open up whole new frontiers for flight,” says Gonzalo Rey, chief technology officer for Moog Inc., a precision aircraft motioncontrols company, who was not directly involved in this work, though he has collaborated with the team. “Digital materials and fabrication are a fundamentally new way to make things and enable the conventionally impossible. The digital morphing wing article demonstrates the ability to resolve in depth the engineering challenges necessary to apply the concept.”

“The broader potential in this concept extends directly to skyscrapers, bridges, and space structures, providing not only improved performance and survivability but also a more sustainable approach by achieving the same strength while using, and reusing, substantially less raw material, ” said Gonzalo Rey, chief technology officer for Moog Inc. And Loubiere, from Airbus, suggests that many other technologies could also benefit from this method, including wind turbines: “Simply enabling the assembly of the windmill blades on the spot, instead of using complex and fuel-consuming transport, would enhance greatly the cost and overall performance,” he says.

Active Morphing Winglets

Aerospace composites specialist FACC (Ried im Innkreis, Austria) has developed Active Morphing Winglets technology. The winglets are designed to adapt automatically to changing flight conditions, switching from vertical to horizontal position, offering potential fuel savings of 2.5% and noise reduction of 2 db.

The innovation features a control flap that adjusts itself in real time to suit the current conditions. FACC says this also ensures optimal aerodynamics for the fuel-intensive take-off and landing procedures, and helps reduce noise and pollution emissions.

In cruising flight, the aircraft is further stabilized in crosswinds and gusts. A freely warping (morphing) gap covering covers the gap produced when the control flap emerges and ensures aerodynamically optimized geometries in every setting. This variability of the wing geometry compensates for the additional load caused by winglets in the central and outer wing structure, making structural reinforcement of the wing unnecessary when winglets are added. Control unit, sensors, and actuators are accommodated in the smallest of spaces.

DARPA Morphing Aircraft Structures (MAS) program

In January 2003 the Defense Advanced Research Projects Agency, DARPA, began a 2 ½ year program whose objective was to design and build active, variable-geometry, wing structures with the ability to change wing shape and wing area substantially.

The MAS program had two primary technical goals:

1) To develop active wing structures that change shape to provide a wide range of aerodynamic performance and flight control not possible with conventional wings.

2) To enable development of air vehicle systems with fleet operational effectiveness not possible with conventional aircraft. This includes both Navy and Air Force operations.

For the one-year first phase of the project, DARPA awarded contracts to three firms, and each took a unique approach. Palmdale, California-based Lockheed Martin Aeronautics Company’s Advanced Development Programs section, also known as Skunk Works, designed an aircraft wing that can fold and be locked in two positions. The structural material, called a shape memory polymer, becomes pliable when stimulated with a moderate amount of current, then returns to a solid state when the stimulus is terminated.

Engineers at NextGen Aeronautics Incorporated, Torrance, California, took a different tack. Their in-plane morphing approach increases the wing surface by using innovative materials put together in a proprietary way, multiple actuators and a computer control system that affect the shape shifting. The wings can expand and contract to multiple positions.

Raytheon Missile Systems, Tucson, Arizona, chose to design morphing wings for cruise missiles rather than for manned or unmanned aircraft. One possible application would be in submarines where the missiles would be stored in tubes with folded wings that would be extended once in flight.

Weisshaar explains that creating a truly morphing aircraft requires that changes can be made in the wing area, span, sweep and thickness. While a minimum of wing area is needed to fly at speeds of Mach 2 or Mach 3, a larger wing is necessary for landing. “So you already have a problem. If you want to go really fast, then you can’t land very efficiently. What we said is ‘let’s change the wing area,’ and it turns out that [an increase of] 50 percent is a pretty good number. If you could change the wing area in flight by 50 percent, you can do lots of different things. You can operate efficiently at high speeds and at low speeds,” he relates.

Flying high and slow—an appealing capability for reconnaissance missions—requires a wide wingspan in addition to a larger wing area, so increasing the wingspan by 50 percent to 75 percent also multiplies applications. “The aircraft could hang out at high altitudes, but it could still respond supersonically or at least high subsonically to a threat. This is a big deal for the military,” Weisshaar notes. “Our goals in this morphing program were to get big area changes, as big as 50 percent; big span changes—50 percent to 75 percent—and then also sweep changes because that is something that you want for high speed.”

References and Resources also include:

http://news.mit.edu/2016/morphing-airplane-wing-design-1103

https://www.wired.com/2016/11/nasas-mighty-morphing-wings-make-efficient-flying/

http://www.popularmechanics.com/flight/a23703/flexible-composite-wings-morph-into-different-shapes/

http://www.afcea.org/content/?q=shape-wings-come