Biomimetic Aircraft Wing Structures

Shaping Ideas to Reality

Satyaki R Singha[1]

[1] *Bachelor of Engineering student (Senior Year), Aeronautical Department, A.C.S College of Engineering, Karnataka, India*

ABSTRACT

Biomimetics by definition is the imitation of the models, systems, and elements of nature for the purpose of solving complex human problems. Adapting biology can involve copying the complete appearance and function of specific creatures like the many toys found in toy stores, which are increasingly full of simplistic imitations of electro-mechanized toys such as dogs that walk and bark, frogs that swim, and such others. Humans have learned a lot from nature and the results help surviving generations and continue to secure a sustainable future. Biological creatures can build amazing shapes and structures using materials in their surroundings or the materials that they produce. The shapes and structures produced within a species are very close copies. They are also quite robust and support the required function of the structure over the duration for which it is needed. Parts and structures also have a biological model of inspiration. The honeycomb is, for the same reasons, an ideal structure for the construction of control surfaces of an aircraft and it can be found in the wing, elevators, tail, the floor, and many other parts that need strength and large dimensions while maintaining a low weight.

Keywords: *Biomimetics, Morphing Wing, Morphing Winglets, Shape memory alloy*

Introduction

Judging from the number of flying insects, birds, and marine creatures, nature has ‘‘experimented’’ extensively with aerodynamics and hydrodynamics. There are several aspects that deserve attention. For instance, birds can catch fish underwater with their eyes closed. They are able to catch fish by taking into account the refraction effect, which creates an illusion as to the location of the fish. Birds and various mammal predators take into account the vector trajectory of the escaping prey, as in the case of hunting a running rabbit or deer. These trajectories are increasingly the capability of military weapons allowing tanks to destroy a moving target while they are moving too. Sophisticated capabilities are used to track the moving target and either adjust the direction in flight or aim upon launch using high-speed missiles or bullets. The ability of the dragonfly to maneuver at high speed is another aspect of flying that considerably inspired humans. Using a liquid-filled sac that surrounds its cardiac system, the dragonfly adjusts the effects of high G on its body during its flight and incredible maneuvers. G represents a unit of gravitational force on Earth where high G is many multiples of one G. This technique inspired a mechanism that allows pilots to fly at high Mach speed with significantly lower effects on the ability of the pilot to stay coherent.

Like biology, botany also takes aerodynamics into account. The seeds of many plants are designed with features that allow them to disperse away from their origin. The need to disperse can be attributed to the possibility of overcrowding of the specific type of plant in the same local area. Seeds use various aerodynamic techniques to be propelled by the aid of winds, for example, the winged seed of the Tipuana tipu (about 6.5-cm long). Such seeds have inspired designs of futuristic missions with spacecraft that would soft-land on planets with atmospheres such as Mars. Adapting this design may allow for designing a parachute with better capability to steer itself to land at selected sites. Some of the issues being studied include the appropriate vehicle size, acceptable descent speed in the Martian atmosphere, mass distribution and platform shape to assure stable autorotation and scalability from an operation on Earth to performance on Mars.

Aerospace Structures based on Bird Wings: Conceiving the idea

When the Wright brothers accomplished their first powered flight more than a century ago, they controlled the motion of their Flyer 1 aircraft using wires and pulleys that bent and twisted the wood-and-canvas wings. This system was quite different than the separate, hinged flaps and ailerons that have performed those functions on most aircraft ever since. Soon after the inaugural flight, Curtiss Aerospace improved the original design with the introduction of hinged flaps, which was soon followed by all aero-structural designers across the globe. But latest research on biomimetics/biomimicry has led to the development of a new bendable “morphing” wing.

Fig-1: 1903 Wright Flyer 1 consisting of flexible wings

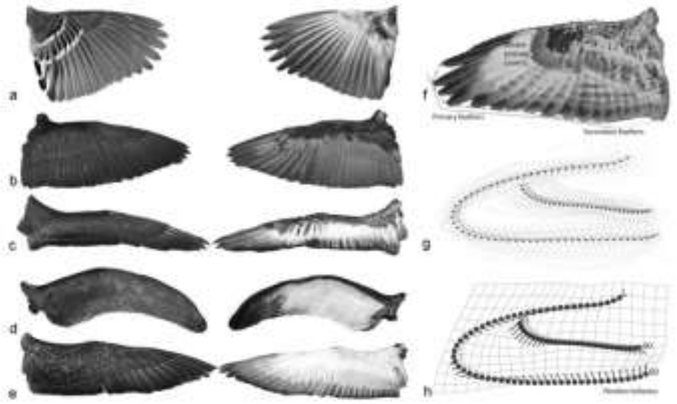

Fig-2: Various Geometry of bird wing

The morphing wing boasts of a monolithic wing structure without the presence of ailerons, flaps or spoilers. The wing bends when a stream of current is applied to its surface. This phenomenon is possible due to the presence of piezoelectric materials. Achieving seamless control surfaces rather than hinged flaps has been an elusive goal for decades. Today, however, the aerodynamic efficiency goal has been achieved. The new wing architecture would greatly simplify the manufacturing process and reduce fuel consumption by greatly improving the wings aerodynamics, as well as improving its agility.

Researchers have been trying for many years to achieve a reliable way of deforming wing. The main problem with this research was that most of these attempts relied on the use of mechanical control surfaces retrofitted to the wing, but these structures tended to be so heavy that they canceled out any efficiency and advantages produced by the smoother aerodynamic surfaces. They also added complexity and reliability issues.

Birth of a solution

Aerospace industry bigwigs like NASA and MIT Research labs have established a concept of a shape-shifting monolithic wing a.k.a morphing wing which is set to change the dynamics of wing structure to a different level. While the construction of light composite wings for today's aircraft requires large, specialized equipment for layering and hardening the material, the new modular structures could be rapidly manufactured in mass quantities and then assembled robotically in place.

Given the importance of fuel costs in both the economics of the airline industry and that sector's contribution to greenhouse gas emissions, even small improvements in fuel efficiency could have a significant impact. Wind-tunnel tests of this structure showed that it at least matches the aerodynamic properties of a conventional wing, at about one-tenth the weight. The modular structure also provides greater ease of both assembly and disassembly: One of this system's big advantages, in principle, is that when it's no longer needed, the whole structure can be taken apart into its component parts, which can then be reassembled into something completely different. Similarly, repairs could be made by simply replacing an area of damaged subunits. Ultralight, tunable, aeroelastic structures and flight controls open up whole new frontiers for flight.

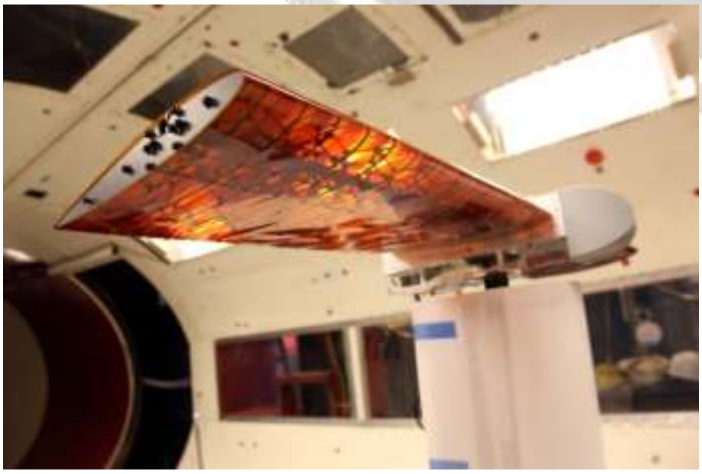

Fig-3: Monolithic Bending wing fabricated by MIT Research Labs

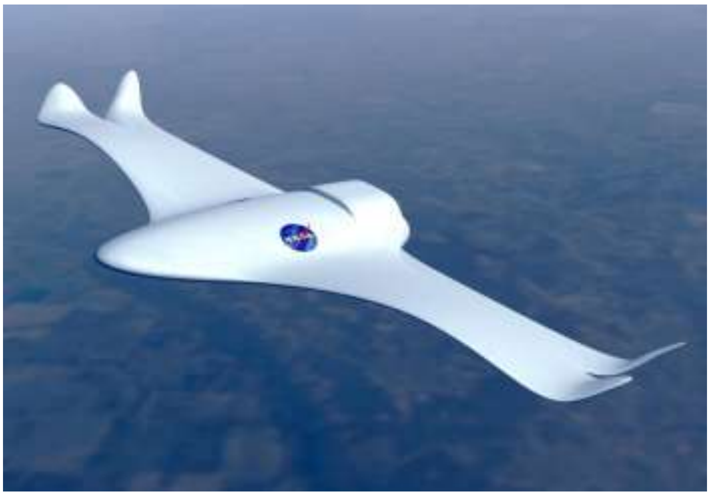

Fig-4: NASA’s conceptual morphing aircraft

Recent Advancement in Technologies and Current Research

A United States based company FlexSys Inc. has patented a morphing wing FlexFoil™ which has a variable geometrical structure. By exploiting the natural grade aviation material the FlexFoil control surfaces changes the camber of a wing during flight by shape morphing rather than through the heavy and cumbersome mechanisms of conventional wing assemblies.

Shape morphing performs the largely controlled deformations (from -9° to + 40°) needed for landing and takeoff without separating from the rest of the wing. Our new approach also permits discrete span-wise twist of the compliant edge at high response rates (30 degrees/sec.) to reduce induced drag and withstand external loads (air loads, inertial loads etc.), yet it is strong and stiff with very small and distributed strains on the mechanical structures and control surfaces. In addition to this major innovation in aircraft control surface design, an even more, far-reaching impact of this technology is drag reduction in the range of 5% to 12% for long-range fixed wing aircraft, and that represents huge savings in fuel consumption. Studies by NASA Dryden Flight Research Center have shown that even a one percent reduction in drag for the U.S. fleet of wide-body transport aircraft could result in savings of approximately 200 million gallons per year.

Bridging the gaps between flap and wing, FlexFoil™ doesn't separate from the rigid part of the wing, unlike conventional flaps that violently disrupt the air flow when they deploy. FlexFoil™ maintains a seamless connection even at its edges. Flexible articulating transition surfaces keep the fixed parts of the wing connected to the shape morphed control surface maintaining a continuous trailing edge that significantly reduces airframe noise. Even with all this flexibility, these control surfaces are able to generate over 11,000 pounds of lift; handling up to 24,000 pounds of load.is makes our structures as strong as or stronger than any conventional design. Using aerospace-grade materials, the shape changing surfaces, including the adjoining compliant fairings, are designed to withstand temperatures from -65°F to 180°F and all the harsh chemicals typically used in air transportation industry.is means that the FlexFoil™ variable geometry control surface offers revolutionary new possibilities but doesn't sacrifice strength for flexibility. Engineers at FlexSys Inc. developed and tested a 50-inch span, 30-inch chord airfoil section, with a 10-inch chord variable geometry compliant trailing edge flap in a high-speed wind tunnel up to

160–240 psi (pounds per square foot) dynamic pressure and a flap cycle rate up to 30 degrees per second. Structural testing was conducted subjecting the subject to twice the maximum design load for 64,000 cycles without failure.

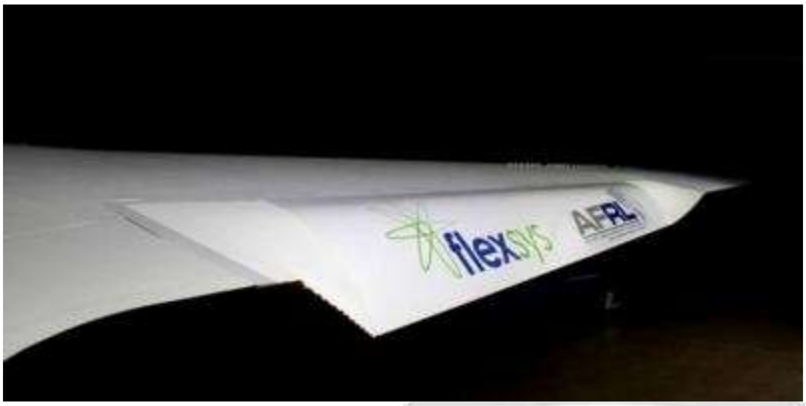

Fig-5: FlexFoil variable geometric surface wing

Modern wing concept: Material and structural approach

The material approach involves the use of smart actuators and smart materials, such as Shape Memory Alloy (SMA). Smart materials are able to change their external shapes significantly after receiving certain stimuli such as temperature, pressure, magnetic field, etc. Therefore, using smart materials to build wings could allow an airplane to change its wing shape in flight as shown in **Fig-6**. Although smart materials can provide lightweight actuation, the scalability is still uncertain, which means that the final shape of the wing may not be the desired wing shape. As a result, the outcome may be disastrous and the airplane may lose its stability in flight. In comparison, the structural approach uses a compliant mechanism, which is “a single-piece flexible structure that delivers the desired motion by undergoing elastic deformation as opposed to the rigid body motion in a conventional mechanism.” **Fig-7** is an example of a compliant mechanism in an adaptive wing, which has the ability to change its shape smoothly without using any rigid wing devices such as hinged flaps and ailerons. The actuator applies a force to the system and causes the compliant mechanism to deform due to structural flexibility. The deformed compliant mechanism then causes deformation of the wing boundary, which, in turn, changes the shape of the wing. The main challenge in this mechanism is that the design needs to be flexible to transmit motion, yet stiff enough to withstand the wing loads.

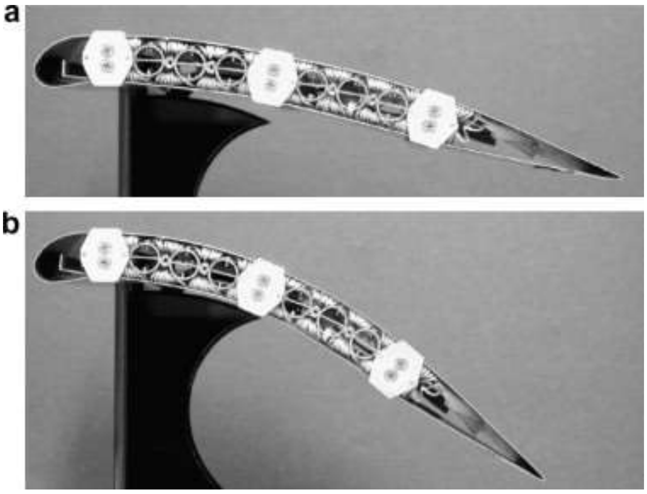

Fig-6: Airfoil using Shape Memory Alloy a} Unflexed b} Flexed

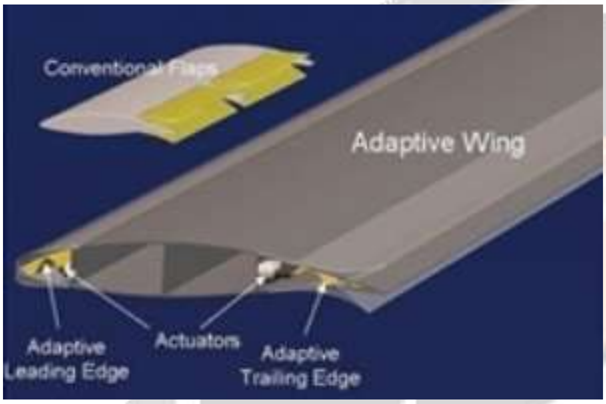

Fig-7: Adaptive Compliant Control Surfaces

Experimental Analysis on Morphing Wing structure and determining the aerodynamic characteristics

Using ANSYS Workbench Software a detailed study of the morphing wing was carried out. The 3D wing geometry was obtained from CATIA and then meshed in ANSYS. By static analysis and solid-fluid interaction, the following data and results were obtained.

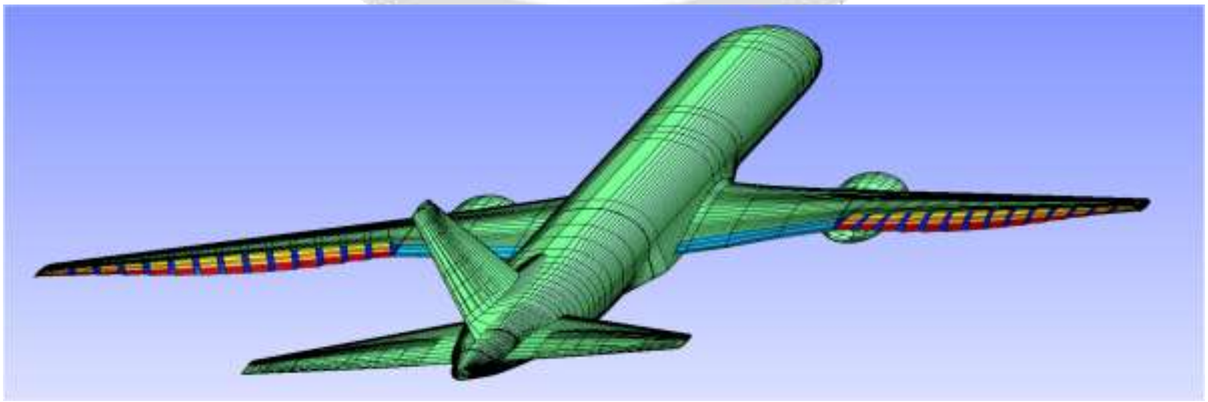

Fig-8: A 3D model of aircraft for rendering and meshing consisting of variable geometry control surface wing designed and imported from CATIA V5

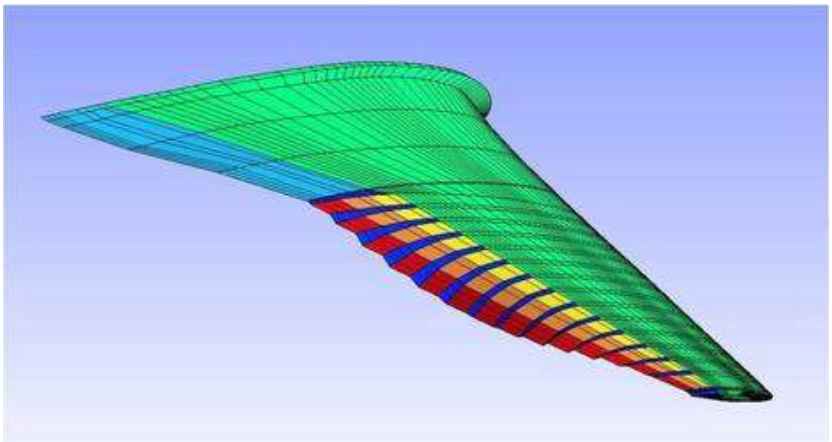

Fig-9: Cut section of the wing geometry for static analysis and solid-fluid interaction

Graphs obtained after analysis

- Structural optimization of the airfoil shape (**Fig-10)**
- Radius of turn (R_{min}) vs. Wing Loading (W/S) (**Fig-11)**
- Wing area vs. Sweep angle (**Fig-12 b)**
- Aspect ratio vs. Sweep angle (**Fig-12 c)**
- C_l vs. C_d (**Fig-12 d)**
- Speed specific lift vs. Speed specific drag for various speeds and sweep (**Fig-12 e** & **f)**

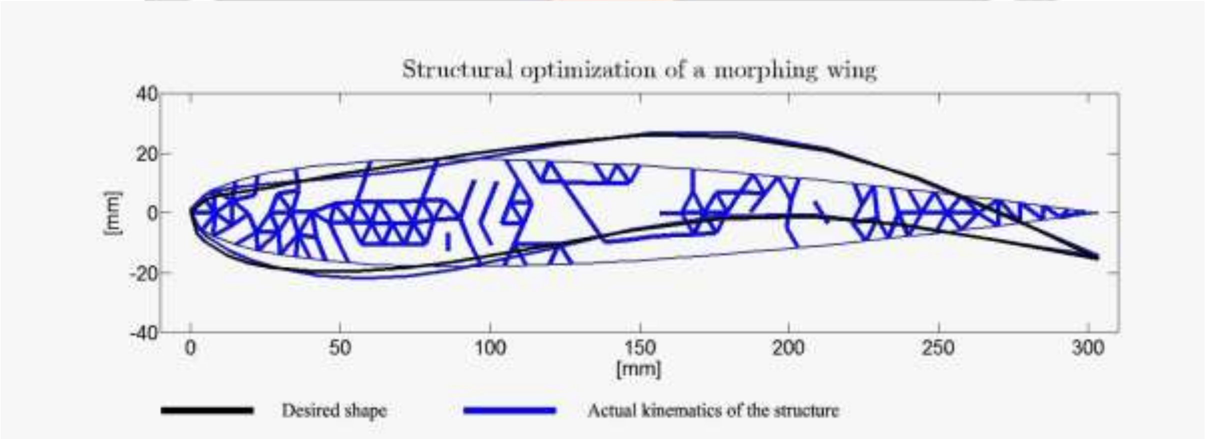

Fig-10

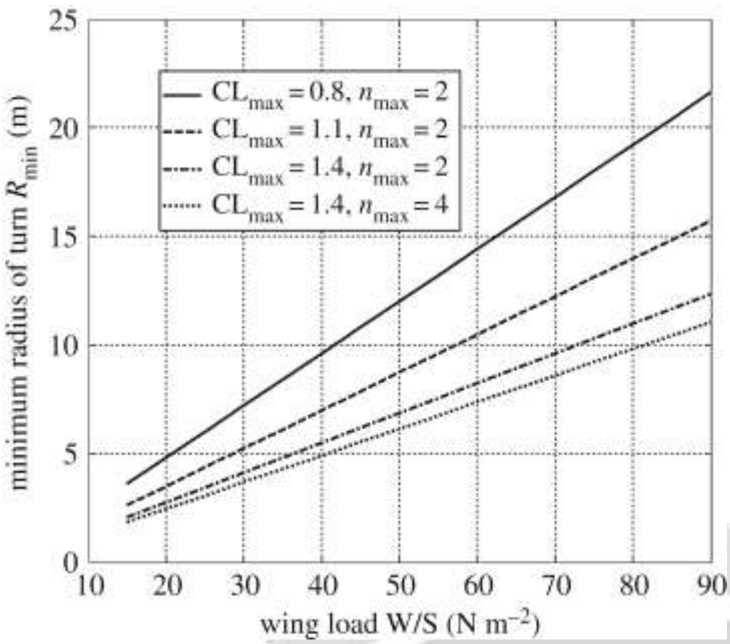
minimum radius of turn R_{min} (m)
wing load W/S (N m^{-2})
$CL_{max} = 0.8$, $n_{max} = 2$
$CL_{max} = 1.1$, $n_{max} = 2$
$CL_{max} = 1.4$, $n_{max} = 2$
$CL_{max} = 1.4$, $n_{max} = 4$
0
5
10
15
20
25
10
20
30
40
50
60
70
80
90

Fig-11

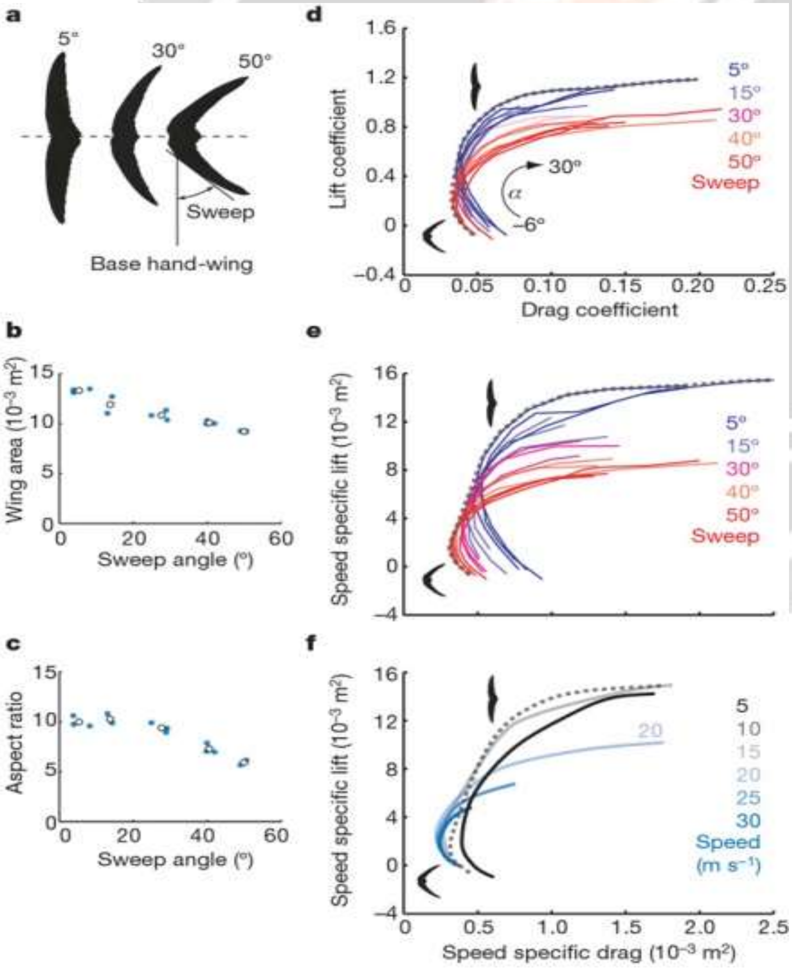
a
5°
30°
50°
Sweep
Base hand-wing
b
Wing area (10^{-3} m^2)
Sweep angle (°)
c
Aspect ratio
Sweep angle (°)
d
Lift coefficient
Drag coefficient
30°
α
−6°
5°
15°
30°
40°
50°
Sweep
e
Speed specific lift (10^{-3} m^2)
5°
15°
30°
40°
50°
Sweep
f
Speed specific lift (10^{-3} m^2)
Speed specific drag (10^{-3} m^2)
20
5
10
15
20
25
30
Speed
(m s^{-1})

Fig-12

Conclusion

Wing-morphing technology is undeniably the future of aircraft design. It allows airplanes to operate efficiently under different flight conditions by changing the wing shape in flight, just like birds that change their wing positions to perform different tasks. The ultimate goal of morphing technology is to optimize airplanes’ fuel efficiency and maneuverability. However, the goal can only be achieved if the limitations such as additional weight, cost and complexity can be minimized. More importantly, researchers need to prove that the morphing technology is able to change the wing shape safely and effectively without causing any risk. If those issues can be resolved, then, the future where “giant birds” can be seen roaming around and morphing their wings seamlessly in the air will not be too far away

References

1. S. Barbarino, O. Bilgen, R. M. Ajaj, M.I. Friswell, and D.J. Inman. (2011, June). A Review of Morphing Aircraft. Journal of Intelligent Material Systems and Structures.
2. T. Weisshaar. (2006, Oct. 1). Morphing Aircraft Technology – New Shapes for Aircraft Design. Aeronautics and Astronautics Department Purdue University West. Lafayette, Indiana.
3. E.A. Leylek and M.F. Costello. Benefits of Autonomous Morphing Aircraft in Loiter and Attack Missions. Presented at AIAA Atmospheric Flight Mechanics Conference.
4. W. Cole. (2002, May). Technology That Enables Wing ‘Warping’ Rolled Out at Dryden.
5. NASA Dryden Flight Research Center. Back to the Future: Active Aeroelastic Wing Flight Research.
6. J. Fausz. (2010). Morphing Flight: Beyond Irreducible Complexity.

Software used for analysis

- CATIA **V5**
- ANSYS **Workbench**