BionicFlyingFox

Ultra-lightweight flying object with intelligent kinematics

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BionicFlyingFox

Semi-autonomous flying manoeuvres based on a natural role model

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The dream of flying is one of the oldest known to humankind. In this respect, we have always looked at the animal world with fascination – a world that shows how it is done in all sorts of ways. In the Bionic Learning Network too, flying is always a recurring theme. In association with universities, institutes and development firms, Festo has, for years now, been developing research platforms whose basic technical principles are derived from nature.

For the BionicFlyingFox, the developers have now taken a close look at the flying fox's special properties and technically implemented them in an ultra-lightweight flying object. With a wingspan of 228 cm and a body length of 87 cm, the artificial flying fox weighs just 580 g.

The natural model: flying without feathers

The flying fox belongs to the order Chiroptera – the only mammals that can actively fly. A particular characteristic is their fine elastic flying membrane. The membrane consists of an epidermis and dermis and stretches from the extended metacarpal and finger bones down to the foot joints.

In flight, the animals control the curvature of the flying membrane with their fingers, allowing them to move aerodynamically and agilely through the air. They thereby achieve maximum uplift, even when performing slow flying manoeuvres.

Agile kinematics

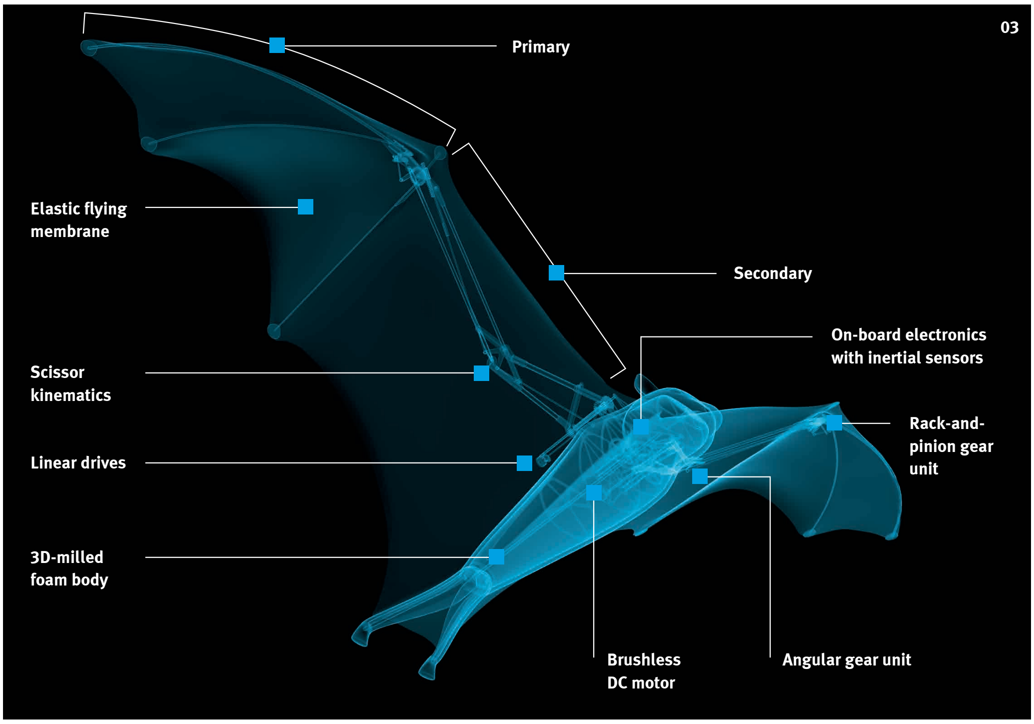
In order to achieve results as close to the natural flying fox as possible, the wing kinematics of the BionicFlyingFox are also divided into primaries and secondaries and covered with an elastic membrane, which continues from the wings down to the feet. As with the biological model, all the articulation points are on one plane, meaning that the artificial flying fox can control and fold its wings together individually.

So that the BionicFlyingFox is able to move semi-autonomously in a defined space, it communicates with a motion-tracking system. The installation constantly records its position. At the same time, the system plans the flight paths and delivers the necessary control commands for this. A person performs the start and landing. The autopilot takes over in flight.

01: **Latest motion-tracking system:** the cameras are soon put into operation and can follow the flying object dynamically.

02: **Unique flying behaviour:** the artificial flying fox moves freely like its natural role model, thanks to the elastic flying membrane and intelligent kinematics.

03: **Sophisticated design:** the on-board electronics built into the body combined with the mechanical system in the wings.



Moving camera system for exact localisation

An important part of the motion-tracking system is two infrared cameras, which rest on a pan-tilt unit. This allows them to be rotated and tilted in such a way that they can track the entire flight of the BionicFlyingFox from the ground. The cameras detect the flying fox by means of four active infrared markers attached to the legs and wing tips.

Machine learning of the ideal flight path

The images from the cameras go to a central master computer. It evaluates the data and externally coordinates the flight like an air traffic controller. In addition, pre-programmed paths are stored on the computer, which specify the flight path for the BionicFlyingFox when performing its manoeuvres. The wing movements required to ideally implement the intended courses are calculated by the artificial flying fox itself with the help of its on-board electronics and complex behaviour patterns. The flying fox gets the control algorithms necessary for this from the master computer, where they are automatically learnt and constantly improved.

The BionicFlyingFox is thus able to optimise its behaviour during the flights and thereby follow the specified courses more precisely with each circuit flown.

In this respect, the controls are governed by the movement of the legs and hence the adjustable wing area. The elastic flying membrane stretches over the complete back of the bionic model – from the fingertips down to the feet. This makes the wing area relatively large, allowing a low area loading.

Drive with sophisticated lever mechanism

The primaries and secondaries can be activated in any state so that the wings move harmoniously and almost without any shaking. For this purpose, the primary is coupled to the secondary and follows the latter due to forced kinematics, whereby dead centres in the movement are prevented. A nine-gram lightweight brushless DC motor in the body of the flying fox drives these flying kinematics by means of a gear ratio. The folding mechanism on the wings can be individually and infinitely adjusted using two small linear drives.

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Agile flying manoeuvres based on a natural role model

Special features of flying foxes

Flying foxes are closely related to bats, together with which they form the order Chiroptera. Unlike their relatives, however, they are not guided by ultrasound, but they are guided with the help of their big eyes. The animals owe their name to the shape of their heads, which look like that of a fox. Another characteristic is their fine elastic flying membrane that stretches from the extended metacarpal and finger bones down to the foot joints. During sleep or rest periods, the animals fold in their wings and hang upside down by their hind toes – an optimal escape position, allowing them to fly away quickly and agilely in case of pending danger.

Technical benefits for Festo

The BionicFlyingFox can also manage a tight flight radius despite its large wingspan. This is made possible by its ingenious kinematics. It works according to the scissor principle. The primary folds in during the upswing and spreads back out for the powerful downswing. This effect is achieved by a sophisticated mechanism: the angular and rack-and-pinion gear units implement the wing movement synchronously with the help of forced kinematics. By means of the inertial sensors on the on-board electronics, the flying manoeuvres can be monitored and corrected with corresponding control signals if need be.


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BionicFlyingFox
Taking a close look at wings in nature


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Besides the ingenious kinematics, the artificial flying fox also owes its agility to its lightweight design and clever use of materials; its body is made of foam, whilst the skeleton consists of milled carbon rods and 3D-printed parts.

Specially developed flying membrane
The model's flying membrane is wafer-thin and ultralight whilst also robust. It consists of two airtight films and a knitted elastane fabric, which are welded together at approximately 45,000 points. Due to its elasticity, it stays almost uncreased, even when the wings are retracted. The fabric's honeycomb structure prevents small cracks in the flying membrane from getting bigger. This means that the BionicFlyingFox can continue flying even if the fabric sustains minor damage.

When it comes to the artificial flying fox, the focus, as with its biological model, is on lightweight constructions. Because the same applies in engineering as it does in nature: the less weight there is to move, the lower the energy consumption. In addition, the lightweight design saves resources in the construction process.

Stimulus for production of the future
The artificial flying fox also provides important findings for industrial automation. In the production of the future, the intelligence from the central control system will be divided into subsystems and components. Even single workpieces will become intelligent and know what product they are supposed to be made into. They will accordingly be able to communicate with the machines and tell them how they must be processed.

Decentralised intelligence and machine learning
In the case of the BionicFlyingFox, the intelligence is also decentralised: the master computer specifies the flight paths and the control commands. During the flight, it compares its calculated intended courses with the actual ones and adjusts these with increasing efficiency using machine learning. It is therefore sufficient to program rudimentary knowledge into the control electronics at the start. The artificial flying fox derives the corresponding ideal settings for its kinematics itself from the calculations. It detects how it must control the wings and legs in order to implement the commands from the master computer in an optimal manner.

01: **Robust flying membrane:** the fabric's honeycomb structure gives the ultra-lightweight membrane the necessary stability.

02: **Constant communication:** the BionicFlyingFox in an ongoing exchange with the motion-tracking system.

03: **Bionic flying objects:** from Air_ray and AirPenguin via SmartBird, BionicOpter and eMotionButterflies to the BionicFlyingFox.

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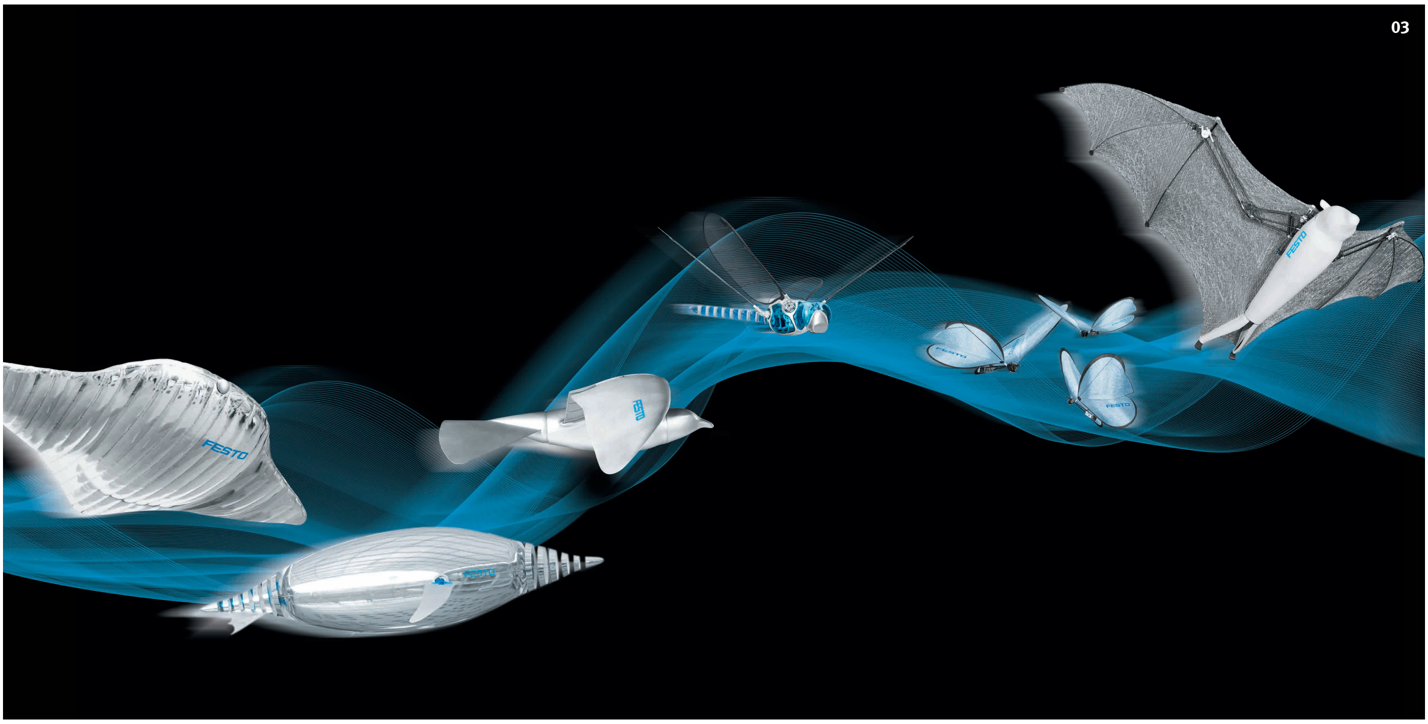


Flying in the Bionic Learning Network
The BionicFlyingFox is being added to a series of flying objects which have already emerged from the Bionic Learning Network. To start with, the developers dived underwater and studied various biological models, which, although they cannot fly, are able to propel themselves by beating their wings.

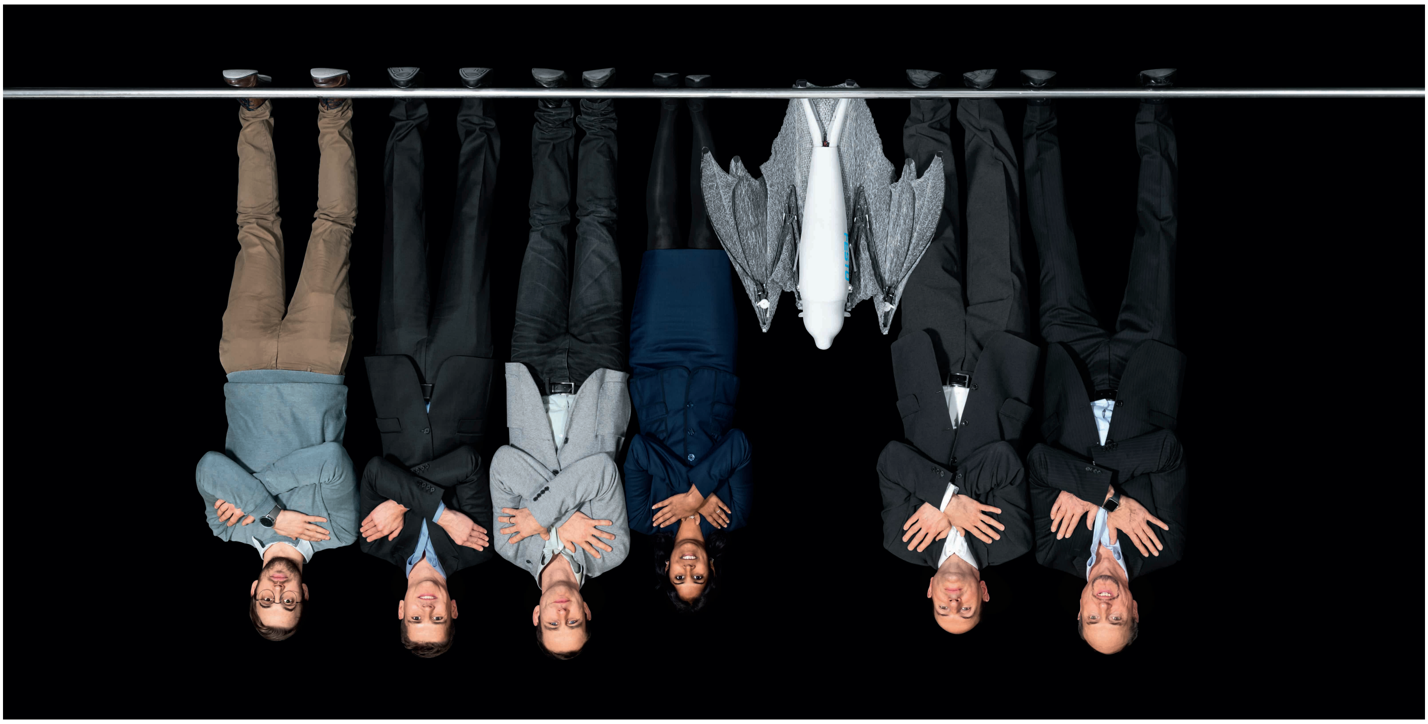
Thanks to its lightweight construction, uplift provided by helium and beating-wing drive, the Air_ray from 2007 moves through the air like the real manta ray moves through water. The AirPenguins from 2009 can fly in a group and can autonomously explore a defined space. In this respect, their flying movements come very close to the swimming technique of their natural role models.

Bird flight decrypted: uplift without helium
The SmartBird from 2011 is inspired by the herring gull. Although the first bionic flying objects were filled with helium, the SmartBird was able to simultaneously provide propulsion and the necessary uplift with its beating wings. With this functional integration, bird flight was decrypted in technical terms.

Flying like a dragonfly and butterfly
In 2013 Festo implemented the highly complex flying characteristics of the dragonfly in the form of the BionicOpter. Thanks to the installed control electronics, the ultra-lightweight flying object can, like its biological model, manoeuvre in all directions, hover in mid-air and glide without beating its wings at all. At the same time, the artificial dragonfly can assume almost any position in any space.

The eMotionButterflies from 2015 can also master the fast movements of their natural role model with the help of their intelligent on-board electronics. So that the artificial butterflies move as a group in a coordinated manner, they are recorded – like the BionicFlyingFox now too – by means of their infrared markers and coordinated by an external motion-tracking system.

With the artificial flying fox, Festo has now technically implemented the unique kinematics of Chiroptera and thus also decrypted the last flying behaviour from the animal world within the framework of the Bionic Learning Network.



Technical data

- Wingspan: .... 228 cm
- Body length: .... 87 cm
- Weight: .... 580 g

Materials used:
- Wing structure: .... carbon fibre
- Wing area: .... knitted elastane fabric with spot-welded PE film, ... approximately 45,000 spot welds
- Body casing: .... foam, milled

Integrated components:
- Motor: .... brushless motor, 40 W
- Active markers: .... 4 infrared LEDs

Motion-tracking system:
- 2× infrared camera
- Frame rate: .... 160 images per second
- 1× central master computer
- 1× pan-tilt unit

Project participants

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