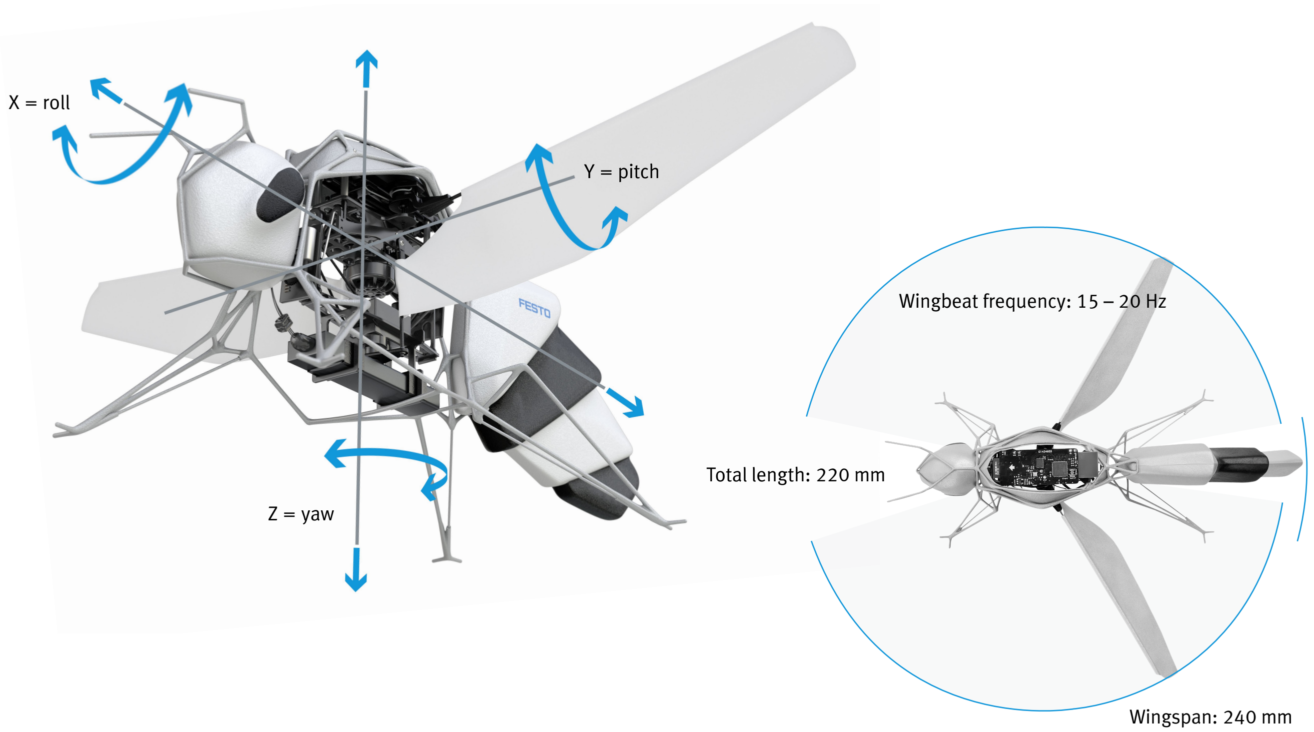
BionicBee

Autonomous Flying in a Swarm

BionicBee

Ultralight Flying Objects with Precise Control

For more than 15 years, our Bionic Learning Network has been focusing on the fascination of flying. Around ten years ago, we technically decrypted the bird flight. Since then, we have researched and technologically implemented numerous other flying objects and their natural principles, learning from biological role models. Autonomous swarm behavior was a major challenge in this respect. With the BionicBee, for the first time our team has now developed a flying object that can fly in large numbers and completely autonomously in a swarm.



Efficient lightweight construction and filigree design
At around 34 grams, a length of 220 millimeters and a wingspan of 240 millimeters, the BionicBee is the smallest flying object created by the Bionic Learning Network to date. For the first time, the developers used the method of generative design: after entering just a few parameters, a software application uses defined design principles to find the optimal structure to use as little material as necessary while maintaining the most stable construction possible. This consistent lightweight construction is essential for good maneuverability and flying time.

Functional integration in a small space
The bee's body contains the compact design for the wing-beating mechanism, the communication technology, and the control components for wing beating and adaptation of the wing geometry. A brushless motor, three servo motors, the battery, the gear unit, and various circuit boards are installed in the tightest of spaces. The intelligent interaction of motors and mechanics allows, for example, the frequency of the wingbeat to be precisely adjusted for the various maneuvers.

Natural flight maneuvers with four degrees of freedom
The artificial bee flies with a wingbeat frequency of 15 to 20 hertz. The wings beat forwards and backwards at a 180-degree angle. The brushless motor drives the beating of the wings without play by means of a precisely guided, ultralight mechanical design. The higher the speed, the higher the wingbeat frequency and the lift. The three servo motors at the wing root change the geometry of the wing in a targeted manner, thus increasing the effectiveness in certain wing positions and leading to a specific variation of the lift generated.

If the bee is to fly forward, the geometry is adjusted so that the lift in the rear position of the wing is greater than in the front position. This causes the body to lean forward (pitch) and the bee flies forward. If the geometry is set so that the right wing generates more lift than the left wing, the bee rolls (roll) around the longitudinal axis to the left and flies away sidewards. Another option is to adjust it so that one wing generates more lift at the front and the second wing generates more lift at the rear. As a result, the bee rotates (yaw) around the vertical axis.

Autonomous flying in a swarm
The autonomous behavior of the bee swarm is achieved with the help of an indoor locating system with ultra-wideband (UWB) technology. For this purpose, eight UWB anchors are installed in the space on two levels. This enables an accurate time measurement and allows the bees to locate themselves in the space. The UWB anchors send signals to the individual bees, which can independently measure the distances to the respective transmitting elements and calculate their own position in the space using the time stamps.

To fly in a swarm, the bees follow the paths specified by a central computer. To ensure safe and collision-free flight in close formation, a high degree of spatial and temporal accuracy is required. When planning the path, the possible mutual interaction through air turbulence "downwash" must also be taken into account.

As every bee is handmade and even the smallest manufacturing differences can influence its flight behavior, the bees additionally have an automatic calibration function: After a short test flight, each bee determines its individually optimized controller parameters. The intelligent algorithm can thus calculate the hardware differences between the individual bees, allowing the entire swarm to be controlled from outside, as if all bees were identical.

Bionic Learning Network

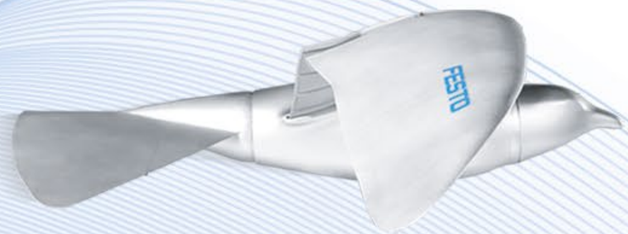
The Evolution of Flying

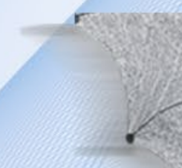
The dream of flying is one of the oldest known to humankind. In this respect, we have always looked at the animal world with fascination – a world that shows how it is done in all sorts of ways. In the Bionic Learning Network too, flying is always a recurring theme. For over 15 years, we have been developing research platforms whose basic technical principles are derived from nature.

Air_ray (2007)
The Air_ray is Festo's first flying object with beating wings. The active torsion of the wing enables an efficient and easily controllable movement of the hovering object filled with helium.
- Wingspan: 4200 mm
- Weight: 1600 g

AirPenguin (2009)
Thanks to its new wingbeat principle with adjustable wing spar, the AirPenguin can fly both forward and backward and rotate on the spot.
- Wingspan: 2480 mm
- Weight: 960 g

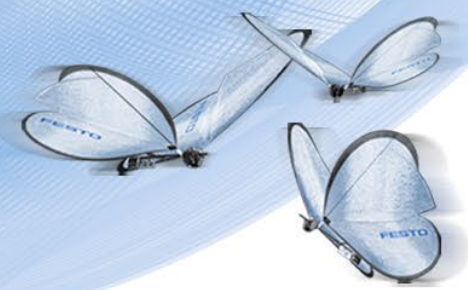
SmartBird (2011)
In the case of the SmartBird, the active torsion tested in the Air_ray meets extremely lightweight construction. For the first time, the flying object manages to take off like a bird, only with beating wings and without the support of helium.
- Wingspan: 2000 mm
- Weight: 450 g

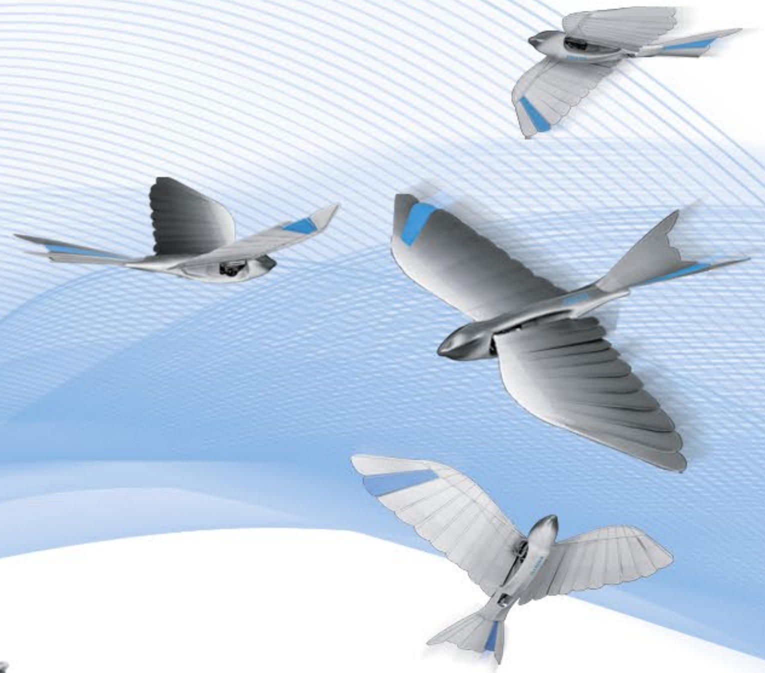




BionicOpter (2013)
Similar to a real dragonfly, the BionicOpter can carry out all flight maneuvers. With nine degrees of freedom, the wings can be individually moved for this purpose.
- Wingspan: 630 mm
- Weight: 175 g

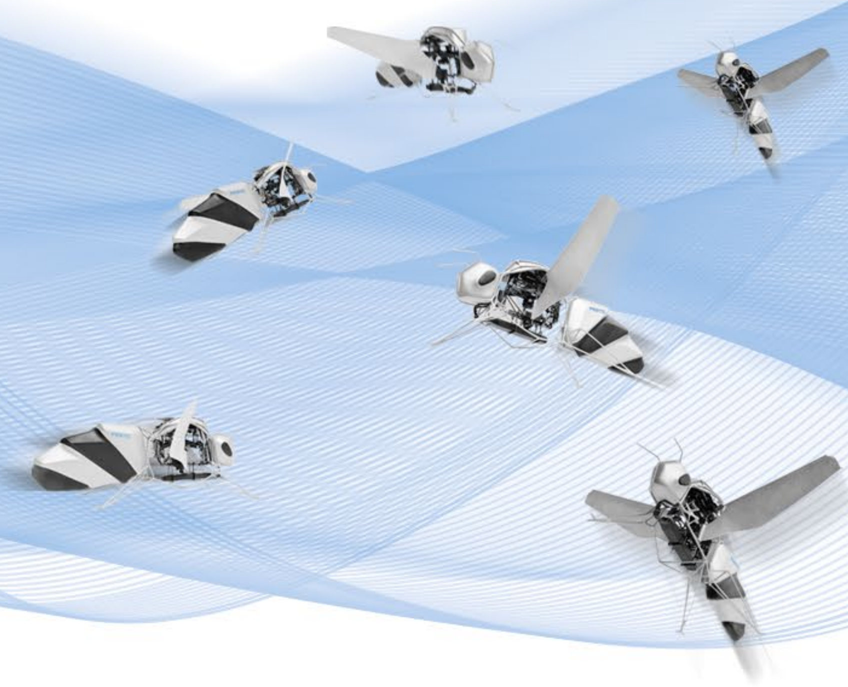
eMotionButterflies (2015)
The eMotionButterflies are our lightest flying objects with a very slow beating wing frequency. Several objects can fly autonomously using infrared camera localization.
- Wingspan: 500 mm
- Weight: 32 g



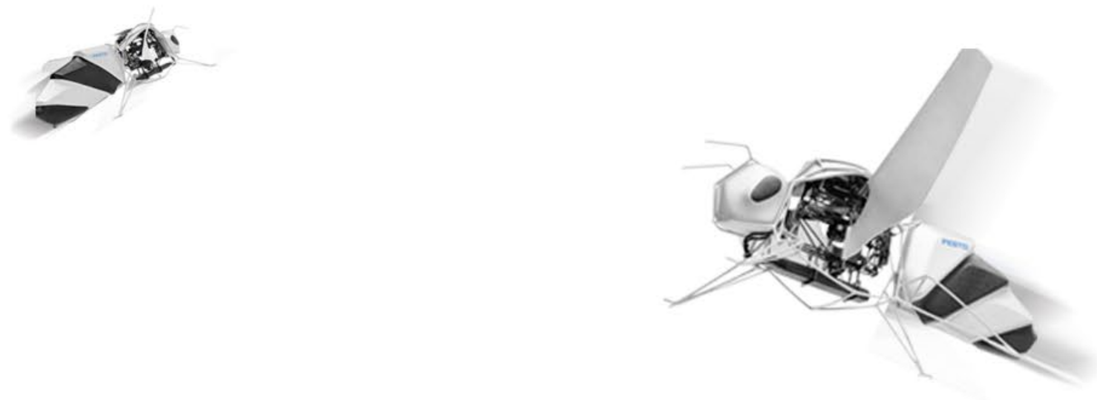


BionicSwift (2020)
The BionicSwifts can fly autonomously using UWB localization. The necessary lift is generated by the feather-like structure of their wings.
- Wingspan: 680 mm
- Weight: 42 g

BionicFlyingFox (2017)
The FlyingFox is a so-called flying wing. The skin of its wings consists of an elastic membrane stretched over the foldable wing kinematics. The flight maneuvers are initiated by the deflection of the skin.
- Wingspan: 2280 mm
- Weight: 580 g



BionicBee (2024)
In the case of the BionicBee, all of the insights gained from the latest projects now come into play. The artificial bee is our smallest flying object, which can also fly in large numbers in a swarm.
- Wingspan: 240 mm
- Weight: 34 g



Project Participants

Project initiator:	Dr. Wilfried Stoll, Managing Partner, Festo Holding GmbH
Project team:	Sebastian Schrof, Xiaojia Yao, Karoline von Häfen, Philipp Eberl, Max Kimpel, Dr. Elias Knubben, Dr. Michael Sinsbeck, Festo SE & Co. KG
Cooperation partner:	Airstage by Effekt-Technik GmbH, Riederich
Partner in research:	Prof. Dr. Markus Ryll, Autonomous Aerial Systems, TU Munich

Technical Data

Flying objects:

Wingspan:	240 mm
Total length:	220 mm
Weight:	34 g
Drives:	1 brushless motor 10,000 rpm/V 1 servo motor with an actuating force of 100 g, weighing 2 g 2 servo motors with an actuating force of 60 g, each weighing 0.7 g
Battery:	Battery with 300 mAh and 4.3 V
Flight time:	approx. 4 min
Wingbeat frequency:	15 – 20 Hz
Wireless circuit boards:	2.4 GHz

Material of flying objects:

Frame structure:	using additive design in 3D printing
Support elements on the inside:	milled from carbon fiber
Body (head and tail):	Vector boards
Wings:	Vector boards

Localization and swarm flight:

8 anchors with UWB technology

Update rate anchor:	15 Hz
Frequency band:	3.5 – 6.5 GHz
	1 central master computer
Path planning:	Swarm algorithm
Software for position detection:	TDoA-Kalman filter
Position recognition:	6-DoF sensor fusion
Flight position controller:	based on geometric control theory
Swarm trajectories:	Trajectories of minimum jerk

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