SmartBird

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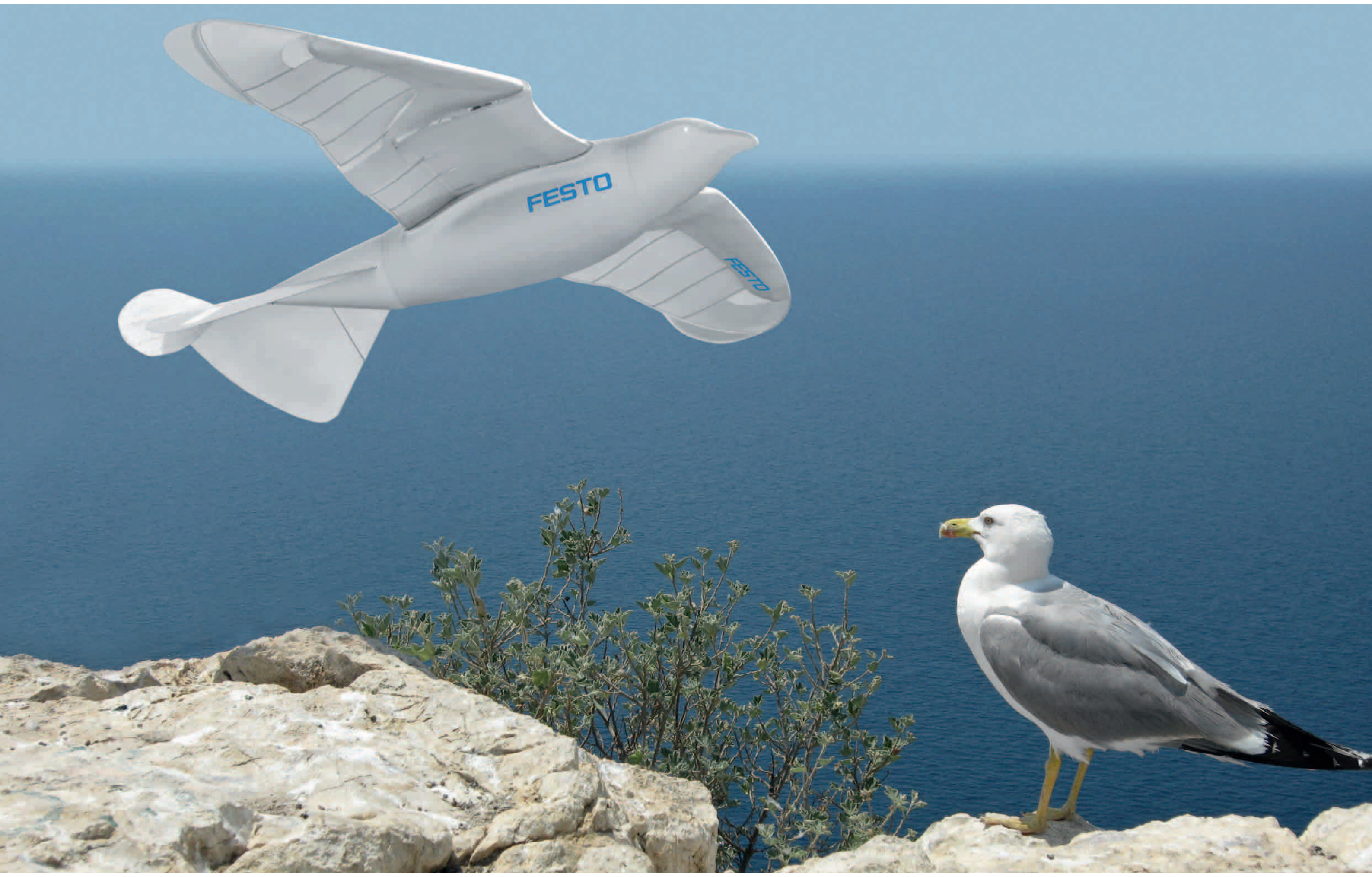


Bird flight deciphered

Aerodynamic lightweight design with active torsion

SmartBird is an ultralight but powerful flight model with excellent aerodynamic qualities and extreme agility. With SmartBird, Festo has succeeded in deciphering the flight of birds. This bionic technology-bearer, which is inspired by the herring gull, can start, fly and land autonomously – with no additional drive mechanism. Its wings not only beat up and down, but also twist at specific angles. This is made possible by an active articulated torsional drive, which in conjunction with a complex control system makes for unprecedented efficiency in flight operation. Festo has thus succeeded for the first time in realising an energy-efficient technical adaptation of the natural model.

Know-how for automation
The functional integration of coupled drive units yields significant ideas and insights that Festo can transfer to the development and optimisation of hybrid drive technology. The minimal use of materials and the extremely lightweight construction pave the way for efficiency in resource and energy consumption. The knowledge acquired in aerodynamics and flow behaviour yields new approaches and solutions for automation.

The fascination of bird flight
One of the oldest dreams of mankind is to fly like a bird – to move freely through the air in all dimensions and to take a “bird’s-eye view” of the world from a distance.

No less fascinating is bird flight in itself. Birds achieve lift and remain airborne using only the muscle power of their wings, with which they generate the necessary thrust to overcome the air resistance and set their bodies in motion – without any rotating “components”. Nature has ingeniously achieved the functional integration of lift and propulsion. Birds measure, control and regulate their motion through the air continuously and fully autonomously in order merely to survive. For this purpose they use their sense organs.

Scientific precursors

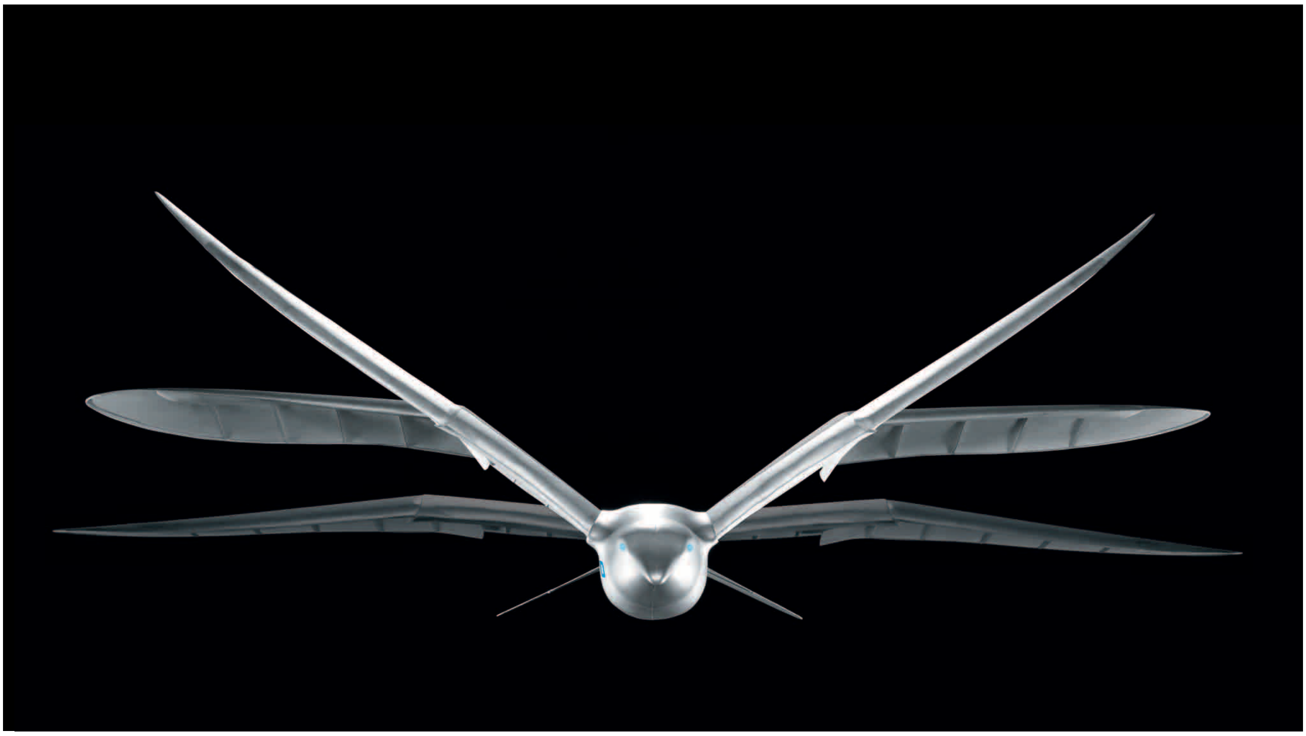
As long ago as 1490, Leonardo da Vinci built rudimentary flapping wing models in order to come closer to achieving bird flight. In 1889, Otto Lilienthal published the book “Birdflight as the Basis of Aviation: A Contribution Toward a System of Aviation”. In the chapter “The Bird as a Model” Otto Lilienthal describes in detail the flight of the seagull. More recent times have seen the development of ornithopter projects such as that of Professor Dr. James DeLaurier and his research team at the University of Toronto. In 2006 this group succeeded for the first time in taking off from a runway with a flying device powered by a flapping-wing mechanism, complete with pilot. In August 2010, a flying machine propelled by its pilot’s muscle power alone covered a distance of about 150 meters after being towed to flying altitude.

Bird flight deciphered

In 2011, the engineers of Festo’s Bionic Learning Network developed a flight model that is capable of taking off autonomously and rising in the air by means of its flapping wings alone, without the aid of other devices to provide lift. SmartBird flies, glides and sails through the air.

The experience gained with the Bionic Learning projects AirRay and AirPenguin was incorporated into the creation of SmartBird. The objective of the project was to construct a bionic bird modelled on the herring gull. The fascination of building an artificial bird that could take off, fly and land by means of flapping wings alone provided the inspiration for SmartBird’s engineers. Moving air in a specific manner is a core competence of Festo that has been a driving force for the company for more than fifty years.

The unusual feature of SmartBird is the active torsion of its wings without the use of additional lift devices. The objective of the SmartBird project was to achieve an overall structure that is efficient in terms of resource and energy consumption, with minimal overall weight, in conjunction with functional integration of propulsion and lift in the wings and a flight control unit in the torso and tail regions. Further requirements were excellent aerodynamics, high power density for propulsion and lift, and maximum agility for the flying craft. Under scientific supervision, an intelligent cybernetic overall design was realised in discrete individual stages.



Precisely twisted: Active torsion during the upward wing stroke

Active articulated torsional drive

Flapping-wing flight comprises two principal movements. First, the wings beat up and down, whereby a lever mechanism causes the degree of deflection to increase from the torso to the wing tip. Second, the wing twists in such a way that its leading edge is directed upwards during the upward stroke, so that the wing adopts a positive angle of attack. If the rotation were solely due to the wing's elasticity, passive torsion would result. If on the other hand the sequencing of the torsion and its magnitude are controlled by an actuator, the wing's torsion is not passive, but active.

The wing: Lift and propulsion in birds

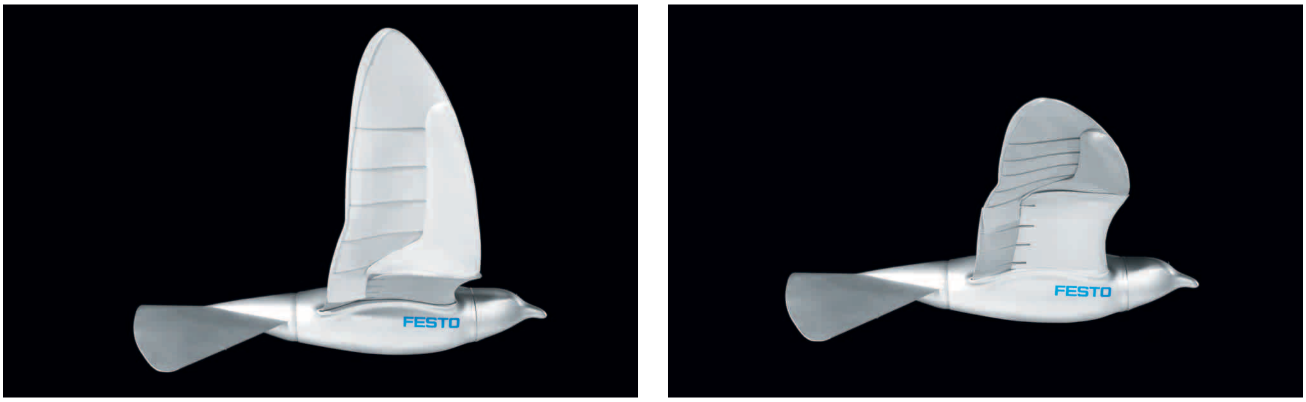
SmartBird's wings each consist of a two-part arm wing spar with an axle bearing located on the torso, a trapezoidal joint as is used in enlarged form on industrial excavators, and a hand wing spar. The trapezoidal joint has an amplitude ratio of 1:3. The arm wing generates lift, and the hand wing beyond the trapezoidal joint provides propulsion. Both the spars of the inner and the outer wing are torsionally resistant. The active torsion is achieved by a servomotor at the end of the outer wing which twists the wing against the spar via the outmost rib of the wing.

Partially linear kinematics for optimal thrust

When SmartBird lifts its wings, the servo motor for active torsion twists the tips of the hand wings to a positive angle of attack, which is then changed to a negative angle a fraction of a wing beat period. The angle of torsion remains constant between these phases. Thanks to this sequence of movements, the airflow along the wing profile can be optimally used to generate thrust.

The torso: a secure housing for the technology

The battery, engine and transmission, the crank mechanism and the control and regulation electronics are housed in SmartBird's torso. By means of a two-stage helical transmission, the exterior rotor motor causes the wings to beat up and down with a reduction ratio of 1:45. This motor is fitted with three Hall sensors that pre-



Lift and propulsion in the one movement: Upward ...

cisely register the wing's position. Both the flapping and bending forces are conveyed from the transmission to the hand wing via a flexible link. The crank mechanism has no dead centre and thus runs evenly with minimal peak loads, thus ensuring smooth flight.

The opposing movement of the head and torso sections in any spatial direction is synchronised by means of two electric motors and cables. The torso thus bends aerodynamically, with simultaneous weight displacement; this makes SmartBird highly agile and manoeuvrable.

The tail section: an aid for lift and control

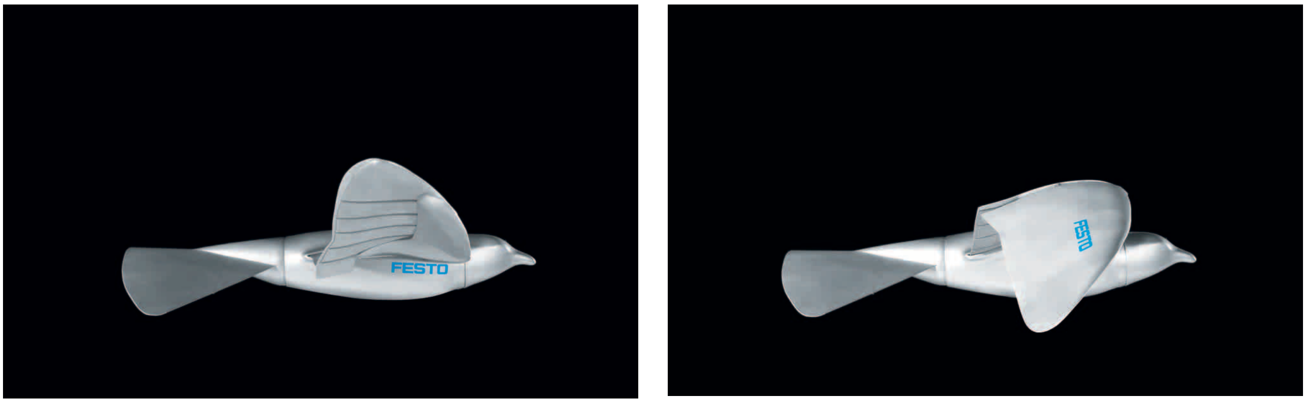
The tail of SmartBird also produces lift; it functions as both a pitch elevator and a yaw rudder. When the bird flies in a straight line, the V-position of its two flapping wings stabilises it in a similar way to a conventional vertical stabiliser of an aircraft. To initiate a turn to the left or right, the tail is tilted: when it is rotated about the longitudinal axis, a yaw moment about the vertical axis is produced.

Measurement, control and regulation

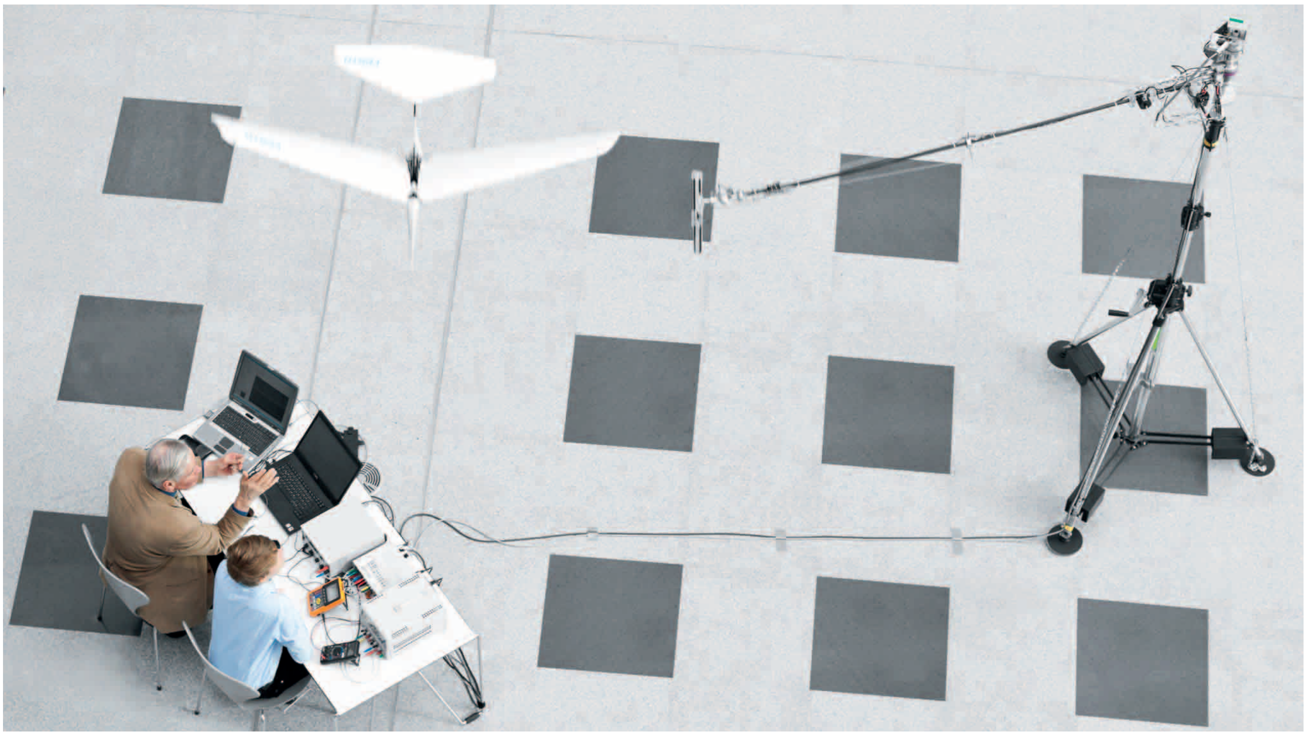
The on-board electronics allow precise and thus efficient control of wing torsion as a function of wing position. For this purpose, a powerful microcontroller calculates the optimal setting of two servo motors, which adjust the torsion of each wing. The flapping movement and the torsion are synchronised by three Hall sensors, which determine the absolute position of the motor for the flapping movement. Since the active joint torsion drive requires precise coordination between the flapping and twisting movements, it is subjected to continuous all-round monitoring.

Intelligent monitoring

The wing's position and torsion are monitored by two-way radio communication with ZigBee Protocol, by means of which operating data are conveyed such as battery charge, power consumption and input by the pilot. In addition, the torsion control parameters can be adjusted and thus optimised in real time during flight. Together with the electronic control system, this intelligent monitoring enables the mechanism to adapt to new situations within a fraction of a second. This facilitates the simple, efficient and weight-optimised mechanical design of the bird model for optimised efficiency of the overall biomechatronic system in flight operation.



... and downward wing strokes



Theoretical basis

A high degree of aerodynamic efficiency can theoretically only be achieved by active torsion, with a small quantity of power required to be supplied by an actuator. With active torsion, the power of the flapping wings is converted very efficiently into thrust. The aerodynamic efficiency factor is the ratio of thrust attained to the flapping and rotary power expended.

Scientific investigation of circular flight

Investigations and measurements of SmartBird were carried out over the course of its development on the basis of the work of French physiologist Etienne-Jules Marey (1830 – 1904), who analysed the flight of birds that were made to fly in a circular path. To determine the electro-mechanical efficiency, a new apparatus was developed which acts as a dynamometrical brake.

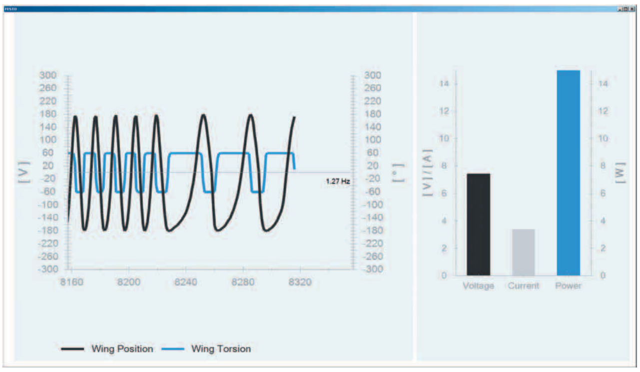
SmartBird’s efficiency factors

SmartBird and its predecessors have an electromechanical efficiency factor of around 45 %. Measurements of circular flight have demonstrated an aerodynamic efficiency factor as high as 80 %.

The overall efficiency factor is the product of the two partial efficiency factors. Since the aerodynamic efficiency factor can be calculated but not directly measured, it is determined from measurements of overall and electromechanical efficiency. To determine the electromechanical efficiency factor, the absorption dynamometer continuously measures torque and angular velocity to calculate the available power expended during flight. For this purpose, the wing stroke movement is transferred to a shaft that is impeded by a brake shoe; the lever arm of the brake is held by a force sensor. An angle sensor measures the rotation of the shaft. The torque and angular velocity together yield the mechanical power. The electromechanical efficiency factor is calculated as the ratio of this quantity to the electrical power supplied.

Optimal use of airflow

Propulsion and lift are achieved solely by the flapping of the wings and have a power requirement of only 25 watts. SmartBird has a total weight of around 400 grams and a wingspan of 2 metres. It is thus an excellent example of functional integration and resource-efficient extreme lightweight design, and demonstrates the optimal use of airflow phenomena.
The control of the time behaviour of wing bending and wing torsion takes place within the tact of a few milliseconds and results in optimum airflow around the wings. The SmartBird flight model has no rotating parts on its exterior and therefore cannot cause injury.



Real-time monitoring of wing position and torsion

A paradigm shift thanks to bionics

With SmartBird, Festo in its Bionic Learning Network is once again successfully transferring a natural principle to a field of technology. SmartBird provides a stimulus for turning to nature in the search for new solutions in automation.

An all-encompassing mechatronic design

SmartBird is an all-encompassing mechatronic and cybernetic design that combines numerous individual solutions into a fascinating whole. SmartBird could only be realised through the integration of intelligent mechanics, electrical drive technology, findings from fluid dynamics, intelligent open and closed-loop control engineering, condition monitoring and the constant scientific validation and transfer of scientific findings into practice.

Festo already today puts its expertise in the field of fluid dynamics to use in the development of the latest generations of cylinders and valves. By analysing SmartBird's flow characteristics, Festo has acquired additional knowledge for the optimisation of its product solutions and has learned to design even more efficiently. This efficiency in design allows the development of compactly dimensioned products that require less installation space and are flow-optimised, and thus more energy-efficient.

Energy-efficient and resource-friendly

With its optimised contours and its lightweight carbon fibre design, SmartBird is an excellent example of energy-efficient motion and of the resource-friendly use of materials. The functional integration of two types of drive into a hybrid solution likewise increases resource efficiency.

Functional integration for hybrid technology

This function integration provides information for the development and optimisation of hybrid drive technologies. With the hybrid axis, Festo is already combining the advantages of pneumatics with those of electric linear axes to achieve rapid, high-precision linear actuator technology.

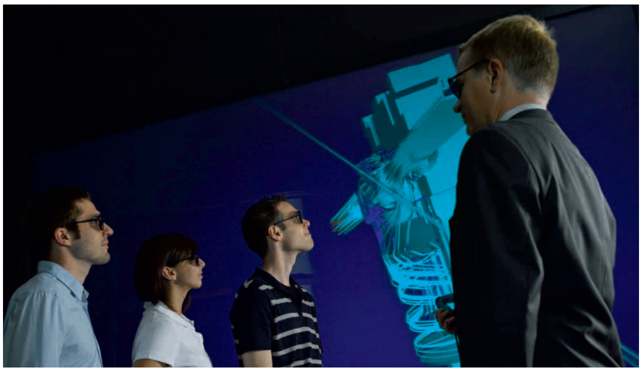
Possible fields of application

The applications of coupled drives for linear and rotary movement range from generators that derive energy from water – so-called stroke wing generators – to new actuators in process automation.

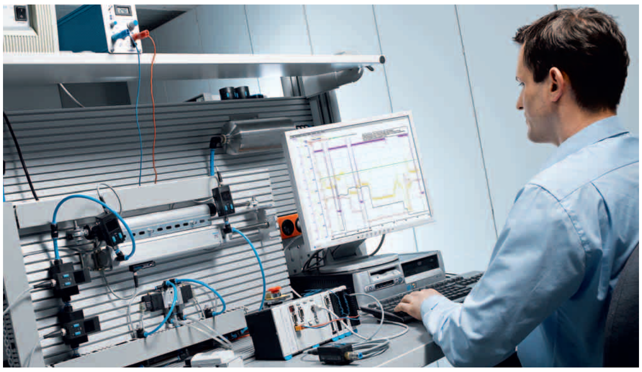
Inspired by the paradigm shift brought about by bionics, Festo has already in the past developed products that have met with acceptance in industry; the focus here is on energy-efficiency and conservation of resources.

Safe operation through condition monitoring

Data on SmartBird's wing position and torsion are constantly registered during flight. The torsion control parameters can be adjusted in real time during flight and thus optimised. This ensures stable flight of the bird for safe operation.



Flow behaviour in the design and simulation of new products



Condition monitoring: Process-safety ensured by permanent diagnosis

Technical data

Torso length:	1.07 m
Wingspan:	2.00 m
Weight:	0.450 kg
Structure:	lightweight carbon fibre structure
Lining:	extruded polyurethane foam
Battery:	lithium polymer accumulator, 2 cells, 7.4 V, 450 mA
Servo drive:	2x digital servo unit with 3.5 kg actuating force for control of head and tail sections 2x digital servo units for wing torsion, with 45 degree travel in 0.03 s
Electrical power requirement:	23 W
Microcontroller:	MCU LM3S811 32-bit microcontroller@50 MHz 64 kByte flash, 8 kByte RAM
Radio transmission:	868 MHz/2.4 GHz two-way radio transmission based on ZigBee Protocol
Motor:	Compact 135, brushless
Sensors:	Motor positioning 3x TLE4906 Hall sensors
Accelerometer:	LIS302DLH
Power management:	2x LiPo accumulator cells with ACS715 voltage and current monitoring
LED activation:	TPIC 2810D

Project partners

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