# AquaPenguin

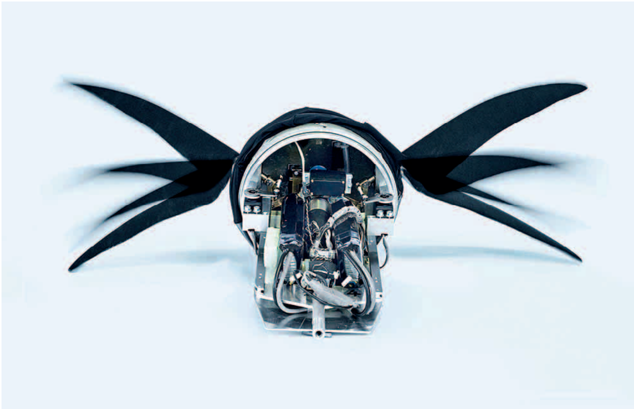

A group of artificial
autonomous penguins

Info

# A biomechatronic overall concept

Penguins are survival artists that brave the icy Antarctic storms to rear their young on land, where they move rather staidly and at times even somewhat clumsily. They feed mainly on small shrimp-like creatures – krill – which they hunt in the depths of the ocean.

The penguins' swimming and diving behaviour has been studied in Antarctica for many years. Using state-of-the-art methods, researchers have succeeded in revealing the secrets of the underwater "flight" of this unusual order of birds.



Wing drive mechanism

**Nature as a laboratory for efficient processes**

In their search for food, penguins often travel more than a hundred kilometres per day; Adélie penguins dive to depths of up to 350 metres, and their larger cousins, the emperor penguins, to as much as 700 metres. In the water they are fast, have a great deal of endurance and are astoundingly agile: they can reach a top speed of almost 30 kilometres per hour, although their speed of travel in the more energy-efficient migratory mode is around 10 to 15 kilometres per hour.

Penguins prove robust and crashproof when landing on an iceberg after an audacious leap or making their way through the pack ice. After 40 million years of evolution, they are perfectly contoured. Their artless elegance is matched by the highest levels of energy efficiency and a streamlined body design.

Haulage tests with cast models of the spindle-shaped penguins' bodies show a flow resistance 20 to 30% lower than the hydrodynamically most favourable known technical bodies (cd-values < 0.02, with Reynolds numbers in the order of 106). The elastically deformable wing surfaces also make for high thrust efficiency. These two factors combine to yield a surprisingly low energy consumption level.

Investigations of the metabolism of living penguins in a specially built swimming tunnel in Antarctica have revealed that Adélie penguins, for example, can swim more than 180 kilometres on a full stomach (approx. 1 kilogram of krill). If the penguins' bodies were operated with petrol, they would thus be able to travel some 1,500 kilometres through the icy Antarctic waters on just one litre of fuel.

These phenomenal feats from the animal kingdom provided the inspiration for the bionic realisation of the AquaPenguin.

**Bionic penguins –**
**technology-bearers as autonomous underwater vehicles**

The bionic penguins are designed as autonomous underwater vehicles (AUVs) that independently orient themselves and navigate through the water basin and develop differentiated, variable behaviour patterns in group operation.

The penguins' hydrodynamic body contours and elegant wing propulsion principle were adopted from their natural archetypes. The wings comprise a skeleton of spring steel elements embedded in an elastic matrix of silicon that gives them their profile; they can thus twist to an optimal angle in interaction with the hydrodynamic forces in each stroke, whereby the pitch angle can also be regulated interactively. The robotic penguins can thus manoeuvre in cramped spatial conditions, turn on the spot when necessary and – unlike their biological archetypes – even swim backwards.

An entirely new feature in robotics is the torso that can move in any direction. To make such an "organic" change of shape possible, the head, neck and tail segments were based on a new 3D Fin Ray® structure. This structure, derived from the tail fin of a fish, has thus been extended into three-dimensional space for the first time. In the realisation selected here, the bending structure consists of flexible longitudinal struts with circumferential connecting elements that maintain the shape of the elastic skin. Steering is effected via the longitudinal struts and mechanically linked draw lines, with small actuators for horizontal and vertical movement. The actuators and control electronics are housed in the dry chamber of the torso.

The shoulder joints are spherical; the wing axes pass through the joints and are also fitted with separately rotatable bearings within the sphere. The additional axis of rotation is controlled by one actuator per wing, which adjusts the wings' pitch angles. This mechanism is used for steering in various manoeuvring situations. A special flapping mechanism acts on the wing axes directed toward the torso, in order to operate the two wings synchronously and to provide the strong up-and-down motion for propulsion.

Rear section as a 3D Fin Ray® structure

This force is provided by one powerful electric motor, whose rotational speed also controls the flapping frequency of the wings; the forces are transferred to the wings by means of a leverage system fitted with a further actuator, which by slightly displacing the pivot points can modify the effective length of the lever arms and thus also the transmission ratio; this in turn regulates the amplitude of the flapping wings.

The entire mechanism is designed in such a way that in conjunction with the elastic wing twist, the kinematics of the penguins' underwater "flight" is imitated almost perfectly, the flapping cycles are practically a self-regulating automatism, and manoeuvring is effected with only a minimum of effort.

The manoeuvres are supported by an intelligent 3D sensor system, which in this case, however, was borrowed from an entirely different group of animals. To analyse their surroundings, the AquaPenguins are fitted with special 3D sonar which makes use of broadband ultrasound signals, similar to those used by dolphins and bats. This enables them to determine their spatial position, constantly measure the distances to the walls of the water basin, avoid collisions and navigate autonomously. A separate pressure sensor is also available for operation at greater depths in free water.

Some of the movement patterns have been combined into programmed elementary manoeuvres. The further processing is carried out by the intelligent onboard electronics that allow the penguins to navigate autonomously and to develop versatile patterns of interaction with the other members of the group.

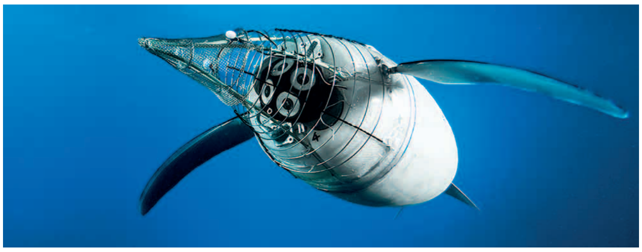
**AquaPenguin –
technology-bearer for the automation technology of tomorrow**

The bionic penguins readily demonstrate what is meant by learning from nature. The use of innovative technical materials and the creative combination of various design and functional principles pave the way for new opportunities in design and automation technology.

The penguins' torso design can be used in automation for flexible tripods, thereby opening up new fields of application in handling technology. The BionicTripod has an operating range that by far transcends that of the conventional tripod configuration; for example, pick-and-place applications with an offset of 90 degrees are possible. In combination with a flexible and adaptive gripper, fragile objects of various shapes can be moved.

With the AquaPenguin, Festo is benefiting from the advantages of versatile contour and structural adaptation and intelligent self-organisation, both on an individual level and in group operation.

Intelligent sensors are also opening up new applications. Thanks to its rapid, precise control, the AquaPenguin can swim collision-free in group operation, with depth control, pressure and temperature compensation, and positional stability. Transfer to automation technology is also to be found in the regulation technology of Festo. For example in the new VPPM and VPWP proportional-pressure regulators for servo-pneumatics.



3D sonar

**Technical data**

| | |
|---|---|
| Overall length: | 0.77 m |
| Dry chamber: | 0.42 m |
| Max. torso diameter: | 0.19 m |
| Wing span: | 0.66 m |
| Weight in air: | 9.6 kg |
| | |
| Materials | |
| Torso: | laminated fibreglass-reinforced plastic |
| Head and tail segments: | 3D Fin Ray Effect® structure of stitched plastic elements |
| Wings: | compound of spring steel wire, silicon, polyamide upper surface |
| Skin: | polyamide, with elastane additive |
| Ropes and lines: | high-tensile polyethylene fibre |
| | |
| Drive/control units | |
| Principal drive: | electric, 12 V (70 mNm) |
| Gearing: | 43:1 planetary gear (7 Nm) |
| Actuators: | Dymond DS 9900 Coreless Digital |
| | |
| Power supply: | LiPo accumulators, 11.1 V, 15 Ah |
| | |
| Operation: | completely autonomous |
| Max. speed: | 5 km/h / 2.7 kn |
| Duration of operation: | 6 – 7 hours |
| | |
| Sensors: | 1 four-beam front-looking sonar<br>1 pressure sensor |
| Onboard processor: | AVR Mega 128<br>2 x RS232, 8-kilobyte EEPROM<br>64-kilobyte RAM |
| | |
| Brands: | Fin Ray Effect® is a trademark of EvoLogics GmbH, Berlin, Germany |

**Project partners**

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