

MODELLING AND MANUFACTURING OF A DRAGONFLY WING AS BASIS FOR BIONIC RESEARCH

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1. Introduction

Working principles in nature have been optimised by evolution for millions of years. Today we try to understand how these principles work and how they could be used in technical applications. Prominent examples for solutions which are inspired by bionic research are the Velcro fastener (inspired by the plant "Arcticum lappa") [Pahl et al., 2003], swim suits (inspired by shark skin) [Thilmany, 2004] and self-cleaning surfaces using the lotus effect [von Baeyer, 2000].

The topic of aerodynamics is another large area for research and innovation in which we still hope to be able to learn from nature. The dragonfly combines very light wing structures with amazing flying abilities [Okamoto, 1996]. In order to study the exact properties of the dragonfly wing and to understand how this properties can be achieved, it is necessary to reproduce the geometry of the wing at a larger scale. This large scale model can be used to conduct further aerodynamic tests in a wind tunnel. The results of such investigations can lead to new impulses for the development of aircraft and micro air vehicles.

In this paper the authors will describe the modelling and building of an enlarged model of a dragonfly wing as base for further bionic research.

2. Dragonfly wing

Dragonflies fulfil amazing flight manoeuvres. They are able to remain stationary in one position in the air and to change to any flight direction instantaneously. This remarkable aerodynamic properties are caused by two main components: the musculature and the wing geometry. This article focuses on the wings, which are highly optimised by nature. One wing weighs only about 3% of the whole dragonfly [Kesel et al, 1993], but at the same time is very robust and stiff.

During gliding, dragonfly wings can be interpreted as acting as ultra-light aerofoils which, for static reasons, have a well-defined cross-sectional corrugation (see figure 1). This corrugation forms profile valleys in which rotating vortices develop [Hien et al., 1996]. The cross-sectional configuration varies greatly along the longitudinal axis of the wing. This produces different local aerodynamic properties.

However, the wing profiles, depending on their position along the span length, attain much high lift values. The detectable lift forces can be compared with those of technical wing profiles for low Re numbers. Pressure measurements (at $Re = 9300$) show that, because of rotating vortices along the chord length (see figure 2), not only is the effective profile form changed, but the pressure relationship on the profile is also changed. Irrespective of the side of the profile, negative pressure is produced in the profile valleys, and net negative pressure on the upper side of the profile is reached only at angles of attack greater than 0° .



Figure 1. Photograph of a dragonfly and their wings

The dragonfly wing has a high c_a (lift) coefficient and at the same time a low c_w (drag) value as shown by the squares in figure 2 (upper part of diagram). In comparison, the circles demonstrate the c_w and c_a values for the lower profile in figure 2 which is thicker than the original dragonfly wing. The original dragonfly wing profile (upper profile) has much better aero dynamical properties than the technical profile (lower profile in diagram). These results demonstrate the importance of careful geometrical synchronisation as an answer to the static and aerodynamic demands placed upon the ultra-light aerofoils of a dragonfly [Kesel, 2000].

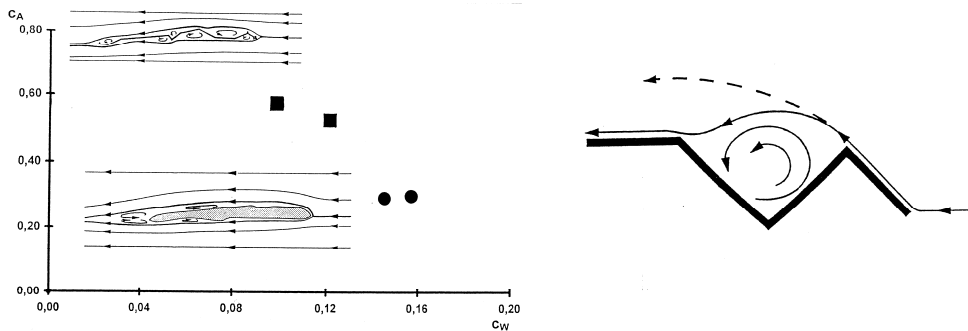


Figure 2. Development of vortices in the valleys of dragonfly wings [Hien et al., 1996; Hien et al., 1996]

The energy efficiency of the dragonfly [Okamoto et al, 1996] makes the dragonfly wing geometry interesting for possible technical applications. Future airplanes could use the effect of the rotating vortices to optimise their flight dynamics and energy efficiency and at the same time satisfying static needs using a minimum of material.

Hence the dragonfly wing has to be researched in further detail in order to increase the understanding of the complexity of the geometry of the wing, especially the corrugation, and relation to the remarkable aerodynamic properties. The corrugation makes it also possible to build an extremely

lightweight wing. At present, numerical simulation is not able to calculate the aerodynamical effects with the required precision. Therefore an enlarged physical model is needed, that helps making tests and build a realistic model of a dragonfly wing and, eventually, of a dragonfly itself.

3. Modelling with parametric CAD

To reproduce the reality as good as possible in a model and to ensure the reproducibility of the wing geometry for further adoptions the authors used a parametric 3D-CAD-system to build a digital model of the wing. Another reason for the use of CAD is the possibility to deduce NC-code semi-automatically to mill a cavity representing a negative form of the dragonfly wing. This cavity is used to produce a model of the wing made of composite materials.

At the department of Zoology, Technical Biology and Bionics of the Saarland University there was a project [Hien, 1997], which had the aim to characterise the exact geometry of a dragonfly wing. One result, besides others, was a detailed documentation of nine cuts perpendicular to the longitudinal wing axis. These nine cuts were made in equal intervals and they were measured by a travelling microscope and documented by coordinates. Figure 3 shows the positions of the cuts on the dragonfly wing and the resulting cross sections.

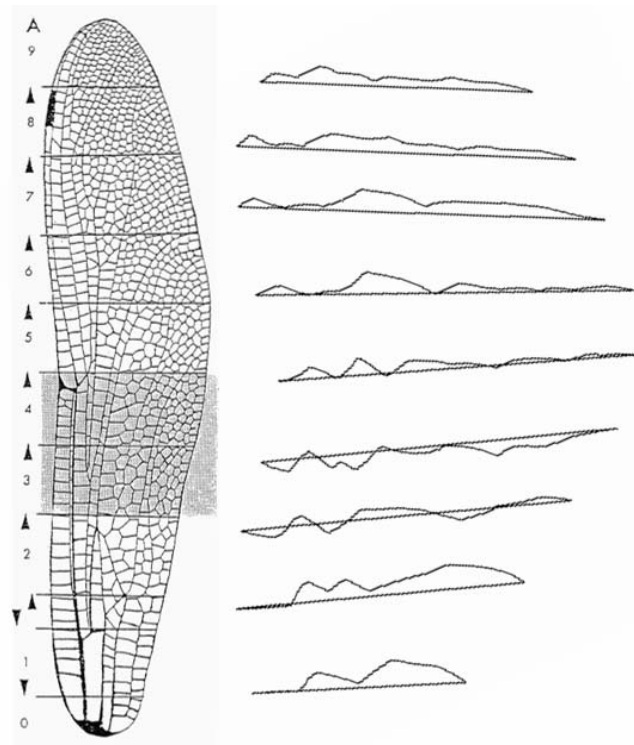


Figure 3. Position of the cuttings on the dragonfly wing [Hien, 1997]

Based on this data a first step was to bring these coordinate nodes in a 3D-CAD-model forming nine curves. These discrete curves were combined in a next step. Interpolating splines connect the curves. Basis for the splines were the veins of the dragonfly wing, which were modelled from photos.

Thus, a net of wireframes was built, which had to be filled by surfaces. The result of these operations was a realistic, digital model of a dragonfly wing (scale 8:1). Figure 4 shows the developed skeleton lines of the dragonfly wing and the resulting surface model of the wing. Since the surface model is not applicable for the following NC-Code generation, a volume model (solid) is needed which was deduced from the surface model (see figure 4).

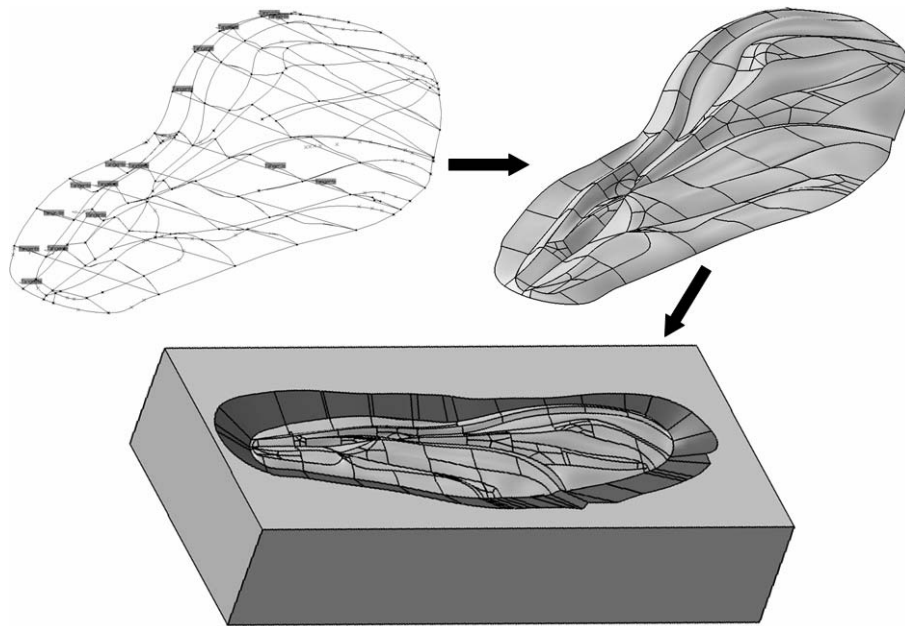


Figure 4. Dragonfly wing wireframe, surface and 3D-CAD- solid model

4. Manufacturing with an integrated CAD/CAM/NC Solution

The CAD-software used (CATIA V5) has an integrated CAM/NC-module that allows for the generation of NC-code semi-automatically, in this case for a 3-axis milling machine. Basis is the 3D-CAD-model. Different approaches had to be investigated in order to find a suitable milling strategy. The resulting tool path was thoroughly simulated and tested prior to the generation of the final NC-code (see figure 5). IBM supported the project by developing the postprocessor needed to translate the general tool path generated by the CAM/NC-module into the machine-specific NC-code.

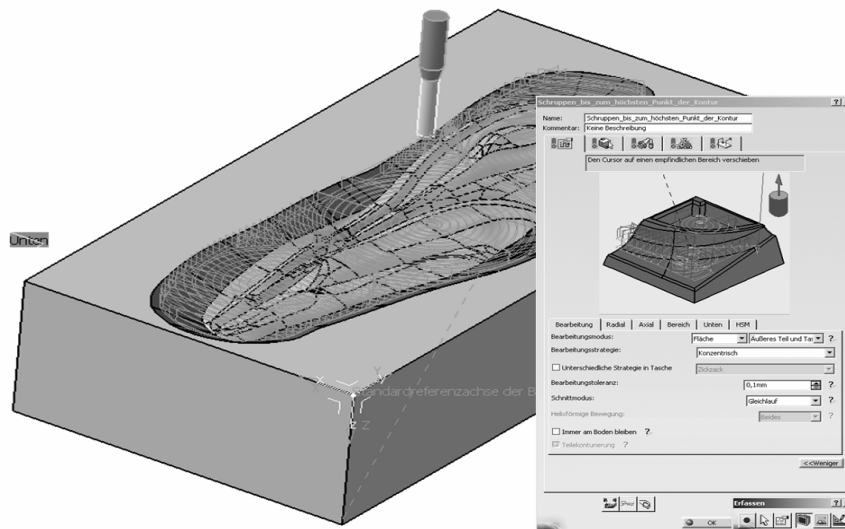


Figure 5. Milling simulation of the cavity

The corrugations were difficult to mill because of the usage of a very thin milling cutter. The transition from one valley to a crest and from one crest to a valley are discrete. To be as close to reality as possible a milling cutter with just 2mm diameter had to be used (see figure 6). Due to the required high surface quality the cutting paths had to be very close together. This caused a milling time of 20 hours per negative form.



Figure 6. Milling of the cavity and the finished form

5. Application of the model

The model which was milled is the negative mould for the building of enlarged positive dragonfly wing models made of fibre reinforced plastics. This single wing will be used to investigate further into the aerodynamic system of the air vortices which are formed by the corrugation of the wing. A second mirror-inverted wing was manufactured for the other side of an aerodynamic model of the dragonfly. In a first step the third and the fourth wing will be exact copies of the first and the second wing. These four wings are fitted to a body model of the dragonfly in such a way that it is possible to change the attack angle and the sweep. To realise the flapping-wing motion Fluidic Muscles by the Festo company will be used. The complete physical, realistic model will be used to research the aerodynamic of the flapping-wing motion and the effects of the interferences between the four wings in a wind tunnel.

The results could be used to build new type of aircrafts with very light wing structures and improved fuel efficiency. First tests with a large scale flapping-wing aircraft have been done by DeLaurier (see figure 7) [DeLaurier, 1993; DeLaurier 1994].



Figure 7. Flight test with an Ornithopter [deLaurier, 2005]

Another field of applications could be Micro-Air-Vehicles (MAV). These small un-manned machines could be used to explore Mars by flying much greater distances than the earth bound rover vehicle could cover [GEO, 2004]. Unfortunately, also armed forces are thinking about the use of autonomous flapping-wing micro aircrafts.

6. Conclusion

In nature we find many examples for highly optimised principles and solutions. The wing of the dragonfly is such a structure. The wing is very light and at the same time very stiff and has impressive aerodynamic properties. In order to understand how nature could achieve such opposed properties it was necessary to build an enlarged model to carry out further research into the aerodynamics of the single wing on the one hand and into the effects of the interferences between the four wings on the other hand in a wind tunnel. The enlarged model of the dragonfly wing was derived from cross cut sections of an actual dragonfly wing using the CAD/CAM/NC solution CATIA V5 and a NC-milling machine.

In the future the findings may be useful to develop light aircraft which have a high fuel efficiency and great manoeuvrability.

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