DELFLY

Insect inspired MAV


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For the last couple of decades there is an increasing interest in the field of Micro Aerial Vehicles (MAV's) for both civil and military missions. A MAV is defined as a small unmanned aerial vehicle (UAV). There are different types of MAV's. One of them is a flapping wing, which is inspired by insects. An example of such a flapping wing design is "DelFly". The project was born in the summer of 2005. Now, almost five years later, the research on DelFly is still going on and improvements are still made.

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MAV's can be used for a multitude of purposes like observation and search and rescue missions. When flying in small confinements, like for example, a building struck by an earthquake in search of survivors, the ability to fly at low airspeed and to have good manoeuvrability is critical. Flapping MAV's have this ability, they can fly at low speeds and are even able to hover. In nature, insects evolved their flapping wings in the course of millions of years, so it is logical to look at them for inspiration.

Five years ago, in the spring of 2005, a team of ten students had to design a flapping MAV inspired by a dragonfly for their Design Synthesis Exercise (DSE) of the final Bachelor year at the faculty of Aerospace Engineering in Delft. They built their design and DelFly was born. Since then it has been successful at various competitions and evolved into a smaller and lighter model called DelFly II. DelFly II has a weight of seventeen grams, uses biplane flapping wings with a span of 28cm, is able to hover and has an onboard camera for observation and vision-based control. DelFly II is already capable of some autonomous flight and the goal is to keep improving the design to a very small full autonomous aircraft. The latest model, DelFly Micro, weighs only three grams and has a wing span of just 10cm from wingtip to wingtip.

At this moment, new thesis research is done to improve the flight characteristics of DelFly II and to gain better understanding of the aerodynamics. Students from the Department of Aerodynamics and the Department of System Engineering & Aircraft Design are working together in this project. Since DelFly Micro is not yet as stable as DelFly II and unable to hover, DelFly II is used as the test platform for the thesis research. The knowledge gained during research on DelFly II will be used to improve DelFly Micro as well.

IMPROVING FLIGHT CHARACTERISTICS

Flight characteristics of a flapping MAV, such as DelFly II, can be optimized by either changing the wing kinematics or wing geometry. During this research, wing kinematics is improved by the use of a new designed crank-shaft mechanism. Injection molding is used for the fabrication process of all the new components. The old crank-shaft mechanism was built by hand, resulting in different flight performance between different DelFly's. DelFly's equipped with the new mechanism perform more consistently and are more robust. Further on, energy is transferred in a more efficient way because gears, push rods and leading edges move in the same plane, as can be seen in figure 1 and figure 2.

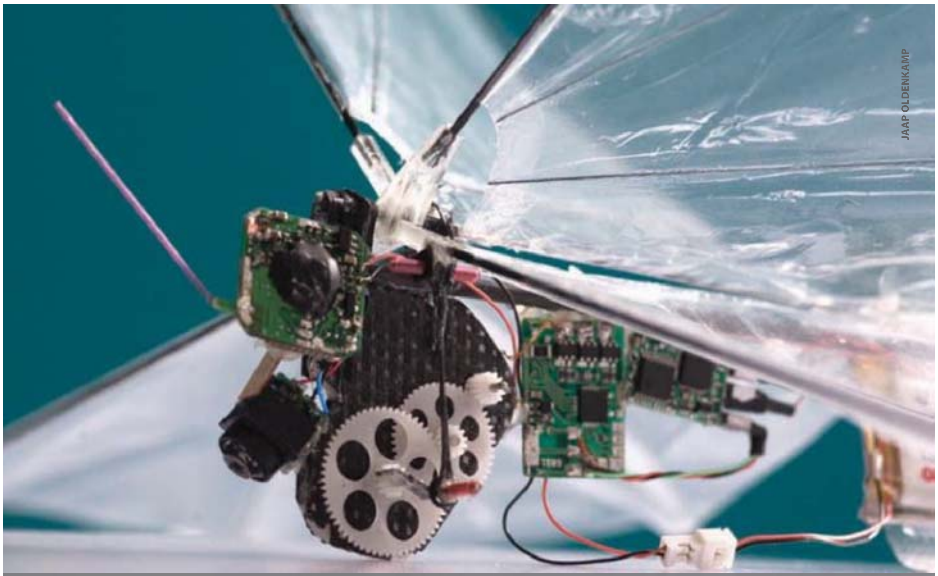

Figure 1. Handmade old DelFly Mechanism

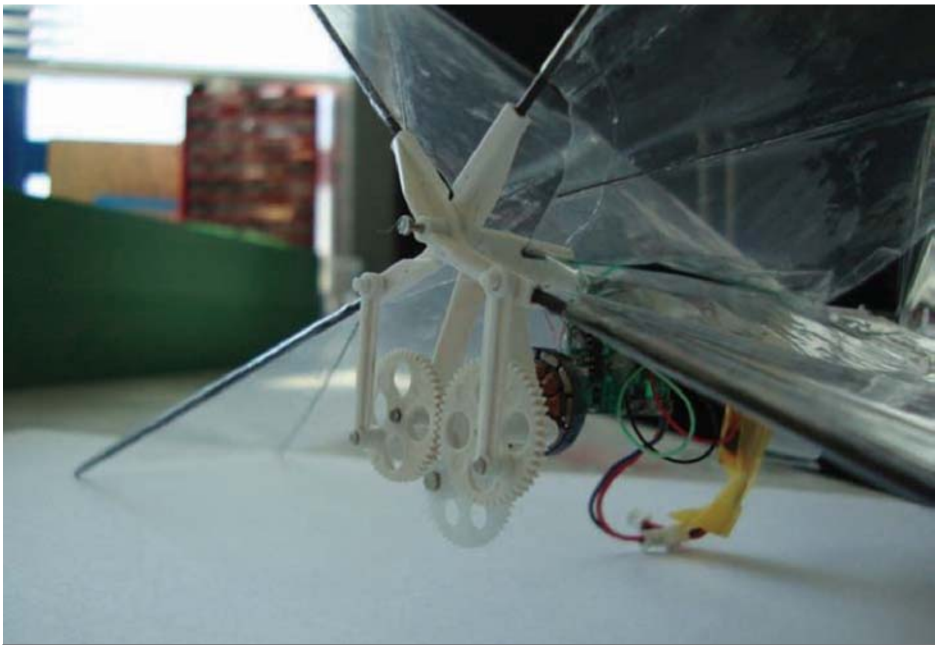
Figure 2. New injection molded DelFly mechanism

The flight characteristics are further improved by changing the wing geometry. Wing geometry does not only signify the shape of the wing in rest, but also the shape when flapping, which influences the aerodynamic flow. The latter can be done by modifying the location and orientation of the stiffeners, which are of great importance for the thrust and power characteristics. A systematic approach, based on Design Of Experiments (DOE), is followed for finding the optimal location and orientation for the stiffeners while the shape was kept constant. Figure 3 shows a plot of the orientation of the stiffeners versus thrust-to-power ratio and figure 4 shows the Frequency versus thrust-to-power ratio of the old and new DelFly wing. In figure 4 it can be seen that the location and orientation of the stiffeners induces an increase in performance of approximately 30%.

The material used for the wing membrane is Mylar foil. This is a thin polyethylene terephthalate polyester film with high tensile strength. Carbon rods are used for the stiffeners and leading edges. In order to be able to compare different sets of wings, a new fabrication method for the wings had to be introduced. The Mylar foil is place on a vacuum table in which grooves are milled. These grooves represent the location of the stiffeners and the contour of the wing. Stiffeners can now be glued with high precision while an engraver mills the contour. This method results in wings with the same tension in the foil every time.

AERODYNAMICS OF FLAPPING FLIGHT

Up until a few decades ago, little was understood about the aerodynamics behind insect flight. Recently experimental studies, of among others (Ellington, 1999), have shown that insects gain extra lift by a bound vortex at the leading edge of the wing. This Leading Edge Vortex (LEV) comes from a state of dynamic stall at low Reynolds numbers. Another mechanism that some insects use to increase their lift is clap and peel (Lehmann, 2004). Due to the bi-plane wing configuration, DelFly II also makes use of this effect. The flap cycle of DelFly II exist of a translation and rotation (where the wing changes direction). At the end of a translation when the gap between the wings is closed, the wings clap together and air is expelled downwards. When the wings start moving apart again, both the upper and lower wing are touching and they peel apart. The clap and peel creates an extra downward thrust and is believed to be beneficiary for the start of the LEV. A better understanding of how these mechanisms create lift for DelFly II is necessary for the development and improvement of smaller the versions.

In order to obtain further insight into flight mechanics improvement, a detailed experimental study is performed of the aerodynamics and aeroelasticity of DelFly II. Using previous research as a reference (De Clercq, 2009), the flow (and wing deformation) is studied with Particle Image Velocimetry (PIV). With PIV, particles in the flow around DelFly II wings are illuminated with a laser. From images taken of the particles the velocity field around

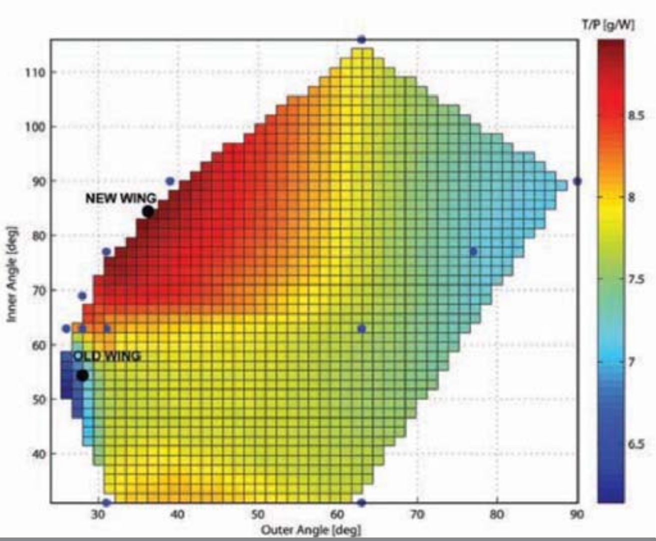

Figure 3. Response surface of the thrust-to-power ratio of different wings versus the angles of both stiffeners. The blue dots represent different test cases. The angles are measured in degrees. The colour is a measure of the trust to power ratio in grams per Watt.

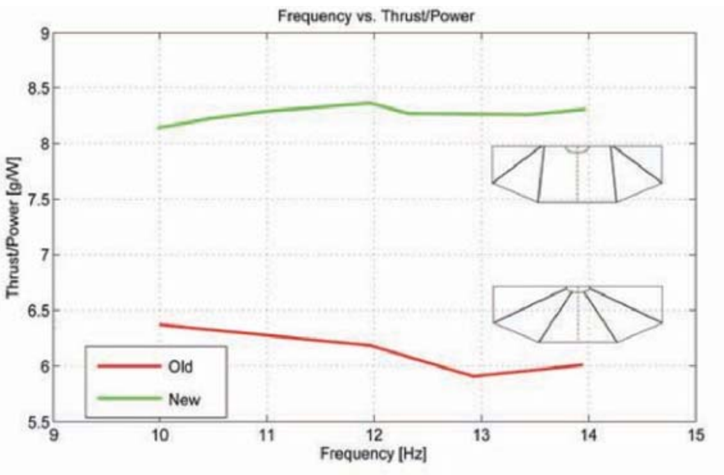

Figure 4. Frequency versus thrust-to-power ratio for both the old and new DelFly wing.

the wings can be calculated. A test setup has been constructed where DelFly II is mounted on a force sensor. The DelFly is placed in a vertical position, which corresponds with its natural position during hovering flight. Hence with this setup not only the instantaneous velocity field during flapping can be seen, but also the instantaneous thrust delivered and power consumption of the DelFly during hovering flight are measured. The velocity field on various positions along the wing span and on various moments during the flap cycle is examined for flapping frequencies varying from 9 to 13Hz for different wing geometries.

Preliminary results of the PIV experiments show the development and shedding of Leading Edge Vortices (LEV) during the clap and peel phase. Figure 5 shows a cross-section of one wing at a span of 12cm from the root (the wing tip is at 14cm) during the beginning of the clap phase. The LEV is clearly visible as well as a starting vortex at the trailing edge. Investigations show that a LEV builds up and is shed four times during the complete flap cycle (twice during the clap phase and twice during the peel phase). So the LEV for DelFly II does not stay attached to the leading edge as it does in insect flight. This could be due to the lower Reynolds numbers for insect flight (10 to 10,000) compared to the DelFly II at hovering (15,000). This could mean that for DelFly Micro the LEV could be more "insect-like".

Due to DelFly's flexible Mylar foil wings, there is a strong fluid structure interaction. The way the wing shape changes during a flap cycle is investigated by extracting it from the PIV images. The new, more efficient DelFly wing turned out to be stiffer during the rotational phase of the flap cycle. Further investigations into the effect of wing shape on the LEV development are being conducted.

CHALLENGING FUTURE RESEARCH

Investigations on DelFly still continue. The people of the MAVlab are trying to improve DelFly every day. More research will be done on DelFly and into the field of flapping wings in general. For instance, DelFly II has to be able to fly fully autonomous with vision-based control in the future. Plans are made to construct a new, even smaller DelFly with a span of 5cm, DelFly Nano. For the aerodynamics, numerical research (CFD) using results of the current research as a reference is also planned for the near future.

Understanding flapping flight is still in its first phase as you can imagine. DelFly is an excellent test platform for this matter. The MAVlab works together with all departments, like Control & Simulation, Aerodynamics and the department of System Engineering & Aircraft Design. Students who are interested in participating in this exciting new field of research, by for example doing their master thesis or PhD research into flapping wings, are encouraged to get in contact with the DelFly team (microuav@gmail.com) or by contacting Hester Bijl (H.Bijl@tudelft.nl) for aerodynamic research.

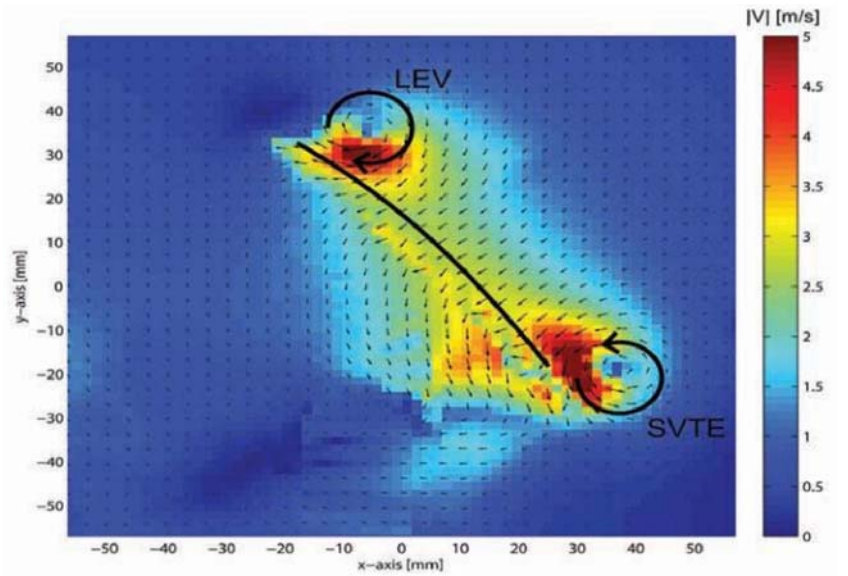

Figure 5. Visualization of the absolute velocity field of a cross-section of a DelFly wing flapping at 11Hz, showing the Leading Edge Vortex (LEV) and Starting Vortex at the Trailing Edge (SVTE)

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