# Wing design and mechanisms | literature review

Wing design

Nan et al. (2017) argues that the best aerodynamic performance can be achieved through high flexibility and optimal wing geometry, including wing length, surface area, aspect ratio and camber angle. Many scientists also have investigated the materials within the wing that contribute to its durability (Truong et al. 2014). To reduce inertial force, light materials such as polyethylene terephthalate (PET) was used for the wing membrane. Stiffeners comprised of carbon prepreg were placed on the wing membrane for reinforcement. (Nan *et al* 2017). They suggested flexible wings over rigid wings because, despite rigid wings' more efficient use of electrical power, flexible wings generate a higher thrust (Nan et al. 2017). Additionally, flexibility has been shown to facilitate twist that increases maximal force by more than 50% and lift power by more than 70% (Nan et al. 2017). It was also discovered that more rigid wings were preferable for soaring flight but performed poorly during flapping motions(M Percin *et al.* 2016). A wing comprised of latex, the most flexible material tested, generated the highest amount of thrust but a rigid wing was found to produce more lift than a flexible wing (Percin *et al.* 2016). The relationship between flexibility, with a focus on structural deformation, and aerodynamic forces was investigated by Wu et al (2010). His findings showed that strong skeletal reinforcement within wings lead to the production of higher thrust at high frequencies, and the opposite occurred at lower frequencies. The relationship between wing twist and aerodynamic forces was investigated by Truong et al (2013). It was discovered that a wing with twist generates 9. 5% more thrust than wings that do not twist. Wings that twist were found to consume 37% less power as well. Achieving optimal wing geometry is important as the wings are directly related to the aerodynamic performance of the vehicle (Nan et al. 2017).

Most studies on wing geometry show that wings perform best when they are shaped with " nearly straight leading edges" and a larger surface area. In a recent experimental study, it was deduced that an aspect ratio of 12 on the leading-edge vortex was found to create the highest lift coefficient (Nau et al. 2017). They did the comparison of the rectangular and the right-angled trapezoidal wings. Flapping frequency of wings has an impact on force generation, which increases with the increasing velocity of the wings during both instroke and outstroke(Percin *et al* 2016). For rectangular wings, at low flapping frequencies the mean lift force increased as the AR was increased. As the flapping frequency increased, the lift reached its maximum at specific aspect ratios. For the higher flapping frequencies, maximum lift is achieved at an AR of 9. 3. At this aspect ratio, a rectangular wing is more efficient and generates the most lift. The effect wing aspect ratio has on the performance of wings is significant. Aspect ratio can be altered by changing chord or span length of wings. A high aspect ratio is more favorable in all conditions(Nau et al. 2017). For trapezoidal wings, a greater lift force can be generated from a higher AR at a constant flapping frequency. Aspect ratios ranging from 5. 6-9. 3 resulted in increased lift force. Aspect ratios from 9. 3-11. 4 saw a decrease in the lift force generated. Therefore, any increase in AR beyond 9. 3 is superfluous. An aspect ratio of 9. 3 gave rise to the highest lift. Both rectangular wings and trapezoidal wings have an optimal aspect ratio of 9. 3 which is similar to the Hummingbird aspect ratio of 9. 1 (Nau et al. 2017). Thus, from culminating all of these results, surface area of 1750mm^2, aspect ratio of 9. 3 and a taper ratio of 0. 552 are optimal values for wing design. These are very similar values compared to natural flyers observed in nature, such as the Hummingbird (Nau et al. 2017).

In studies conducted to investigate the role of twist and camber in force production, it was shown that both hind and forewings have positive camber during downstroke and negative camber for a short period of time during upstroke. A simulation of a dragonfly's forewing was created to investigate the effect camber has on force generation. Through this, it was revealed that camber generates high forces of lift and drag (Percin et al. 2016).

Wing mechanism

When studying the different flight forces and principles, birds and insects are compared. In birds, the flapping stroke pertains to a mostly vertical nature with the force of flight largely due to the downstroke motion. Due to this, birds find it difficult to hover (Huang et al. 2017).  On the contrary, insects can hover through both downstrokes and upstrokes. Insects flap their wings at a faster speed- meaning they can travel through flight at lower speeds (Huang et al. 2017). To control their fight, birds and insects use alternate mechanisms, with birds using their tail and insects using their flapping wings. Insects do this through wing kinematic modulations and the changing of their centre of gravity (Huang et al. 2017). The way in which they do this is through a very complicated process, meaning mimicking these actions in a FW-MAV is a very arduous and difficult task (Huang et al. 2017). The Nano Hummingbird is the first tailless FW-MAV that could fly solely with two flapping wings. This vehicle was incredibly sophisticated mechanically

(Huang et al. 2017). The higher the number of wing sections, the better resolution in regard to force and moment data. However, a higher number of wing sections can increase the risk of using too much computing power and increasing the overall cost of the project. Therefore, the minimum number of wing sections that could render results at a higher resolution was deduced. The result was that any number of wing sections equal to or lower than 20 would reproduce the most accurate results within this experiment (Ansari et al. 2006). The mechanism mimicking the Rhinoceros beetle called a KU-Beetle has been a point of contention within the scientific community (Huang et al. 2017). The design includes a four-bar linkage and pulley string mechanism to convert the rotary motion of a coreless DC motor to the flapping motion of the wings (Huang et al. 2017). Scientists want to be able to mimic the folding mechanism in a flapping wing system. In the case of the FW-MAV, if the wings could be stowed then the system may operate for a longer period of time. The motions of the beetle were mimicked, which come from muscle activation in the thorax of the beetle. The unfolding process involves a beating motion of the hind wings and rotational motion around the wing base. Both of these facilitate a swift unfolding of the wings. This is a contrast to the folding process which involves both symmetrical and asymmetrical folding and takes longer than that of the unfolding process. Muscle actuation stimulates a scissor-like motion between a section of the wing called the RA (Radius Anterior) and the MP (media posterior)- which is integral to the unfolding of the hind wings. Artificial wings were created using Shape Memory Alloy wires which required external power of 5V at 1. 5A- meaning a large external power source would need to be installed as a source for the FW-MAV. This needs to be considered as it would add to the weight of the FW-MAV. SMA wires also generate heat which could lead to damage in other areas of the FW-MAV. Therefore, it is more ideal for the folding mechanism of the wing to occur manually without a power source (Truong et al. 2014). The DelFly II is an MAV that operates via a flapping-wing mechanism, creating a clap-and-fling motion to generate thrust and lift. Clap-and-fling is a wing interaction that occurs during stroke reversal. It has been shown to greatly increase lift generation when insects implement this mechanism. The stark increase in lift generation is attributed to multiple factors including stimulation of large leading-edge vortex and low-pressure region at the beginning of the fling, the momentum created at the end of the clap and the attenuation of the vortex at the beginning of the fling. Flexibility plays a role in the clap-and-fling motion, with more flexible wings operating via a “ clap-and-peel” motion.

Reference


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