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# A Review on MAV Design Challenges

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**ABSTRACT**

Micro Air Vehicle (MAV) design imposes several technical challenges due low aspect ratio sizing (LAR) and complex-system level of design requirement. Thus, a detail design consideration must be carried out to avoid the complexity and complication of aerodynamic-structural behaviour. Thus, this paper intend to highlight the recent challenges in designing the MAV. The review are focused more on aerodynamic impact and structural complication due to the selection of basic component on MAV such as wing planform design, fuselage design, propeller effect and control surface actuation. Based on these review, there are several solutions was invented by previous researchers with view to improve the conventional MAV design.

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## INTRODUCTION

MAV imposes several challenges and significant technical barriers among which aerodynamics is one of the most interesting. The combination of small length scale and low velocities results in a flight regime of very low Reynolds Numbers which is totally different from conventional aircraft flying regime(Al-qadi, Al-Bahi, & Arabia, 2006). A flyable fixed-wing MAV is designed with a complete system consisting of airframe (e.g. fuselage/nacelle, wing, tail), propulsion (e.g. propeller, engine, motor), payload (e.g. battery, fuel) and avionics (e.g. actuators, remote control systems)(Chen, 2013). However, the development process of each component is very challenging due to complex-system level of design requirement. Thus, this paper intend to highlight the recent challenges in designing the MAV. The review are focused more on aerodynamic impact and structural complication due to the selection of basic component on MAV such as wing planform design, fuselage design, propeller effect and control surface actuation.

### *Mav Wing Planform Design:*

The airfoil section and wing planform of the lifting surface are critically important to the performance of all flying vehicles. Therefore, MAVs share the ultimate goal of a stable and controllable vehicle with maximum aerodynamic efficiency (Mueller & DeLaurier, 2003). According to Bataillé (Bataillé, Poinsot, Thipyopas, & Moschetta, 2007), an easy way to maximize lift on the monoplane wing is by maximizing the wing surface adopting a disc plan form. Although maximum lift is an important parameter for low speed flight, other aspects of aerodynamic such as aerodynamic performance also need to be considered. Thus, a thorough experimental study has been performed in reference (Bataillé *et al*., 2007) to determine the best wing planform in order to maximize lift while maintaining a good lift-to-drag ratio. The results showed that Zimmerman planform (presented in Figure 1) seem to be the best performers (among the wing) in maximizing lift while keeping a good aerodynamic efficiency in cruise conditions(Bataillé *et al*., 2007). Bataillé had suggested three important MAV wing design rules in order to reach low speed flight while keeping good aerodynamics performance in cruise: Zimmerman planform as the best wing candidates, wing aspect ratio should be kept under 1.7 and moderate camber value to maximize the lift-to-drag ratio (Bataillé *et al*., 2007).

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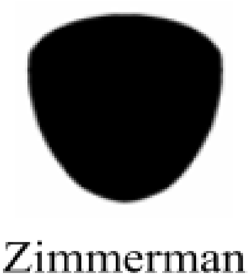

**Fig. 1:** Zimmerman wing planform (Bataillé *et al*., 2007)

Zimmerman planform have been used in numerous studies for fixed and flapping wing MAVs (Stewart, Canfield, Snyder, & Kapania, 2013). Stanford (Stanford, 2008) had optimized the membrane and shell topology of a fixed-wing Zimmerman planform. Torres and Mueller (Mueller & Torres, 2001; Torres & Mueller, 2000) experimentally studied the lift and drag on Zimmerman, inverse Zimmerman, rectangular, and elliptical planform for varying aspect ratios and for low Reynolds numbers. While, Chen had an extensive study of Zimmerman wing planform under the influence of propeller and fuselage presents (Chen, 2013).

Perimeter Reinforce (PR) and BR (Batten Reinforce) wing designs shown in Figure 2 are based on Zimmerman wing planform which introduced by the UF MAV team (Stanford, 2008). Both wings are seen as the most successful flexible or membrane wing design so far in the application of MAV (Abudaram, Rohde, Hubner, & Ifju, 2013; Stanford, Ifju, Albertani, & Shyy, 2008; Stanford, 2008). The deformation of a PR wing is characterized by adaptive aerodynamic twist. The lift, drag, and pitching moments on PR wing are consistently stronger than measured from the BR wings, as a result of the cambering motion. The slope of the pitching moment curve is considerably steeper, providing much-needed longitudinal static stability to a wing with severe space and weight constraints (Shyy *et al*., 2009; Stanford, 2008). PR configuration allows the membrane to bulge out at increasing angles of attack and higher speeds which resulting into higher lifting efficiency (Abudaram *et al*., 2013). Meanwhile, the flow over the flexible BR wing is characterized by pressure undulations over the surface, where the membrane inflation between each batten re-directs the flow which resulting into the decreases of the adverse pressure strength (Shyy *et al*., 2009). Stanford had suggested that both membrane wings are favorable to be adopted as a morphing wing in which, substantial wing shape changes can be easily inflicted through the use of torque rods or warping cables without an overwhelming amount of required power. Based on current PR and BR wing configuration, both wings comply with the basic requirement of MAV wing in terms of aspect ratio (below 1.5) and wingspan (below than 15 cm). However, PR wing is considerably easier to build (compared to BR wing) since the design eliminates the details consideration about batten configuration such as numbers of batten, batten relative distance and pre-tension membrane conditioning (Abudaram *et al*., 2013). In fact, the structural behaviour of the PR wing is conducive for twisting mobility due to minimal structural resistance but retaining enough structural stiffness for small deformation under aerodynamic loading.

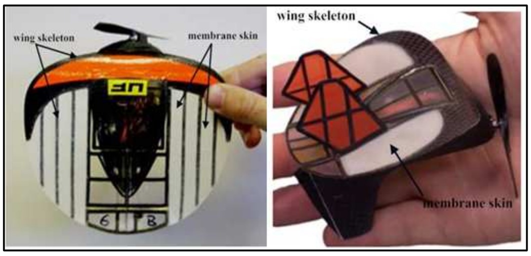

**Fig. 1:** BR (left) and PR (right) MAV wing by the UF MAV team (Stanford, Albertani, & Ifju, 2007; Stanford, 2008).

Most importantly, PR wing possessed relatively has higher lift efficiency compared to BR wing (Stanford *et al*., 2008). The study on PR wing concept has been extended in recent research conducted in the Universiti Teknologi MARA(Ismail *et al*., 2013; Ismail, Zulkifli, Abdullah, Basri, & Abdullah, 2014). The results showed that lift performance of PR wing has been significantly improved through twist morphing wing mobility.

### ***Fuselage Design:***

MAV design, in contrast to UAV, can be built without a visible fuselage (blended fuselage-wing configuration)(Hassanalian, Khaki, & Khosravi, 2014)(Durai *et al*., 2011; Radmanesh, Nematollahi, & Hassanalian, 2014; Vale, Lau, & Suleman, 2013). However, if MAV required a fuselage, the design must be done with attention to the general principals of an aircraft fuselage design. The fundamental reason for fuselage design in MAV is to place electronic equipments(Hassanalian *et al*., 2014). Fuselage design for MAV should be done by considering the important circumstances such as: location of the wing and its installation angle, planform type, dimension of equipment installed in MAV, location of engine, central position of aircraft tail's type and location of its installation, dihedral angle wing, stability issues and mechanism to launch(Hassanalian *et al*., 2014). Reference (Hassanalian *et al*., 2014) had suggested the important parameters that should be considered during the MAV fuselage design include:

1. Fuselage design that produce the lowest influence of drag
2. Eliminate the sharp angle of fuselage-wing connection to prevent the separation flow
3. Fuselage that creates the lowest impact in lift distribution on the wing
4. Fuselage structure strength

MAV fuselage shape has been associated with both aerodynamic characteristics and the fabrication difficulties. A streamlined or blended MAV fuselage may have reasonable good aerodynamics but it would require a detail aerodynamic consideration to build(Dimchev, 2012). The blended wing-fuselage (as shown in Figure 3) is introduced mainly to reduce the interference drag and profile drag between the wing-fuselage (Durai *et al*., 2011; Radmanesh *et al*., 2014). The blunt fuselage is relatively simple to build. However in aerodynamic perspective, a blunt MAV fuselage had significantly contributed in decreasing the overall aerodynamic efficiencies of MAV wing. Ramamurti(Ramamurti, R., Sandberg, W., and Lohner, 2000) had shown that fuselage component had reduced the magnitude of aerodynamic efficiency for a particular MAV wing. In recent MAV study, Zhaolin(Chen, 2013) showed that fuselage component had contributed to decrease (30%) the overall Zimmerman wing's aerodynamic efficiency. Flow structure results revealed that fuselage induced larger separation areas near the wing-fuselage connection.

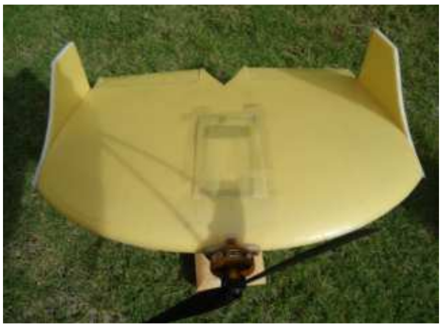

**Fig. 3:** The blended wing-fuselage configuration proposed by Durai (Durai *et al*., 2011)

***Propeller Effect:***

Most of the fixed-wing MAVs are equipped with electric motored propulsion system to provide the forward thrust (Gur, O., and Rosen, 2009). The propulsion system had adopted the propeller component as the main thrust force generation. However, the flow over the wing has been dramatically altered by the propeller and it usually generates an unsteady pressure field downstream. Dimchev(Dimchev, 2012) found that the swirling flow contributed by the propeller component significantly modifies the surface pressure distribution and a considerably shift of the centre of pressure location. The swirling flow produced by the propeller also generates an additional yawing moment and additional side slip on MAV(Phillips, W. F., and Niewoehner, 2006). Witkowski (DP Witkowski, AKH Lee, 1989) had shown that the propeller would effectively modify the angle of attack of the downstream wing, thereby changing the wing's circulation. In fact, the local angle of attack on the propeller blades is also influenced by the location of wing behind the propeller. The downward rotating blade increases the local angle of attack and increases the local lift and blade loading, which augments the thrust and torque on the blade. Lynch(Lynch III, D. A., Blakend, W. K., and Mueller, 2005) pointed out that the wake due to propeller combines with normal wake to form a new turbulence wake (named as slipstream effect) behind MAV as shown in Figure 4. The slipstream effect has a significant higher turbulence intensity level, which would retarded the upper wing surface separation. Catalano(Catalano, F. M., and Stollery, 1993) found that turbulence separation points can be moved downstream by up to 56% of chord length due to the propeller. He also pointed out that the propeller slipstream effect effects are very dependent on the propeller/wing relative position, and the propeller effect will be small if the propeller is positioned more than one propeller diameter behind the wing, in a pusher configuration. The presence of the wing behind the propeller has the effect to the wake geometry and hence modifies the overall performances. A good understanding on the interaction between the wing and the propeller is required and it requires to characterize both the propeller slipstream effect on the wing and the reciprocal influence of the wing presence on the propeller flow field and performances [28]. The propeller slipstream effect on the MAVs becomes the main challenge due to not only aerodynamics but also the overall stability as additional forces and moments can be produced due to the interactions between the propeller and the wing planform(Chen, 2013). The researchers found a significant increase of the wing's mean drag as compared to the case without the propeller. In fact, the induced lift was reduced at low rotational speeds(Deng, Oudheusden, Xiao, & Bijl, 2012). In order to include the propeller effect on MAV, Zhaolin (Chen, 2013) had suggested a detail investigation on propeller installation (i.e. the distance between the propeller to wing or fuselage); propeller installation angle and propeller rotational speeds are needed.

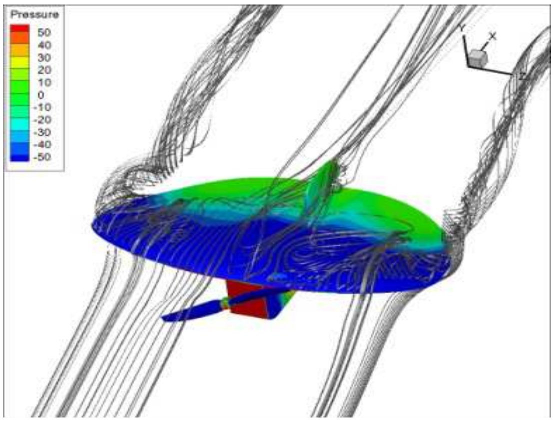

**Fig. 4:** Propeller slipstream effect (Chen, 2013)

***Horizontal And Vertical Stabilizers:***

Horizontal and vertical stabilizers (empenage) are mainly used to stabilize the MAV and provide control moments needed for maneuverability (Radmanesh *et al*., 2014). Due to critical weight management of MAV, the stabilizers are often sized to be as small as possible(Koch, 2012). Although in some cases, the empenage is design based on optimal sizes based on the required control power(Chen, 2013).

A large variety of horizontal and vertical stabilizer shapes have been employed on aircraft over the past century. These include configurations often denoted by the letters whose shapes they resemble in front view such as T, V, H, Y and inverted V tail(Gamble & Reeder, 2006). The empenage selection for MAV configuration involves complex stability-level considerations, thus only few stabilizer geometries (e.g V tail, conventional tail) have been implemented on MAV scale. The conventional empenage configuration with a low horizontal tail is a normal choice for MAV since roots of both horizontal and vertical surfaces are conveniently attached directly to the fuselage. In this design, the effectiveness of the vertical tail is large because interference with the fuselage and horizontal tail increase its effective aspect ratio(Beguin, 2012; Paranjape, Chung, Hilton, & Chakravarthy, 2012). Increasing the vertical stabilizers area would be helpful to alleviate the Dutch roll instability appeared during the MAV flight(Paranjape, Chung, & Selig, 2011). Despite the effectiveness theory of vertical stabilizer function on MAV, Paranjape(Paranjape *et al*., 2012) and Tongchitpakdee(Tongchitpakdee, 2013) had successfully built and flew a MAV model without a vertical stabilizer (Figure 5). In most of MAV study, the implementation of horizontal and vertical stabilizers on MAV wing is purposely to understand its stability and control authority. However, in order to understand the stability and the aerodynamic influence of stabilizers, it required a detail works in finding the optimum stabilizer sizing. Thus, in order to eliminate the aerodynamic and structural effect of empenage, some of previous MAV wing study had intentionally omitted the stabilizer components (Ismail *et al*., 2013, 2014).

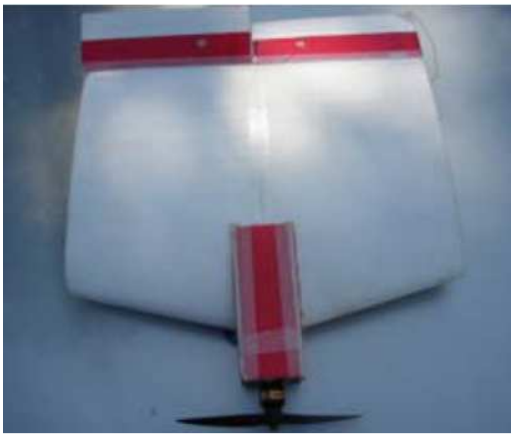

**Fig. 5:** MAV model without a vertical stabilizer(Tongchitpakdee, 2013)

### *Control Surface Actuation:*

In the context of wing control surface, it is very challenging for a MAV wing configuration that is it must be stiff enough to prevent flutter and divergence but compliant enough to allow the range of available motion(Bilgen, Arrieta, Friswell, & Hagedorn, 2013). In global definition, the control surface objective is to provide an efficient, multipoint adaptability that includes macro, micro, structural and/or fluidic approaches(Tandale, 2004). An efficient MAV's control surface is seen as simpler, light weight and energy efficient mechanical system. On the other hand, multipoint morphing is seen as an alternative technique that should eliminate the conflicts and compromises arises from the conventional control surface. However, morphing technique has strong association with other contradicting concept such as expensive morphing materials(Radmanesh *et al*., 2014), lightweight (Hassanalian *et al*., 2014) or less complicated (found in morphing wing) but the design must be accomplished by using exotic adaptive or compliant materials( a. M. Pankonien, Faria, & Inman, 2014). Thus, smart materials have been widely introduced for MAV wing control surface as well as morphing concept. Typically the smart materials used are shape memory alloys (SMA), shape memory polymers (SMP), piezoelectric ceramics such as Lead Zirconate Titanate (PZT), or piezoelectric composites which use PZT, such as the Macro Fiber Composite (MFC)( a. M. Pankonien *et al*., 2014; A. M. Pankonien, Faria, Inman, & Introduction, 2013). However, there are also challenges involving the smart material usage such as slow speed actuation, fatigue and low energy efficiency(Colorado, 2012). In fact, the actuation limitations of smart material design are governed largely by the limitations of the specific smart material being used. Despite the significant weight reduction in smart material-morphing wing, the volume and weight contributed by the electronic devices to stimulate the smart materials must also be taken into consideration(John, Iii, Hickling, Stiltner, & Karni, 2012).

### *Conclusion:*

MAV developers facing huge challenges in making decision especially on wing planform design, fuselage design, propeller configuration and control surface actuation. Despite the difficulties to find the best configuration on MAV, a few possible solution was found by previous MAV researches. Based on these review, author found that the Zimmerman shape is currently the best wing planform to be implemented as the MAV wing shape. This is due to its better lift performance (compared to the other planform) that can be further improved by introducing the membrane wing component such as PR wing. On the other hand, the blended wing-fuselage configuration offers a huge potential in reducing the interference drag and profile drag between the wing-fuselage. Pusher type propeller configuration was found to have huge potential in order to reduce the slipstream effect on MAV. An effective control surface must also include for successive MAV flight, thus the morphing technique with embedded compliant-smart material actuation is seen as an alternative method that should eliminate the complication arises from conventional control surface.

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