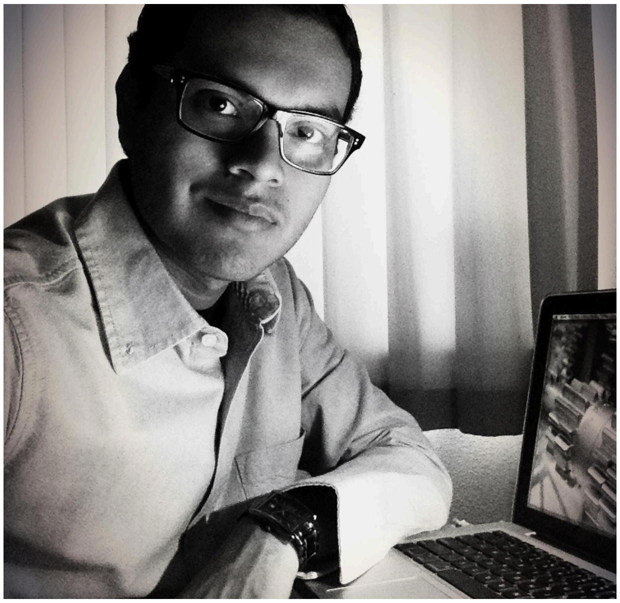

Carlos Benavente

Carlos Benavente is a second year undergraduate Mechanical Engineering major with a minor in Applied Mathematics. His love for Engineering and Mathematics started while attending CAMS (California Academy of Mathematics and Science) High School after taking fundamental Engineering courses. Through his academic work and through 7 years of participating in MESA (Mathematics, Engineering, Science, Achievement) club, his passion for Engineering and Mathematics became into his two preferred fields of study at UC Merced. His research on MAV technology was inspired by the current race to build the most efficient one. Carlos wants to look for opportunities after graduation that involve the advancement of similar technologies in the field.

Micro Air Vehicles: A Biological Future

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Over the last decade, the MAV (micro air vehicle) field has developed in that there have been great improvements in designs due to advances in computer aided technology, power supply due to better battery technology, and visual communications due to better transmitters and receivers. Different kinds of MAVs are now in existence, all with their own specific capabilities and limitations.

Despite the progress in various areas, the advancement of Micro Air Vehicles (MAVs) is limited due to the large but necessary onboard technology, obstacles involving the overall weight, and the need for ideal wing designs. These challenges are due to the need to have onboard MAV technology must include sensors and processors in order to fully achieve autonomous flight operation. Unfortunately, current hardware is too big to be handled by smaller components than those in present day UAVs. One of the biggest concerns is the battery life since there are multiple things operating on an MAV. Further research must be done in order to shrink the battery to a promising size while still providing the MAV hardware with enough energy to function. Weight is an important element to consider on an air vehicle for it effects what is referred to as the turning radius; the angle at which a flying vehicle can make a sharp turn around an obstacle, e.g., a building. Furthermore, weight also affects other key elements for flight such as drag and lift. While comparing biological wing models, there is noticeable, recurring "flapping" wing design such as on birds or insects. For most of today's flight technology, they are mainly focused on using static wing designs. As these two wing designs have difference advantages, the overall issue then becomes the determination on whether or not one is more expedient than the other when implemented into an MAV design.

A Micro Air Vehicle is not whole all on its own; it is composed of multiple, independent concepts that must harmonize in such a way that they simultaneously compensate for each other's flaws while reinforcing their strengths for optimizing performance and efficiency. Primarily, an object's weight is what is noticed first when flight is a desired task. Because MAVs must carry specific tools for designated missions, their own weight is important. For example, the more it weighs, the less they can carry. Closely related to this concept, another crucial element to an MAV's development and performance is its size. While examining this thought, it can be acknowledged that there are many biological and synthetic objects of many sizes that possess the ability of flight. With this fact, we can initially conclude that size has no correlation with flight, but when observed closely, the style and efficiency of flight is directly dependent on the weight of the object. Furthermore, if we look at a biological example, the flight of a honeybee is completely different to that of a fully-grown hawk. However, when looking one step forward, observations would reveal their wings are completely different. Today, when thinking about flying objects, there are only a few ideas that come to mind when thinking about their wings. An MAV's performance strongly relies on the kind of wing design it has. More specifically, with the example of the honeybee and the hawk, though both excellent candidates of flight, the honeybee's wing design allows it to be much more maneuverable while flying than the hawk and its different wing design. Thus based off of this example, should an MAV's wing design be more carefully decided? It is evident that putting an efficient MAV together is a challenge, but in the individual research for these independent elements, an ideal relationship will arise. For these reasons, researchers must take into account various factors to try to create a balance in design.

Physical Dimension Constraints

Weight

One of the main key features for an ideal MAV is its weight; expected MAV masses are to be around 0.5 kg [2]. Today, it is unfortunate to say that because of these weight constraints, MAVs currently do not possess the necessary payload for the hardware needed to carry out a complete mission [2]. Because of an MAV's purpose, in order to be mission ready, it is desired for the weight to be as small as possible [1]. A vital concept is the weight of an object because it directly affects the ability to react in certain situations, which is also premised on the task while the actual weight determines whether or not the response quality is good or bad. A study conducted by MLB Company that compares lithium battery powered MAVs and internal combustion engine (ICE) powered MAVs concludes that because of the low power density of the lithium battery, the weights of the electric powered MAVs are negatively affected when contrasted to those designs powered by the ICE [1]. Furthermore, their acquired data also suggests that the lithium powered MAVs transport a surplus of energy for the designated tasks, which in turn results in having a lower payload margin (< ½ ounce for all designs under a 6 inch size), making the ICE powered MAV the best of the two designs [1]. Clearly, increasing the weight of an MAV negatively affects the payload quantity for onboard hardware, and this limitation is one of the fundamental challenges blocking major advances.

Size

Recently, there has been much focus to shrink down the size for most of our technology. Because of the drag forces that act on air vehicles, an MAV, due to its size, will experience aerodynamic drawbacks [2]. MAVs are now expected to be no greater than a linear dimension of six inches, mainly because this would result in a reduction in the manufacturing price, unlike larger UAVs [1]. MAV size is crucial in the sense that it directly affects the vehicle's turning radius, i.e., the bigger the size of the MAV, the smaller the turning radius becomes [1]. Also, the overall size is highly important when considering the vehicles lift coefficient [1]. The MLB Company's experiment also touches upon the importance of the vehicles overall size. For their research, they used a computerized, multidisciplinary optimization (MDO) method in order to calculate the feasibly smallest dimensions for their MAVs while considering six design variables who each comply with another six complimentary mission constraints, while also minimizing the largest wing dimension by using Equation 1 [1]. The variables consisted of wing area, wingspan, cruise, loiter, gross take-off weight, and installed power, all of which are the essential elements to consider in the making of an MAV. The constraints consisted of duration, operational radius, minimum turn radius, minimum climb angle, maximum altitude, and number of climbs. These six constraints are what the experiment focused on when deciding the efficiency of the MAV. For example, as seen on the table, the duration of the flight was made equal to five hours; therefore, trials that yielded experimental values that did not follow this time constraint were discarded form those considered. Similarly, the minimum turning radius was set to be equal to or less than ten feet. Anything greater than ten was not considered.

As far as the MDO results, the data suggests that size is directly correlated with the vehicle's turning radius and the payload mass. By examining the graphs, it can be concluded that because a larger wing area is needed in order to increase maneuverability, the payload mass decreases.

For a 6 inch, ICE MAV design, the payload mass results to 2 ounces, but if maneuverability is increased, the payload suffers (< 1 ounce for each additional 20 ft in turning radius) [1]. Conclusively, the radius and the payload mass are inversely proportional to each other no matter what the size, whether it be the ICE MAV or the lithium battery power MAV. But if the size is initially large, the less the payload suffers to an increasing radius.

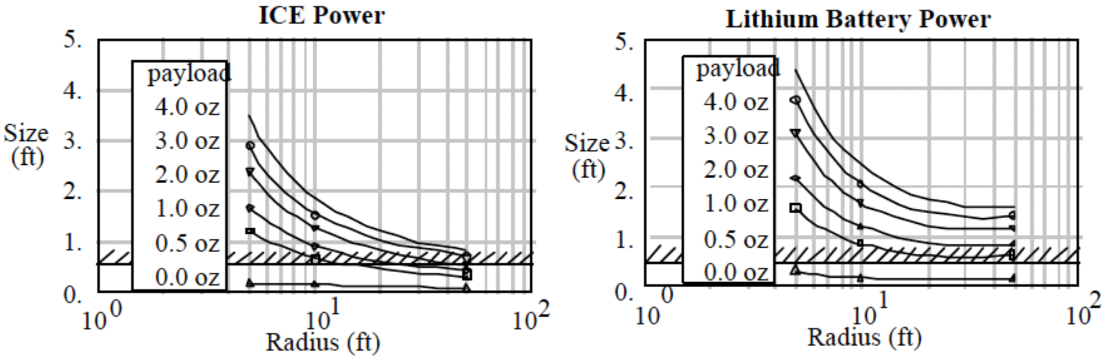


Figure 2 ICE powered MAV versus Lithium battery powered MAV [1].

Wing Configurations

Static

Today, most of our aeronautical technology uses a fixed-wing design, whether it is a small jet or a Boeing 747. A fixed wing design is valid no matter what the configuration is. For MAVs, the advantage for this design is the fact that it is simple when compared to the other wing designs as well as it increases the stealth of the MAV [4]. Much like a bird, if the wing configuration is to be fixed, it can essentially conserve energy at reasonable altitudes by way of taking advantage of three independent conditions: vertical air motion, spatial gradients in the wind field, and temporal gradients, i.e., wind gusts [2].

Vertical air motion, or orographic lift, is caused by the deflection of air oscillation consequences, due to air-mass movements, off of mountains or high altitude hills. If this phenomenon is exploited properly, flying time and distance can be significantly increased [2].

The act of using the spatial gradients in the wind field, otherwise known as dynamic soaring, is a flying technique in which energy is gained by crossing different velocity levels of wind; typically, these high velocity wind areas are found close to the surface. Because of its close proximity to the ground, it is strictly limited to vehicles with advanced maneuverability [2].

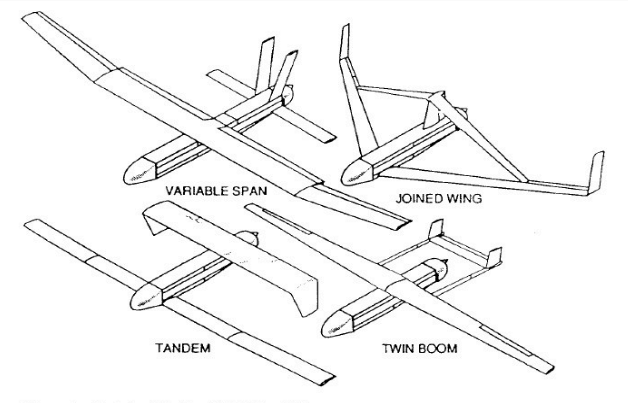


Figure 3 Sketch of the four LAURA vehicles [8].

A more straightforward condition, air gusts, is what we are used to feeling on a windy day. It improves flight performance for large birds but MAVs are currently being improved to take advantage of these short, but powerful, gusts [2].

Despite the various advantages, the ultimate issue with this design is that even though a large wing loading is great for outdoor use, it is not ideal for indoor operation and vice versa [4]. Furthermore, the act of hovering is also limited with this design, and even though it can be assisted with an additional propeller, the control is restricted because of the lack of airflow; the propeller also needs to be large enough for this approach to even be feasible [4].

Flapping

When analyzing flapping-wing MAV (FMAV) designs, the overall question becomes whether or not they are better alternatives for fixed wing designs [3]. But for these specific sets of designs, it is easy to use nature as our main example; FMAV is a term that can be coined to many biological examples such as birds and insects [4]. By studying the way that they flap their wings in order to obtain the ability of flight, we can ultimately mimic those same properties and incorporate them into FMAVs to increase their efficiency. It can be observed that the wings on a bird deform as they flap on their axis, allowing them to create lift for flight. However, there is a very important difference in the aerodynamics of bird and insect wings, i.e., with the exception of the hummingbird, birds only create lift from the downstroke, thus not being able to hover in place while insects on the other hand, create lift from both the downstroke and upstroke enabling them to hover [4]. For the purpose of optimizing the maneuverability for an MAV, the ability to hover becomes vital. It is because of this that FMAVs do not focus on wing designs that mimic those that only rely on downstroke for lift. Also, with this essential aerodynamic tool, it should be noted that these designs could potentially use more energy to create the aerodynamic forces needed for hovering motion, thus eliminating the notion of conserving energy [3].

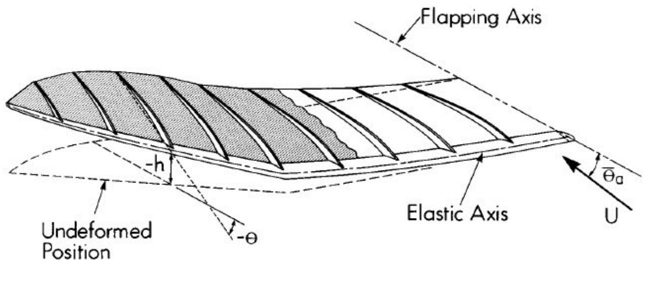
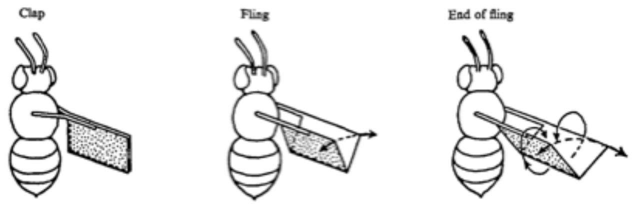


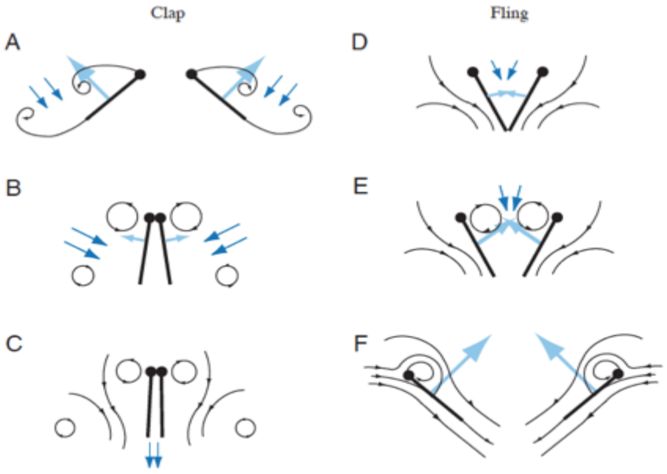
Figure 4 Flapping Wing Deformation [8].

The kinematics that are in effect in the wings of insects are some of natures best work. When compared to the kinematics of a bird’s wing, those of insects do not follow the traditional ‘up and down’ routine, rather the motion is defined by three variables: the flapping frequency, the angle of the stroke plane to the vertical, and the positional angle of the wing along the stroke plane [4].



(a)

The wing cycle, for the majority of insects, consists of four parts: downstroke, supination, upstroke, and pronation.



b)

Figure 5 (a) Depiction of the wing motion (Clap and Fling) for a wasp [4]. (b) Depiction of the forces created by Clapand Fling [7].

Through further examination, essential characteristics of the cycle were discovered – the clap, fling, and flip. As shown in Figure 6a, the clap refers to the point in time where the wings of an insect are together as a result to the end of a stroke, the fling refers to when the wings are opened much like a book, and the flip refers to then the wings are pitched rapidly through about 180° [4]. Because of the big circular motion from these three steps, they ultimately produce the necessary lift for flight. In greater detail, Figure 6b demonstrates the forces that are created by way of the clap and fling. The black lines represent flow lines, the dark blue arrows represent induced velocity, and the light blue arrows show net forces acting on the airfoil [7]. Through the synthetic replication of these essential flight kinematics for insects, FMAVs will continue to advance in more sophisticated ways. More specifically, the hummingbird, which shares similar wing kinematics characteristics of insects, has become of much interest to the design of FMAVs.

Conclusion

The technology that is currently available for the advancement of Micro Air Vehicles is limited due to our time and age, but it is slowly progressing. With this in mind, society cannot afford to slow down this progress. It is evident that there is much to consider when designing an MAV that is truly “ideal”. Stealth is a much-desired characteristic for an ideal MAV, but this is matched up with the size of the vehicle. Comparable to UAVs today, they are not so stable mainly because of their size. An MAV on the other hand, must be at least 75% smaller than a regular UAV and yet still perform as such, if not better. Through much testing, it is determined that size is directly correlated to the stability of an MAV, i.e., the smaller the vehicle is, the less stable it becomes. This becomes a major factor in the success of an MAV because in order for it to accomplish delicate missions, it must be highly stable for flight. Wing designs, other factors to consider, seem to be one of the most complex parts to an MAV. A static wing design can be considered the most ideal because they require no external energy, mainly because they closely rely on the free power of wind, while a flapping wing design makes the efficiency for power significantly less. The correlation between the flapping wing designs for MAVs can be derived from biological examples such as insects, which have proven to be ideal flyers with their complex aerodynamic wing patterns. They have shown us that we can learn much from mimicking their wing technology. Though there are examples of this that have proven to be semi-successful, improvement should not be ignored. Since the entire purpose for an MAV is easy maneuverability for missions that require great tact, the flapping design comes out as the better option. Despite the fact that these elements are very different to one another, they are without a doubt, connected and must work together. The permutations of these elements are endless, but the perfect one deserves the time to be discovered so that it can fuel the success for future MAV technology.

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