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Design and Analysis of MAV Used For Defense

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ABSTRACT

Flapping wing micro air vehicles (MAVs) offer several advantageous performance benefits, relative to fixed-wing and rotary-wing MAVs. The goal of this project is to design a flapping wing MAV that achieves improved performance by focusing on the flapping mechanism and the spar arrangement in the wings. Two variations of the flapping mechanism are designed and tested, both using compliance as a technique for improved functionality. In the design of these mechanisms, kinematics and dynamics simulation is used to evaluate how forces encountered during wing flapping affect the mechanism. Finite element analysis is used to evaluate the stress and deformation of the mechanism, such that a lightweight yet functional design can be realized.

A framework for iterative improvement of the MAV is described, that uses the results of physical testing and simulations to investigate the underlying causes of MAV performance aspects; and seeks to capture those beneficial aspects that will allow for performance improvements. Wings and flapping mechanisms designed in this thesis are used to realize a bird-inspired flapping wing miniature air vehicle. This vehicle is capable of radio controlled flights indoors and outdoors in winds up to 6.7m/s with controlled steering, ascent, and descent, as well as payload carrying abilities.

This project will be describing the mechanism and working of a flapping wing and various design aspects using CATIA and ANSYS, also focusing on future technology in this field of future aviation.

Introduction

Inspiration of Micro Air Vehicles

A micro air vehicle (MAV), or micro aerial vehicle, is a class of unmanned aerial vehicles(UAV) that has a size restriction and may be autonomous. Modern craft can be as small as 15cms. Development is driven by commercial, research, government, and military purposes; with insect-sized aircraft reportedly expected in the future.

The small craft allows remote observation of hazardous environments inaccessible to ground vehicles. MAVs have been built for hobby purposes, such as aerial robotics contests and aerial photography.

Figure1.1: bio-inspired MAV's

Bio-inspiration: A new trend in the MAV community is to take inspiration from flying insects or birds to achieve unprecedented flight capabilities. Biological systems are not only interesting to MAV engineers for their use of unsteady aerodynamics with flapping wings; they are increasingly inspiring engineers for other aspects such as distributed sensing and acting, sensor fusion and information processing. Various symposia bringing together biologists and aerial robotics have been held with increasing frequency since 2000 and some bookshaverecently been published on this topic.

In recent years, unmanned aerial vehicles (UAVs) have become an increasingly attractive option in a variety of applications. Larger UAVs have already proven their value in fields such as military, farming, border patrol, search and rescue, mapping, and scientific research, among others.

An exciting result of continued research into the aerodynamics of flight at small size scales has been the steady miniaturization of unmanned aerial vehicles. Miniaturization offers exciting new possibilities that are not possible with larger aircraft. Applications that UAVs have dominated with great success for years are becoming manageable with smaller, lighter, and cheaper MAVs. For the purposes of this work, miniature air vehicles are defined as less than 100 grams of total weight.

An important distinction is that miniature air vehicles are not the same as micro air vehicles, which DARPA defines as having dimensions of less than 6 inches. In the wake of recent natural disasters including the Haitian earthquakes and hurricane Katrina, search and rescue teams are presented with challenging terrain preventing them from accessing many areas.

Typically, a search and rescue team will consist of about ten people, including dogs and handlers, a paramedic, a structural engineer, and specialists using a variety of equipment to locate victims. If these specialists were armed with a micro air vehicle, debris could be rapidly surveyed without requiring the team to enter potentially hazardous area information collected by each MAV would be at a very short distance to the target area.

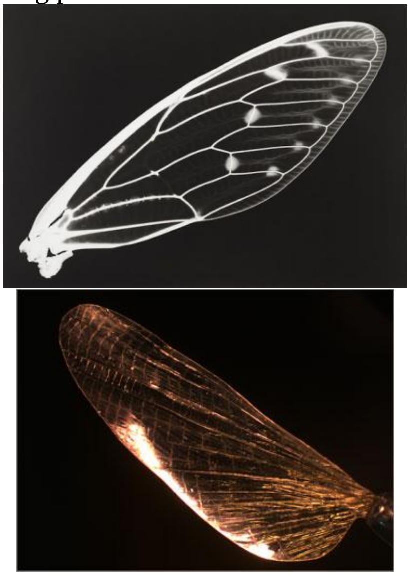
With low cost and ease of portability and deployment, it would be simple for a team to deploy multiple MAVs and collect data rapidly. With one man portability, disposability from a cost perspective, rapid deployment times, and greater availability to a wide range of consumers in commercial, military, and private markets, miniaturized UAVs clearly have unique benefits. As research grows in relevant fields, MAVs continue to improve their usefulness in many areas.

Wing Design

One of the main challenges in designing a flying flapping wing MAV is the design of the wings. As the wings flap, thrust is generated, propelling MAV through the air.

Aerodynamic loading causes significant deformation of the wings, resulting in a large lifting surface. With good wing design, the balance of lift and thrust will contribute to flight performance in multiple ways, including manoeuvrability, controllability, climbing rate, payload capacity, and flight longevity. Therefore the wing design is a key factor determining the overall MAV performance.

Due to the small size of MAV wings, it is challenging to apply conventional aerodynamic theories to the design of flapping wings for a number of reasons. As wings are scaled down, low Reynolds number aerodynamic effects become more significant. Additionally, the large deformations of the wings can be difficult to accurately predict. With these two effects together, simulation becomes very difficult with acceptable accuracy. Therefore, we will present a test method for determining the lift and thrust performance for a wing design and use this method to select a design with satisfactory results, while simultaneously observing the underlying reasons for differing wing performance.



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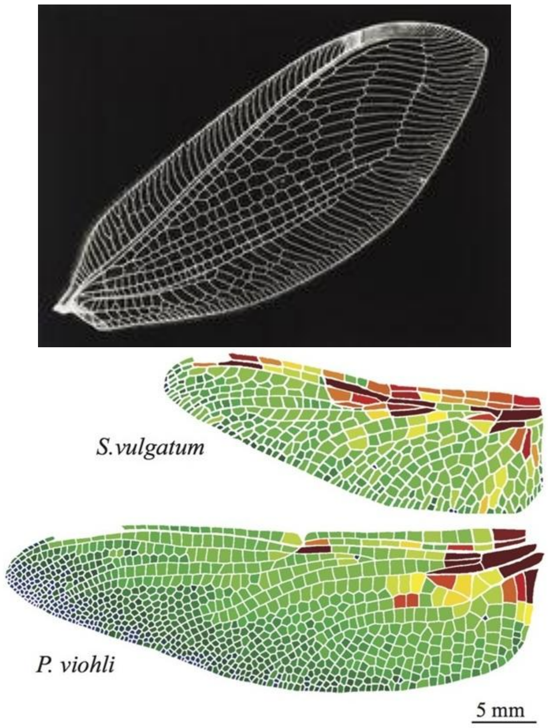


Figure1.6: Complicated bio-inspired wing designs of MAV'S

Mechanism Design

The design of a successful MAV must balance a number of performance metrics that willcontribute to the overall suitability of the system. The flapping mechanism mustefficiently transmit the power, while keeping weight to a minimum. In addition, themechanism should be strong enough to withstand adverse weather conditions, largepayloads, and crashes. While the mechanical function is important, other considerationsalso exist, including the cost and the complexity of construction and assembly.

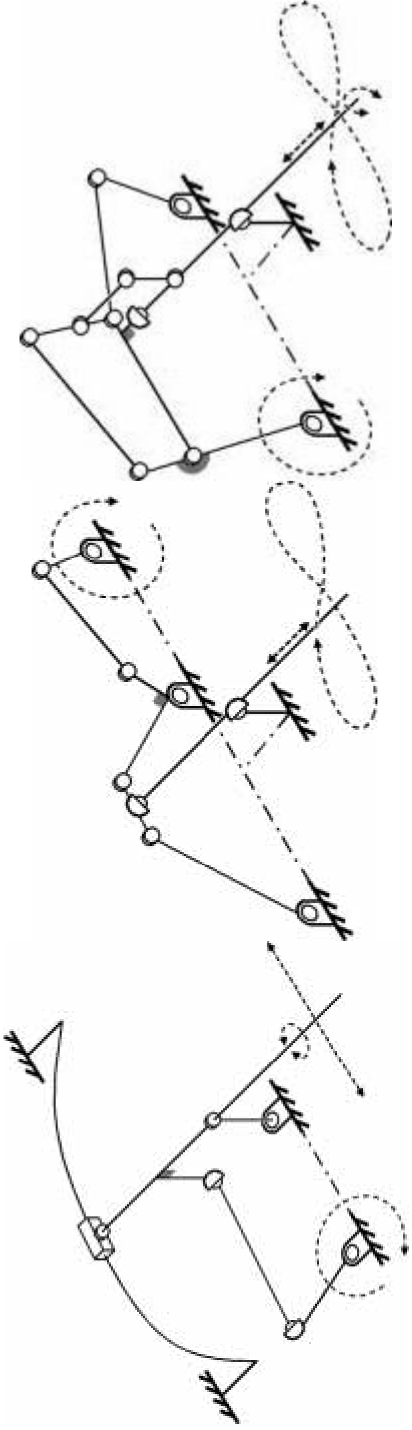
It is important to consider the manufacturing process of the MAV mechanism for avariety of reasons. At present, MAVs tend to be produced one at a time, with very labourintensive assembly processes. Due to a focus on the functional requirements of theMAV, part counts tend to be very large, resulting in greater manufacturing costs. This isa significant challenge for consumers that would like to have rapid storage and fielddeployment abilities. Since MAVs are expected to operate in hazardous environments in many cases, it would be beneficial to have a system that is easy to repair and maintain.

In addition, if the assembly process can be partially or fully incorporated into the manufacturing process, mass production will be faster and cheaper. If the overall cost of the MAV can be reduced sufficiently, then consumers will see MAVs and disposable from a cost perspective. This is an attractive feature for military and search and rescue teams, where hazardous missions will likely result in many losses. Without the need to recover the MAVs used in these types of missions, efficiency will be increased, allowing the focus to remain on more important mission aspects, instead of equipment recovery.

The flapping mechanism of the MAV is a key mechanical component of the overall system, and is largely responsible for flight characteristics. The main function of the drive mechanism is to reduce motor's rotary motion and convert it into flapping motion of the wings. In other words, the drive mechanism transmits the energy from the motor to the wings. The efficiency of this power transmission is of major concern. Any power losses will result in reduced performance of the MAV and increased power requirements for the motor. Low-friction bearings cannot be used due to weight considerations.

The concept of compliant drive mechanisms is promising for minimization of power losses in the transmission. Additionally, compliant joints can often replace rigid body joints, leading to reduced number of parts in the assembly. However, interconnection of the materials poses several challenges in the considered scale, as current methods for interlocking chemically incompatible materials cannot be directly scaled down for the miniature flapping wing drive application. Therefore a method to create robust miniature hinges will have to be developed to allow for full utilization of compliant mechanisms advantages in power transmission efficiency.

Limited payload capabilities of the current flapping wing MAV designs contributes to insufficient functionality and operational range for practical applications. Reduced weight of the MAV drive mechanism can contribute to increased payload carrying capability, which can be used for carrying more auxiliaries or batteries. Reduction of weight however cannot compromise the structural strength of the mechanism under operation loads. Therefore a detailed analysis of various forces acting on the structure has to be performed to optimize the drive mechanism design; namely minimize the weight and retain structural strength.



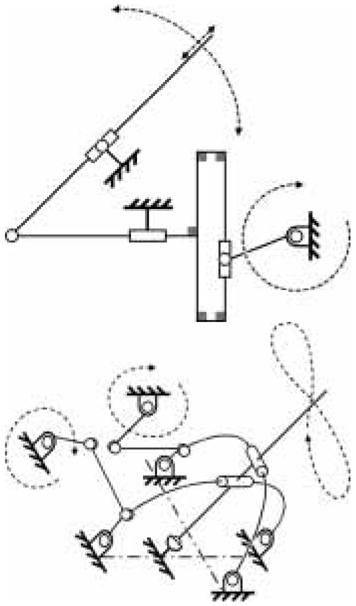


Figure1.7: Various kinematic mechanism of a flapping wing MAV

Modelling

A useful tool in designing an efficient flapping mechanism is a kinematics and dynamics model. This model should use measured forces as inputs, and output useful information such as motor torque, loading on mechanism parts, and time history of forces. In conjunction with physical force measurement, models are used to gain a better understanding of how to move from desired performance metrics to required physical MAV parameters.

Proper design of the MAV flapping mechanism requires a detailed understanding of the forces generated by the wing flapping motion. The forces the wings are producing can be measured using physical measurement techniques, but kinematic and dynamic models are required to understand how the forces propagate through the links and joints in the mechanism.

By computing the forces throughout the mechanism as a function of time, many useful performance metrics can be observed and optimized with less reliance on exhaustive physical testing. In addition, models can be used to optimize the performance of the mechanism in terms of weight and strength, thus maximizing payload capacity and prolonging flight endurance.

With modelling tools, the process of design optimization is accelerated significantly, leading to better performance of the flapping mechanism. Using an iterative cycle of modelling tools and physical test results it is possible to verify that the models are accurately predicting the behaviour of the mechanism.

The central component of this iterative cycle is the dynamic simulation model, which uses measured lift and thrust forces as inputs, and predicts how all the mechanism components are loaded as outputs.

The mechanism components are then examined with a finite element solver to determine the factor of safety. As the analysis is conducted, areas of the mechanism are identified that require changes. After a few iterations, the mechanism is made increasingly efficient and lightweight, while satisfying the various constraints on strength, manufacturability, and kinematics.

Once the wings, mechanism, and modeling work are completed, a fully functional flapping wing MAV is developed that meets the following goals:
1. The MAV will be low cost, due to incorporation of manufacturing automation that results in reduction of assembly steps.

2. The payload capacity of the MAV will offer significant improvements over previous versions, allowing for a wider mission scope due to enhanced sensor-carrying abilities. Alternatively, the endurance will be enhanced when a lighter payload is carried, resulting in a more versatile MAV.

3. The MAV will be robust and capable of withstanding multiple crashes without sustaining excessive damage. In the event of damage, the MAV will be easily repaired.

4. The MAV will be capable of a manual hand launch or an automated launch from ground vehicles.

Wing Designs
Flapping Wings

The category of flapping wing locomotion is the most well-known, and is often seen as the traditional method of flapping flight. Flapping wings are used by a wide variety of animals including birds, bats, and a variety of insects.

The general principle of operation is that two wings are flapped to produce both lift and thrust, thus overcoming gravity and drag to provide sustained flight. Generally, flapping fliers can most easily be distinguished based on their respective size scale and flight speed or the Reynolds number experienced in flight, and therefore flight style. By observing nature, one can see the difference in flight style between a large soaring bird such as an albatross, and a hummingbird, which must flap its wings very rapidly to stay aloft.

A similar relationship holds for man-made flapping wing fliers. At larger size scales, higher Reynolds numbers are encountered and therefore slower flapping and soaring are the most effective modes of flight. Fliers in the centimetres scale however, experience very different aerodynamic effects, with less favourable lift to drag ratios.

The general trend is that as the flier decreases in size, the wings must flap faster to produce the necessary lift and thrust to support flight. This creates a unique challenge for miniature MAV designers, because traditional aerodynamics break down with such small wings. However an interesting trade-off is that with higher rates of flapping comes the opportunity to realize greater control resolution, and some impressive acrobatic manoeuvres become possible.

Figure 2.4: MEMS BASED FLAPPING WINGS

A number of successful flapping wing miniature fliers, both commercially available, as well as research platforms have wing surface made of a thin Mylar film, stretched over the stiffeners. As the wings flap, the configuration of the stiffeners combined with aerodynamic loading causes the wings to create a rounded air foil shape, providing lift. Since these wings are handmade, construction repeatability becomes an issue due to the small difference between sets of wings created.

Four Clapping Wings

This category includes any MAV that uses one or two pairs of wings flapping opposite each other, such that the vertical inertial oscillations present in a two-winged flier are cancelled out. This style of flight offers the key benefit of greater stability, which could allow for more delicate sensors and payloads to be carried successfully. In this category, there are a variety of examples that use generally the same principle of operation.

The Osaka Slow Fliers Club 1.5g ornithopteris one of the lightest that has completed a successful flight. The toy market has contributed models such as the WowweeFlytech Dragonfly, and WingsmasterOrnithopters all use a pair of wings constructed of thin film with stiffener ribs, flapping in opposing phase.

The Delfly, Delfly II, and Delfly Micro all use a similar style of wings, with the added benefit of their vision-stabilization system. This makes these MAVs more suited to outdoor flights, and capable of more advanced manoeuvres.

Figure2.5: Delfly II

The Delfly II is the most capable of the three, with the ability to fly forward, hover, and even fly backward at low speed. The Naval Postgraduate School MAV is an unusual entry into this class, however due to the manner of its wing flapping; it has been classified as a clapping wing MAV.

The NPS MAV uses a flying wing fuselage shape with a pair of wings that flap in a vertical plane mounted to the rear. These wings flap in counter phase, thus thrusting the wing through the air and providing lift. The design and operation of this MAV is unlike any of the others discussed, however the performance of this MAV offers some interesting performance trade-offs. The speed is controlled by trimming the pitch of the flapping wings, pre-flight, and the altitude is controlled by varying the flapping rate. This is anunusual configuration for an MAV; however the manoeuvrability is very good.

Folding Wings

Observation of larger birds in nature reveals that wing flapping is tailored to therequirements and conditions faced at the time. When a bird is taking off, the wings areflapped differently than during cruising flight.

Since the bird does not have the airstream, flowing over their wings from the static position, lift must be somehow augmented, sinceaerodynamic lift is lacking in this condition. Therefore, birds will flap their wingsdownward, fold them in towards their body, during the upward flap, and then re-extend theirwings during the downward flap. This results in maximum wing area during the downflap, which is producing helpful upward lift.

During the up flap, the area is minimized,thus reducing the magnitude of harmful negative lift. By using this style of flapping, thebird is able to get airborne,then transition to standard flight.

For a MAV to recreate thisstyle of flapping, passive wing folding is an attractive option due to the excessive weightof actuators that would be needed.

There are successfully flyingMAV that uses wings with one-way compliance to accomplish the desired folding effect. The result is that the wings can lift the same amount of weight, but with slower forwardvelocity. Thus, behaviour much like the bird during take-off is accomplished with foldingwings.

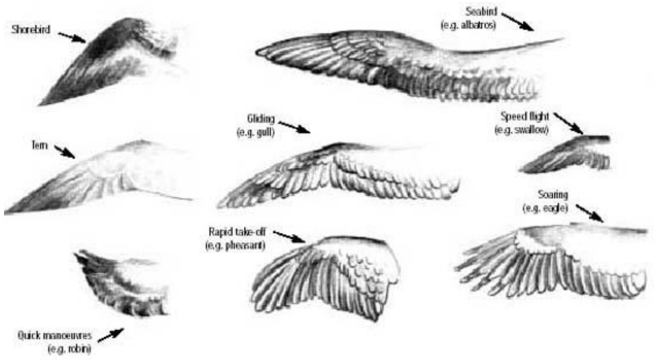


Figure 2.7: folding wings of birds

Mechanism designs

There are four primary classifications of mechanisms used by the MAVs discussed:

(1)Double pushrod,
(2) Double crank,
(3) Single pushrod, and
(3) Side-mounted crank.

Eachof these four mechanisms presents a trade-off of multiple important performanceattributes. Some of the considerations for selecting a mechanism layout include theparticular geometry and weight constraints for the MAV, as well as the required forces to be transmitted and the rate of flapping. Other concerns include the manufacturability ofthe selected design, especially with very small and light MAVs.

As the size ofmechanisms grows ever-smaller, the human limitation becomes a factor in theconstruction of more complex mechanism layouts. Due to the reduced stability of MAVplatforms, a durable mechanism is desired, due to a variety of damaging factors includingdirt contamination, crashes, assembly stresses, and the fatigue effects of high flappingrates.

DESIGN

This chapter deals with the basic design of a flapping wing MAV. In this series there are a no. of design stages dealing with construction of separate parts and dimensioning. These designs are made using CATIA described briefly in the following chapter.

Every design begins with a basic idea and the idea implemented here is derived from ornithopter construction of phoenix which is to be found on ornithopter.org.

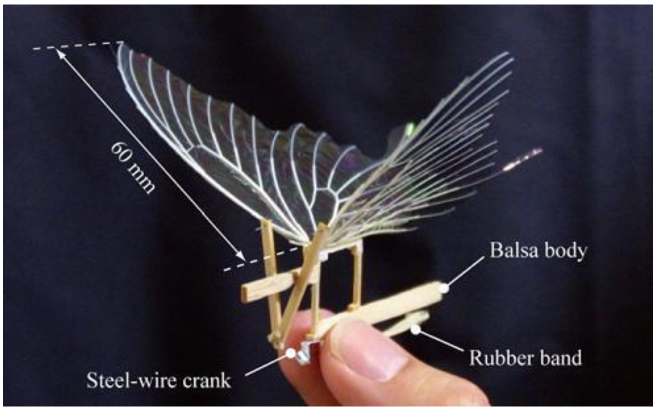


Figure 4.1: phoenix ornithopter

Initial dimensioning was calculated using the necessity of construction and type of wing and wing span chosen.

Here the wing span required is 50 mm and hence the remaining necessities were calculated as follows:

- Crank 1 radius: This is the radius of the first crank arm.
- Crank 2 arms: design has a double crank, like Phoenix, this is the distance from the first crank arm to the second one. For single crank designs this is set to zero.
- Crank 1 angle: This is the position of the crank at any given moment. You can reposition the crank either by dragging it with your mouse or by changing this number.
- Crank 2 bend angle: This is the angle to the second crank arm.
- Width: The distance between wing hinge points.
- Height: The vertical distance between the crank centre of rotation and the wing hinge points.
- Lever: The distance between the wing hinge point and the connecting rod attachment point.
- Spar offset: The angle between the wing spar and the lever that flaps the wing. Changing this does not affect the operation of the mechanism but it directly affects the wing position.
- Conrod: The length of the connecting rod.

Results and conclusion

As MAV works under conditions which are difficult for a static wing model to fly under aerodynamic conditions; wings are necessary to be dynamic.

According to the lift formula:

$$L = \frac{1}{2}\rho V^2 S C_L$$

Where;
L is lift force,
ρ is air density,
V is true airspeed,
S is planform area, and
C_L is the lift coefficient at the desired angle of attack, Mach number, and Reynolds number.

Here ‘S’ is the planform area or the surface of the wing, hence it is directly proportional to the lift produced. But in MAV’s the surface area is reduced to a greater amount producing very less lift for a static wing to fly.

Under these conditions density, CL value, S cannot be changed; therefore velocity factor has to be changed. This is possible only when static wing is changed to dynamic wing, giving velocity to the wing. Therefore wings flapping or rotational suits appropriate to the situation.

As the wing will be in motion, the wings should be of less weight and elastic in nature to reduce stress and fracture.

Also the structure of wing has to resistant and strong to winds; therefore wing has to be light in weight; strong enough to deform; and symmetrical in distribution.

As the results shows stress and temperature distribution high at wing root; wing root has to be dense and distributed to the rest of the body.

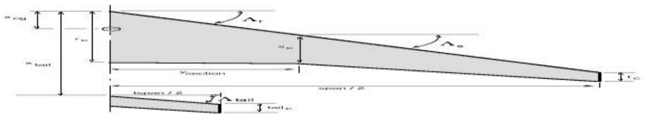


Figure: Wing root

Insects have aptly adapted to the situation where wings are light in weight and elastic in nature to avoid deformation

Also the distribution pattern is much adaptable for the vortex formed around the wing in wake of flapping.

Due to the vortex formation, manoeuvrability is quick and multi directional. This is due to trapping of vortex under the space of the wing.

Analysis shows the temperature distribution is more along the tips; hence area around the tip is gradually decreased.

Future Scope and Application

Flying into the Future Micro Aerial Vehicles could help with warfare, agriculture and more Could MAV’s do!

- Kill harmful insects.
- Crawl or fly down smokestacks to measure emissions.
- Monitor concentrations of chemical spills.
- Look over the next hill in combat situations.
- Manoeuvre through buildings looking for survivors after a disaster
- Fly spy missions, either outside or indoors.
- Measure ammonia concentration in agriculture.
- Track wild animal herds.
- Toys.

MAV’s can be greatly used in space explorations where there will be harsh climate low aerodynamic nature.

Micro Aerial Vehicles play an important role in future aviation technology and space research. It may also have wide application in future warfare in increasing situational awareness and increase precisely attack ranges with minimal damage in urban battle fields. Mainly in space field it has a major application in its low Reynolds number specialization where density of gases will be low. And this has been the major concern in this project.

Recent technological discoveries has shown presence of harsh weather conditions; low gravity conditions on many neighboring heavenly bodies which are sought to be explored for any traces of life sustaining in its complex form. In present aerodynamics fixed wing models would prove inefficient. In this situation MAV with flapping wing model would prove much efficient and economical.

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