

Micro Air Vehicle: Technology Review and Design Study

Mohd. Shariff Ammoo, Md. Nizam Dahalan
Department of Aeronautic & Automotive
Faculty of Mechanical Engineering
Universiti Teknologi Malaysia
81310 Skudai, Johor

Abstract: This paper presents the technology review and design study now carrying-out at UTM on the micro air vehicles (MAVs). There are several existing MAVs in the market with various configurations and built for a designated function. These vehicles may carry visual, acoustic, chemical or biological sensors for such missions as traffic management, hostage situation surveillance, rescue operations and a few more. In this report, all existing technology for MAV airframes and systems was reviewed. After reviewing all the configurations, the concept of rotary wing MAV was selected for our design study. The concept was selected mainly due to its stability during manoeuvres. The components selection and system integration required for building the MAV were also discussed. The components were arranged in such a way that the centre of gravity of the MAV is located at the centreline of the body. This is to stabilise the vehicle statically and dynamically.

Keywords: micro air vehicles (MAVs), rotary wing, design study.

1.0 INTRODUCTION

United State Defence Advanced Research Projects Agency (DARPA) has defined a MAV as a semiautonomous airborne vehicle, measuring less than 6 inches in any dimension (length, width or height) and weighing about 4 ounces, which can accomplish a useful military mission at an affordable cost (less than US\$1,000 if it is to be throwaway system). In 1995, DARPA began initial discussions on this type of aircraft and they have invested about US\$30 million in research and development of flight-enabling technologies for the MAVs. Many foreign universities have adopted novel approaches to almost every aspect of the aircraft including flight control, propulsion and wing design[1].

The process to design a MAV is completely different from designing a conventional aircraft. This is because, due to its small size and low airspeed, the MAV have different aerodynamics characteristic, propulsion, power source, flight stability and control system. MAVs should be thought of as aerial robots as six-degree-of-freedom machines whose mobility can deploy a useful micro payload to a remote or otherwise hazardous location where it may perform any of a variety of missions. Although the 6 inches limitation may appear somewhat arbitrary, it derives from both physics and technology considerations. The technology challenge to develop and integrate all the physical elements and components necessary to sustain this new dimension in flight will require an unprecedented level of multi-functionality among the system components.

2.0 MISSION FOR MAV

Micro air vehicle is capable of wide range of useful in military missions. The one most often identified is reconnaissance mission as illustrated in Fig. 1. The current concept suggests that reconnaissance MAVs need to range out to possibly 10 km, remain aloft for up to an hour, reach speeds of up to 20 m/s, and be capable of real time day/night imagery.

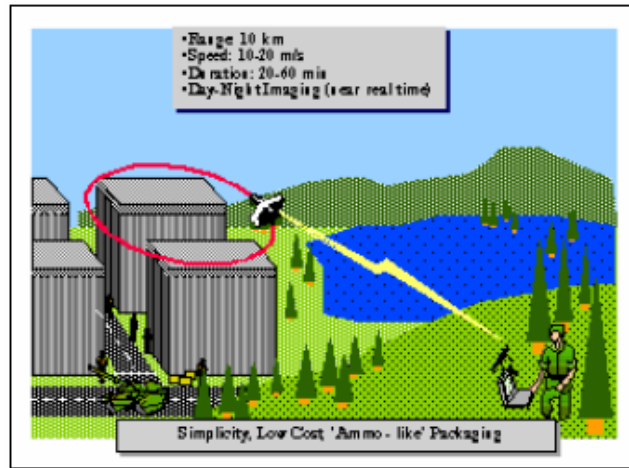


Fig. 1 “Over-the-hill reconnaissance” mission [1].

In contrast, some surveillance applications may require less range to payload performance. In these instances, the MAV would relocate to a suitable vantage point and serve as a fixed, unattended surface sensor with capabilities ranging from imagery to seismic detection. At the same time, MAVs must be launched and operated relatively simply with an easy-to-operate ground station. Ground stations may employ directional antennas to maintain contact with the long range.

In urban operations as illustrated in Fig. 2, MAVs, acting in small, cooperative groups, will enable reconnaissance and surveillance of inner city areas, and may serve as communication relays. They may also enable observations through windows, and sensor placement on vertical and elevated surfaces. Their application to building interiors is the most demanding envisioned. The capability to navigate complex shaped passageways, avoid obstacles and relay information will require yet another level of technology [1]. Other than that, MAV can also be used to monitor the traffic flow if necessary.

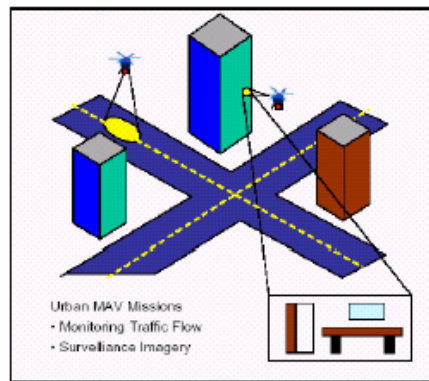


Fig. 2 Urban operations missions [1]

Biochemical sensing is another potential mission for MAVs. With gradient sensors and flight control feedback, MAVs will be able to map the size and shape of hazardous clouds and provide real time tracking of their location. MAV's may also find application in search and rescue operations. An MAV could be packed into the ejection seat mechanism on fighter aircraft. If the pilot has to "punch out", the MAV is released from the ejection seat and lingers in the air for up to an hour, providing the downed pilot with reconnaissance information, or sending a signal to rescue vehicles.

While the challenge of developing self-propelled MAVs capable of achieving all the requirements alluded to previously is daunting, a more near-term application may be possible using assisted propulsion. Unpropelled MAVs

could be launched from overhead flight vehicles or from barrel-launched munitions. Upon release above a target area, MAVs could provide targeting information and battle damage assessment back to the operator.

A large number of potential commercial applications also exist. These include traffic monitoring, border surveillance, fire and rescue operations, forestry, wildlife surveys, power-line inspection and real-estate aerial photography. There is also a sizeable market MAVs among radio controlled model aircraft enthusiasts.

2.0 MAV REQUIREMENTS

The basic requirements for MAV are to fulfill the military missions, since the main driving force behind all the research and development effort is DARPA. Based on the missions that have been discussed before, the MAV should have the following characteristic:

- High image resolution
- Lightweight
- Safe and simple to operate
- Affordable
- Covert
- Expandable or easy to repair
- Rapid and secure electronic connectivity
- Shock protected until operated

3.0 TECHNOLOGICAL FEASIBILITY

The earliest suggestion of technical feasibility appeared in the 1992 RAND Corporation investigation of micro-systems. It was projected that flying vehicles with a wingspan of 1 cm and a payload of less than 1 g were feasible in ten years. Then in 1996, an MIT Lincoln Laboratory study concluded that MAVs were feasible, given two to three years of "aggressive" technology development in key areas such as sensors, propulsion, aerodynamics and packaging. The study also came to some basic conclusions about the MAV's core mission.

To be truly useful, MAVs need to carry a short-range day/night area imaging system with enough resolution for operators to discern important details in the transmitted scene. The system must feature an accurate geolocation capability so users will know where the images come from. Sufficient vehicle range and real-time communications are also essential. Moreover, MAVs have to be lightweight and robust enough to be carried in a soldier's backpack. If possible, MAVs should be sufficiently inexpensive to be expendable [2].

5.0 SHAPE OF MAV

It was apparent that many successful designs for MAV are fixed wing aircraft. This is because the concept of the design is quite similar to a conventional fixed wing aircraft which some of the data are relevant for the MAV. Names like "Trocoird" (Fig. 3), "Micro STAR" (Fig. 4), "Flyswatter" (Fig. 5), "MITE" (Fig. 6), "Batplane" (Fig. 7), "Wasp" (Fig. 8) are few examples of fixed wing MAV that have been designed and developed.



Fig. 3 The Trocoird [3].



Fig. 4 MicroSTAR MAV [4]

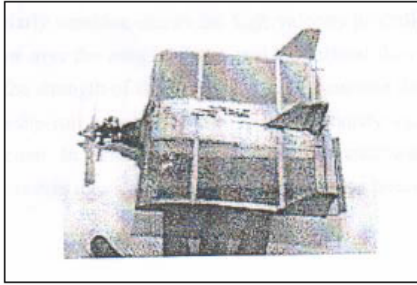


Fig. 5 The Flyswatter [5]

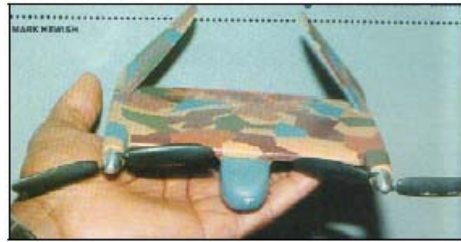


Fig. 6 MITE MAV

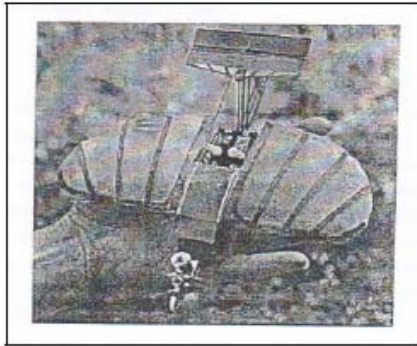


Fig. 7 The Batplane



Fig. 8 The Wasp

However, the concept of rotary wing was also created a center of attention from researches. Among the MAV, which is in this category are “Micro Craft iSTAR” (Fig. 9), “Gyrosaucer” (Fig. 10), “Helirocket” (Fig. 11), and “MICOR” (Fig. 12).



Fig. 9 The Micro-Craft Istar [6]



Fig. 10 The Gyrosaucer [7]



Fig. 11 Helirocket MAV

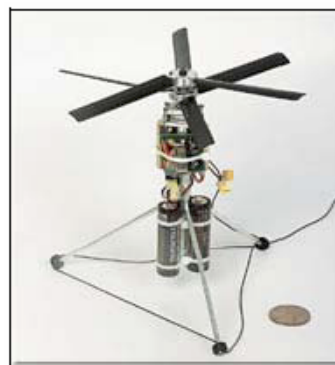


Fig. 12 The MICOR [8]

Due to the lightweight of the MAV, there is another method of technology to fly the vehicle namely “flapping wing”. It is completely similar to how the birds fly. The insect-like wing-flapping flight would appear to be very suitable for applications in confined spaces such as inside building, stairwells and tunnels. Examples of the MAV are “Entomopter” (Fig. 13) and “Microbat” (Fig. 14).



Fig. 13 The Entomopter [9].

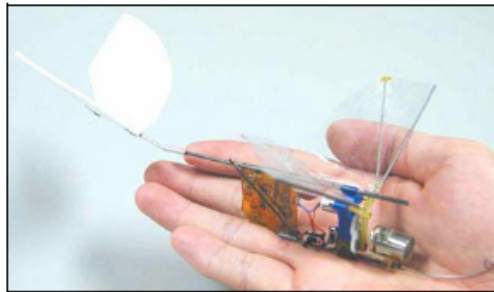


Fig. 14 The Microbat [10].

6.0 UTM’s MAV DESIGN STUDY

The concept of rotary wing has been chosen for the design study of UTM’s MAV. This is because rotary wing MAV is more stable in flight compares to other fixed wing or flapping wing MAV. Other than that, rotary wing vehicles have significant advantages over fixed wing vehicles for some cases of missions, particularly when the vehicle is required to remain stationary (hover) or maneuver in tightly constrained environments. However, the power required for maintaining hover approximately twice the power of a similarly loaded for forward moving of fixed-wing vehicle. Therefore, the primary driver of the MAV design is low weight.

The proposed material for main structures of the MAV is carbon fibers. This is because carbon fiber relatively has small stiffness to weight ratio, good thermal resistance, high fatigue strength and much cheaper than the other composites material like Kevlar [11].

The airframe was designed with the consideration of system installation and relevant components available. Fig. 15 shows the final design of the airframe. The cross-sectional of the body is from NACA 2412 airfoil series and the approximate weight of the airframe is 380 grams.

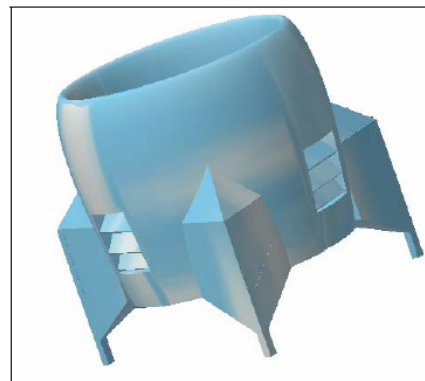
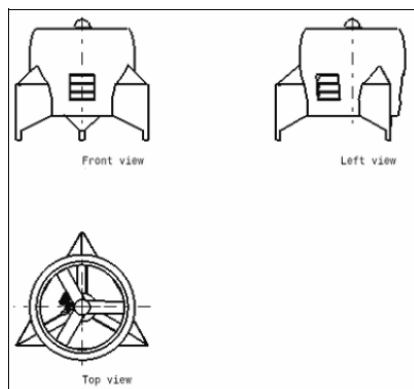


Fig. 15 The final design of the UTM’s MAV [12].

The MAV is powered by a 4.064 cc engine. The engine has a rate of 850 cc/hour and with a vehicle weight of 0.176 kg, the MAV can fly about 15 minutes.

The MAV is equipped with servos used to control the engine speed and vehicle maneuvers, a multi-channel receiver, which receives signals before passed it to the servos and a lightweight battery as power supply. Optional accessory such

as video relay system or video camera will be fitted to suit the designated mission. Example of components arrangement is shown in Fig. 16.

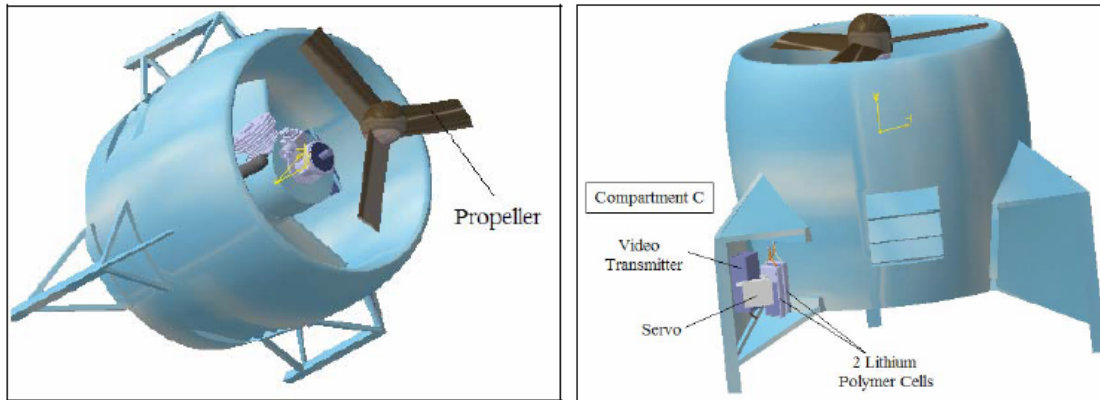


Fig. 16 Proposed components layout.

For the stability concern during hover and maneuvers, the center of gravity of the MAV must be located at the center axis of the airframe after all the components and accessories are deployed. For this case, the center of gravity for the MAV is achieved by using CATIA software and with the supports of Microsoft Excel. Fig. 17 shows the center of gravity for the empty weight (142.471 mm) and take off weight (145.982 mm).

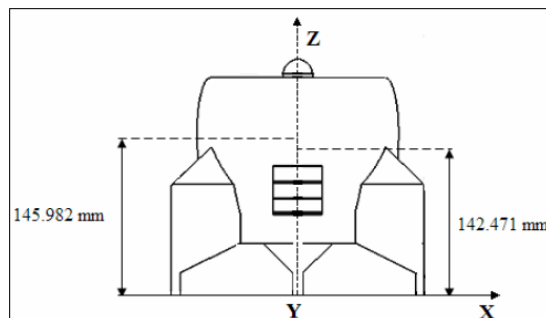


Fig. 17 Center of gravity.

7.0 DISCUSSION

In order to design and fabricate useful MAVs, it will require overcoming a host of significant technology and operational obstacles. These lie in the following areas: aerodynamics, propulsion, flight control, communications, autonomy, payload and system integration.

7.1 Aerodynamics

Aerodynamics for MAV is completely different from the conventional aircraft. This is because MAV is very small in size and operate at low airspeed comparing to a conventional aircraft like Boeing 747. From the studies that have been made, MAV's operate at low Reynolds Number (20,000 to 1,000,000) over their entire flight envelope. The flow over airfoils in this regime includes effects that are difficult to model, such as hysteresis stall due to laminar separation bubbles, but it is possible to conservatively account for the effects of low Reynolds Number by assuming large parasite drag and low C_{Lmax} .

7.2 Propulsion

Propeller's aerodynamics must be efficient because the vehicle depend solely to the propeller to lift from the ground. However, propellers below 3 inches in diameter have efficiencies of about 50% or less. The weight factor of the vehicle, in other way, much be reduced should the power available is confined. Parts like micro electromechanical systems (MEMS), low power electronics and component multifunctional are highly candidates for the weight reduction.

7.3 Flight control

MAV need a flight control system that can maintain its course in the face of turbulence or sudden wind gust. Line of sight stabilization is an essential issue if the MAV has an imaging mission. The challenge here is the miniaturization of the necessary electronics like MEMS.

7.4 Communications

Once in the air, the MAV will need to maintain communications with its user. Communication problems relate primarily to the MAV small size (hence small antenna size) and to the limited power available to support the bandwidth required for image transmission. Image compression helps reduce the bandwidth requirement, but increases on-board processing and hence power requirements. For urban operations, approaches other than line of sight communication have to be explored.

7.5 Payload

For MAVs to be useful, they will have to carry payloads ranging from television cameras to infrared and chemical/biological sensors in a package weighing just 15 gram. These advanced sensor systems are thought to be the basic cost driver for MAV systems.

7.6 Autonomy

Proposed means of making MAV autonomous include using a geographic information system to provide a map of the terrain, or a Global Positioning System (GPS) device, which determines location by triangulating from satellite signals. Before they can be used on MAVs, GPS devices need further miniaturization.

7.7 System Integration

Designing a tiny unmanned aircraft like an MAV would entail making severe compromises. At the size of about 6 inches (15 cm), the concept of "stuffing" an airframe with subsystem becomes extremely difficult. According to the Lincoln Lab 13 study, systems integration affects the selection of components and design of the vehicle. For example, batteries need to severe multiple functions, such as contributing to the vehicle structure. Electronic functions have to be combined and thus, a single application specific integrated circuit could be used for the entire vehicle. Mass can be reduced by thinning electronic circuitry and using interconnections printed onto the vehicle shell in the place of interconnecting wiring. The close proximity of vehicle subsystems also provides challenges such as control of heat dissipation, vibration from internal combustion engines and electromagnetic interference from electric motors.

8.0 CONCLUSION

The design of the UTM's MAV has been described in detailed. However, this early specifications has to be refined after the actual weight of the MAV is known. First of all, the payload for MAV has to be calculated and then the location of the components must be arranged to stabilize the vehicle with the prime attention is the right location of the center of gravity.

The main payloads that have been chosen are internal combustion engine, servo, transmitter, video camera, battery, and video transmitter. It has also been decided to choose carbon fiber composites to be the material for the airframe. This is due to its low stiffness to weight ratio.

A structural and aerodynamics analyses has to be carried out before the MAV is to be fabricated and test flight. The flight test will allow the general performance of the aircraft to be evaluated. Other than that, a full analysis on propeller design should be carried out. This is to know the propeller efficiency and performance because the only lift resource for the MAV depends entirely to the propeller. Stability and control techniques could also be studied to make sure that the MAV is statically and dynamically stable.

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