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REVIEW PAPER

Emerging Technologies for Micro-Unmanned Air Vehicles

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ABSTRACT

Technology, which has attracted the interest of engineers and scientists in recent times, is the development of micro-unmanned air vehicles (MAVs), with the largest linear dimension no greater than 15 cm. MAVs are a great challenge to scientists and technologists. Current technology is underway to meet the design and development of MAVs. In this paper, a literature survey of various emerging technologies in aerodynamics, propulsion, structures, controls, navigation, communication, and payloads for MAVs, is presented.

Keywords: Micro-unmanned air vehicles, reciprocating chemical muscle, microelectromechanical systems, sensors, aerodynamics, small-scale propulsion systems, payloads, navigation and control, micro-technologies, low power electronics, MAVs, MEMS

1. INTRODUCTION

Micro-unmanned air vehicles (MAVs) belong to a class, whose dimensions are comparable to those of bees and insects. These significantly small vehicles are not scaled down versions of larger unmanned air vehicles (UAVs). These are fully functional small flight vehicles in a class of their own. The definition employed in Defence Advanced Research Projects Agency's (DARPA's) programme limits these craft to a size less than 15 cm in length, width or height. The implications of this physical size can be seen in the technology requirements for the development of these vehicles.

2. TECHNOLOGICAL FEASIBILITY FOR DEVELOPMENT

Technological feasibility follows from advances in several microtechnologies. The desire to downsize components to micro levels has led to many innovative developments in the field of electronics, propulsion, controls and structures. An interesting synergistic development is the microelectromechanical systems known as MEMSs. These combine microelectronics components with comparably sized mechanical elements of varying complexities to achieve useful, and often unique functionality (e.g. integrated systems of sensors, actuators and processors). Another interesting developmental field is that of sensors. Microsystems, such as tiny CCD-array cameras, equally small infrared sensors and chip-sized hazardous substance detectors are in the pipeline. Small size of an MAV results in severely constrained weight and volume. This has resulted in a situation where the aerodynamics of the vehicle are completely different from that used in the existing flight vehicles. Scientists are looking at nature for aerodynamic solutions from the flight of small birds, bees and insects. Conventional designs will not work for MAVs. Innovative technical

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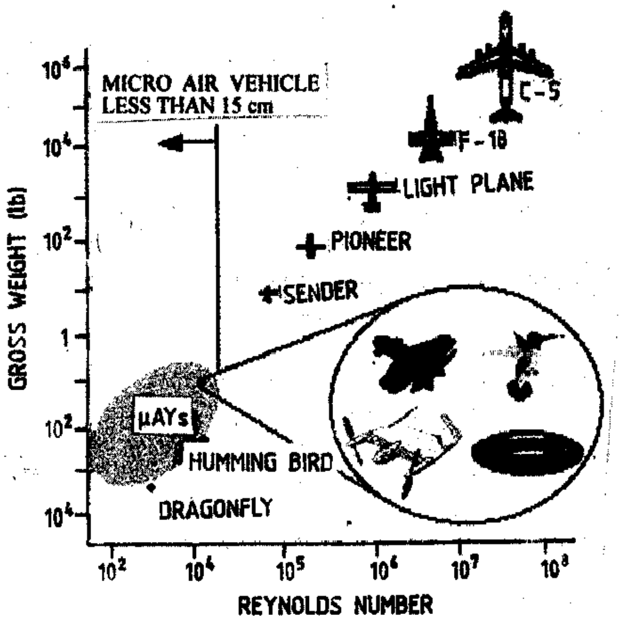

Figure 1. Flight regime of micro-unmanned air vehicles

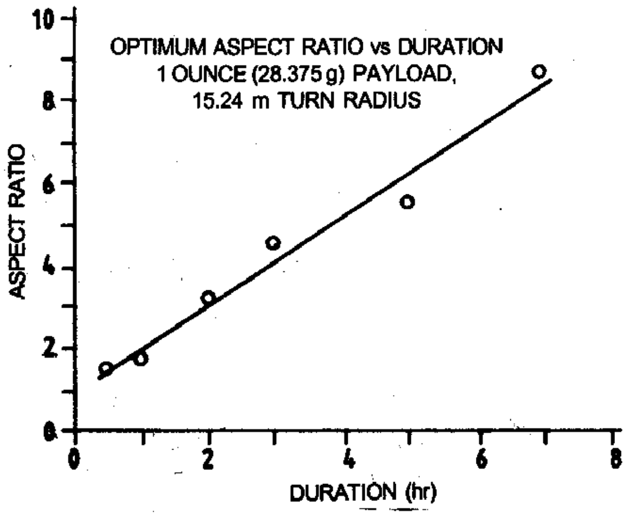

Figure 2. Aspect ratio requirements of micro-unmanned air vehicles.

solutions are being sought for aerodynamics and control, propulsion and power, navigation, and communication.

2.1 Aerodynamics

The flight regime of MAVs compared to existing flight vehicles[1] is shown in Fig. 1.

The flight regime of MAVs results in a fundamental shift in aerodynamics. Prominently, it is an environment more common to the smallest birds and the largest insects. Basic understanding of the aerodynamics encountered here is at present very limited. The flight behaviour of these exotic creatures of nature cannot be predicted with the familiar high Reynolds number aerodynamics commonly used in UAV design. Low Reynolds number aerodynamics of MAVs may result in unusual configurations, such as low aspect ratio fixed wings to rotary wings, and even more radical concepts like flapping wings.

A plot of optimum aspect ratio requirement for MAV flight[2] duration is shown in Fig. 2. Aspect ratio imposes a severe limitation on the performance of MAVs.

2.2 Propulsion System

Small-scale propulsion systems will have to satisfy extraordinary requirements for high energy density and high power density. Acoustically, quiet systems will also have to be developed to assure covertness. It is noted that propulsion would require 90 per cent of the available power and 70 per cent of the total weight for an MAV. A video system that operates at only one frame every two seconds is needed. Higher frame rates will increase the demand for high power and high energy density sources. Additional power would be required for onboard image compression and far higher data rate communication that are yet to be developed. MAVs must be capable of staying aloft, for perhaps 20 min to 60 min, while carrying a payload of 20 g or less, to a distance of perhaps 10 km. Finding high density sources of propulsion and power is a pivotal challenge.

Some of the propulsion issues are linked with low Reynolds number aerodynamics of MAVs. The usual high lift-to-drag ratio concept used in larger vehicles does not hold. The low Reynolds number wings have 1/3 to 1/4 the lift-to-drag ratio of conventional aircraft. Propellers less than 7.62 cm in diameter have poor efficiency, of the order of 50 per cent less. One way envisaged to overcome these limitations is to maximise the wing area leading to low-wing loadings, and the power required will be reduced considerably. The 15 cm limitation of MAVs requires increasing the wing chord to maximise wing area, leading to low aspect ratio configurations.

Finally to reduce power requirements, technologies like MEMSs, low power electronics, and component multifunctionality will help. High energy density (i.e. lightweight) power sources are essential. Battery-based systems would power the first-generation MAVs, but more exotic technologies, like fuel cells are being developed for follow-on systems.

The reciprocating chemical muscle (RCM) is a mechanism that takes advantage of the superior energy density of chemical reactions as opposed to that of electrical energy storage, which is the approach currently being taken by most MAV researchers[3]. For example, the energy potential in one drop of gasoline is enormous as compared to that which can be stored in a battery of the same volume and weight.

The RCM is a regenerative device that converts chemical energy into motion through a direct noncombustive chemical reaction. Hence, the concept of a muscle as opposed to an engine. There is no combustion taking place, nor is there an ignition system required. The RCM is capable of producing autonomic wing flapping as well as small amounts of electricity for control of MEMS devices.

2.3 Controls for Micro-Unmanned Air Vehicles

The inertial effects being very negligible, unsteady flow effects arising from atmospheric gusting or vehicle manoeuvring are very pronounced on MAVs. The concept of flapping wings to generate unsteady flow can be used to create both lift and propulsive thrust. MAVs can also use flapping wings to control their flights. Full-sized aircraft use motors and hydraulic actuators to move wing and tail structures that provide directional control. Because of the weight restrictions, MAVs have to use radically different control techniques. Studies are being carried on investigating electrically actuated piezoelectric structures that differentially alter lift. Different techniques for applying direct engine thrust across the wings are also being investigated. Several studies are in full swing to integrate sensors, actuators, thrust developing capabilities and lift production in the wings of MAVs. Some flight scenarios envisaged for MAVs require that they be independent enough to avoid obstacles and maintain stable flight by themselves.

2.4 Navigation & Communication

Inertial navigation for MAVs awaits the development of low-drift micro gyros and accelerometers. Constricted corridors of complex geometry, multiple obstacles – and some of them moving – must all be reckoned with if the MAV is to become functional. Real-time human interaction to provide vehicle stabilisation and guidance is being considered for early designs. In some of the more demanding applications, for example vehicle agility for gust response, may well surpass a human operator's ability to cope with, and real-time human control may not be possible except in the simplest scenarios. Significant advances in miniature navigation, guidance and control systems are yet to be developed.

Communication problems relate to small antenna size and limited power available to support the bandwidth required (2-4 Mbits/s) for image transmission. Control functions demand much lower bandwidth capabilities, in the 10's of kbit range. One approach to solve communication problems relating to MAVs is to explore cellular communication architectures.

3. PAYLOAD CAPABILITIES

A variety of sensors will have to be adapted and integrated into MAV systems. These may include optical, IR, acoustic, biochemical, nuclear, and others. Severe weight restrictions demand new types of avionics systems to fit within the 50 g allowed for the vehicle and its payload. Synthetic aperture radar (SAR), a microsensor of extremely low weight and power, and small size, is being developed as an imaging payload for MAVs. The sensor offers all-weather/all-visibility conditions, high resolution imaging capability to small units for surveillance and targeting purposes. In addition to being able to see through smoke, fog, etc. and its

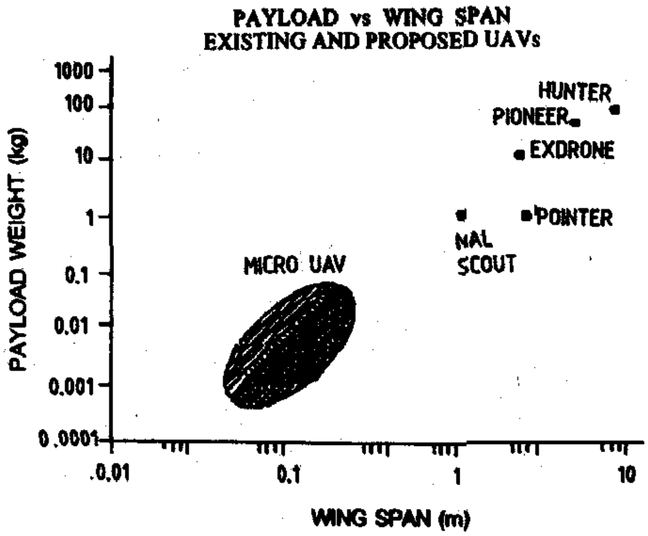

Figure 3. Payload versus wing span for unmanned air vehicles

round-the-clock mission capability, SAR provides the valuable range information and it is particularly sensitive to man-made metallic objects, such as tanks, artillery pieces. Video camera system which would weigh only 1 g and occupy roughly 1 cm^3 and would have 1000 × 1000 pixels and require as little as 25 mW are in the pipeline. An interesting graph of payload versus wing span is depicted in Fig. 3 for various MAVs. Depending on system parameters, the total weight of the imaging payload can be expected to range[4] between 45.359 g to 226.796 g.

4. APPLICATIONS OF MAVs

The tasks envisioned for MAVs are radically different from those of other flight vehicles. The main motivation for the development of these vehicles arose from military battlefield requirements. MAVs are expected to be a great asset to the platoons and to a single soldier too. These will give the individual soldier information about his surroundings, resulting in better situational awareness. MAVs have more applications besides military-based ones. MAVs can deploy a useful micro payload to a remote and hazardous location, where it may have to perform a variety of missions, like reconnaissance and surveillance, targeting, tagging and biochemical sensing.

5. ORGANISATIONS DEVELOPING MAV TECHNOLOGY

Designers of MAVs face formidable challenges and a host of unknowns. The degree of design synergy required has never been achieved in a flight vehicle design. The earliest suggestions of technical viability appeared in the early 1990s from studies, such as RAND Corporation's investigation of microsystems and MIT Lincoln Laboratory's early investigations of micro flyers. The outcome of that effort was a newly created DARPA programme to develop this new dimension in-flight. DARPA selected the following six organisations to develop technologies relating to MAVs. These are:

- Massachusetts Institute of Technology, Cambridge, Massachusetts. Microelectromechanical systems based micro-gas turbine engines for micro-unmanned air vehicles.
- DSTAR Engineering, Shelton, Conn. Low-observable, safe-operation, fuel efficient, lightweight propulsion and power system for advanced micro-unmanned air vehicles.
- Technology in Blacksburg Inc., Blacksburg, Va. Thermoelectric-based advanced micro-unmanned air vehicles.
- SRI International, Menlo Park, California. Flapping-wing propulsion using electrostrictive polymer artificial muscle actuators.
- Vanderbilt University, Nashville, Tenn. An elasto-dynamic ornithoptic flying robotic insect.
- California Institute of Technology, Pasadena, California. Micro Bat.

The following four small business houses were selected by DARPA to receive contracts under phase II of the Business Innovation Research Programme to continue research and development in support of the micro-unmanned air vehicle effort:

- IGR Inc., Beechwood, Ohio, to complete the development and demonstration of a very lightweight solid oxide fuel cell, tailored to the electrical power requirements of micro-unmanned air vehicles.

- M-DOT Inc., Phoenix, Ariz., to continue its development of a very small (535.0292 g thrust) gas turbine engine.
- AeroVironment Inc., Simi Valley, California, to continue its development and flight demonstration of an electric-powered, fixed-wing, reconnaissance micro-unmanned air vehicle.
- Aerodyne Corp., Billerica, Massachusetts, to continue its development of a hover vehicle that will also explore the capabilities of the mini-scale engine being developed by M-DOT.

6. CONCLUSION

The keen interest evinced by various universities and research organisations to develop various micro technologies that go into making of an MAV will make them see the light of the day. Scientists are figuring out spectacular solutions to basic questions, such as what makes them fly, what to power them with, how to make them see, how to integrate all systems into these tiny flyers. Research to develop these technologies is in full swing, and this will complement the development of micro air vehicles ushering in an era of MAVs.

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