ABSTRACT

Recent advances in micro-technology have created an opportunity to mount miniature surveillance equipment on small flying aircraft known as Micro Air Vehicles (MAVs). Such micro-technology includes tiny CCD cameras, sensors and computer chip sized hazardous substance detectors. MAVs are used for both military and civilian applications to gather information where human doesn’t have access. There is increasing interest in the development of MAVs, which can be used for outdoor flights as well as very small microscopic aircraft for indoor flights. Worldwide considerable work is in progress on miniaturizing the vehicle size for wide range of commercial and defence operations. As per the DARPA (Defence Advance Research Projects Agency, USA) definition, the MAV size is expected to be in the order of 10-15 cm with total weight of 10-50 grams and the flight endurance of 20-40 minutes with payload (camera and transmitter) of 2 grams. MAV technology presents a variety of engineering challenges: they are (i) Miniature propulsion, (ii) Aerodynamics, (iii) Micro Electro Mechanical Systems (MEMS), (iv) Small-scale power storage (battery), (v) Avionics, (vi) Flight controls and many others.

The thesis, “Design and Development of Flapping Wing Micro Air Vehicle (MAV)”, concentrates on development of a flapping flight vehicle using miniature electric propulsion (battery operated electric micro-motor) and the aerodynamic characteristics study. This work is focused on the
development of miniaturized flapping mechanism, optimized wing planforms
development, integration of the airframe and wing planform and the
characteristics study of the MAV. There are many technical barriers in
designing a flapping wing micro air vehicle; out of these the prime technical
challenge is to fly the vehicle with payload capabilities. As the knowledge of
flapping wing unsteady aerodynamics was not yet explored to a large extent,
there exists a need of experimentation to reveal the unsteady aerodynamic
characteristics of flapping wing. Such unsteady aerodynamic study carried out
is dealt in this dissertation.

Extensive simulation and analysis were carried out for the flapping
mechanism development. Different mechanisms i.e., sliding link mechanism,
movable hinge mechanism, fixed hinge mechanism, the rack and gear
mechanism and double connecting rod mechanism were developed and tested
for the optimal flapping frequency. Based on the comparison made, the
miniaturized rack and gear mechanism has been selected for flight test.

The wings were developed and tested in the following perspectives:
Planform Shape, mid spar angle, leading edge shape, Aspect Ratio, Torsional
flexibility, Span and Chord wise camber effects. For the wing design data
from natural fliers and literatures were used. The different wing planforms
were designed (using AUTOCAD, Pro-E and CATIA), fabricated and tested
for its aerodynamic characteristics. In order to have less weight and enough
stiffness, Balsa wood, Carbon rods and Carbon pre-preg materials were used
in the wing skeleton / spar development. Mylar and latex sheet were used as
wing skin.
The strain gauge type load cell is designed and developed. Initially, cantilever type of lift measuring load cell (single component) and then two components (lift and thrust) load cell of inverted ‘L’ shape cantilever beam have been developed. The load cell output is fed into the computer through ‘STRAIN-SMART’ Data Acquisition System (DAS), which has the 12-bit Analog to Digital Converter (ADC). The Opto-coupler type of sensor was used in the flapping frequency measurement.

The open jet tabletop tunnel having test section 350x350mm has been constructed and used the aerodynamic characteristics study. The test section has the velocity uniformity of + or – 5%. The tunnel has the capability to generate the free stream velocity upto 10 m/s. A series of experiments were conducted to determine the effect of flap angle, flapping frequency, free stream velocity, aspect ratio and planform shape on the lift and thrust characteristics of the flapping wing MAV.

The computational work was carried out for the flapping wing using CFX package. Totally four set of wings (Flat Wing (FW), Chord Wise Camber Wings (CWC-I&II) and Spanwise Cambered Wing (SWC)) were simulated in computational study. Since the flapping wing needs three-dimensional unsteady flow analyzes CFD package is used for the approximation. Unstructured, adaptive meshes have been used for solving fluid dynamic problem, because of their ability to adjust according to variations in the flow field. To obtain Natural flow conditions as in experimental, the flapping technique is obtained from “Edit Expression”, as Simple Harmonic Motion. Fluid flow field variables were controlled by
writing required expression in “Additional Variable Editor”. The results obtained from the post-processor i.e., the forces obtained were time dependent. The net lift and thrust forces during one cycle (i.e., upstroke and down stroke) was calculated as Root Mean Square values. Contour plot, Vector plot and Streamline plot were obtained to get flow field variables. Contour plot was used to get forces on the flapping wing during oscillation. Vector plot has been used to get rotational velocity variation with respect to time interval. Streamline plot was used for flow visualization over flapping wing during flapping. The results were plotted (C_L, C_D curves with respect to Reduced frequency and Advance Ratio) and compared with experimental values.

From the results it is observed Flat Wing seems to produce better lift than other wings. And also the shape of the planform influences large extent in the lift and thrust characteristics even though it has same wing area. From the experiments it is observed that the chord wise flexible wing produces good lift and thrust than any other wings. The stalling characteristics of the wing planforms have been carried out. The Centre of Gravity (C.G) of the MAV model has been calculated using Pro-E software, and this data is used for integrating wings with the mechanism and for the stability analysis.

Series of flight tests have been carried out. Initially the ground test has been carried out for examine the production of sufficient thrust followed by free flight, tethered flight tests have been carried out. Finally the vehicle has been flown upto 10 seconds and series of flight tests have been attempted.