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EQUIPMENT FOR DETERMINING AERODYNAMIC FORCES ON FLAPPING WINGS

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Abstract – Present work is devoted to the experimental determination of the non-steady aerodynamic forces acting on the flapping wings of the micro air vehicles (MAVs). At the National Institute for Aerospace Research from Bucharest, Romania, a multidisciplinary collective of scientists performed both theoretical and experimental research on flapping flight. In this work we present some aspects concerning the force measurement procedure in the range of small forces. The moment components given by the forces acting in two directions (perpendicular and parallel to the wing plane) are tensometrically measured while the flapping and pitching angles are determined using two precision potentiometers. All signals are transmitted to computer via a multifunction DAQ National Instruments PCI-6221, Windows compatible. LabVIEW SignalExpress LE together with NI-DAQmx can gather, register, export and visualize experimental data. The analysis includes the extraction of the inertial forces which are the predominant ones, making possible the accurate determination of the aerodynamic forces on the flapping wings.

Keywords: flapping wings, aerodynamic forces, piezo-resistive strain gauges

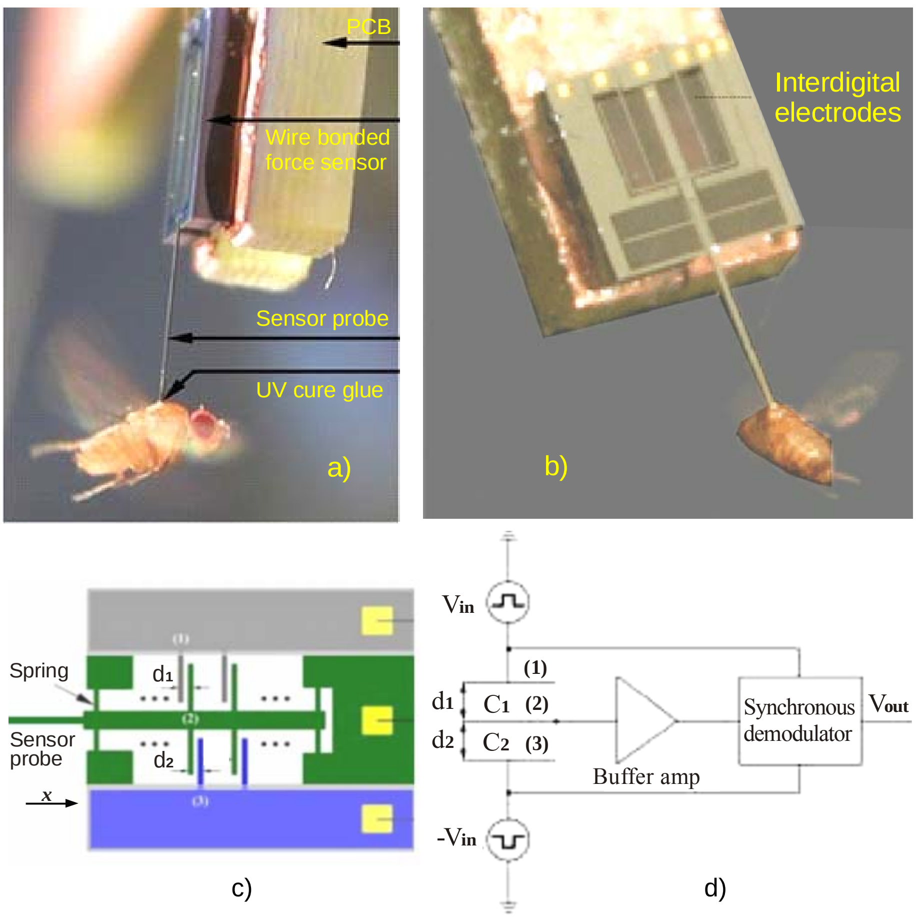

Fig. 1 (adapted from [2]). Fruit fly flight behavior characterization using MEMS force transducers: resistive wire (a) or interdigital electrodes (b), and complex capacity lay-out (c) and associated electronic circuitry (d).

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1. INTRODUCTION

The present work is devoted to the experimental determination of the non-steady aerodynamic forces acting on the flapping wings of the micro air vehicles (MAVs). The first attempts to explain the lift generation on the wings of the insects used the so-called “steady-state” aero-dynamics, i.e. that theory successfully applied in aircraft design. The result was a failure, leading to the conclusion that “a fly cannot fly”. The “steady-state” theory could not explain the high lift necessary for an insect to fly.

Later, both experimental and theoretical investigations proved that flapping flight uses specific aerodynamic mechanisms that are able to increase the lift [1-2]. Since these aerodynamic phenomena are much complicated in case of the hovering flight, an experimental study of this case is very useful [3-4].

2. MICROMECHANICAL FLYING CONTROL AND SCALING ASPECTS

At the first level of MFI (micromechanical flying insect) is the wing control system based on wing and/or thorax mounted force transducers. Traditionally, measuring forces on a flying insect is performed by fixing the insect to a cantilever and measuring its variable position by resistive, capacitive or optical means. The direct flight forces measurement involves measuring the moments on the wing using strain gages mounted directly in the wing spars.

The results obtained for 5X scale experiments wing spar sensing are, conform [4]:

- lift force: 32 mN (aprox. 3.2 grams),
- drag force: 25 mN (aprox. 2.5 grams).

Decreasing the mechanisms dimensions requires serious adjustment of the engineer’s judgment regarding relative dimensions and loads [5]. The attraction forces between contacting or nearly contacting surfaces are in the macro world usually much lower than the gravity forces while in the micro world, however, forces due to electrostatic charging, Van der Waals forces or surface tension of water films might well dominate gravity.

Piezoresistive and capacitive gauges are the commonly used microsensors to evaluate the flying insects (Fig. 1) but the problem is the extremely low change of physical quantities like resistance or capacitance on changing the relative position, being difficult to discriminate noise from the useful sensor signal.

As Christofer Hierold, from ETH Zurich, Micro and Nanosystems Department, states: While in microelectronics miniaturization and further integration, following Moore’s law, have succeeded in better performing measuring devices (smaller, faster, cheaper), transducers confronting with inertia do not benefit from scaling in general [6]. They have compared three types of sensors for measuring pressure, acceleration and yaw rate. All of them measure a force as a result of the physical unit applied that displaces a sensing element (resistive, capacitive, electromagnetic etc) against a spring force.

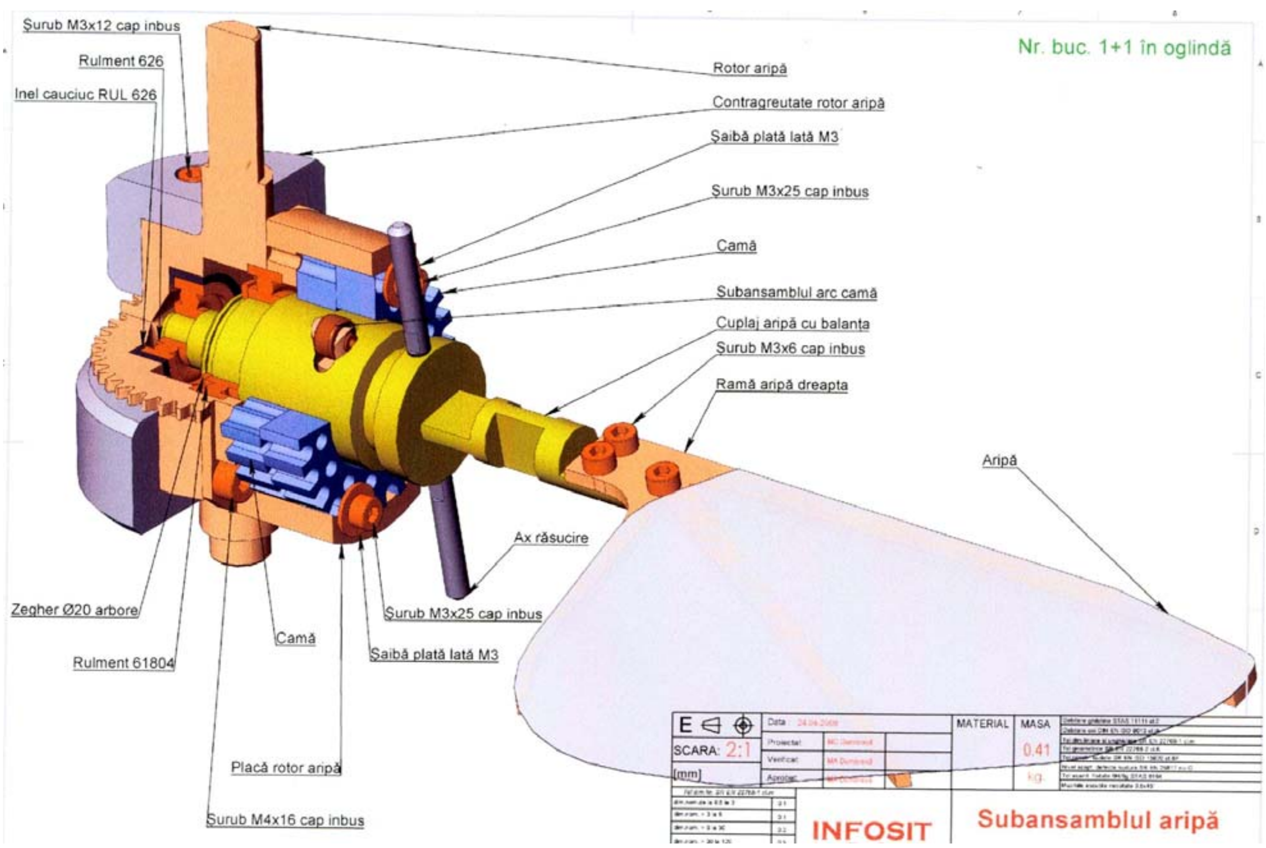

Fig. 2. The mechanism that produces beating and flapping motions – the right wing.

3. EQUIPMENT FOR MEASURING AERODYNAMIC FORCES ON FLAPPING WINGS

In this work we present some aspects concerning the force measurement procedure in the range of 20 N; instant forces could be more than ten times greater comparing with the mean force of flying insects.

Figure 2 shows the experimental installation designed and constructed to perform biomimetic motion of the wings. Within this mechanism, driven by an electric motor and described in detail in [7], the moment of the global forces on the wings is measured using strain gauged transducers (Fig. 3) while their azimuth and lifting angles are determined by means of two Smart Position Sensors.

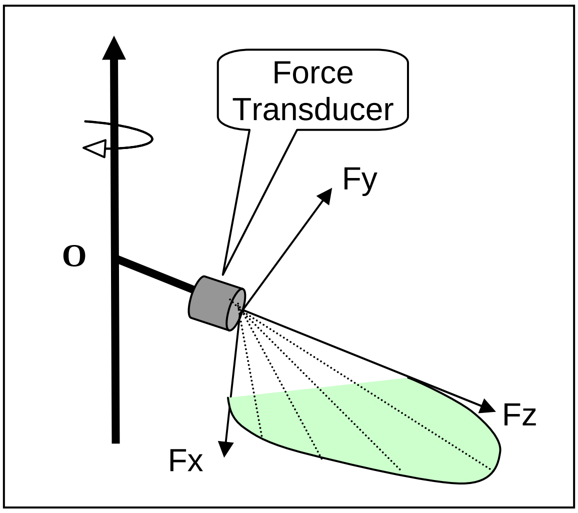

Fig. 3. Bicomponent force transducer mounted on the wing axle.

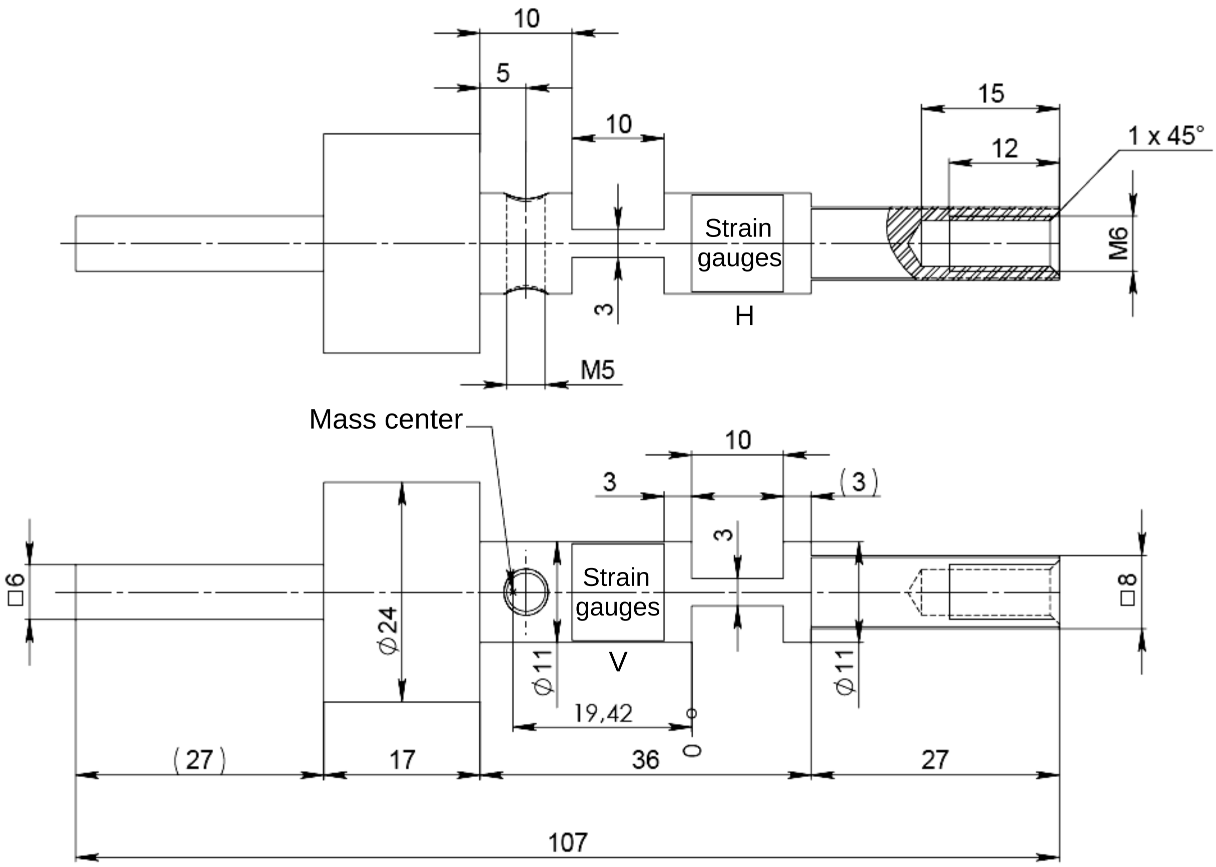

Fig. 4. Customized cantilever beams measuring forces in two perpendicular planes (H – horizontal and V – vertical) by means of strain gauges (type 0.6 /120 LY11 made by Hottinger).

4. EXPERIMENTAL RESULTS

The moment components given by the forces acting in two directions (perpendicular and parallel to the wing plane) are tensometrically measured (Fig. 4) while the flapping and pitching angles are determined using two precision potentiometers, type 601-1045 made by Vishay-Spectrol. All signals are transmitted to computer (Fig. 5) via a multifunction DAQ National Instruments PCI-6221, Windows compatible.

LabVIEW SignalExpress LE together with NI-DAQmx can gather, register, export and visualize experimental data. The analysis includes the extraction of the inertial forces which are the predominant ones, making possible the accurate determination of the aerodynamic forces on the flapping wings.

Our first results are in good agreement with those obtained by B. Singh et al., Department of Aerospace Engineering, University of Maryland at College Park [3], as they are presented in Figure 6. There are a lot of challenges concerning the geometrical, aerodynamic and functional similitude between the real insects and the micro air vehicles to be resolved in the near future, using better financial resources.

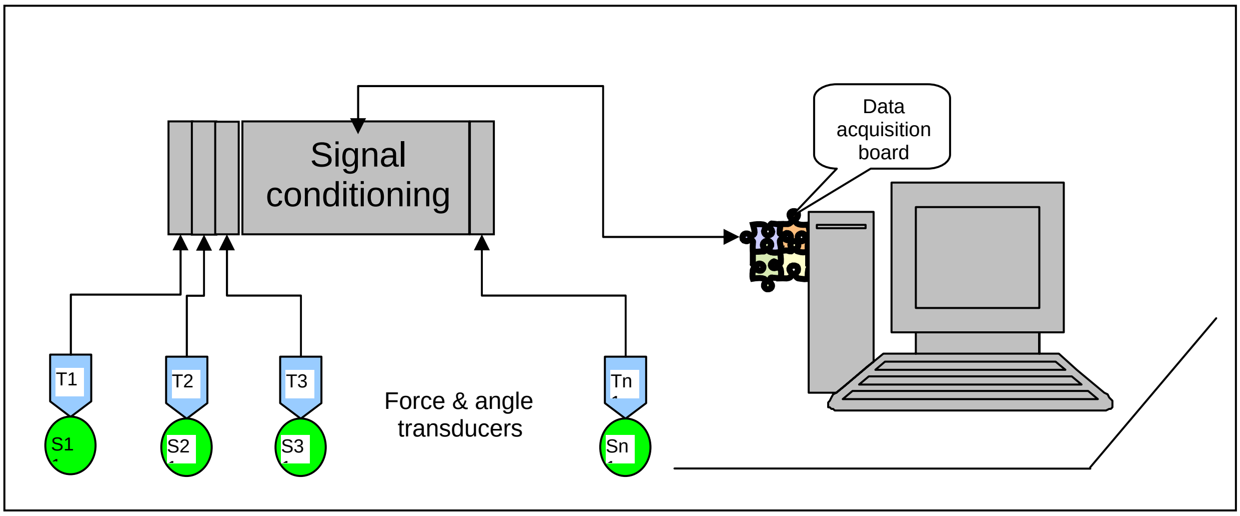

Fig. 5. Functional scheme for computerized measuring of two forces acting in perpendicular directions and two rotation (flapping and pitching) angles.

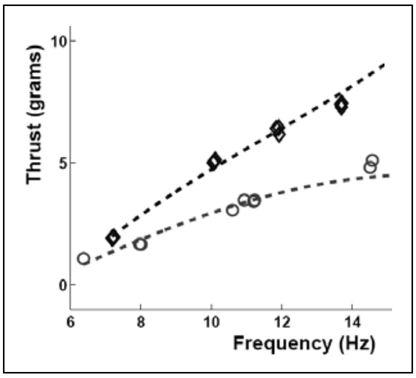

Fig. 6. Thrust measured for flapping motion of the wing.

5. CONCLUSION

At the National Institute for Aerospace Research from Bucharest both theoretical and experimental researches on flapping flight were performed. One can mention the complex experimental set-up, as well as an original solution concerning the using of a set of large scale wings, creating two main advantages:

i) the frequency being small, the inertial forces are not so great;
ii) the area being large, the aerodynamic forces could be made large enough to be precisely measured.

The complex experimental setup for measuring the aerodynamic forces on flapping wings is still in course of development in order to improve its metrological characteristics.

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