FEM Analysis, Modelling and Control of a Hexacopter

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Introduction

This work is supported by the PO. FESR 2007/2013 subprogram 4.1.1.1 "Actions to support the research and experimental development in connection with the production sectors, technological and production districts in areas of potentiality excellence that test high integration between universities, research centers, SMEs and large enterprises"; (Prog. "Mezzo Aereo a controllo remoto per il Rilevamento del TErritorio - MARTE" Grant No.10772131). The aim of the project is to realize a new platform for the representation of the terrain in a georeferenced raster map by using free and open source Geographic Information System (GIS). In this work a FEM structural analysis and the mathematical model and control of a hexacopter airframe is presented. In particular, the six-rotors are located on the vertices of a hexagon and they are equidistant from the centre of gravity; moreover, the propulsion system consists of three pairs of counter-rotating fixed-pitch propellers in order to balance the torque actions. The structure has been made up by a composite sandwich configuration characterized by CFRP skins and closed cells foam core. The analysis has been performed by the code ANSYS V 14.5 Academic Version with the ACP tool to pre-postprocess the composite structures. In order to describe the movement of the drone in space, an efficient mathematical model has been introduced associated with a robust control technique that has been implemented by means of MATLAB software.

FEM structural analysis

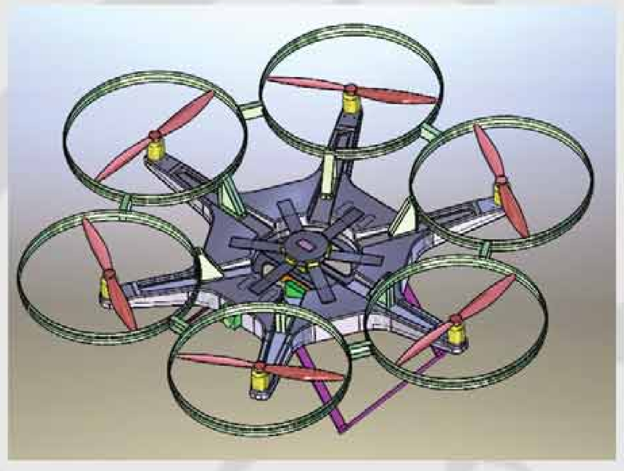


Figure : View of the hexacopter assembled CAD geometry (SolidWorks 2013)

	Single mass [Kg]	System mass [Kg]
Brushless Motor	0.4	2.4 (0.4x6)
ESC	0.1	0.6 (0.1x6)
Battery	0.9	5.4 (0.9x6)
Payload	4	4
Electronics	2	2
Structure	1.6	1.6
Tot.	—	16

Table : Masses applied on the drone

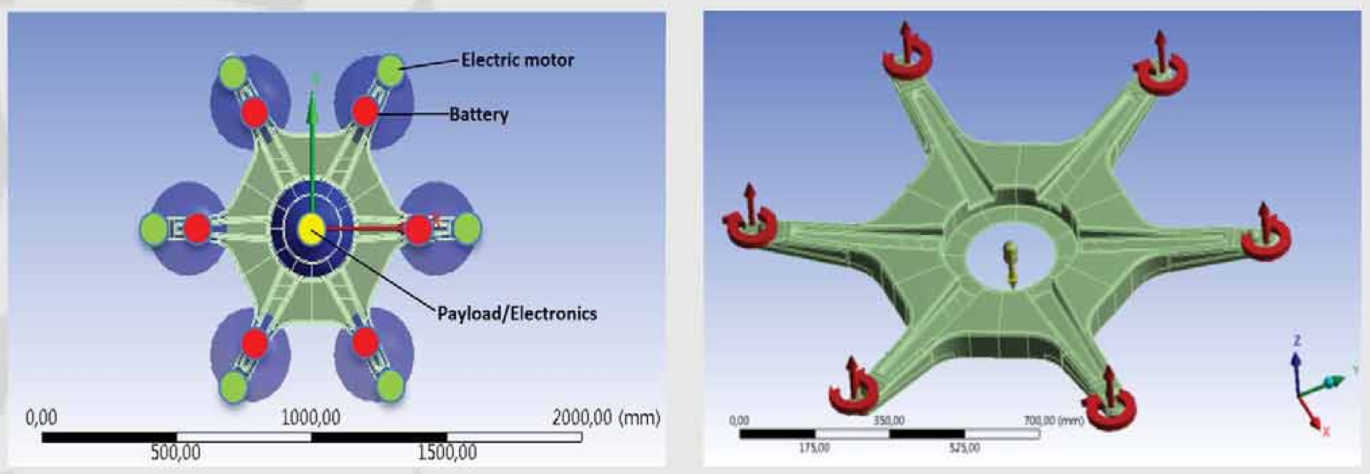


Figure : Loads on the structure: Weights in gravitational field considered as concentrated masses; thrusts and reaction moments by electric motors.

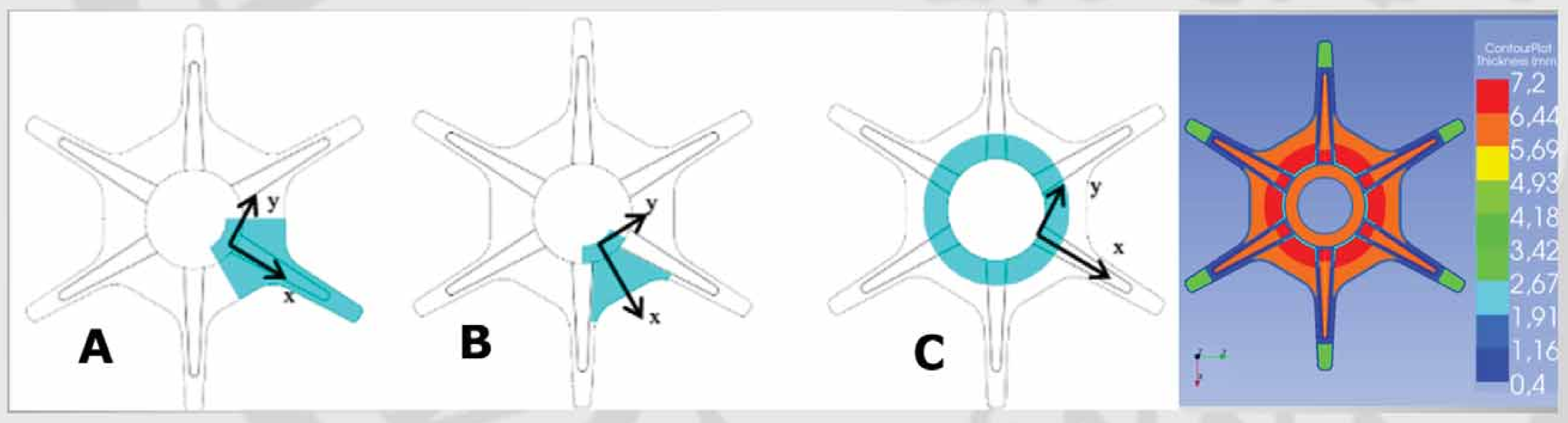


Figure : A,B,C are typical units of the layup with axial symmetry and last picture shows the structure thickness

- Units B are assembled on the mold (outer skin), according to the B local reference system
- Units A are assembled with a stacking sequence $[0_2/Core/0_2]$, where the angle 0° is coincident with xA axis. Then the structure is completed by assembling the inner skin as well as the outer one (units B)
- A local annular reinforcement is stacked following the $[0/+30_2/-30_2/0]$ layup referred to the C local coordinate system.

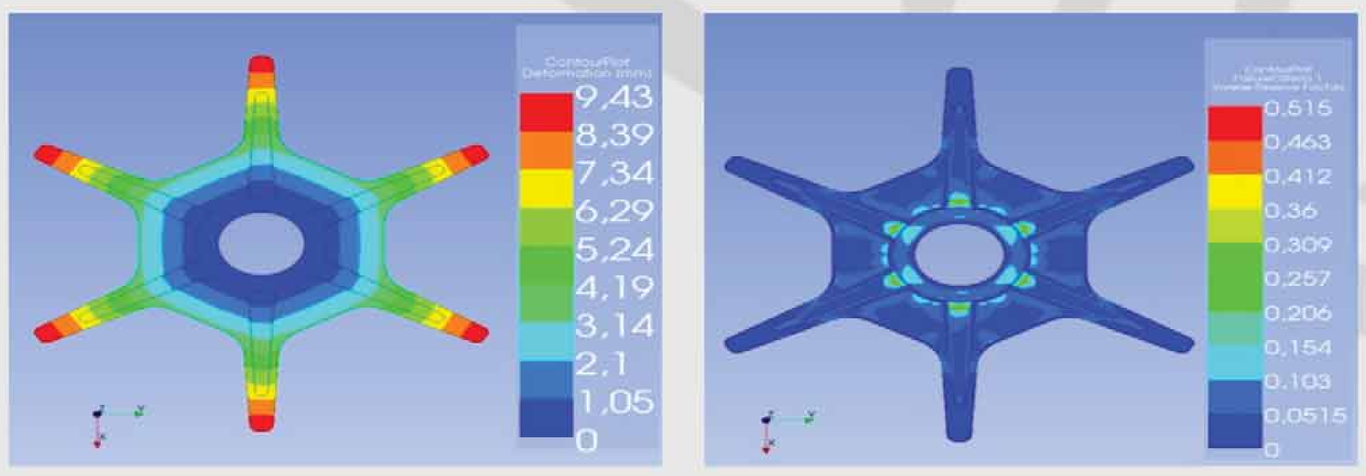


Figure : Total deflection [mm] on the left, IRF under axisymmetric load at n=3 on the right..

	Carbon fiber Skin	PVC Core
Ex	70000 MPa	35.8 MPa
Ey	65000 MPa	
Ez	10000 MPa	
vxy	0.05	0.38
vyz	0.3	
vxz	0.3	
Gxy	5000 MPa	13 MPa
Gyz	1500 MPa	
Gxz	1500	
ρ	1530 Kg/m^3	32 Kg/m^3

Table : Materials mechanical data

Mode	Frequency
1	14.572
2	14.642
3	17.075
4	18.015
5	**43.166**
6	**43.342**
7	**73.429**
8	**75.572**
9	**76.835**
10	92.051

Table : First 10 frequencies

The modal analysis of the hexacopter is performed with the aim to compare the natural frequencies of the structure with the forcing frequencies deriving from the thrust of the electric motors. The first 10 frequencies are listed in the table.
- Forcing frequencies from the thrust of the electric motors (max rpm $\approx$ 9000)
- Hovering condition $\approx 1/2$ Max power motors (4500 rpm)
- Normal flight regimes $\approx \pm 20\%$ Hovering rpm (3600 $\div$ 5400 rpm) $\rightarrow$ 60 $\div$ 90 Hz. n
So a superposition is possible from 7th to 9th mode.

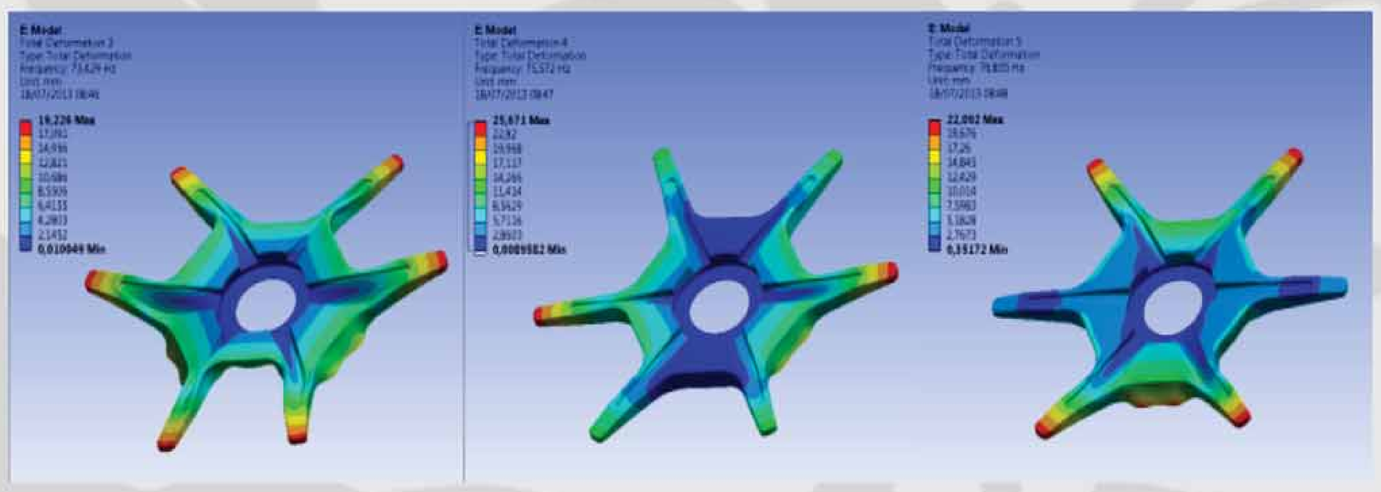


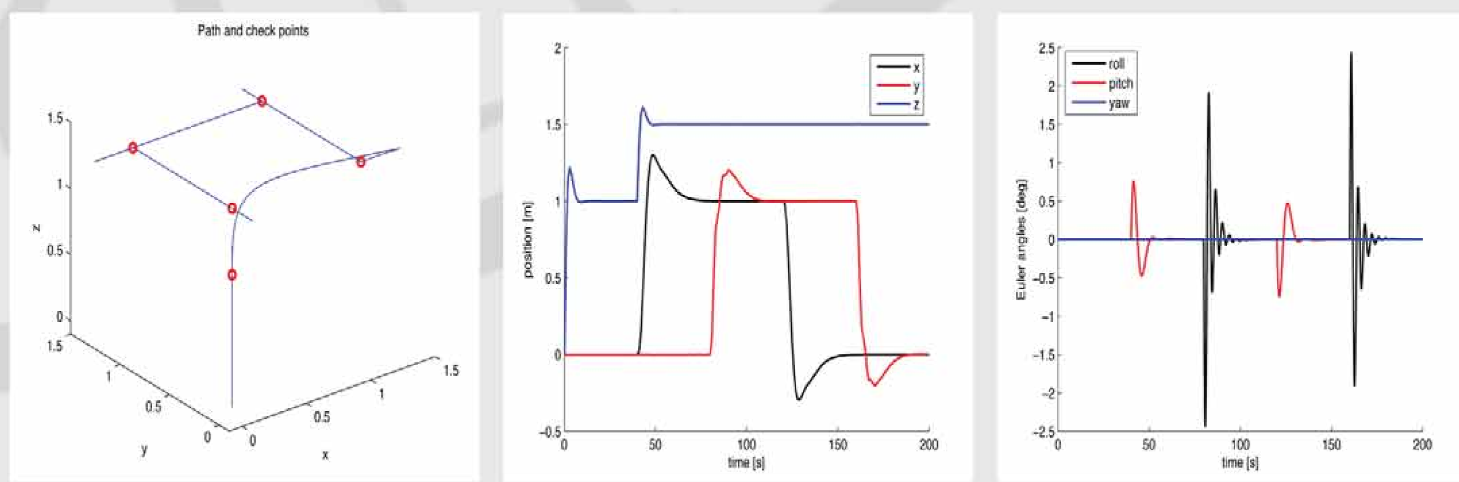
Figure : Modal shapes (from 7 to 9).

Mathematical Model and control

Supposed the drone as a rigid body, its dynamics is deduced from the classical Newton - Euler equations but in terms of quaternions. Taking into account all the internal and external influences, the translational and rotational components of the motion read

$$\begin{cases} m\ddot{\xi} = \mathbf{F}_g + \mathbf{Q}\,\mathbf{T}_B \\ \mathbf{I}\,\dot{\nu} + \nu \times (\mathbf{I}\,\nu) + \mathbf{\Gamma} = \tau_B \\ \dot{\mathbf{q}} = d\,(\mathbf{S}\,\nu)/d\,t \end{cases}$$

in which m is the mass of the drone, $\xi = (x, y, z)$ represents its position vector with respect to the inertial frame,$\mathbf{q} = (q_0, q_1, q_2, q_3)$ represents the quaternion describing the angular position, $\mathbf{F_g}$ is the gravitational force, $\mathbf{T_B}$ is the total thrust, $\mathbf{Q}$ is the orthogonal transformation matrix from the body frame to the inertial one, $\mathbf{S}$ is the velocity transformation matrix and $\nu = (p, q, r)$ is the angular velocity, $\mathbf{I}$ is diagonal inertial matrix, $\mathbf{\Gamma}$ represents the gyroscopic effects and $\tau_B = (\tau_\phi, \tau_\theta, \tau_\psi)$ the roll, pitch and yaw moment torque vector.
To maneuver the flight and to manage the hexacopter, a PID control technique has been implemented.



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