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Finite element modeling for structural strength of quadcoptor type multi mode vehicle

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ABSTRACT

Quadcoptor (QD) type multi mode vehicle is modeled for the structural strength using finite element method (FEM). Static as well as dynamic mass and stiffness matrix were developed for key component of such vehicle that includes base plate, mounting frame, arm, support frame, propeller and wheel set. The components, thus generated are preprocessed for meshing, material selection, constraining, loading. The boundary condition is set and mesh convergence is tested before solving the model. The results, such as deformation, von Misses stress are analyzed for each component as well as for the upper half of the multi mode vehicle. The results depict the critically stressed zone of various key components of QD.

1. Introduction

Quadcoptor (QD) type multi mode vehicle is a conceptual and unmanned aerial vehicle (UAV). It can be operated in land, air and water for reconnaissance, search and rescue operations. Further, it can also provide efficient and first response to military and tactical operations. Such vehicle is designed to be used in hostile situation to reduce risk of human counterpart. It is also used in nuclear power plant to replace the man mission for remotely hazardous regions exposed to radioactive emission. The further practical applications of QD include assistance bot for exterior work of high rise buildings, searching and disposal of bombs, assistance for people working on erection and commissioning of pipe network, fire assistance, search and rescue, cleaning bot and aerial photography etc. There are many challenges to the sustainability of these vehicles; for example the continuous power supply on board and structural stability for life as well as during flight.

As we know, the fixed wing aircraft because of constant flow requirement over fixed wing found to be unreliable for aerial surveillance. Multi rotor aerial vehicle is considered more suitable for fixed point hovering in the air. It is termed as multi mode vehicle or multi coptor as it can travel in land, air and also can navigate in water and have more than two blades. For example, a QD has four rotor blades with constant pitch. In case of QD, the rotor pitch does not vary as the blade rotates. The motion control is achieved by varying relative speed of each rotor that changes the thrust to produce torque. Along with QD, there are hexacoptor or octocoptor like multi mode vehicles.

The QD type multi mode vehicle is controlled and stabilized using electronic data acquisition system. It can flow indoors or outdoors because of small size and agile maneuverability. Further, it is mounted with two sets of fixed pitch propeller, similar to other helicopters. Because of simultaneous clock wise rotation of one set propeller and anti clockwise rotation of other set, the lift or torque is produced. The QD motion control is achieved by changing the rpm of one or more than one rotor.

In order to maintain steady structural strength, a versatile design analysis of this QD requires intelligent link between conventional computers aided drafting (CAD) and sophisticated analytical FEM tool [1]. The result of such combined simulation affects greatly to the decision making mechanism of QD type vehicle design.

Hence, it is necessary to interface the key component analysis to advanced simulation tools. An example of such interfacing to CAD model of QD is super sandwich beam finite element formulation [2]. The sandwich beam is mainly considered as two nodded element. All axial and flexural loads are assumed to be taken by the face sheet. The core is subjected to shearing. The formulation of such beam element is based on first order shear deformation theory. The super convergent of the formulated beam element is established by number of numerical experiments on static condition, free vibration and wave propagation.

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The QD under analysis consists of shaft on which the propeller is mounted. The shaft like components under combined load can be analyzed for buckling strength using finite element based buckling methodology. Accurate output for the shaft buckling failure due to combined loading can be obtained by using Riks algorithm [3]. Palani et al. [4] developed an efficient as well as reliable FEM solution for ship structural components. That includes posteriori error estimator and h-adaptive refinement strategy for static and dynamic analysis of stiffened plate and shell. Using bisection or equal subdivision method, transient dynamic analysis of stiffened plate or shell panel is analyzed, however, the QD shaft is to design mainly to sustain load/moment arise due to air flow in the blades accompanied with the vehicle weight.

One of the key components of QD is base plate. It is a sandwich beam structure subjected to dynamic axial compression. An understanding of such beam is essential for structural analysis of base plate. Shankar et al. [5] developed a FEM of debonded sandwich beams subjected to axial compression. They developed load–elongation curve for variety of test specimen. Further, the energy released at crack tip was computed by applying J-integral and plotted against load. The effect of parameters like debond length, fact sheet and the core on load carrying capacity of the sandwich beam was studied using Graeco-Latin factorial plan. A combined method of nonlinear post-buckling analysis followed by elasto-plastic model of the core was developed to analyze the compression behavior of debonded sandwich beams.

The QD consists of four propeller blades designed to rotate in a vertical axis. An understanding of blade strength is highly recommendable. Lin et al. [6] used the FEM to analyze a wind turbine blade made up off fiber-reinforced polymer (FRP). They used inclination angle correction method and developed a combined numerical and FEM model to solve non-prismatic blade like FRP beam. Such analysis is advantageous because it reduces computational time, helps understanding mechanical behavior. Further, the overestimated axial stiffness out of the topology of the beam is corrected due to correction in the inclination angle.

The QD consists of many key components that must work in coordination to deliver the overall response in its operation. A Multi body system (MBS) programs may be developed keeping in mind to simulate the complex systems consisting of number of beam elements. EI-Ghandour et al. [7] used such software programs to study the contact force between the railroad and vehicles. They developed a coupled FEM and MBS technique. The rails, fastners, sleepers and substructures are molded by taking those as beam, solid and spring elements. Under dynamic loading conditions, mode shapes of the finite element model are extracted for use in a MBS code to analyze the deformation of the track and substructure. Sasaki and Shabana [8] predicted dynamic stress using non-linear floating frame of reference. It is used to derive the reference kinetic equation derived from general continuum equation. A bulldozer type flexible upper structure is developed and simulated using Mindlin shell finite element. However, the application to QD structural analysis is not found in those research works.

There are many constrained and non-constrained points in a QD design. It needs separate attention. Afzali-Far and Lidstrom [9] studied the general theory of the dynamics of multibody systems under constraints. The use of Euler angles, constrained quaternions and constrained linear coordinates are analyzed in detail in this research work. Further, Masarati [10] developed a general purpose multibody formulation implementing a pseudo-arc-length algorithm. Such algorithm even supports the analysis of problems subjected to bifurcation and turning points in nontrivial static structures.

Multi-rigid-body system dynamics can be used to investigate the dynamics of a mechanical system of rigid bodies while the FEM is often utilized to model the quasi-static elastic deformations of an elastic structure. However, neither of these two methods can resolve the real dynamics of a mechanical system when both rigid displacements and elastic deformations coexist. Yu et al. [11] therefore, proposed a meshing method to simulate the mechanical system with uniform mass point movements. They splited the specified solid structure into a set of regularly distributed dynamic units. This method is especially useful for real mechanical systems where the rigid displacements and elastic deformations coexist. A QD designed on this principle may yield more realistic results for stress and deformation.

Wu et al. [12] studied the dynamic characteristic of a uniform rectangular plate with four boundary conditions. They have taken for analysis, three kinds of multiple concentrated elements such as rigidly attached point masses, linear springs and elastically mounted point masses. QD key components could be classified in this way to address the different load and boundary conditions. Firstly, the closed-form solutions for the natural frequencies and the corresponding normal mode shapes of a rectangular 'bare' (or 'unconstrained'), plate (without any attachments) with the specified boundary conditions were determined analytically. Next, by using these natural frequencies and normal mode shapes incorporated with the expansion theory, the equation of motion of the 'constrained' plate (carrying the three kinds of multiple concentrated elements) was derived. Finally, numerical method was used to solve this equation of motion for natural frequencies and mode shapes of the 'constrained' plate. To confirm the reliability of previous free vibration analysis results, a finite element analysis was also conducted. It was found that the results obtained from the above-mentioned two approaches were in good agreement.

For better life expectancy, the predictive analysis of QD propeller blade is essential using advanced condition monitoring technique. Power and Ganguli [13] studied the rotor track balance technique for non-destructive testing (NDT) approaches, such as modal methods, acoustic emission, and wave-based approaches for rotor health monitoring. They discussed its use for commercial health and usage monitoring systems. Through their research, aeroelastic analysis for rotor system fault modeling was carried out using neural network and fuzzy logic.

Further on blade analysis, Rammurthy and Srinivasmurthy [14] developed a FEM for pre-twisted and tapered blades that determines the stresses and deformations. For this analysis, they used three-dimensional, twenty-noded isoperimetric elements to perform extensive analysis for various pre-twist angles, skew angles, breadth to length ratios, and breadth to thickness ratios of the blades. Their experimental investigation showed a good arrangement with finite element finding.

Use of functionally graded material (FGM) ensures variation in composition and structure as per need over the volume. It results in corresponding improvement of properties of structure. Making of QD components using FGM would be of better choice as the high stress variation can be achieved for different components. In order to apply FGM in QD, a detailed knowledge of shear and normal deformation [15], thermo elastic bending [16] of the same is needed. To address the dynamic and vibration issues, the QD base structure is worth assuming sandwich beam of laminated plates [17–20,22]. The thermo mechanical bending and hygro-thermo-mechanical loading condition [24,25] found useful for such laminated base plate structure. The free vibration of the arm because of mounting of the propeller motors at free end [21,23,26] requires a novel higher order shear deformation analysis.

Based on this literature review it is understood that there are many fundamental methods developed in analysis of beams and structure for both static and dynamic loading conditions. Few applications are reported and discussed. Particularly, a QD type multi mode vehicle and its key components are not analyzed for its strength using these advanced techniques. Hence, FEM for struc-