Chapter 24
Finite Element Analysis of Amphibian UAV Structure

Ting Kee Sheng, Balasubramanian Esakki and Arunkumar Ponnambalam

Abstract Unmanned aerial vehicles are extensively exploited for diverse applications importantly surveillance, reconnaissance, defense, and military. Development of unmanned amphibious vehicle with integrating features of multirotor and hovercraft principles to navigate along and above water body, land surface, and also flying in the air is a challenging task. This article presents a conceptual design of amphibious vehicle for the payload capacity of 7 kg with an endurance of 20 min and provision for mounting water sampler to collect water samples in remote water bodies. Finite element analysis (FEA) is performed to evaluate the structural strength characteristics of each part of the amphibious vehicle, and the integrity of the structure is analyzed. FEA results indicated that the designed amphibious vehicle structure is well within the stress limit and the minimal displacement is obtained. Materials for various parts of vehicles are determined through structural analysis, and the overall amphibious structure is analyzed with a due consideration of lift carrying capacity, payload, battery, and other electronic module weights.

Keywords Amphibious UAV · Quadcopter · Hovercraft · Structural analysis · Finite element analysis

24.1 Introduction

Unmanned aerial vehicles (UAVs) are classified with reference to body shape and size are fixed, flapping and rotary wings [1]. These UAVs made a vivid impact in multifaceted applications including environmental monitoring, search and rescue, bridge inspection, traffic monitoring, mapping of mines, wildlife surveying, precision agriculture, etc. [2]. Design and development of aerial vehicles with diverse

T. K. Sheng
Polytech Orleans, Orléans, France

B. Esakki (✉) · A. Ponnambalam
Vel Tech Rangarajan Dr. Sagunthala R & D Institute of Science and Technology, Chennai, India
e-mail: esak.bala@gmail.com

payload capacity and an ability to perform necessary missions pertaining to specific applications are in the rise. There are few research works on the development of amphibious vehicles [3–8]; the design of hovercraft systems [9–14] and many works have been carried out on the development of quadrotor systems. However, the usage of UAVs in water quality monitoring and collection of water samples in remote water bodies are scarce. Especially, the design of amphibian characteristics UAVs can fly, land, and glide along the water surface imposing a lot of challenges in terms of control in flight transition, selection of materials, propulsion, energy consumption, and payload capacity. In addition, other factors such as durability, reliability, safety, and minimal cost are utmost important for industrial demand and customer requirement. There are few floating UAVs which have been developed and commercialized in the market. However, integrating the characteristics of multirotor and hovercraft systems is not being explored in the literature. These vehicles are aimed to cover large areas of water bodies in a short span of time. Unlike other floating vehicles, due to the principle of hovercraft, the friction between the vehicle and water surface is avoided and thereby a huge amount of energy is saved. The vertical takeoff and landing ability of vehicle can position the vehicle in precise water locations across rivers, ponds, and other water bodies to collect water samples. Designing amphibious vehicle with sufficient strength characteristics to withstand lift conditions and carrying necessary payload are considered to be challenging. In this work, an amphibious model is developed to carry a payload of 7 kg. Finite element analysis is performed for UAV frame, hull, skirt, and amphibious structure through varying the materials to examine the structural strength and integrity of the structure.

24.2   Conceptual Model of Amphibious Vehicle

Amphibious model is conceptualized through integrating the principles of quadcopter and hovercraft as shown in Fig. 24.1. The basic H-UAV frame is used to act as quadrotor, and at the four corners, lightweight motors and propellers are assembled to generate sufficient thrust force to lift the entire vehicle. The lifting capacity can be increased by providing coaxial propellers so that payload carrying capacity may be increased. At the middle of the vehicle, a water sampler mechanism is placed, and at the rear, a duct fan is positioned to achieve directional control while in hovercraft mode. The batteries, electronic accessories, flight controllers, and other electrical elements are appropriately distributed to balance the center of gravity of the vehicle.
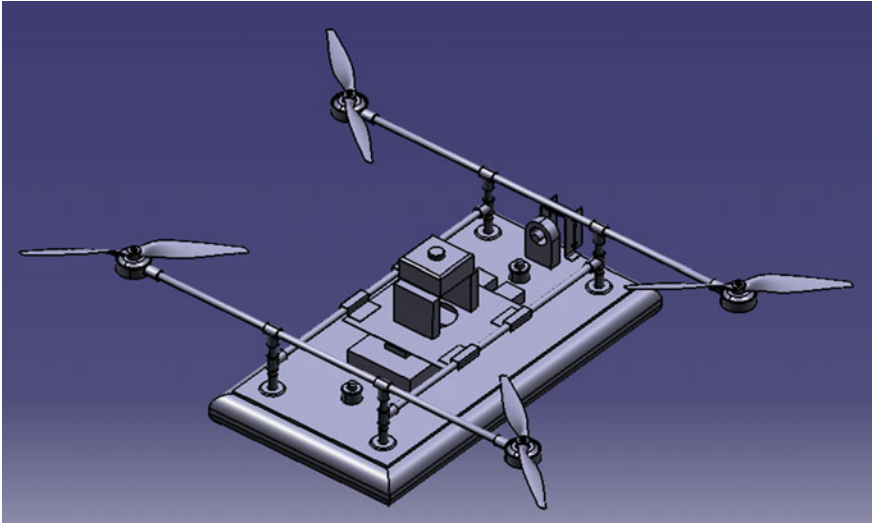
Fig. 24.1 Conceptualized model of amphibious vehicle

24.3 Finite Element Analysis of Amphibious Parts and Integrated Structure

In order to determine the suitable material for each amphibious part, structural analysis is performed through varying the materials. They are selected with respect to high strength-to-weight ratio, manufacturability, low cost, and also its availability.

24.3.1 Quadrotor Frame

The quadrotor frame is meshed (Fig. 24.2) with tetrahedron element having three degrees of freedom (DOF) with skewness of 0.978 and an aspect ratio of 2. The elements are maintained with maximum tetrahedron angle of 102° and length of the element is 6 mm. The generation of thrust force from each propeller of about 10 kg is applied at each corner of the motor frame; a central load of 7 kg as the payload is concentrated for payload; and batteries and other loads are distributed appropriately in the frame structure. For various materials (Table 24.1), structural analysis is carried out to determine the minimal displacement and stress. Aluminum obtained the maximum stress of 15 MPa (Fig. 24.3) and the displacement of 2.22 mm (Fig. 24.4).

It is also observed from Table 24.1 that carbon fiber and aluminum obtained better performance in comparison with other materials. However, with respect to cost and availability, aluminum is preferred.
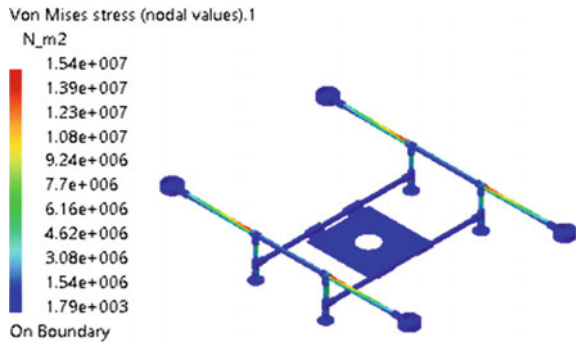
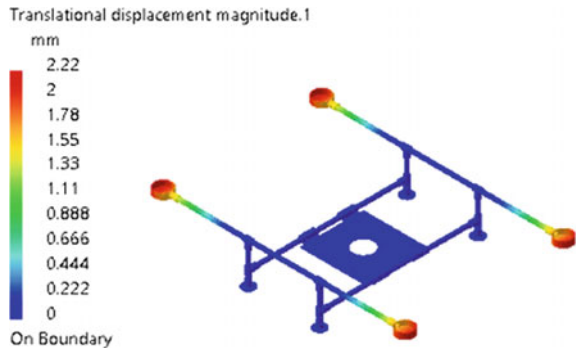**Fig. 24.2** Finite element model with boundary conditions

Table 24.1 Structural analysis results of various materials for UAV frame

Materials	Max stress (MPa)	Max displacement (mm)	Structure mass (kg)
Aluminum	15.4	2.2	6.6
Carbon fiber	12.4	1.7	3.9
ABS	12.2	45.8	2.6
PEEK	12	30.5	3.2
ULTEM	11.9	39.4	3.1

Fig. 24.3 Stress contour of UAV frame-aluminum

Von Mises stress (nodal values).1
N_m2
1.54e+007
1.39e+007
1.23e+007
1.08e+007
9.24e+006
7.7e+006
6.16e+006
4.62e+006
3.08e+006
1.54e+006
1.79e+003
On Boundary

Fig. 24.4 Deformation of UAV frame-aluminum

Translational displacement magnitude.1
mm
2.22
2
1.78
1.55
1.33
1.11
0.888
0.666
0.444
0.222
0
On Boundary

Fig. 24.5 Stress contour of hull
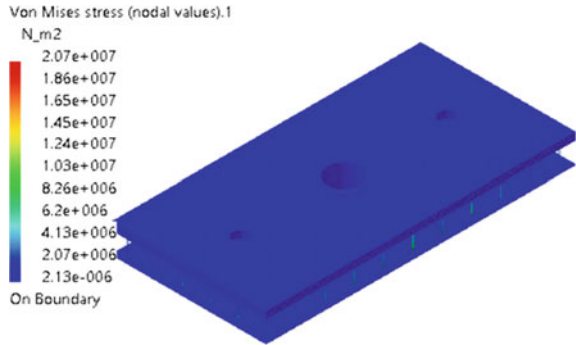
Fig. 24.6 Deformation of hull
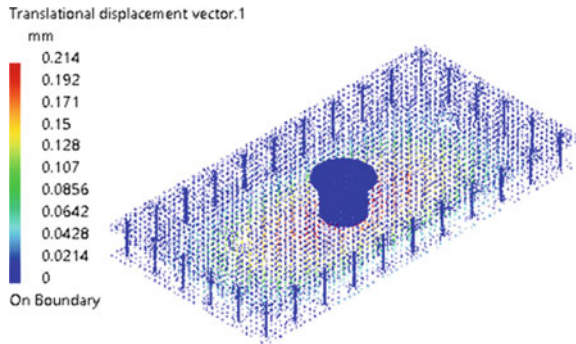
24.3.2 Hull

It serves as a platform to fasten the frame of the quadrotor together and hold the electronics hub. It also incorporates all hardware units, propulsion, wireless communications, soldered circuitry, and battery. The structure is made up of wood/foam sandwich to achieve minimal weight. Finite Element Analysis (FEA) is performed for the internal hull pressure of 731 Pa, 10 kg battery weight and other loads of 1.5 kg are acting on the hull is also considered for the analysis. Simulation results indicated that maximum stress (Fig. 24.5) of 20 MPa and deformation of 0.21 mm (Fig. 24.6) are experienced at the hull structure.
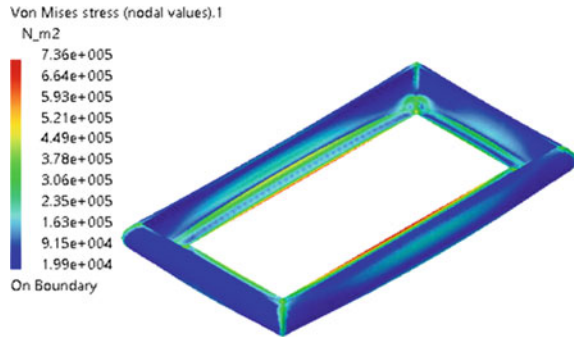
24.3.3 Skirt

The skirt is inflated during hovering mode, and it creates a cushioning effect between the vehicle and surface. An internal pressure of 731 Pa is applied along the periphery of the structure, and the static analysis is performed for diverse materials as given in

Table 24.2 Structural analysis results for various skirt materials

Materials	Max stress (MPa)	Max displacement (mm)	Structure mass (kg)
Natural rubber	0.74	352	0.969
Nylon impregnated with urethane	0.743	0.307	1.204
Urethane nylon	0.736	0.43	1.332
Neoprene coated nylon	0.736	0.202	1.278

Fig. 24.7 Stress contour of skirt

Von Mises stress (nodal values).1
N_m2
7.36e+005
6.64e+005
5.93e+005
5.21e+005
4.49e+005
3.78e+005
3.06e+005
2.35e+005
1.63e+005
9.15e+004
1.99e+004
On Boundary

Fig. 24.8 Deformation of skirt

Translational displacement magnitude.1
mm
0.202
0.182
0.162
0.141
0.121
0.101
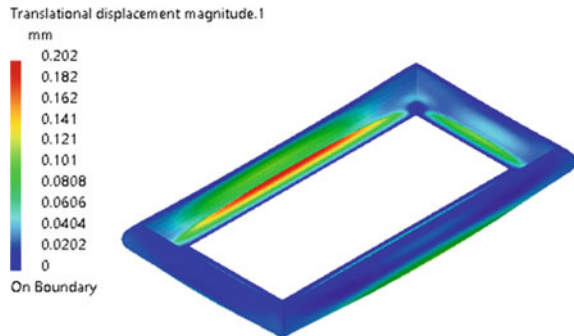0.0808
0.0606
0.0404
0.0202
0
On Boundary

Table 24.2. Due to the pressure loading, the minimal stress of 0.74 MPa (Fig. 24.7) and the displacement of 0.2 mm (Fig. 24.8) are obtained for nylon family materials.

24.3.4 Integrated Structure

After integrating UAV frame, hull, and skirt for the earlier material properties and applying appropriate boundary conditions, FEA is carried out to evaluate the integrity and strength of the amphibious structure.
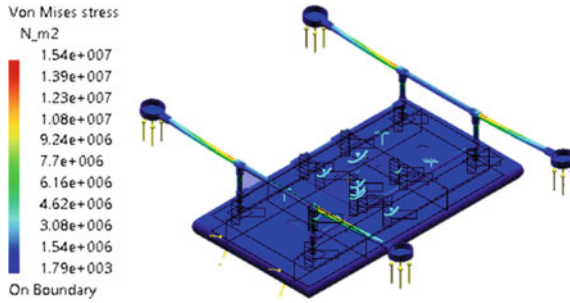
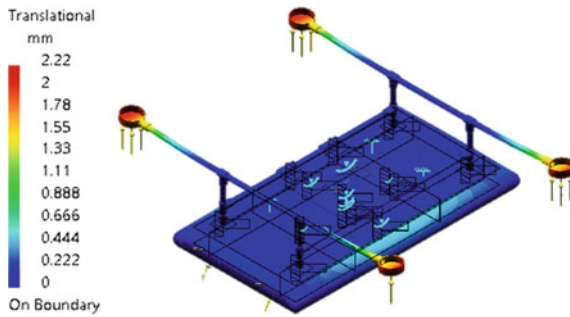**Fig. 24.9** Stress contour of amphibious structure


Fig. 24.10 Deformation of amphibious structure

Static analysis results indicate that the designed structure is well within the allowable stress (Fig. 24.9) and deformation of 2 mm can be seen at the four corners due to cantilever structure (Fig. 24.10).

The convergence of the solution is guaranteed with reference to analysis as shown in Fig. 24.11.

24.4   Conclusion

Amphibious vehicle is conceptualized for air, water, and land-borne operations to carry a payload capacity of 7 kg. Each part of an amphibious vehicle such as UAV frame, hull, and skirt is structurally evaluated with diverse material properties, and appropriate boundary conditions are considered. The following are the conclusions drawn from FEA:

- For the UAV frame, aluminum and carbon fiber obtained minimal displacement and stress. However, aluminum is cost-effective than carbon fiber.
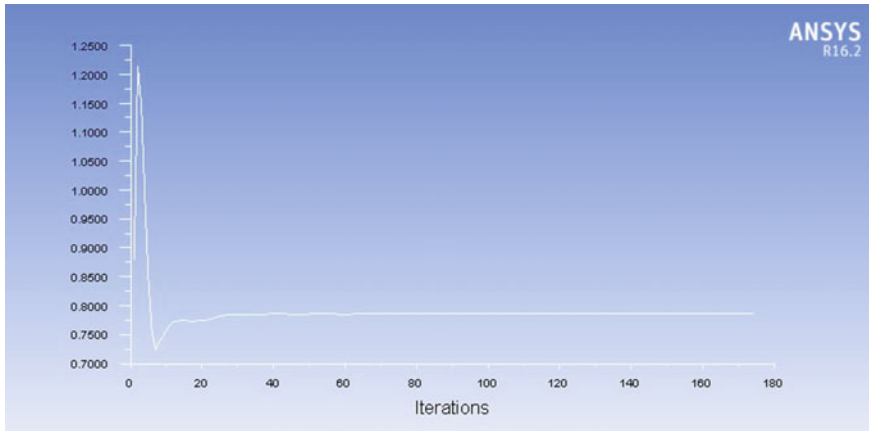
Fig. 24.11 Convergence of solution

- Hull material made of wood/foam sandwich structure has better load-carrying capacity to withstand the payload, weight of the battery, and other electronic modules.
- Neoprene-coated nylon obtained minimal displacement and stress in comparison with other nylon-based material, and it can be selected for the skirt.
- The integrated structure of quadrotor and hovercraft experienced minimal displacement and stress. Hence, the conceptualized amphibious structure can be built through these materials and it ensures the rigidity of the structure.

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