Stress and vibration analysis of a drone

M Urdea*

1Department of Manufacturing Engineering, Transilvania University of Brasov, 29 Eroilor, Brasov 500036, Romania

*E-mail: urdeam@unitbv.ro

Abstract. This paper refers to drones. The development of drones has been extremely fast in the last few years. They can be used in many different areas of military or of civil life, for industrial and agricultural purposes. In some fields this unmanned aerial vehicles may open up new horizons. These vehicles can solve a range of problems, in law enforcement contexts. Their two basic functions are flight and navigation. The purpose of this paper is to present this device, to develop a CAD model of it using SolidWorks and to perform FE analysis study. The drone frame was simulated and analysed in various conditions such as lift and vibration.

1. Introduction
A drone is an unmanned aircraft. It can be named a flying robot that can be controlled during the flight by a special software which works in conjunction with on-board sensors and GPS. On the other hand it can be associated with unmanned aerial vehicles (UAVs).

They were used initially only in the army, but now, the drones, are also used in the civil life, like traffic monitoring, civil surveillance, weather monitoring, search and rescue, surveillance of volcanoes, of fires, sensational footage in nature, aerial photos and movies, construction, utilities and telecom businesses, etc.

In the history of the army it is assumed that the first drones appeared in 1935 as unmanned aircraft. They have also evolved in this direction in the military, having been noted in civil plan since 2006. The use of drones on a large scale began in 2007, as a border monitoring between the U.S. and Mexico. In the last years the purpose of these devices is very important, their technology is improving, namely the altitude, the flight duration, the weight of payload, the speed, etc. In 2013 Amazon Company developed a project for delivering packages using drones and after that other companies have followed it [1].

The two basic functions of the drones are flight and navigation. The drones have, normally, a support like a frame, this is typically made of lightweight, composite materials. The goal is to reduce weight and to increase manoeuvrability in the flight. Drones require a flight controller, to launch, navigate and land the drone. Every controllers communicate with the drone using radio waves 2.4 MHz [2].

Other important components are: Electronic Speed Controllers (ESC - transmit voltage to motors), an electronic circuit that controls the motor speed and direction, GPS module (for some drone), Flight Controller (FC), video transmitter (VTX), 4 batteries, antenna, receiver (receives signals from the station), propellers, cameras, sensors, accelerometer, for measuring the speed and altimeter, for measuring altitude.

Most of the frame drones are manufactories using various materials such as aluminium, carbon fibre, plastic, ABS, ABS-PC. The manufacturing of the frame and the arms can be processed by laser cutting, by milling, by using 3D printing technology, etc.
Figures 1 and figure 2 present racing drones with complete equipment. The frame of the second drone will be a model for studying the future device.

![Racing drone](image1.png)  ![Drone used in analysing process](image2.png)

**Figure 1.** Racing drone.  **Figure 2.** Drone used in analysing process.

2. **The drone frame**

It starts from an existing frame, ready for a future racing drone (figure 3). Figure 4 presents the frame modelled in SolidWorks using for dimensions a real racing drone frame. The material of the components for the studied frame is aluminium 6061 Alloy. Aluminium is ideal for drones because it is a light and strong material, resistant to corrosion.

The frame is designed in SolidWorks with four arms, motors and propellers as in figure 5.

![The drone frame](image3.png)  ![The drone frame modelled in SolidWorks](image4.png)

**Figure 3.** The drone frame.  **Figure 4.** The drone frame modelled in SolidWorks.

![The modelled drone frame](image5.png)

**Figure 5.** The modelled drone frame.
3. Static analysis case for the frame

3.1. Preparing the frame for simulation

For performing FE analysis it is important to define all the forces acting on the frame. The weight of the frame and all components (ESP, GPS module, flight controller, motors-weight, battery, antenna, propellers and camera) is normal to the ground. Static loading involves a static study for calculating the response of bodies on which loads are applied statically or slowly.

For simulation, it is very important to create customized SolidWorks coordinate system, for remote loads locations. Figure 6 presents the coordinate systems for all the loads, this will be used for defining the remote loads in the static analysis. For theses loads the Remote Loads function will be used, figure 7 presents the Remote Loads defined as external loads. Gravity is attached like an external load [3, 4].

![Figure 6. The drone frame with coordinate system.](image-url)

![Figure 7. Remote Loads.](image-url)

The forces acting on the frame. The traction force of the motors was multiplied by a safety factor and divided for each arm. For a static analysis the fixtures ware attached. Namely Fixed Geometry to an arm leg and Roller Slider to the other three arm legs [3].

![Figure 8. Remote Loads for the motor.](image-url)

![Figure 9. Remote Loads/Mass window.](image-url)

The steps for activating the remote loads are presented in the following figures. For each load a mass is assigned in the Remote Loads/Mass window, also the location and the suitable coordinate system are selected. There results some parameters visible for motor positioned on the drone arm in the cylindrical area, (figure 8) and for all electronics components positioned in the frame centre (figure 9). The weight of the components is estimated as follows: battery 0.165kg, motor 0.04kg, VTX video transmitter 0.01, ESC 0.03kg, FC 0.01, receiver 0.01, other components 0.02 and camera positioned in front of the frame, 0.015kg.
In this step the frame is prepared for the static simulation. Figure 10 presents the external loads with the remote loads, gravity and the fixture.

![Figure 10. The drone frame prepared for static analysis.](image)

3.2. *The analysis results*

The next step is named post-processing. In this part, after meshing, images are generated corresponding to analysis results, specific to static analysis cases, namely Von Mises Stress (figure 11), used to measure the level of stress and Displacement (figure 12) used for measuring the maximum deflection. The most deformed area is the centre of the drone.

![Figure 11. Von Mises for static analysis.](image)
4. Linear dynamic study for an arm

The simulation for the arm of drone can require a Dynamic study, namely a Linear Dynamic with the Harmonic (Harmonic-fatigue of sinusoidal loading) option. Dynamic analysis is important when an applied load, due to the vibration, isn’t constant and isn’t applied slowly. In linear dynamic analysis, the applied loads are time-dependent [4].

Run Frequency is activated from Dynamic pull down menu and Remote Loads are defined for the arm according to the previous chapters. List Resonant Frequency open the List Mode window for dynamic study with Frequency values. Figure 13 presents the frequency (Hertz) default value, and figure 14 presents the frequency curve defined using the new period for every frequency. It is activated from Force window using Curve option namely Edit button. In this situation, for this analysis, 1N on the arm, is defined [3].

The selection Curve could be used for specifying the own variation of load versus frequency. The frequency column is the same from the List Modes, a new curve has been edited using other period values [3, 4].

With the Dynamic Properties one can open the Harmonic window and Solver/Direct sparse solver can be selected as in figure 15. The Direct Sparse solver is available for frequency, linear dynamic, and nonlinear studies [4]. The following values are defined in this window: Number of frequencies 10, by Frequencies Options, Frequencies upper limits 12583 by Harmonic option [5] (figure 16).
The final results of the linear dynamic study from an arm are the Von Mises stress distribution, the most requested area is the bolt area and the Displacements, the most deformed area is on the end of the arm, there is small displacement (figure 17 and figure 18).

5. Natural frequency study for the drone frame
Each structure tends to vibrate with frequencies. A natural frequency study calculates the natural frequencies, adding also the body’s mode shapes. For this study one can use the same External Loads structure and the FFEPlus Solver, the solver used for calculating the resonant frequencies. This option is viewed in the Properties/Frequency window, also the number of frequency [6, 7] (figure 19).

Figure 15. Direct Sparse solver.
Figure 16. Frequencies upper limits.

Figure 17. Von Mises.
Figure 18. Displacement.

Figure 19. Amplitudes.
After running a frequency study, the amplitude of vibration results in each mode (figure 19). Here the Mode Shape/Amplitude Plot can allow to manage the mode shapes for frequency. Figure 19 presents one of the resulted amplitude values.

There can be multiple results using double click an icon in a Results folder. For example, List Resonant Frequencies gives the list with requested number of resonant frequencies. The most requested area is the extremity area of the arms.

6. Conclusion
Several finite element analysis studies can be performed on a drone using SolidWorks. For instance: Assembly Static Analysis, Nonlinear Static Analysis, Nonlinear Dynamic Analysis, Structural Analysis, Vibration Analysis, Natural frequency study, and so on. These analyses can also be performed on an arm or even on a sectioned arm being symmetrical. SolidWorks is able to perform these analyses.

In this paper the results are based only on the use of FEA analysis in SolidWorks. In these analysis it was considered that the centre of gravity of the body coincides with the origin of the axes.

This paper uses SolidWorks modelling, supports the importance of SolidWorks study and aims to demonstrate the ease of use of this program and finally the many possibilities for developing finite element analysis. For the demonstration, a drone was chosen, being approved by inexperienced people. The material chosen was aluminium, lightweight, corrosion resistant. Attempts were also made to use AS34 carbon fibre, but the material library did not fully define this material.

The work can be continued with other studies by using carbon fibre in the arms or in the whole frame, in that case in which ANSYS will be used.

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