Design and manufacture of a UAV using additive technologies and composite materials

Razvan Alexandru MIHAILESCU*,[1,a], Ionel SIMION[2,b]

*Corresponding author
[1]S. C. Eurowind Energy S.R.L.,
8th Coltei Street, 2nd floor, office 11, District 3, 030244 Bucharest, Romania,
razvan.mihailescu98@yahoo.com*
[2]Department of Engineering Graphics and Industrial Design,
POLITEHNICA University Bucharest,
Splaiul Independentei 313, 060042, Bucharest, Romania,
ionel.simion@upb.ro

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Abstract: *The aim of the study is the development of a VTOL (Vertical Takeoff and Landing) bicopter, utilizing Autodesk Inventor and Ultimaker Cura software. Design models were inspired by the V22-Osprey and Samson SA-2 from the Avatar movie. Composite materials (carbon fiber and PLA for 3D printing) were chosen due to their high-performance capabilities, as aerospace technology is in an ongoing development and evolution. The construction of the bicopter employed the FAAT method, and for control, the MATEK F411-WSE was utilized to process data from sensors, with specific firmware and the BetaFLIGHT interface for optimizing drone performance.*

Key Words: *VTOL, bicopter, 3D printing, carbon fiber, PLA, Autodesk Inventor, Ultimaker Cura, V22-Osprey-inspired, Samson SA-2-inspired, FAAT method, MATEK F411-WSE, specific firmware, BetaFLIGHT interface*

1. INTRODUCTION

Significant Changes in the Aerospace Industry in the 21st Century, such as fuel economy and innovative recyclable materials, have led to improvements in aircraft performance and contributed to the emergence of drones.

Unmanned aircraft, commonly known as drones, are flying devices controlled by an onboard digital autopilot or from a ground control center. These flying devices have a significant impact on both civilian and military life.

Drones can be classified into two groups: military and civilian. Military drones are used for spying, surveillance, reconnaissance, and combat operations.

Civilian drones come in two types: recreational and commercial. Recreational drones are used in sports competitions, drone racing, aerial acrobatics, or for FPV (first-person view)

[a] MSc. Ing.
[b] Prof. Dr.

flight [2], [3]. Commercial drones are used for purposes such as aerial filming, large-scale surface measurement, scientific research, product delivery, etc [1].

The development of new composite materials supports the research and development of high-performance aircraft, justifying the relevance of this topic in the context of the ever-evolving aerospace technology.

2. DESIGNING AND MANUFACTURING OF A BICOPTER UAV

A Bicopter is an aircraft with two main rotors, which provide directional control and stability through individual adjustment of the speed and torque generated by each rotor. The Bicopter offers notable advantages, including excellent maneuverability, simple construction, and lower costs.

However, it also presents some disadvantages such as lower stability compared to multi-rotor aircraft, limited carrying capacity, and shorter flight times due to high energy consumption [4], [5].

In the process of our research, we aimed to develop a VTOL (Vertical Takeoff and Landing) Bicopter using Autodesk Inventor and Ultimaker Cura software.

Composite materials, specifically PLA+ and carbon fiber, were employed for the construction of the Bicopter.

Black Norditech PLA+ filament was used for printing the components, while carbon fiber tubes were utilized and adapted as needed. Assembly was carried out using M2 and M2.5 steel screws, and special provisions were made for electronic components, including positioning the baseplate, steering servo brackets, steering servos, ESC (Electronic Speed Controller), controller, etc.

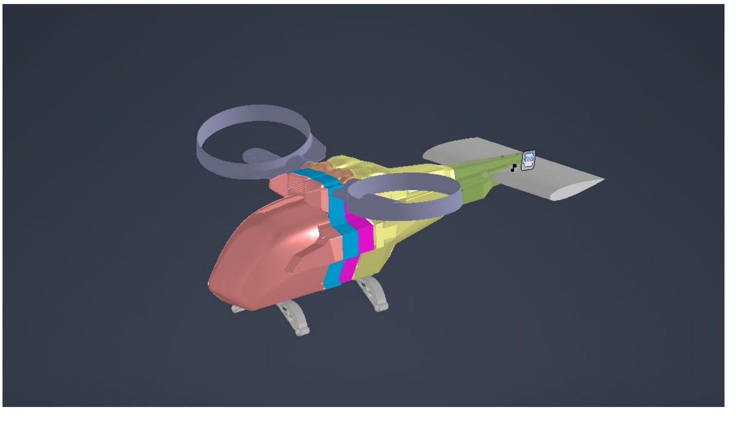

Figure 1. - Theoretical Representation

Figure 2. - The Constructed Prototype

The major challenge in controlling bicopters is stability because yawing motion can also induce rolling movements, and bicopters are unable to perform vertical ascents or descents. To control pitch up or down, the rotors can be tilted around their vertical axes [6].

There are three primary solutions for bicopter stability control: Forward-Aft Active Tilt (FAAT): Control is achieved by altering the rotor speeds.

Oblique Active Tilt (OAT): It utilizes gyroscopic forces generated by tilting rotors for stabilization, offering quicker control responses compared to FAAT. Precision Motion: This concept involves the concept of gyroscopic precession, which pertains to the rotational movement of a rotating object under the influence of an external torque, resulting in a conical trajectory for its axis of rotation [6].

In the case of the bicopter, two control methods were studied: FAAT and OAT, with OAT incorporating an additional gyroscope for enhanced reactivity.

The construction of the bicopter involved the use of the FAAT method, utilizing servo motors for tilting the support arms of the motors made from carbon fiber and PLA structure.

The MATEK F411-WSE controller was employed to process data from sensors, featuring specific firmware and the BetaFLIGHT interface to optimize drone performance [6].

3. EQUATIONS OF MOTION AND ESTIMATED PERFORMANCE OF THE BICOPTER

Vertical Motion

$$\sum F_v = M * a_v \tag{1}$$

$$F * \cos\theta - M * g = M * a_v \tag{2}$$

$F * \cos\theta$ = vertical component of thrust force
$\theta = \text{angle (rotor axis, vertical)}$

$$a_v = -g + \frac{F \cos\theta}{M} \tag{3}$$

a_v = rate of climb
At the limit a_v = 0 (takeoff condition)

$$(F \cos\theta)_{min} = M * g = 7N \tag{4}$$

Horizontal Motion

$$\sum F_h = M * a_h \tag{5}$$

$$F \sin\theta - kv^2 = M * a_h \tag{6}$$

$F \sin\theta$ = horizontal component of thrust
$-kv^2$ = air resistance force (drag)

$$F \sin\theta - kv^2 = M * \dot{v} \tag{7}$$

$$k = \frac{1}{2} * C * A * \rho \tag{8}$$

C = drag coefficient = 1

A = cross section drone fuselage ≈ 0.02 m^2
ρ = 1.225 kg/m^3 (air density)
k = 0.02 NS^2/m^2 (calculated)

$$F \sin\theta - kv^2 = M * \dot{v} \tag{9}$$

$$\dot{v} = \frac{-k}{M} * v^2 + \frac{F \sin\theta}{M} \tag{10}$$

$$\frac{dv}{dt} = \frac{-k}{M}\left(v^2 - \frac{F \sin\theta}{k}\right) \tag{11}$$

Separable differential equation

$$v(F,\theta,t) = \sqrt{\frac{F \sin\theta}{k}} * \frac{1 - e^{\frac{-2k}{M} * \sqrt{\frac{F \sin\theta}{k}} * t}}{1 + e^{\frac{-2k}{M} * \sqrt{\frac{F \sin\theta}{k}} * t}} \tag{12}$$

$$a_h = \dot{v} \quad \Rightarrow \quad a_h(F,\theta,t) = \frac{4F \sin\theta}{M} * \frac{e^{\frac{-2k}{M}\sqrt{\frac{F \sin\theta}{k}} * t}}{\left(1 + e^{\frac{-2k}{M}\sqrt{\frac{F \sin\theta}{k}} * t}\right)^2} \tag{13}$$

$$V\,max = \lim_{t\to\infty} v(F,\theta,t) = \sqrt{\frac{F \sin\theta}{k}} \tag{14}$$

$$a(t=0) = \frac{F \sin\theta}{M} \tag{15}$$

Table 1 - The terminal velocity and acceleration at time $t = 0$ for two different rotor tilt angles

θ	30°	45°
$V\,max(m/s)$	18.7	22.2
a (t=0) (m/s^2)	10.0	14.1

The graph of horizontal velocity/ acceleration as a function of time.

where:

$F := 14$ — F: the thrust force is measured in Newtons (N)
$\theta := 30\text{deg}$ — θ: angle(deg) (rotor axis, vertical axis)
$M := 0$ — M: the mass of the drone is measured in kilograms (kg)
$k := 0.02$ — k = constant that depends on both the geometry of the object and the fluid (air)
$t :=$ — t: the time interval from 0 to 14 seconds

We will use the following derived equations for velocity and acceleration:

$$v := \sqrt{350} \cdot \frac{1 - e^{-2\cdot\frac{\sqrt{10}}{35}\cdot t}}{1 + e^{-2\cdot\frac{\sqrt{10}}{35}\cdot t}} \tag{16}$$

$$a := 40 \cdot \frac{e^{-2\cdot\frac{\sqrt{350}}{35}\cdot t}}{\left(1+e^{-2\cdot\frac{\sqrt{350}}{35}\cdot t}\right)^2} \tag{17}$$

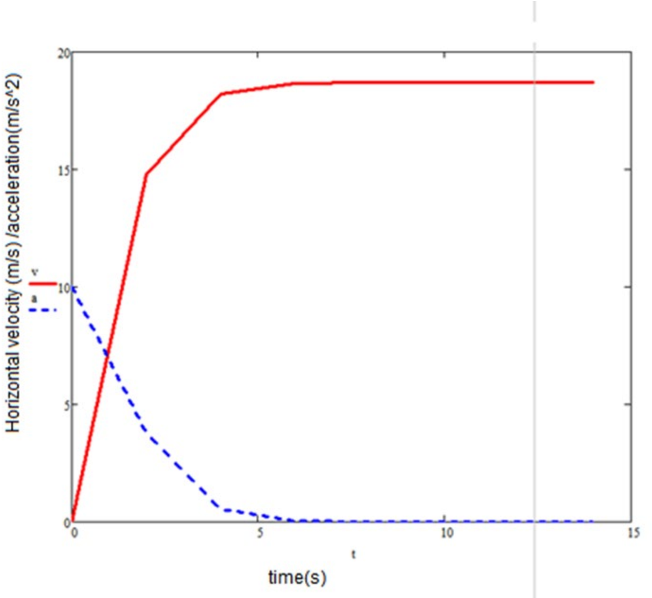

Figure 3. - The graph of horizontal velocity/acceleration as a function of time

According to calculations, it is estimated that the horizontal velocity reaches its maximum value in approximately 8 seconds.

4. CONCLUSIONS

The research paper provides a detailed overview of the development process of the drone, including its design, materials used, geometric modeling, and components. It opens up promising avenues for future research in the field of bicopters, with a focus on the development of advanced controllers and stability enhancements.

The paper can serve as a starting point for future research in the field of drones and innovative propulsion technologies. On my quality as the author, I emphasize my personal contribution to the research and development of this UAV through improvements to the design and manufacturing processes, the development of electronic settings, and the creation of a functional prototype.

I also highlight the potential introduction of sensors such as ultrasonic sensors, thermal anemometers, and lidar to enhance the bicopter's functionality. The prototype can be applied in various fields, and future research can explore the integration of ultrasonic sensors, autopilot systems, and GPS into this system.

This prototype provides a solid foundation for further research and brings to the forefront multiple avenues of exploration in the field of bicopters.

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