International Journal of Computer Applications Technology and Research
Volume 13–Issue 12, 01 – 04, 2024, ISSN:-2319–8656
DOI:10.7753/IJCATR1312.1001

Design Parameters Effects on a Quadrotor Mini-UAV Consumed Energy

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Abstract: This article focuses on the influence that a selection of design parameters has on the energy consumption of a quadcopter minidrone. The minidrone was modeled as a rigid body of the cylinder type with a 30 cm of radius, a 1,47 kg of weight and a 20 cm of height to assess the impacts of the piloting mode. To determine the mass and size effects, 250 g of loads were added, radius and height were increased 5 cm. A cubic minidrone and an oblate spheroid minidrone were studied to understand the influence of the shape choice. It was found that the oblate spheroid minidrone is the least energy-consuming, if we refer to the traveled distance and the maximum reached altitude with the same consumed energy. MATLAB-SIMULINK are used for the simulation.

Keywords: piloting mode, cubic minidrone, oblate spheroid minidrone, energy-consuming, shape choice

1. INTRODUCTION

UAV design is based on three notions: the desired performance, the required energy and the weight and size of the embedded equipment. Even if the list of equipment can be determined, the risk of energy consumption increasing, it's subsist. Obtaining optimal energy autonomy remains a challenge for designers [1]. Integrating parameters into the assessment of the minidrone energy consumption from the design stage is an option to consider. In this article, we will focus our analysis on the piloting mode, the mass and size and the shape and general appearance of a minidrone. To simulate the impacts of these parameters, some modifications are made to the model presented in reference [2].

2. PILOTING MODE

Two piloting mode are considered: hard piloting and soft piloting. These piloting modes will be identified from the motor speeds variations. Hard piloting corresponds to rapid changes motor speeds, which is the opposite of soft piloting.

2.1 Parameters and hypothesis

For the simulation, the quadrotor is modeled as a rigid body of the cylinder type with a 30 cm of radius, a 1,47 kg of weight and a 20 cm of height. We assumed that for soft piloting, 12 s is necessary to change to another speed, and for hard piloting, this duration is 2 s. Figure 1 shows the motor speeds evolution according to the piloting mode.

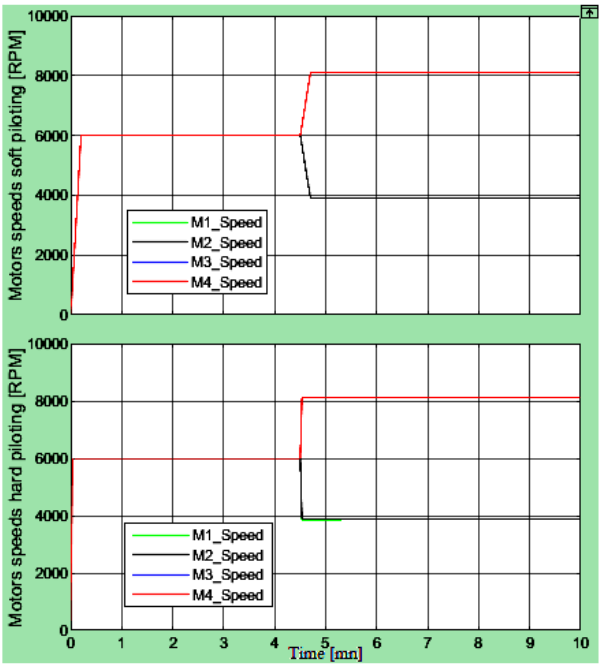

Figure. 1 Motor speeds evolution according to the piloting mode

For soft piloting, the starting time is 12 s to reach 6000 RPM. We kept this speed for all motors for 4 min 18 s. We change the speeds of the motors 4 min 30 s after starting and we use as new values : $\omega_1=\omega_2$ = 3900 RPM and $\omega_3=\omega_4$ = 8100 RPM. For hard piloting, we push the motors to reach 6000 RPM in 2s. We maintain this speed for 4 min 28 s. And 4 min 32 s after starting, we access the new values: $\omega_1=\omega_2$ = 3900 RPM and $\omega_3=\omega_4$ = 8100 RPM.

2.2 Consumed powers

These speed values correspond to a take-off and a forward movement simulation. Figure 2 shows the evolution of the consumed powers according to the piloting mode.

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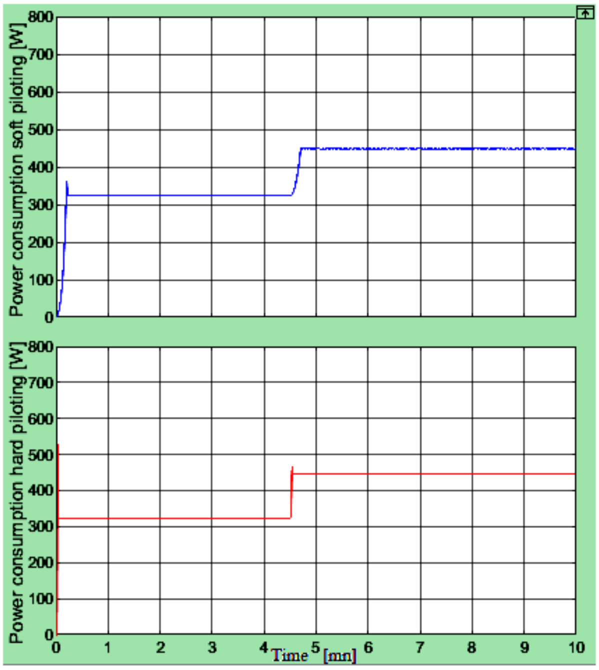

Figure. 2 Consumed powers evolution according to the piloting mode

The required power peak at start-up reaches 360 W for soft piloting, compared to 515 W for hard piloting. Still for the hard piloting mode, a second peak of 467,75 W corresponding to speed changes was observed. Apart from these peaks, the consumed powers remains the same for all piloting mode and varies from 323,5 W to 446,5 W.

2.3 Traveled distances

With soft piloting, the minidrone covered a distance of 10 m in 5 min 18 s without deviating from its trajectory. The maximum altitude of 111,25 m is reached in 7 min 42 s after starting the motors. For hard piloting, the minidrone covered a distance of 9,13 m with a slight deviation to the right in 5 min 28 s. The maximum altitude of 123.65 m is reached in 7 min 36 s after starting the engines. Figures 3 and 4 illustrate these movements.

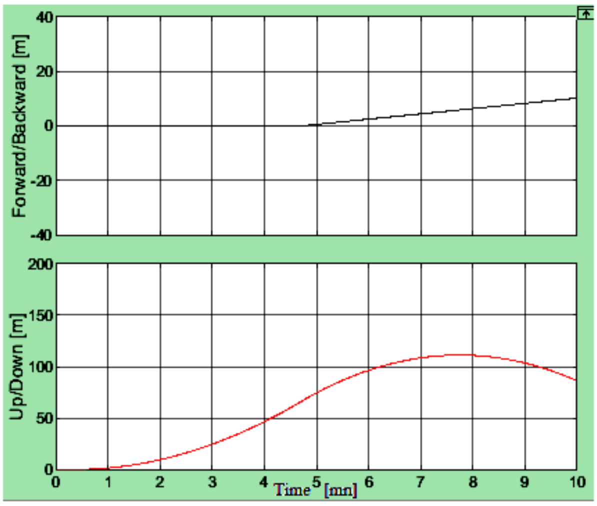

Figure. 3 Traveled distances for soft piloting mode

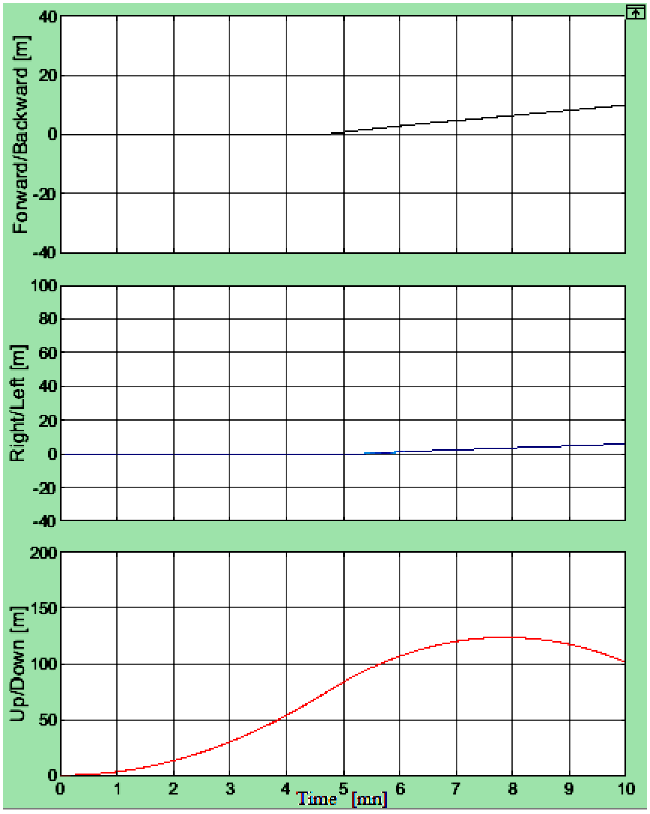

Figure. 4 Traveled distances for hard piloting mode

Assuming that the research results presented in reference [2] are obtained from a moderate piloting mode, Table 1 shows the comparison of some parameters according to the piloting mode.

Table 1. Comparison of all piloting mode

Parameters	Piloting mode		
	Soft	Moderate	Hard
Traveled distances [m]	10	9,4	9,13
Maximum altitude [m]	111,25	117,9	123,65
Take-off after starting motors [s]	34	18	4
Peak at start-up [W]	360	394,5	515

3. ADDING LOADS WITH UAV SIZE EXPANSION

The size and mass of the payloads and their power requirements are the main determinants of the layout, size and total mass of a minidrone [3]. To simulate adding payloads with UAV size expansion, we will modify the model in reference [2], adopting a radius of 35 cm, a height of 25 cm and a weight of 1,72 kg.

3.1 Consumed powers

For the simulation, we chose the moderate piloting mode. Figure 5 shows the evolution of the power consumed by the minidrone.

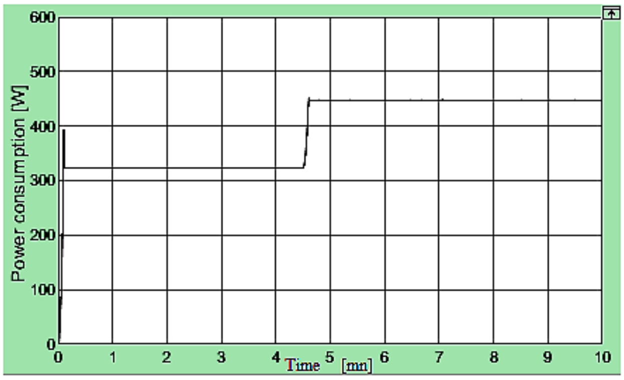

Figure. 5 Consumed powers evolution with additional loads

From the figure, we obtain the same result as the first simulation of the reference [2]. This shows that even if we add loads while expanding minidrone size, with the same values for the motor speeds, consumed powers remains unchanged.

3.2 Traveled distances

The minidrone continues to climb and begins to move forward 4 mn after takeoff. In 5 mn 12 s, the minidrone has traveled a distance of 9,59 m without deviating from its trajectory. The maximum altitude of 61,58 m is reached 7 mn 30 s after takeoff. Figure 6 illustrate these movement with additional loads and an expanded size.

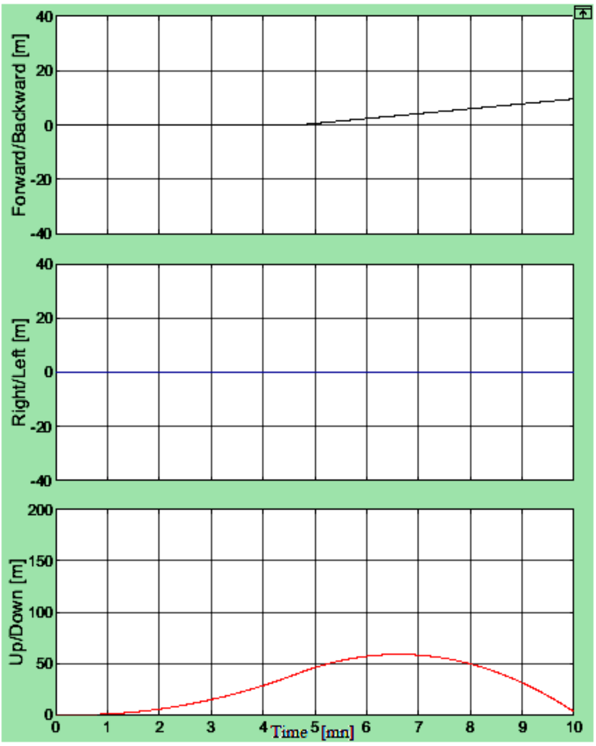

Figure. 6 Traveled distances with additional loads

4. SHAPE CHOICES

To have an improved energy autonomy, either we increase the number of on-board batteries or we implement another power embedded system. This approach would have an impact on the choice of the shape of the minidrone. The prototype in Fig. 7 could be considered for a minidrone that embeds a network of rectennas to reinforce the battery.

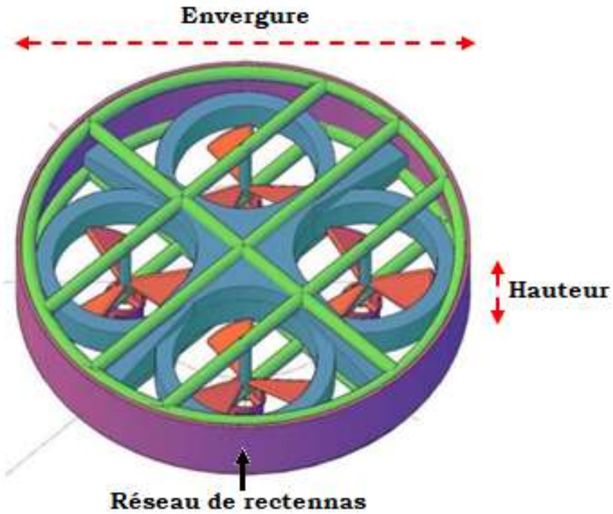

Figure. 6 Prototype with embedded rectennas networks [4]

Figure 8 illustrate the general appearance of a solar-powered quadcopter UAV from different views.

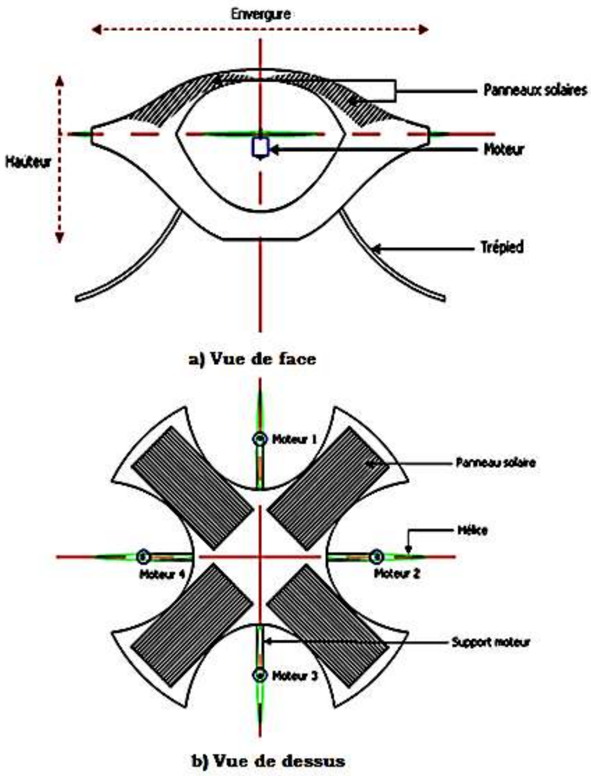

Figure. 6 Prototype of a solar-powered quadcopter UAV [5]

As the cylindrical shape is already mentioned in reference [2], we will focus our analysis on two other shapes: the cubic shape and the oblate spheroid shape.

4.1 Inertia matrix

The inertia matrix of a cubic shape is given by the relation:

$$\begin{bmatrix} I_{xx} \\ I_{yy} \\ I_{zz} \end{bmatrix} = \frac{1}{6}.m.a^2 \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (1)$$

where *m* is the weight and *a* is the edge of the cube.

For the ellipsoid shape of length 2a, width 2b and height 2c, the inertia matrix is given by the relation:

$$\begin{bmatrix} I_{xx} \\ I_{yy} \\ I_{zz} \end{bmatrix} = \frac{1}{5}.m \begin{bmatrix} (b^2+c^2) & 0 & 0 \\ 0 & (a^2+c^2) & 0 \\ 0 & 0 & (a^2+b^2) \end{bmatrix} \quad (2)$$

Also, to have an oblate spheroid shape, we adopted a = b < c, and the relation that defines the inertia matrix becomes:

$$\begin{bmatrix} I_{xx} \\ I_{yy} \\ I_{zz} \end{bmatrix} = \frac{1}{5}.m \begin{bmatrix} (a^2+c^2) & 0 & 0 \\ 0 & (a^2+c^2) & 0 \\ 0 & 0 & (2.a^2) \end{bmatrix} \quad (3)$$

Equations (1) and (3) are implemented in the "Inertial_system" block of the main model presented in reference [2], to identify the interaction between the chosen shape and the consumed energy. With the initial cylindrical shape, Table 2 resume the shape specifications of the studied minidrones.

Table 2. All shape specifications

Parameters \ Shapes	Cylindrical	Cubic	Oblate spheroid
Weight [kg]	1,72		
Radius / Edge [cm]	35	46	34
Height [cm]	25	-	20
Volume [m^3]	0,09		

4.2 Simulation results

The same parameters were used as those of the first simulation of the reference [2]. We therefore simulate a take-off and a forward movement for 10 mn. Table 3 recaps the results of our simulations for these shapes.

Table 3. Recapitulation of the simulation results

Results \ Shapes	Cylindrical	Cubic	Oblate spheroid
Traveled distances [m]	9,59	7	9,31
Maximum altitude [m]	61,58	63,31	64,32
Take-off starting motors [s]	36	36	30
Total thrust [N]	24,5 to 27,5		
Peak at start-up [W]	394,5		
Consumed powers [W]	323,5 to 447,5		

From this table, we can conclude that the oblate spheroid shape minidrone is the least energy-consuming, followed by the cylindrical shape. This conclusion is based only on the traveled distance and the maximum altitude reached by the minidrone, with the same power consumption.

5. CONCLUSION

Many parameters can affect the energy consumption in a quadcopter minidrone. In this article, we focused on the piloting mode, the addition of loads and the choice of shape. Simulations were performed with MATLAB-SIMULINK to identify the impacts of these parameters on the energy consumed. It was found that with the aggressive piloting mode, power peaks appear at each acceleration. With the additional loads, the mass, size and shape of the minidrone could be modified, as needed. It was concluded that the oblate spheroid shape minidrone is the least energy-consuming, if we refer to the traveled distances and the maximum altitude reached with the same consumed energy.

6. REFERENCES

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