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Original Article

Conceptual Design of a Hybrid Power System for a Spraying UAV Applied to Family Farming in Arequipa – Perú

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Abstract - *The effective use of UAVs in agriculture, especially crop-spraying drones, requires a more extended flight range. Batteries currently limit a drone's flight time since purely electric drones tend to consume more electrical energy with their higher payload capacity. For this reason, the present project proposes the improvement of an Agras MG-1P octocopter drone batteries' load supply through a load system consisting of a double-cylinder VVRC RCGF 70cc combustion engine and a KDE10218XF-105 brushless motor as a generator. The brushless motor operates as a generator since it weighs less than an alternator or generator. The weight is significant, and the octocopter can stay longer in the air. This project aims to increase the Agra MG-1P Octocopter UAVs flight time by more than two hours, as well as its payload, having a 9 l variable load of fumigant and a 4.4 kg load of added components, which are enough for spraying operations or FAP (Farm Agroforestry Planning) in Peru.*

Keywords - *Hybrid power system, Agriculture spraying drone, Octocopter flight time, Fumigation using drone.*

1. Introduction

Globally, agricultural production and consumption are projected in 2050 to be 60% higher than quantified in 2007. Despite the agricultural sector's historic capability to meet such demand, the limits to food production for a growing world population are still a matter of debate and concern [1]. Family farming in Latin America and the Caribbean plays a fundamental role in the fresh food supply, employing more than 60 million people in the said production process, representing between 57% and 77% of employment in the said region [2]. The agricultural technologies and methods most used for spraying by these farmers are based on spray planes and motor sprayers-type backpacks [3], [4].

Peruvian agriculture is diversified and heterogeneous for geographical, productive, and socioeconomic reasons, where family farming represents 97% of the crops with extensions of less than 10 hectares [5]. Pest control technology for small crop areas in Peru consists of backpack pumps or motorized backpack sprayers [6]. The application of pesticides using these means could be more efficient because:

- The spraying of the agrochemical product is carried out at a height between 10-20 centimeters from the ground, which causes an approximate over-concentration of up to 90% of chemicals in the crops, generating possible contamination of the fruit or agricultural product. This spray method requires a more significant amount of agrochemicals and spraying time [7];
- More workers are needed to cover large areas, requiring too much physical effort, which increases production costs [8];
- Farmers wear either inadequate or no protective equipment when operating motorized backpack sprayers [9]. Most farmers have had symptoms of pesticide poisoning at least once [10].

Although the technology of tractors and aircraft facilitates spraying, this requires the presence of a specialized pilot or operator whose coat is economically feasible for family farming. However, an alternative to reduce operating costs and obtain greater efficiency is the application of agrochemicals by autonomous or remotely controlled Unmanned Aerial Vehicles (UAVs) or Drones [10].

The drone or spraying UAV is an alternative to performing precision tasks with greater efficiency, speed, and less human intervention in adverse terrain conditions and at various heights [11]. In addition, these UAVs can also be used in other tasks in the sector, such as agricultural surveillance and adequate and accurate crop data, showing the difference between infected or diseased crops and ready-to-grow crops, reducing human effort [12].

For this reason, using UAVs as an innovative technological tool can solve the problems mentioned above. However, one of the most critical factors in using this technology resides in its flight range to complete designated tasks related to its energy capacity. Most of these systems use batteries as the power source, limiting UAV performance [13]. For this reason, this research develops a conceptual design of a hybrid system (internal combustion engine and a brushless motor as a generator) to increase the flight autonomy of a DJI Agras MG-1P spraying octocopter.

2. State of the Art

2.1. Unmanned Aerial Vehicle (UAV) for Civil Use

UAV classification depends on the principle of aerodynamic flight: fixed-wing or rotating wings [14]. More recently, the so-called V-Tol UAVs combine these principles of aerodynamic flight. Depending on the mission or objective, one of these models will prevail over the other [15].

UAVs can quickly integrate into the civil and military industry by implementing various accessories (sensors and actuators) at lower prices. The UAVs have the potential to change various industries drastically, and their use is increasing in various social and economic sectors [16], [17]. The most promising civilian markets are precision agriculture and public safety, representing 90% of the potential market [18].

UAV technology is necessary for places with difficult access and a labor shortage. Already in agriculture, the use of UAVs for fumigation tasks reduces the probability of health problems in people who spray the agrochemical manually, in addition to performing this task more effectively and quickly [19].

2.2. Power Supply Technologies for UAVs

Batteries are the primary commercial power supply technology for UAVs. Li-ion batteries have a low memory effect, high specific power (W/kg), high specific energy (Wh/kg), and long lifespan. These features make them suitable for electric hybrid vehicles [20], [21], [22].

A hybrid propulsion system comprises two or more energy sources or technologies to improve the flight autonomy limitations of UAVs in different applications [23]. In addition to batteries, there are technologies such as internal combustion engines, fuel cells, solar cells, ultracapacitors, or a combination of these with batteries.

Gasoline continues to be a primary energy source since it has an energy density of 12 kWh/kg and Li-ion batteries 160 – 230 Wh/kg. Various authors maintain that currently, a hybrid system with these two technologies is the most recommended based on advantages and technical characteristics, as well as less technological complexity for its integration and cost of implementation. [23], [24].

$$D = D_{Gasoline} * e_{CI} * e_{Gen} \tag{1}$$

Where, $D_{Gasoline}$ is the energy density of gasoline, e_{CI} combustion engine efficiency, and e_{Gen} is the efficiency of the generator, according to [24], [25]:

$$D_{Gasoline} = 12\,\frac{kwh}{kg}$$

$$e_{CI} = 25\ \%$$

According [26]–[28]:

e_{Gen} is between 75% y 90%

Resulting in 75 % of $e_{Gen} = 2.25\,\frac{kwh}{kg}$

Resulting in 90 % of $e_{Gen} = 2.70\,\frac{kwh}{kg}$

Therefore, gasoline's energy density is higher than batteries.

2.3. Application Characteristics of a Spraying UAV

There is a wide variety of spraying UAVs on the market. The DJI Agras MG-1P is the main UAV used in Peruvian agriculture due to its characteristics, lower cost, and technical capabilities suitable for various agriculture tasks. The Agras MG-1P is an octocopter designed to help farmers spray large farmland areas with agrochemicals (pesticides and fertilizers).

The characteristics of the Agras MG-1P allow it to carry up to 10 kg of liquid payload, and it can cover between 0.4 and 0.6 hectares with one battery in only 10 minutes, which is considered 70 times faster compared to backpack pumps [29].

2.3.1. Its Main Advantages

- Reduction of working time.
- Reduction of worker contact with chemical products.
- Its control can be manual, semi-automatic, or automatic.
- More precise and efficient fumigation, avoiding an over-concentration of the agrochemical.

2.3.2. Disadvantages

- Short flight time concerning crop areas to be covered.
- Several sets of batteries are required to work and cover large areas.

2.4. Arequipa (Peruvian) Agriculture

Agriculture in Peru is an economic activity in which 85% of farmers have less than 10 hectares of land. The majority are between 3 and 10 hectares [30]. *Arequipa* is a region located in the south of Peru, and its principal economic activities are mining and agriculture. This region is responsible for 14.8% of the country's food production [31].

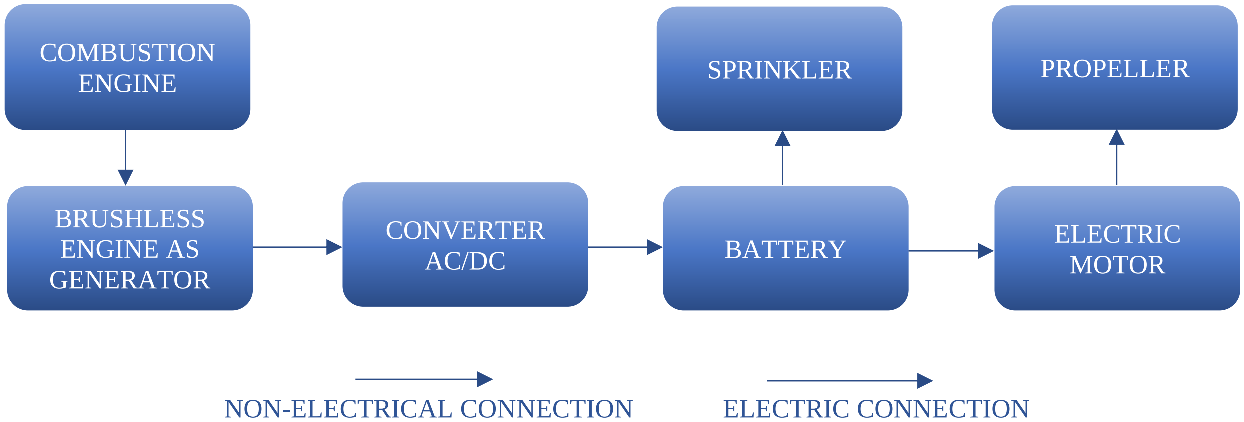

Fig. 1 Serial configuration [21]

Intermediate family farming in Arequipa typically cultivates in areas of 2.4 to 5.5 hectares. Achieving productive performances is mainly due to the excellent composition of the soil and climatic conditions rather than the efficient use of agrochemical technologies [48].

3. Methodology

3.1. Block Diagram of the Conceptual Design

The proposed hybrid system (battery-fuel) considers a series configuration that can be extended easily to the electric power system. Figure 1 illustrates the block diagram, where is mechanically connected the combustion engine to the brushless motor using a shaft. The combustion engine will move the brushless motor at the RPM required to produce the necessary voltage. The engine power is converted from combustion into electrical energy through a generator [23].

The brushless motor used as a generator provides alternating current. For this reason, the output of the brushless motor shall be connected to a converter to transform alternating current into direct current. The converter output will be connected to the battery to provide a constant charge. Used the electrical energy to power the UAV directly or stored in the battery through a charging process [23]. The battery powers the sprinkler and the electric motors of the propellers.

3.2. Brushless Motor Selection

Conventional power generators or automotive alternators are too heavy and have brush wear problems. Conventional direct current motors operate naturally as generators when subjected to a motive force and equipped with permanent magnets or magnetic fields generated in the winding of their coils. Model aircraft brushless motors have neodymium magnets, giving them a brushless permanent magnet field and an excellent power-to-weight ratio. These motors can be seen schematically as conventional three-phase motors but with permanent magnets [33].

In this way, these motors have three terminals that oscillate in a sinusoidal way equivalent to a vehicular alternator; changing the frequency with the rotation makes it necessary to use a three-phase rectifier bridge to polarize the voltage and be able to take advantage of the energy generated [33]. The selection of the Brushless motor depends directly on the characteristics of the UAV's operation. Table 1 describes the power consumption of the DJI Agras MG-1P.

Table 1. DJI Agras MG-1P Power Consumption [34]

Maximum power consumption	6400 W
Hovering power consumption	3800 W (23.8 kg takeoff weight)

Table 2 shows the built-in battery in the DJI Agras MG-1P.

Table 2. DJI Agras MG-1P Battery Features [34]

Model:	M-12000P
Voltage:	44,4 V
Degree of protection:	IP54
Capacity:	12,000 mAh
Weight:	4.0 kg

In order to satisfy the power consumption and maintain the battery charge of the DJI Agras MG-1, one of the Brushless motors described in Table 3 should be selected based on maximum rotational speed, maximum voltage, power, weight, and cost.

To select one of the brushless motors in Table 3, one should find the maximum RPM necessary to produce 50.4 V, which is required to load the DJI Agras MG-1P battery [34]. The criteria adopted for choosing and purchasing the engine generator are the motor speed constant (KV) measured in RPM per volt [35].

Table 3. High Power Commercial Brushless Motors

Model	U11 KV120	Q80-7L V2	MAD M20 IPE KV100	KDE10218XF-105
Maximum Power (W)	4000	7000	8419.78	7355
Maximum Voltage (V)	50	58	49	60.9
Maximum Current (A)	80	120	171.86	142
Speed constant (RPM / V)	120	155	100	105
Maximum spin speed (RPM)	6000	9000	4900	6394.5
Weight (kg)	0.730	1.255	1.031	1.180
Cost ($) (*)	349.90	699.99	429.0	815.95

(*) The cost does not include shipping, so the values change according to the place of purchase.

$$V = \frac{N}{KV} \quad (2)$$

Where: V is the voltage in volts, N is the rotational speed of the motor in revolutions per minute, and KV is the speed constant of the motor in RPM per volt.

Applying equation (2) where V = 50.4 V and the speed constants depending on the Brushless motor model indicated in Table 3, obtaining the results in Table 4.

Table 4. Rotational speed required for producer 50.4 V

MODEL	U11 KV120	Q80-7L V2	MAD M20 IPE KV100	KDE10218 XF-105
N (RPM)	6048	7812	4032	5292

The values in Table 4 represent ideal conditions without considering losses. However, when coupled with an electrical load to drain power, losses will occur for various reasons, including ohmic losses in the windings and the rectifier bridge. This value must be higher to produce a high voltage to compensate for losses [33].

Brushless motors typically perform between 50% and 95% efficiency [26]. Since manufacturers do not usually provide their equipment's efficiency, a middle term of the theoretical range should be considered 85% for applying equation 3.

$$V_g = \frac{V_e}{\eta} \quad (3)$$

Where: Vg is the voltage generated across the circuit; Ve is the voltage delivered at the external terminals to the generator; n is the efficiency.

$$V_{g1} = \frac{50.4}{0.85} = 59.29\ V$$

For this reason, it is advisable to use a brushless motor with the highest possible efficiency so that do not need to generate high voltages.

The criteria adopted for choosing and purchasing the motor generator are the constant motor speed (KV) measured in RPM per volt [35]. Applying equation (2), where the speed constant of the brushless motor is 105, and in function on the voltage found above, Table 5 is obtained:

Table 5. Maximum rotational speeds

Generator voltage across the circuit	Brushless motor model			
	U11 KV120	Q80-7L V2	MAD M20 IPE KV100	KDE10218 XF-105
$V_g(V)$	N (rpm)	N (rpm)	N (rpm)	N (rpm)
$V_{g1} = 59.29$	7115.29	9190.59	6522.35	**6225.88**

Table 6 details the brushless motor selected based on the adequate rotational speed of the motor to generate a voltage of around 59.29:

Table 6. Brushless motor selected [37]

Model:	**KDE10218 XF-105**
Maximum power:	7355 W
Max voltage:	60.9 V
Peak current:	142 A
Speed constant:	105 (RPM/V)
Maximum turning speed:	6394.5 RPM
Weight:	1.180 kg

Also, to produce more voltage with the KDE10218 XF-105 brushless motor with a KV=105 RPM/V, it is necessary to increase the RPM of the combustion engine.

Table 7. Commercial combustion engines

Model	NGH GTT70 70CC	VVRC RCGF 70CC	VVRC RCGF 120CC	EME70 70CC
Capacity (CC)	70	70	120	70
Speed range (RPM)	1200-7000	1500-8600	1500-7600	1200-7500
Maximum power (W)	5891.03	5518.18	9321.25	5294.47
Weight (kg)	2.270	1.805	2.925	2.155
Price ($) **	350.70	413.91	512.37	606.06

(**) The cost does not include shipping, so the values change according to the place of purchase.

Table 8. Selected internal combustion engine [38]

Model:	**NGH GTT70 70CC**
Capacity:	70 CC
Speed range (RPM):	1200-7000 rpm
Maximum power:	7.9 HP o 5891.03 W
Weight (kg):	2.270

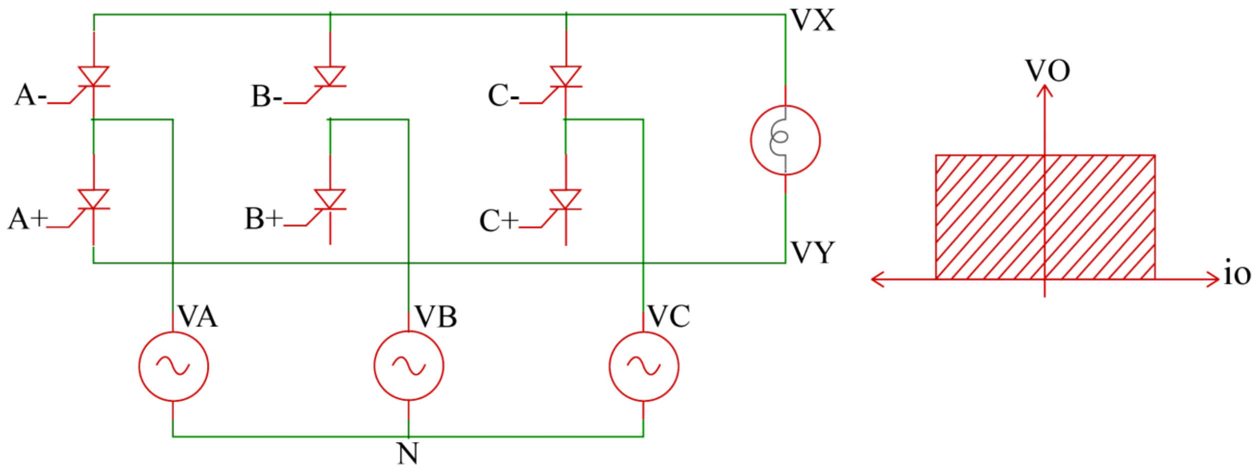

Fig. 2 Three-phase rectifier

3.3. Combustion Engine Selection

After calculating the maximum rotational speed, it is necessary to obtain the maximum power consumption of the DJI Agras MG-1P. A combustion engine with the required power and speed must select one of the following commercial engines described in Table 7.

Due to the effects of altitude above sea level, the indicated engine performance decreases throughout the entire engine cycle [36]. Another influencing effect is the richness of the mixture of fuel with air for combustion effects.

The manufacturer indicates that the combustion engine generates 7.9 HP of power. However, this measured is at sea level. In the city of Arequipa, at approximately 2,800 meters above sea level, much of this power is lost as the amount of oxygen required for combustion is insufficient. Gagg & Ferrar's model [37] is used in combustion engines to obtain the engine's absolute power using equations (4) and (5):

$$P_{alt} = P_{sl}(1.132\sigma - 0.132) \quad (4)$$

Where: P_{alt}= power at the considered height, P_{sl} = power above sea level.

σ = Air density ratio

$$\sigma = \frac{Pd}{Po} \quad (5)$$

p_d = Air density in Arequipa =1.16$\frac{kg}{m^3}$ [41]

p_0 = Air density at sea level =1.225$\frac{kg}{m^3}$ [40]

$\sigma = \frac{1.16}{1.225}$

P_{alt} = 7.9 ∗ (1.13 ∗ 0.9469 − 0.13)

P_{alt} = 7.4259 Hp

P_{alt} = 5.5375 Kw

Therefore, the choice of the NGH GTT70 70CC engine is the most appropriate to operate in the geographical conditions of Arequipa.

3.4 AC/DC converter

An AC / DC converter or a three-phase full-wave rectifier allows the average output voltage to be varied using power thyristors for its function, with which the firing angle and the power delivered to the load can be varied [38].

4. Calculations and Theoretical Results

4.1. Battery Life Calculation and Thrust

According to power consumption specifications in Table 1, battery characteristics in Table 2, and the propulsion system in Table 3, the battery life of the DJI Agras MG-1P drone is checked:

Table 9. DJI Agras MG-1P Flight Parameters [34]

Total weight (without battery):	9.7 kg
Standard Takeoff Weight:	23.8 kg
Max Takeoff Weight:	24.8 kg (at sea level)
Hovering Time 13.8 Kg (takeoff weight):	20min (@12000 mAh)
Maximum Time 23.8 Kg (takeoff weight):	10 min (@12000 mAh)
Maximum power:	770 W
Number of motors:	8
Maximum thrust:	5,1 kg/rotor
Weight with a fan:	0.280 kg

Applying the estimated flight time formula [39], [40]:

$$t_{consumption} = \frac{E}{P} = \frac{Ah*v}{w} \quad (6)$$

$t_{maximum\ consumption} = \frac{12Ah*44.4v}{6400w}$ = 0.08325h = 5min

$t_{hovering\ consumption} = \frac{12Ah*44.4v}{3800w}$ = 0.1402 h = 8min 25seg

According to [41], [42], the estimated thrust is calculated as follows:

$$Thrust \ = 2 * total\ mass \quad (7)$$

Thrust = 2 * 23.8 = 47.6 kg

Thrust of each rotor = $\frac{47.6}{8}$ = 5.95 kg

The eight rotors must work at 100% of their acceleration to obtain this thrust.

$p_{max=}$ 8 * $770_{motor\ at\ 100\%}$ = 6160 W

The difference between the theoretical calculation and the manufacturer's specification for maximum power consumption is 240W, which is used to supply flight control electronics.

4.2. Calculation of the Time to Spray the Agrochemical

Table 10 details typical characteristics of the application of agrochemicals by spray UAVs.

Table 10. Work area and amount of fumigant poured per nozzle [34].

Agrochemical capacity	10 L
Work area in 10 min	0.4 – 0.6 hectares
4 Nozzle: 0.525L / min (TX-VK8 recommend model)	2.1 L/min

The DJI Agras MG-1P with maximum load capacity can apply 10 L of agrochemicals for 0.4 or 0.6 hectares in 10 minutes. If the UAV sprays 0.4 hectares (slower spraying), covering 2.4 and 5.5 hectares requires approximately 60 L and 137.5 L of agrochemicals, respectively.

Analyzing the liters per minute at which the UAV sprayer operates, the 4 nozzles take 4 min 46 sec to apply 10 L of agrochemicals, leaving 5 min 14 sec for takeoff, flight to the spraying start point, and return to refuel. Depending on the point of departure and return, this time may need to increase, requiring an appropriate agrochemical and battery refueling strategy to cover the average crop area.

4.3. Calculation of the Ratio-Weight

The most used ratio in electric UAVs declares that the power system of a UAV must consume at least 88.18 to 110.23 W/kg. For adequate aerobatics capabilities, 154 W/kg is necessary. A modern brushless motor changes this data from 77 to 99 W/kg for sports performance and 132 W/kg for aerobatics [47].

Based on hovering and maximum powers consumption, according to Table 1, the extra weight the UAV would carry depends on the power-to-weight ratio of 132 W/kg. Which obtained the following results:

Table 11. Weight that the drone loads according to its power and power-to-weight ratio

Power (W)	Weight (kg)	Power-weight ratio (W/kg)	Power (W)	Weigh t (kg)	Power-weight ratio (W/kg)
3800	28.6	132.87	**6400**	48.3	132.51
	28.7	132.40		48.4	132.23
	28.8	**131.94**		**48.5**	**131.96**
	28.9	131.49		48.6	131.69
	29	131.03		48.7	131.42
	29.1	130.58		48.8	131.15

Table 12. Weights of the DJI Agras MG-1P own components [34].

Total weight	
Standard weight	23.8 kg
Maximum weight a.s.l.	24.8 kg
Weights that compose it	
Useful load	10 kg
Battery	4 kg
Weight without battery 9.8 kg	
Rotor (280gr) x 8	2.240 kg
Propellers (58gr) x 8	0.464 kg
Weight of structure and other components	7.096 kg

Table 11 shows that the UAV load can be increased by 5 kg and 24.7 kg if it works with its hovering power consumption (3800 W) and maximum consumption (6400 W), respectively.

4.4. Weight Calculation for UAV Modifications

With the combustion engine and generator motor specified, it is necessary to determine the UAV support structure's weight.

Table 6, Table 8, and Table 12 allow determine the weights of the following components.

Table 13. Calculation of the extra weights of the components.

Weight of components to be added	
Combustion engine	2.27 kg
Motor generator	1.18 kg
Inverter weight	0.45 kg
Structure weight	0.50 kg
Total Weight	**4.40 kg**

Based on data obtained in the previous tables, the calculation indicates that the UAV could carry 5 kg more than its weight. Added components have a total weight of 4.40 kg, leaving 0.6 Kg for additional components or fuel.

4.5. Calculation of the Rotation Speed as a Function of the Voltage generated by the Brushless Motor

Use equation (8) to calculate the approximate KWh of the engine [44]:

$$KWh_{mci} = 12KWh_{gasoline} * e_{CI} \quad (8)$$

Where KWh_{mci} is the approximate consumption of the 2-stroke combustion engine. Also, 1kg of fuel generates $12\, KWh_{gasolina}$, and e_{CI} the efficiency of the 2-stroke combustion engine varies from 15 % to 20 % [45].

Giving as a result:

$KWh_{mci\ al\ 15\%}$ = 1.8 Kwh

$KWh_{mci\ al\ 20\%}$ = 2.4 Kwh

Therefore, 1kg of fuel results in an approximate consumption of:

$\frac{1\ Kgr}{1.8} = 0.556\ \frac{Kgr}{Kwh}$

$\frac{1\ Kgr}{2.4} = 0.4167\ \frac{Kgr}{Kwh}$

The combustion engine has two internal cylinders with a capacity of 70cc each, then the approximate time the 2-stroke internal combustion engine will run will be as follows:

$$C_{used} = \frac{(C_{Real\ aprox} * P_{alt} * t)}{p} \quad (9)$$

Where:

C_{Used} is the fuel capacity of the engine 70cc = 0.07 L for each inner cylinder.

$C_{Real\ aprox}$ is the approximate consumption calculated previously $\frac{Kgr}{Kwh\ mci}$.

P_{alt} = Real motor power

t = The approximate time that the fuel will last

p = Specific weight of fuel (gasoline) [46] = $0.680\frac{Kgr}{L}$

Solving the approximate time given to consume the fuel by its two internal cylinders of the combustion engine:

$Time_{mci\ al\ 15\%}$= 0.01546 hours; 0.9276 min

$Time_{mci\ al\ 20\%}$= 0.0206 hours; 1.236 min

The UAV covers an area between 0.4 to 0.6 hectares at 10 min [34] and has the consumption time calculated for when the engine works at 15% and 20% efficiency. The obtained work areas covering to combustion engine are:

When the UAV cover 0.4 hectares = 4000 m^2:

$work\ area_{\ mci\ al\ 15\%}$ = 371.04 m^2

$work\ area_{\ mci\ al\ 20\%}$ = 494.4 m^2

When the UAV cover 0.6 hectares = 6000 m^2:

$work\ area_{\ mci\ al\ 15\%}$ = 556.56 m^2

$work\ area_{\ mci\ al\ 20\%}$ = 741.6 m^2

Table 14. Calculation of the area, amount of fuel, and fuel consumption time.

Slower spraying – 0.4 hectares				
Area (m2)	**Fuel 15 % (L)**	**Consumption time (min)**	**Fuel 20 % (L)**	**Consumption time (min)**
8480.9	1.6	21.20	-	-
11300.6	-	-	1.6	28.25
Quick spraying – 0.6 hectares				
Area (m2)	**Fuel 15 % (L)**	**Consumption time (min)**	**Fuel 20 % (L)**	**Consumption time (min)**
12721.37	1.6	21.20	-	-
16950.85	-	-	1.6	28.25

Considering the 0.6 kg (available weight) and reducing the weight of the agrochemical by 1 kg, 1.6 L of fuel is obtained to supply the UAV. Table 14 describes the application of equation (9) considering the Arequipa family farm's cultivation area and the combustion engine's efficiency to determine the coverage area and flight time.

The amount of fuel selected is 1.6, giving us an operating time of 21min 12sec in the slower spraying case and 28min 15sec in the quick spraying case. If the engine works at 15% efficiency, it can cover 0.84 hectares in a slower spraying mode and 1.27 hectares in a quick spraying mode. For 20% efficiency, the cover is 1.13 and 1.69 hectares, respectively.

4.6. Weight Calculation with UAV Modifications

With the combustion engine and generator motor specified, it is necessary to determine the time to spray for 2.4 to 5.5 hectares (typical cropping area in Arequipa).

To cover 2.4 hectares (when the engine works at 15% efficiency in slower spraying mode), the calculated fuel required is 4.52 L to flight 59 min 53 sec. In this sense, table 15 shows the calculation for different engine efficiencies to cover 2.4 and 5.5 hectares.

Table 15. Calculation of the amount of fuel and fuel consumption time for 2.4 and 5.5 hectares

Slower spraying – 0.4 hectares				
Area (m2)	**Fuel 15 % (L)**	**Consumption time (min)**	**Fuel 20 % (L)**	**Consumption time (min)**
24000	**4.52**	**59.98**	**3.39**	**59.99**
55000	**10.37**	**137.48**	**7.78**	**137.49**
Quick spraying – 0.6 hectares				
Area (m2)	**Fuel 15 % (L)**	**Consumption time (min)**	**Fuel 20 % (L)**	**Consumption time (min)**
24000	**3.02**	**39.99**	**2.27**	**39.99**
55000	**6.92**	**91.65**	**5.19**	**91.66**

Table 16. Amount of fuel, agrochemicals and time it takes the drone to fumigate 5.5 hectares

2.4 hectares / Slower spraying / Fuel 15 %				
Fuel quantity (L)	**Fuel refill (N°)**	**Agrochemical refill (N°)**	**Agrochemical quantity (L)**	**Time (min)**
4.52	**2.83**	**6.66**	60	59.98
5.5 hectares / Slower spraying / Fuel 15 %				
Fuel quantity (L)	**Fuel refill (N°)**	**Agrochemical refill (N°)**	**Agrochemical quantity (L)**	**Time (min)**
10.37	**6.48**	**15.27**	137.5	137.48

With these calculations, it is now possible to determine the number of times the fuel and fumigant require refilling to cover the demand of 2.4 and 5.5 hectares, respectively.

For 2.4 hectares, the UAV sprayer will have to recharge 5 times the fuel (8L), 7 agrochemical refills (63L), and 59 min 59 sec to complete the work. For 5.5 hectares, it is necessary to recharge 11 times the fuel (17.6L), agrochemical refills 16 times (144L), and it will need 2h 17min 29sec to complete the work.

5. Conclusion

This work presents the calculation and selection of components to couple a hybrid system with existing spray UAVs on the market to increase their flight time. Their electrical system has different energy requirements to complete their mission. The additional flight time the UAV sprayer will have will be 21min 12sec provided by the 1.6L of fuel. The total flight time will be 31min 12sec provided with fuel, and 10 min, provided by the UAV's battery.

Employing hybrid technology, the UAV sprayer will have a variable load of agrochemicals (in this case, 9 liters) and additional components (4.4 kg for propulsion). For the cover, 5.5 hectares in slower spraying considering 15 % of fuel efficiency, the hybrid design permit flight for 2h 17min 29sec using 17.6L of fuel and 144L of agrochemical. It will be possible to avoid spending on battery sets that help the UAV fulfill its mission, thus covering a wide area of fumigation for Arequipa's family farming, saving time and money, and avoiding direct contact with people with chemicals.

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