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Original Article

Technical, economic, and environmental feasibility of electrifying light Sport Aircraft (LSA)

Viabilidad técnica, económica y ambiental de la electrificación de aeronaves deportivas ligeras (LSA)

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Spanish version

Abstract

Introduction: the replacement of internal combustion engines with electric propulsion systems represents an alternative for improving energy efficiency and reducing operating costs and emissions in light sport aircraft (LSA).
Objective: to evaluate the technical, economic, and environmental feasibility of replacing a gasoline engine with a battery-powered electric motor in an MXP-150 aircraft.
Methodology: an energy characterization was performed on an MXP-150 aircraft equipped with a 100-hp ROTAX® 912 ULS engine through the analysis of 20 actual flight cycles. Fuel consumption and energy demand for one hour of flight were determined, and the energy obtainable from the AVGAS® 100LL consumed was estimated. Subsequently, the thermal efficiency of the internal combustion engine was compared with the electromechanical efficiency of an 80-kW ROTEX REB-90 motor with 93% efficiency. Finally, operating costs and CO_2 emissions were analyzed.
Results: a fuel consumption of 2.60 L and a net energy demand of 8.29 kWh per traffic pattern circuit were obtained. This energy demand can be met using a battery system coupled to the electric motor. An approximate 60% improvement in energy efficiency and a 67% reduction in operating costs per flight hour were determined, together with the elimination of direct propulsion emissions, avoiding 41.11 kg of CO_2 per hour.
Conclusions: the proposed replacement is technically, economically, and environmentally feasible under the conditions analyzed.

Keywords: Electric propulsion, light-sport aircraft (LSA), electric motors, aviation controllers, energy efficiency, cost reduction, CO_2 emission reduction.

Resumen

Introducción: la sustitución de motores de combustión interna por sistemas de propulsión eléctrica constituye una alternativa para mejorar la eficiencia energética y reducir los costos operativos y las emisiones en aeronaves deportivas ligeras (LSA).
Objetivo: Evaluar la viabilidad técnica, económica y ambiental de sustituir un motor de gasolina por un motor eléctrico alimentado por batería en una aeronave MXP-150.
Metodología: se realizó una caracterización energética de una aeronave MXP-150 equipada con un motor ROTAX® 912 ULS de 100 hp, mediante el análisis de 20 ciclos de vuelo reales. Se determinó el consumo de combustible y la demanda energética para una hora de vuelo, y se estimó la energía obtenible del AVGAS® 100LL consumido. Posteriormente, se compararon la eficiencia térmica del motor de combustión interna y la eficiencia electromecánica de un motor ROTEX REB-90 de 80 kW y 93 % de eficiencia. Finalmente, se analizaron los costos operativos y las emisiones de CO_2.
Resultados: se obtuvo un consumo de 2,60 L de combustible y una demanda neta de energía de 8,29 kWh por circuito de tráfico aéreo. Esta demanda puede ser atendida mediante un sistema de baterías acoplado al motor eléctrico. Se determinó una mejora aproximada del 60 % en la eficiencia energética, una reducción del 67 % en los costos operativos por hora de vuelo y la eliminación de las emisiones directas de propulsión, evitando 41,11 kg de CO_2 por hora.
Conclusiones: la sustitución propuesta presenta viabilidad técnica, económica y ambiental bajo las condiciones analizadas.

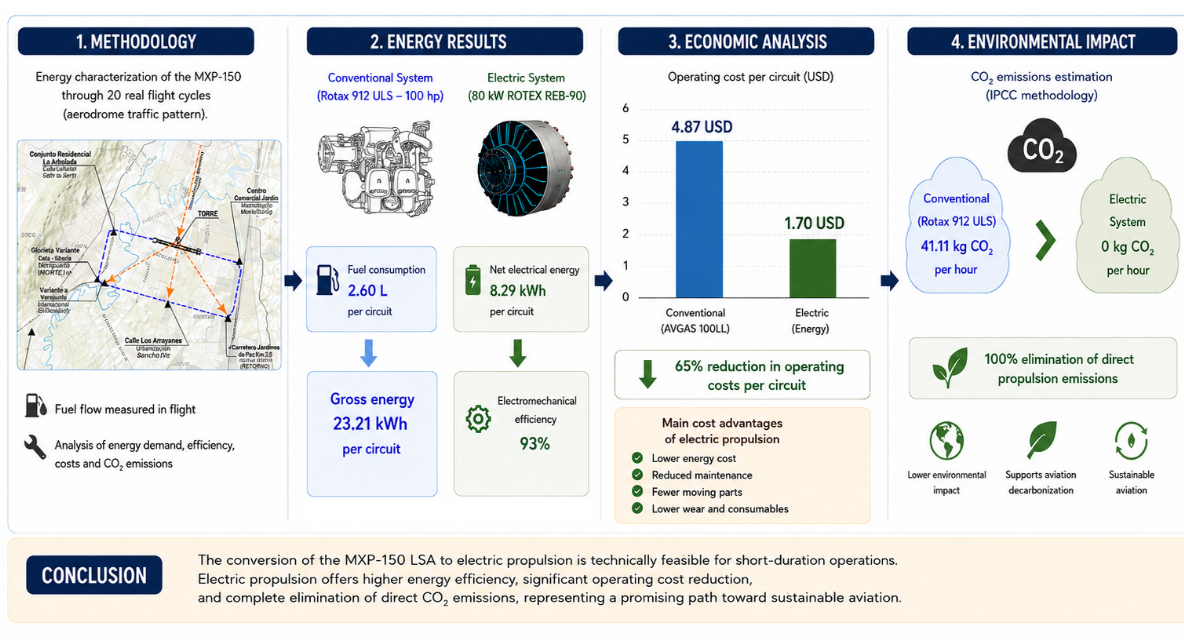
Palabras clave: Propulsión eléctrica, aeronave deportiva ligera (LSA), motores eléctricos, controladores de aviación, eficiencia energética, reducción de costes, reducción de emisiones de CO_2.

Why was the study conducted?
This study was conducted to evaluate the technical feasibility of converting a Light Sport Aircraft (LSA) powered by a conventional internal combustion engine into a battery-electric propulsion system. The research aimed to quantify the aircraft's energy requirements under real operating conditions, estimate the environmental benefits associated with eliminating fossil fuel consumption, and assess the potential of electric propulsion as a sustainable alternative for light aviation in Colombia.

What were the key findings?
The analysis demonstrated that current electric propulsion technologies can satisfy the energy demand of short-duration LSA operations. Furthermore, replacing AVGAS 100LL with electrical energy reduced operating energy costs by approximately 65% and eliminated direct in-flight CO_2 emissions associated with fuel combustion.

What do these findings contribute?
The findings provide quantitative evidence supporting the technical, economic, and environmental viability of electric propulsion for light aircraft applications. The study contributes experimental flight-based data that can support future aircraft electrification projects, regulatory discussions, and sustainable aviation initiatives in Colombia. Additionally, it establishes a methodological framework for evaluating the energy requirements and emission reductions associated with the conversion of conventional aircraft to electric propulsion systems

Graphical Abstract



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Introduction

Fossil fuels, including coal, petroleum products, and natural gas, are currently the primary energy sources used across applications such as power generation, transportation, industry, and agriculture; however, they also represent one of the greatest causes of pollution and climate change. (1). In addition, investments in new technologies for energy generation and improvements in electric mobility and propulsion and global policies such as the Paris Agreement seek to limit the use of these fuels and curb climate change (2).

Aviation is one of the sectors most dependent on fossil fuels; despite improvements aimed at engine efficiency, aviation remains a significant source of greenhouse gas emissions (3), primarily because of the altitude at which aircraft operate, which leads to substantial quantities of carbon dioxide (CO_2) in the atmosphere (4). In particular, light-sport aircrafts represent an ideal testbed for the implementation of electric motors, given their light weight and typically short mission profiles. The transition from internal combustion engines to electric propulsion systems in LSA could not only reduce pollutant gas emissions but also lower operating costs and environmental impact (5). Nevertheless, this conversion poses technical and economic challenges that require a detailed analysis to evaluate its feasibility (6).

This study focuses on evaluating the energy performance of an LSA aircraft in order to analyze the feasibility of conversion to electric propulsion. The primary objective is to assess the current energy output of a specific LSA aircraft and determine the technical feasibility of converting it to a battery-powered electric propulsion system (7). To this end, a comprehensive evaluation will be carried out, encompassing the following:

Analysis of energy consumption and thermal efficiency of the existing internal combustion engine: Operational flight data will be collected to establish an energy performance baseline under actual high-altitude operating conditions.

Economic and environmental analysis: The costs associated with the propulsion system conversion, long-term maintenance requirements, and environmental impact derived from the reduction of direct combustion emissions will be assessed.

In the Colombian context, a research seedbed comprising faculty and students constructed the country's first electric aircraft. This effort is led by the Environmental Research and Innovation Group (GIAM) at the Pascual Bravo University Institution in Medellín, Colombia (8). The initiative emerged to address heat emissions, acoustic pollution, particulate matter CO_2, and other gaseous emissions. The aircraft achieves a velocity of 18 meters per second utilizing two 10 kW motors.

As noted previously, the development of this work corresponds to a research project supported by the Universidad Distrital Francisco José de Caldas, titled the Phase I Manned Electric Aircraft Prototype. This study aims to support the energy transition toward electric motors in the design of ultralight aircraft, presenting an opportunity for emission reduction, energy efficiency improvement, and lower operating costs by substituting the gasoline engine with a battery-powered electric motor.

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Reference Framework

Historically, these aircraft have used aviation gasoline (AVGAS-100LL) and, in some cases, automotive gasoline (MOGAS) as the primary energy source (9). The use of AVGAS 100LL in light aircraft dates back to the mid-20th century, when recreational aviation began to gain popularity (10). With the development of more efficient and environmentally friendly engines, some LSA models have begun using unleaded MOGAS, which is a more affordable and accessible option (11).

Light sport aircraft (LSA) arrived in Colombia in the late 20th century; their popularity increased because of lower operating costs than those of conventional aircraft and the ease of maintenance (12). Aviation companies and schools began importing models from renowned manufacturers such as ZENITH AIR®, TECNAM®, and PIPISTREL®, adapting these aircraft to Colombian geographic conditions and regulations (11). The manufacturer AGROCOPTEROS®, later AEROANDINA®, and more recently, WACSA SAS, built nearly 500 LSA aircraft in Jamundí, Valle del Cauca, Colombia, the vast majority of which were exported. Notably, the MXP-740® model and currently the MXP-150 KIMBAYA® model are the equipment used in the present project for implementing the prototype.

Aviation regulations in Colombia are governed by the Special Administrative Unit of Civil Aeronautics (Aerocivil), which establishes operating, certification, and maintenance requirements for LSA aircraft (13). Some relevant regulations include the following:

- RAC 21 (Colombian Aviation Regulation): This regulation involves the certification of aircraft and components and is applicable to the conversion of aircraft to electric propulsion systems.
- RAC 91: General operating rules for aircraft, including restrictions and technical requirements for light sport aircraft (LSA).
- RAC 23 and RAC 33: Pertaining to airworthiness requirements and the certification of engines.
- RAC 26: Light Aircraft Category. Amendment 3.

In the international context, the Federal Aviation Administration (FAA) (14) and the European Union Aviation Safety Agency (EASA) (15) have begun updating their regulatory frameworks for light aviation with electric propulsion. The FAA, through its MOSAIC program (Modernization of Special Airworthiness Certificates), has proposed expanding the certification criteria for LSA aircraft with alternative propulsion systems, explicitly acknowledging the integration of electric motors and high energy density batteries (14). For its part, EASA, through its CS-LSA regulation and the CS-23 Amendment 5 normative framework, establishes the airworthiness requirements applicable to general aviation and special category aircraft (15).

Additionally, the RTCA/DO-311A standard defines the minimum performance requirements for rechargeable lithium-ion batteries used in aircraft, establishing safety criteria for fault conditions, overcharge, and thermal variations (16). Likewise, the RTCA/DO-160G document establishes the environmental conditions and test procedures for aeronautical equipment, such as vibration, temperature, altitude, and electromagnetic compatibility (17). Finally, the IEEE 519 standard regulates harmonic distortion limits in electrical systems, which is pertinent for ensuring the quality of power supplied to the propulsion system and preventing interference with flight instruments (18).

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These international regulations constitute an indispensable technical reference for electric conversion projects such as the one presented herein (19). Table 1 presents a comparison between gasoline engines and electric motors applied to light sport aircraft (LSA) (20).

Table 1. Comparison between gasoline engines and electric motors in light-port aircraft (LSA).

Parameter	Gasoline internal combustion engine (ICE)	Electric motor (battery-powered)	Rationale for the change
Environmental	Emits CO_2, NOx, and particulate matter.	Zero local emissions; substantial reduction in pollutants.	Supports sustainability and reduces environmental footprint.
Energy efficiency	Energy efficiency: 25–40%; significant losses due to heat and friction.	Energy efficiency > 90–95%; minimal energy losses.	Optimizes the use of stored energy and enhances performance.
Technical maintenance	Numerous moving parts exposed to wear and high temperatures; requires frequent maintenance	A single moving part (rotor); low wear and minimal maintenance.	Increases reliability and reduces maintenance costs.
Motor	Complex and costly motor due to components and instrumentation.	Less expensive motor with fewer components and simpler maintenance.	Reduces the initial and operating cost of the aircraft.
Energy costs	Gasoline Avgas 100LL is costly and pollutant; efficiency is low (≈30%).	Cheaper and cleaner electricity; efficiency approaching 95%.	Significantly reduces operating costs per flight hour.
Innovation	Mature technology with few recent disruptive innovations.	Advances in batteries, controllers, and composite materials.	Drives the technological transformation and modernization of light aviation.
Reliability	High probability of failures due to complexity and thermal demands.	High reliability due to mechanical simplicity and lower thermal demands.	Enhances operational safety.

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Methodology

The methodology for the development of the present study includes the following phases:

- Selection of the airfield for conducting the test flights
- Selection and details of the traffic pattern circuit for the chosen airfield.
- Theoretical determination of the energy required for the traffic pattern circuit at the selected airfield.
- A precision onboard a fuel measurement system is installed to determine actual fuel consumption.
- Flights are conducted to record the time and fuel consumption for each leg of the traffic pattern at the selected airfield.
- Validation of the results through data analysis by comparison with the manufacturer's consumption tables for the ROTAX® 912 ULS engine.
- Determination of the energy requirements for sizing the battery system for a proposed aerodrome traffic pattern flight.
- Assessment of environmental and economic benefits associated with replacing the internal combustion engine with the battery-powered electric motor.
- Evaluation of the feasibility of implementing the prototype to perform one (1) traffic pattern circuit.

Additionally, the following components will be taken into account, which will allow for a more sufficient description of the scientific validation of the process and the proposed methodology.

Standardization of flight conditions: The 20 characterization flights were conducted under flight conditions at Guaymaral Aerodrome (SKGY). Parameters such as ambient temperature, altimeter setting, surface wind (direction and speed), total aircraft weight, and fuel quantity at engine start were recorded or constrained.

Pilot standardization: All measurement flights were performed by the same certified pilot to minimize inter-operator variability in throttle management and traffic circuit geometry.

Engine warm-up protocol: Prior to each measurement flight, a standardized engine warm-up procedure of fixed duration was applied to ensure uniform thermal conditions at the onset of data acquisition.

Data acquisition protocol: Fuel consumption data were continuously recorded at the native sampling frequency of the sensor by means of the MGL-FF1 computer, and the pilot manually logged segment transitions. The raw data files from the 20 flights constitute the primary dataset for the statistical analysis described in Section 5.

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Classification of Variables and Data Sources

Table 2 presents a structured classification of the variables employed throughout the research. Manufacturer-specified variables refer to data obtained directly from the technical documentation provided by the combustion engine and electric motor manufacturers (21) (22), as well as from the aeronautical authority (UAEAC®/ICAO SKGY). The studied variables, in contrast, correspond to quantities measured under actual flight conditions or computed from said measurements by means of the methodological framework.

Table 2. Classification of Variables

Variable	Unit	Source type	Manufacturer	Studied by authors
Maximum combustion engine power	kW/ CV	Manufacturer	73.5 kW / 100hp	-
Maximum continuous combustion engine power	kW/ CV	Manufacturer	69.0 kW / 90CV	-
Theoretical fuel consumption	L/h	Manufacturer	14,0-27,5 L/h	-
Combustion engine thermal efficiency	%	Manufacturer	30%	-
Nominal electric motor power	kW	Manufacturer	80 kW	-
Electric motor efficiency	%	Manufacturer	93%	-
Calorific value AVGAS 100LL	kWh/L	Manufacturer	8,9 kWh/L	-
Aerodrome elevation (SKGY)	Ft/m	UAEAC®	8.400 ft (2.557 m.a.s.l)	-
Maximum available combustion engine power	kW	Studied	-	55 kW to 8.400 ft (corrected by means of manufacturer's curve, Fig. 8)
Actual fuel consumption per segment	L	Studied/ Measured	-	0,17-0,78 L
Total actual fuel consumption	L	Studied	-	2,6 L
Energy demand	kWh	Studied	-	23,21 kWh
Total energy required by batteries	kWh	Studied	-	8,29 kWh

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Fig. 1 presents the block diagram corresponding to the methodology employed in the development of this study. This schematic provides a structured overview of the theoretical, experimental, and validation stages, from airfield selection and traffic pattern definition to the assessment of the technical, energy, and environmental viability of the proposed system. The diagram enables visualization of the logical sequence of the process, as well as the integration of experimental data with the analytic models used.

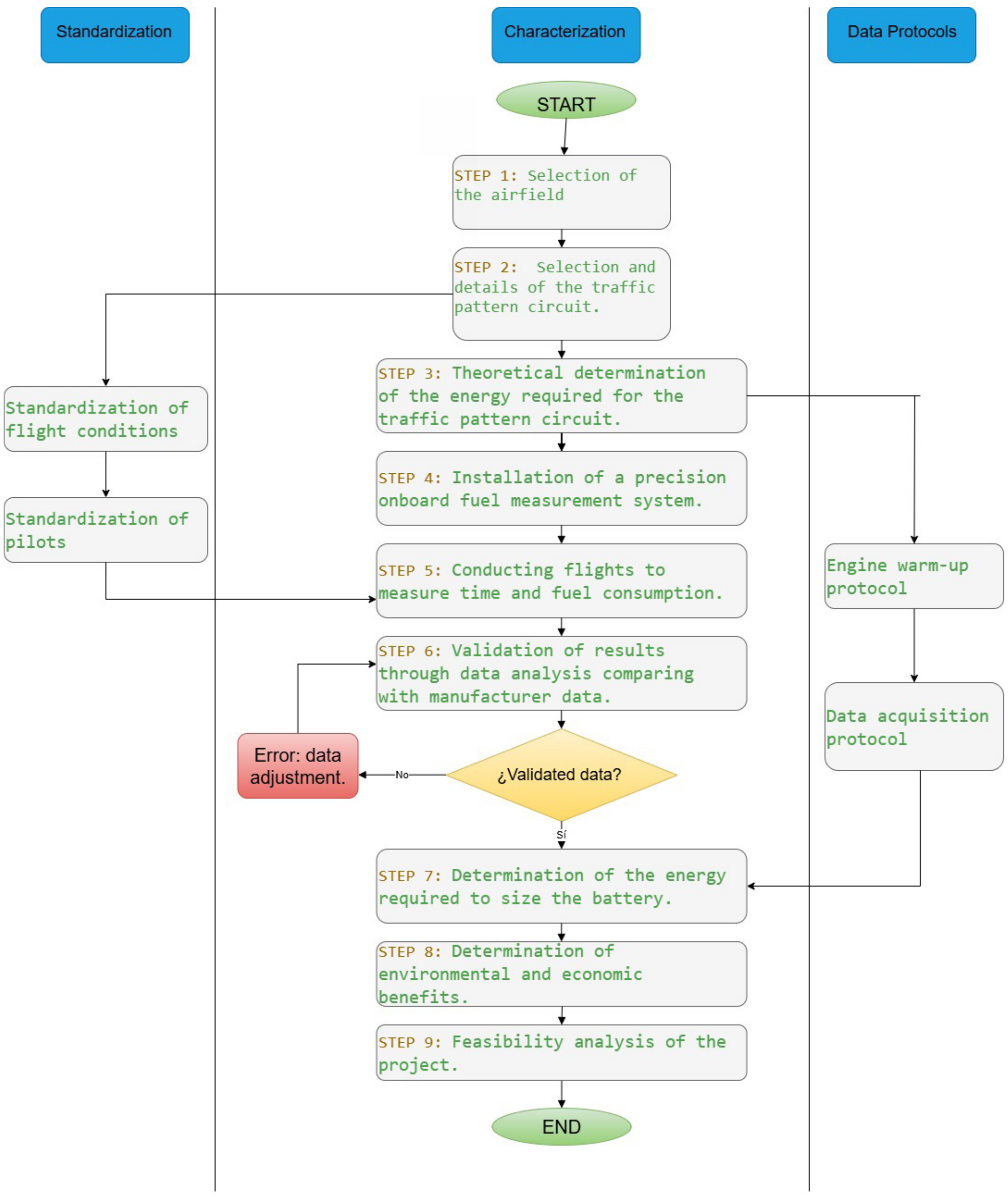

Figure. 1 Block diagram of the methodology employed.

Study to determine the technical, economic, and environmental aspects involved in switching to an electric motor for the light sport aircraft (LSA)

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Selection of the airfield for conducting the test flights

The selected airfield is located in the municipality of Chía, Cundinamarca, in central Colombia. It is designated by the code OACI- SKGY, named Flaminio Suárez, and the data obtained directly from the aviation authority are presented in Table 2.

Table 3. Airfield data Guaymaral - Flaminio Suarez - OACI SKGY

	Data	Indication
1	ARP coordinates and site at AD	044845.00 N 0740354.30 W
2	Direction and distance from (city)	16 km
3	Elevation/Reference temperature	Elev: 8389 FT (2557)/T: 14°C
4	Geoid Undulation at AD ELEV PSN	NIL
5	Magnetic Variation/Year (annual change)	8°W (2022)/0°1"W
6	Address	Special Administrative Unit for Civil Aeronautics Guaymaral Aerodrome

The airfield was selected because it is where LSA-HJ417 is stationed, which is available for the project and equipped for flights with an internal combustion engine. The flight for the electric motor is planned to be conducted in the municipality of Flandes, Tolima Department, Colombia, on the Aeroclub runway where the aircraft with registration OACI-SKGY operates in Aerosport operations.

Selection and details of the traffic pattern at the chosen airfield

Energy characterization of the light sport aircraft (LSA) is based on a traffic pattern as defined by the Colombian aviation authority in accordance with the International Civil Aviation Organization (OACI) standards, as shown in Fig. 2. Following the energy characterization, a propulsion system with an electric motor, controller, and energy from a battery bank is proposed to perform two (2) traffic pattern circuits.

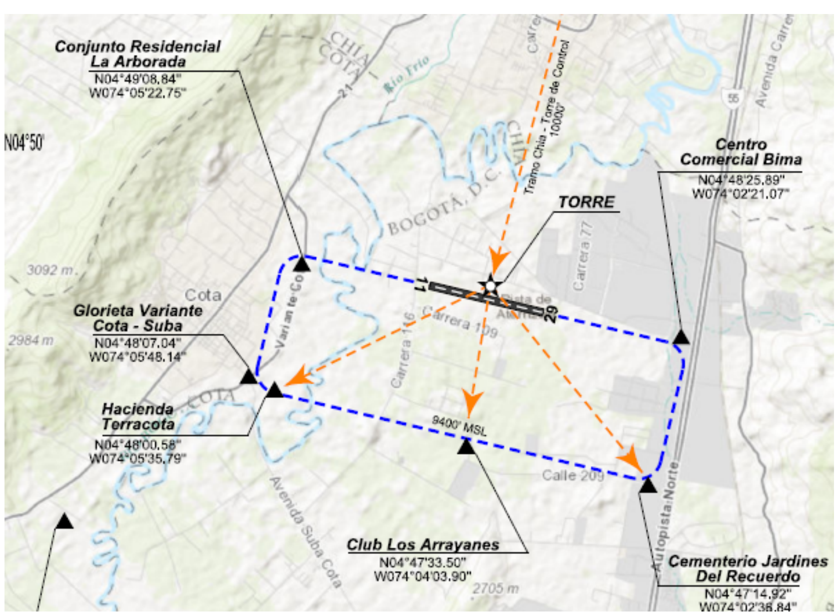

Figure. 2 Proposed traffic pattern in accordance with AIP AD2-SKGY-1. UAEAC®

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Fig. 2 shows the standardized traffic pattern for Guaymaral Airport, with code OACI: SKGY and name Flaminio Suárez; the energy characterization begins with the takeoff roll.

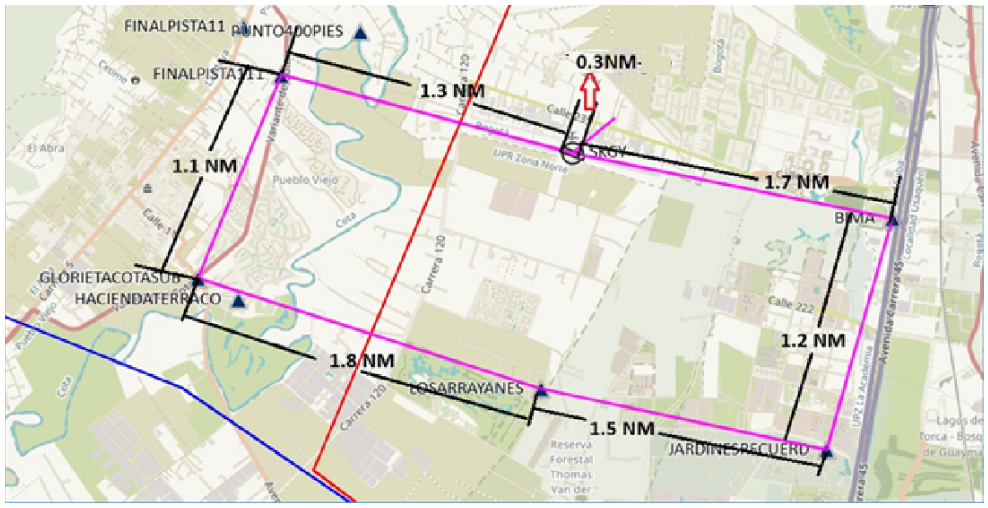

Figure. 3 Right-hand traffic pattern, runningway 11-SKGY, implemented in AIRMATE®.

The implementation of the right-hand traffic pattern for Runway 11 was performed via the free flight planning tool AIRMATE®, from which the actual measurements were obtained after the model was implemented on the basis of the Aeronautical Information Publication (AIP) of the Colombian Special Administrative Unit of Civil Aeronautics (UAEAC®). To facilitate the analysis, the segments are described according to the traffic pattern for an aerodrome circuit in accordance with OACI and the AIP for Guaymaral Flaminio Suárez Camacho, with the code SKGY.

Table 4 .Characterization of the traffic patterns for different distances and altitudes

Segment	Waypoint	Waypoint	Standardized segment name	Length (nm)	Altitude (ft)	Altitude difference (ft)
1	Outbound position Runway 11	Rotation point	Takeoff roll with headwind on Runway 11	0,3	8.400	0
2	Rotation point	BIMA Shopping Center	Flight segment with a headwind	1,7	8.800	+400
3	BIMA Shopping Center	Jardines del Recuerdo Field	Segment with crosswind	1,2	9.400	+600

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4	Jardines del Recuerdo Field	COTA-SUBA roundabout	Segment with a tailwind	3,3	9.400	+0
5	COTA-SUBA roundabout	La Arborada residential complex	Basic segment	1,1	9.000	-400
6	La Arborada residential complex	Runway 11 threshold	Final segment	1,3	8.400	-600
	TOTAL DISTANCE			8,9		

Theoretical determination of the energy for an aerodrome traffic pattern

The manufacturer of the ROTAX® engine presents in the following graphics and tables the torque characteristics and power versus revolutions per minute for the ROTAX 912 ULS engine, which is similar to the engine installed on the project's LSA aircraft (21). The manufacturer noted that at a maximum revolution of 5.800 rpm, the engine should not operate for more than five (5) minutes to avoid potential damage to the engine.

Table 5 presents the most relevant data related to the engine rpm, power (kW)/(hp), fuel intake pressure (in. Hg) (manifold), and torque (Nm) – (ft·lb) (21).

Table 5. Relationships between the operating point and engine manifold pressure for the ROTAX® 912 ULS

Power Setting	**Engine speed (rpm)**	**Performance (kW)/(hp)**	**Torque (nm)/ft.lb)**	**Manifold pressure (in.Hg)**
Take-off power	5.800	73,5/100	121,0/89,24	27,5
Max. continuous power	5.500	69.0/90	119,8/88,36	27
75%	5.000	51,0/68	97,4/71,84	26
65%	4.800	44,6/60	88,7/65,42	26
55%	4.300	38,0/50	84,3/62,17	24

On the basis of the information provided by the manufacturer, the theoretical fuel consumption and the consumption in liters per hour are determined for each operating condition according to the supplied data.

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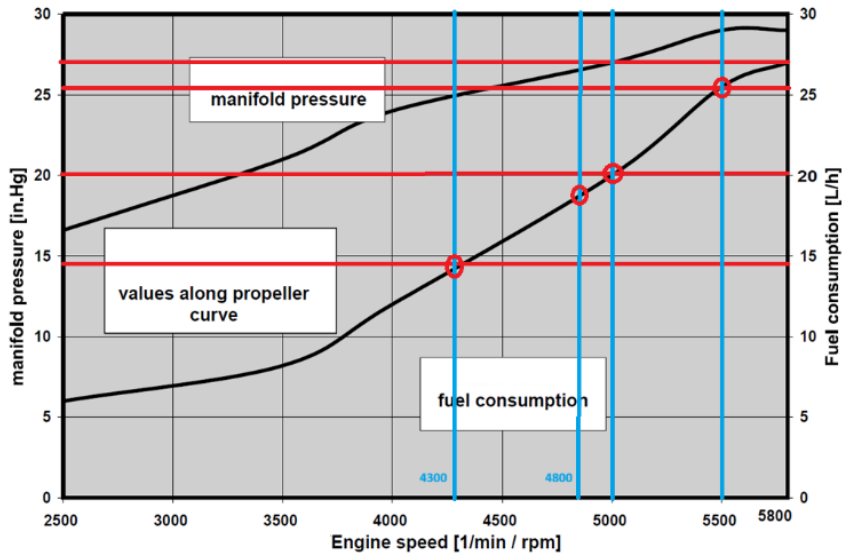

Figure. 4 Fuel consumption in liters/hour versus rpm (21).

Table 6. Relationships between power (kW)-(hp), engine rpm and fuel consumption

Segment	Standardized segment name	Power (%)	Power (kW)	Power (hp)	rpm	Fuel consumption CCFT (L/h) (gal/hr)
1	Takeoff run segment	100	74,6 kW	100 hp	5.800	27,5 L/h
2	Segment with headwind (Climb)	90	69,0 kW	90 hp	5.500	26,0 L/h
3	Segment with crosswind (Climb)	90	69,0 kW	90 hp	5.500	26,0 L/h
4	Segment with a tailwind (Leveling off)	75	51,0 kW	68 hp	5.000	20,0 L/h
5	Basic segment (Descent)	65	44,0 kW	60 hp	4.800	18,0 L/h
6	Final segment (Descent)	55	38,0 kW	50 hp	4.300	14,0 L/h

Theoretical determination of fuel consumption and energy to determine the airport traffic pattern at Guaymaral-SKGY

The heating value (calorific value) of AVGAS 100 LL expressed in kWh is 8,9 kWh/L.

The fuel consumption for each leg is determined as follows:

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$$CCT = CCFT * \left(\frac{1}{3600sg}\right) * (Tsg) \quad (1)$$

Where

CCT= Fuel consumption for the leg expressed in liters.

CCFT= Fuel consumption for the leg according to the manufacturer (L/h). See the right-hand column in Table 5.

Tsg= Duration of fuel consumption in the leg.

Table 7 Theoretical determination of fuel consumption according to the ROTAX® 912 ULS engine manufacturer specifications

Segment	**Standardized segment name**	**Length (nm)**	**Power (kW)**	**Time (s)**	**Fuel consumption in the leg (L)**	**Total shaft energy of the electric motor kWh**	**Energy kWh**
1	Takeoff roll with headwind on Runway 11	0,3	73.5	29	0,22	1,97	0,59
2	Flight segment with a headwind	1,7	69.0	85	0,61	5,46	1,63
3	Segment with crosswind	1,2	69.0	78	0,56	5,01	1,50
4	Segment with tailwind	3,3	51.0	150	0,83	7,41	2,13
5	Basic segment	1,1	44.0	76	0,38	3,38	0,93
6	Final segment	1,2	38.0	89	0,34	3,08	0,94
	TOTAL	8,8		507	2,95	26,32	7,71

The theoretical energy required to perform the traffic pattern is 7,71 kWh, with a fuel consumption of 2,95 liters and a flight duration of 507 seconds (8 minutes 27 seconds). The distance traveled is 8,8 nautical miles, and the average speed is 62,5 kt.

Determination of real fuel consumption under Guaymaral airfield (OACI- SKGY) conditions

The FLOSCAN 201A® sensor (23) and the FF1 instrument manufactured by MGL Avionics® were installed, with which the actual fuel consumption measurements are planned to be obtained for performing the traffic pattern characterized in the first part of this document.

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Installation of a precision onboard fuel measurement system

For this project, a Light Sport Aircraft (LSA) affiliated with the Colombian Club of Sport Aviation – CCAD, registered HJ417, was used. To date, a total of 360 flight hours have been accumulated, which have supported the characterization process, fuel measurement, and determination of the energy required to perform the traffic pattern.

Figure 5. MXP-150 Kimbaya-type LSA. HJ-417. Available for the project

The system implemented in the aircraft consists of the MGL-Avionics® FF1 system and the FLOSCAN® 201AV turbine-type flow sensor (23). The FF1 measurement system was installed solely with the configuration enabling real-time fuel consumption monitoring (24).

A series 200 flow transducers are designed to measure steady-state flow rates. The specified accuracies and pulse counts were obtained using heptane in a flow stand with rotary pumps and are reproducible in flow systems utilizing rotary or gear pumps. Following the manufacturers' instructions, the measurement system was installed as shown in Fig. 6 and Fig. 7.

Figure. 6. Installation of the FLOSCAN 201A sensor in the project's LSA aircraft.

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Figure. 7. Final installation status of the project's LSA aircraft.

Results of in-flight consumption measurements

For each stage of the 20 flights performed, real-time measurements were taken via the FLOSCAN 201A meter and the MGL-FF1 computer, and the following fuel consumption values were determined. Notably, the actual power delivered at the altitude of Bogotá 8.400 ft (2.560 m.s.n.m.) differs from the sea-level conditions specified by the manufacturer; therefore, a power correction must be applied on the basis of the curve shown in Fig. 8.

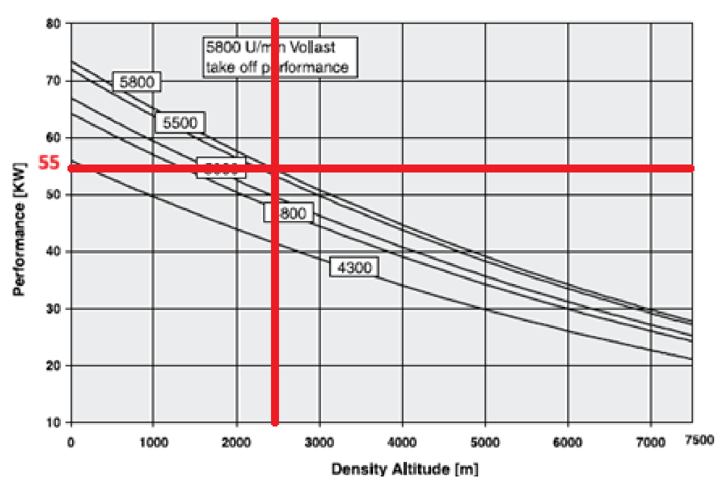

Figure. 8 Final configuration of the installation in the project LSA aircraft (21).

Fig. 8 shows that the maximum available power under the elevation conditions of the Guaymaral Aerodrome (SKGY) is 55 kW. The results shown in were obtained on the basis of the manufacturer's prescribed correction to account for increased altitude. Table 8.

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Table 8 Determination of actual fuel consumption on the basis of measurements obtained from twenty (20) flights

Segment	Standardized segment name	Length (nm)	Power (kW)	Time (s)	Fuel consumption in the leg (L)	Energy kWh
1	Takeoff roll with headwind on Runway 11	0,3	55	29	0,17	1,51
2	Flight segment with a headwind	1,7	54	85	0,48	4,29
3	Segment with crosswind	1,2	54	78	0,44	3,94
4	Segment with tailwind	3,3	50	150	0,78	7,00
5	Basic segment	1,1	47	76	0,38	3,38
6	Final segment	1,2	43	89	0,34	3,08
	TOTAL	**8,8**		**507**	**2,60**	**23,21**

Thus, the gross energy required to complete the traffic pattern is 23,21 kWh, the fuel consumption is 2,60 L, and the flight duration is 507 s (8 min 27 s). The distance traveled is 8,8 nautical miles, with an average speed of 62,5 kt.

Statistical treatment of computed variables

This section describes the statistical approach employed to characterize the performance variables obtained in Table 7. Population parameter estimation was carried out for the relevant magnitudes, and measurement repeatability was assessed through sample-based estimators; to this end, 20 measurements were considered for each of the trajectories.

The magnitudes subject to estimation were the following:

- Sample mean (C_i): estimation of the central tendency of each variable, derived from the sample of actual flights.

$$C_i = \frac{1}{n}\sum_{j=1}^{n} C_{ij}, n = 20 \quad (2)$$

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- Standard deviation (S_i): dispersion of the observations with respect to the population mean.

$$S_i = \sqrt{\frac{1}{n-1}\sum_{j=1}^{n}(C_{ij} - C_i)^2} \quad (3)$$

- Standard error of the mean: precision of the estimation of C_i from the sample; a lower standard error implies greater reliability of the mean as a predictor. $SE_i = \frac{S_i}{\sqrt{n}}$ (4)

- Coefficient of variation (CV_i): measure of relative homogeneity of variability. $CV_i = \frac{S_i}{C_i} x100\%$ (5)

Taking the foregoing into consideration, the estimation is carried out by means of Table 9.

Table 9. Statistical treatment

Segment	Standardized segment name	Fuel consumption in the leg (L)	Sample mean	Standard deviation	Standard error of the mean	Coefficient of variation
1	Takeoff roll with headwind on Runway 11	0,17	0,1700	0,00480	0,00107	2,82%
2	Flight segment with a headwind	0,48	0,4800	0,01162	0,00260	2,42%
3	Segment with crosswind	0,44	0,4400	0,01149	0,00257	2,61
4	Segment with tailwind	0,78	0,7825	0,01736	0,00388	2,22%
5	Basic segment	0,38	0,3800	0,00691	0,00154	1,82%
6	Final segment	0,34	0,3400	0,00920	0,00206	2,71%

According to the theory for experimental aeronautical characterization, CV_i values below 5% are considered indicative of satisfactory measurement repeatability. In cases where CV_i exceeds this threshold, the source of variability will be discussed and improvement measures will be proposed (sensor calibration, standardization of flight profiles, increase in sample size). Taking the foregoing into consideration, the results for the 6 segments with a reference criterion of CV_i < 5% provide an explicit basis for strengthening the research and its findings.

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Determination of the net energy required to complete the aerodrome traffic pattern

The aircraft used in this project is equipped with a 100 hp ROTAX® internal combustion engine (21) whose manufacturer-provided specifications are summarized in Fig. 9:

WEIGHT		kg	lb
Engine with propeller speed reduction gearbox i = 2.43		56.6	124.5
Exhaust system		4.0	8.8
Overload clutch		1.7	3.7
Engine suspension frame		2.0	4.4
External alternator		3.0	6.6
Air guide baffle		0.8	1.8
Airbox		1.3	2.8
PERFORMANCE			
73.5 kW		100 hp	5800 1/min.
TORQUE			
128 Nm		94 ft. lb.	5100 1/min.
MAX RPM*			
			5800 1/min.
BORE		**STROKE**	
84.0 mm	3.13 in	61.0 mm	2.4 in
DISPLACEMENT		**FUEL**	
1352 cm³	82.6 cu in	min. MON 85 RON 95* min. AKI 91*	

Figure. 9 Characteristics of the Rotax 912 ULS internal combustion engine.

For the internal combustion engine used in the tests of the ROTAX® brand, model 912 ULS, rated at 100 hp (74.6 kW) and fuelled with AVGAS 100LL—the manufacturer specifies an efficiency of 30% (25).

Determination of the energy supplied by the battery system to power the electric motor

To determine the energy required by the electric motor, the selected unit for the project is a ROTEX REB-90 rated at 80 kW, with a manufacturer-specific efficiency of 93% (22) (26).

Table 10. Net energy required to account for electric motor efficiency

Net Energy required kWh	Electric Motor Efficiency (%)	Total energy required by the electric motor kWh
7,71	93	8,29

As shown in Table 8, the electrical energy that must be supplied by the battery pack to complete the traffic pattern is 8,29 kWh, enabling a flight duration of 8 min 27 s (27).

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Cost analysis for economic viability

This section presents an economic feasibility analysis of converting an MXP-150 LSA aircraft, currently equipped with a 100 hp ROTAX® 912 ULS internal combustion engine (21), to a battery-powered electric propulsion system (28). For this comparison, the total energy required for the traffic pattern reported in Table 7 and the energy content per liter of AVGAS 100LL were considered (29). These data were used as the basis for estimating the fuel cost associated with completing the traffic pattern, as shown in Table 9. The exchange rate from Colombian pesos (COP) to U.S. dollars (USD) as of March 29, 2026, was used, along with the cost per liter of AVGAS 100LL in Colombia on the same date (30).

Table 11 Total fuel cost for the traffic pattern

Energy supplied by gasoline kWh	Energy per liter of AVGAS 100LL gasoline (kWh/L)	Required volume of fuel (L)	Cost per liter of AVGAS 100LL gasoline (COP $)	Exchange rate from USD ($) to (COP $)	Cost per liter of AVGAS 100LL gasoline (USD $)	Total cost of gasoline for the traffic pattern (USD $)
23,22	8,90	2,61	6.869,22	3.672,17	1,87	4,87

For the second part, the analysis was based on the electrical energy required by the selected motor ROTEX REB-90, 80 kW, and the cost per kWh in Bogotá, Colombia, using the tariff for residential stratum 3 for March 2026. These inputs were used to estimate the total electricity cost for the proposed electric flight, as shown in Table 10.

Table 12. Total electrical energy cost for the proposed flight

Required electrical energy (kWh)	**Cost per kWh (COP $)**	**Total electrical energy cost (COP $)**	**Total electrical energy cost (USD $)**
7,49	834,12	6.245,14	1,7

The above results indicate that, from a cost analysis perspective, the total cost associated with gasoline use for the flight circuit with an internal combustion engine is substantially greater than the total cost of the electrical energy required to operate the proposed battery-powered electric system. Specifically, when equivalent flight hours are projected and fuel costs are accounted for, gasoline represents a significantly larger fraction of the total operating cost than the electricity consumed over the anticipated operating hours.

The results show a substantial advantage for the electric option. Under the proposed operating scenario, the total cost associated with gasoline use for the traffic pattern amounts to USD 4,87, whereas the total cost of the electrical energy required for the same operating cycle when the electric motor is used is USD 1,7. This disparity corresponds to an approximate cost reduction of 65% when transitioning to electric propulsion. If sustained over the projected operating horizon, these savings indicate a favorable impact on the economic viability of the project.

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Estimation of CO_2 emissions

The Intergovernmental Panel on Climate Change (IPCC) has played a fundamental role since its establishment in 1.988, providing scientific assessments of the causes, impacts, and potential mitigation strategies related to climate change (31). At the international level, initiatives such as the Paris Agreement establish commitments to limit the increase in global temperature by reducing GHG emissions, promoting the transition toward cleaner and more sustainable energy technologies, including the electrification of air transport (32).

Within this framework, CO_2 emissions in the present study were estimated following the methodological guidelines proposed by the IPCC (2006), which establish that emissions from fossil fuel combustion can be calculated on the basis of fuel consumption and a specific emission factor (33), as shown in Equation (2):

$$Emissions\ CO_2 = Fuel\ Consumption * Emission\ Factor \qquad (2)$$

For aviation gasoline (AVGAS 100LL), the IPCC specifies an emission factor of 69,3 kg CO_2/GJ, which is based on an average carbon content of 18,9 kg C/GJ and its corresponding conversion to carbon dioxide. To express this factor on a volumetric basis, the fuel's heating value was used, which, according to Section 4.4 of this document, is 8,9 kWh/L. Performing the energy conversion:

$$Emissions\ CO_2 = 69{,}3\ KG\ \frac{CO_2}{GJ} * 0.03204\ \frac{GJ}{L}$$

$$Emissions\ CO_2 = 2{,}22\ Kg\ \frac{CO_2}{L}$$

Table 13 EmissionsCO_2

Required fuel volume (L)	Traffic pattern duration (s)	Number of traffic patterns per hour	Fuel consumption (L/h)	Emission factor $(Kg\ \frac{CO_2}{L})$	Emissions $(kg\ \frac{CO_2}{hora})$
2,61	507	7,1	18,52	2,22	41,11

Consequently, for one hour of operation, the aircraft generates approximately 41,11 kg of CO_2. Therefore, replacing the internal combustion engine with an electric propulsion system directly avoids this amount of emissions during operation, representing a significant environmental benefit aligned with global strategies in the aviation sector.

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Discussion of Results

The results obtained in this research demonstrate that the conversion of an LSA-type aircraft, originally equipped with an internal combustion engine, to a battery-powered electric propulsion system is technically feasible for the operational profile evaluated. The experimental data collected during the flight tests made it possible to determine the actual fuel consumption of the aircraft under representative operating conditions.

From a technological perspective, the results are consistent with those reported by (5), (7) and (16), who identify electric propulsion as one of the most promising alternatives for reducing the environmental impact of aviation. From an economic standpoint, replacing AVGAS 100LL fuel with electrical energy results in a significant reduction in operating costs. The estimated cost of completing the traffic pattern using electrical energy was approximately USD 1.70, whereas the cost associated with conventional fuel reached USD 4.87. This difference represents a cost reduction of approximately 65%.

In environmental terms, the research confirms the benefits associated with the electrification of light aviation. Replacing the conventional propulsion system with an electric powerplant eliminates direct in-flight emissions, thereby contributing to the global decarbonization goals of the aviation sector. Finally, this study provides quantitative information that may serve as a reference for future light-aircraft electrification initiatives in Colombia, as well as for the development of technical and regulatory guidelines that facilitate the integration of these technologies into the national aeronautical sector.

Conclusions

The energy analysis conducted on the MXP-150 aircraft established that the proposed flight route requires an energy demand of approximately 8.29 kWh, a value that can be met by a battery-powered electric propulsion system. The design of such a system is proposed as future work within the "Manned Electric Aircraft Prototype Phase I", currently under development by the GESETIC research group at Universidad Distrital Francisco José de Caldas.

A comparison of the thermal efficiency of the internal combustion engine against that of the electric motor demonstrated an improvement on the order of 60%, confirming that the conversion is technically feasible for a Light Sport Aircraft (LSA) within the evaluated operational profile.

From an economic standpoint, the proposed conversion yields a 67% reduction in operating cost per flight hour, attributable to the lower number of mechanical components and the simplification of auxiliary systems. These results confirm an overall reduction in operating costs, supporting the economic viability of the project.

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From an environmental perspective, the electrification of the aircraft eliminates direct AVGAS 100LL fuel consumption during flight, achieving a 100% reduction in direct emissions from the propulsion system and avoiding the release of approximately 41.11 kg of CO_2 per hour of operation. Furthermore, the elimination of leaded fuel use results in a 100% reduction in direct emissions of this pollutant.

Finally, a review of the Colombian regulatory framework supports the conclusion that the project is both legally and operationally viable, given that the Aerocivil regulations applicable to LSA aircraft and the guidelines set forth in RAC 21 provide for the development, evaluation, and certification of modifications of this type under controlled safety and airworthiness conditions. Accordingly, the project is concluded to be technically, economically, and environmentally viable, and represents an innovative and relevant alternative for advancing the energy transition of light aviation in Colombia.

This study establishes a solid foundation for the technical, economic, and environmental feasibility of replacing a gasoline engine with an electric motor in an LSA-type aircraft. As a natural continuation, it is proposed to advance the project "Manned Electric Aircraft Prototype Phase I," led by the GESETIC research group at Universidad Distrital Francisco José de Caldas. Future work will focus on experimental implementation and performance validation, with emphasis on the acquisition of key components and verification under real operating conditions.

List of abbreviations

LSA Light Sport Aircraft
AVGAS Aviation gasoline
GESETIC Research Group on Energy Systems Management Based on Information and Communication Technologies
SAF Sustainable aviation fuel
Aerocivil Special Administrative Unit of Civil Aeronautics
OACI International Civil Aviation Organization
AGL Above ground level
AMSL Above Mean Sea Level
UAEAC Colombian Special Administrative Unit of Civil Aeronautics
AIPC Aeronautical Information Publication
CCT Fuel Consumption for the Leg Expressed in Liters
CCFT Fuel Consumption for the Leg According to the Manufacturer
Tsg Duration of Fuel Consumption in the Leg
CCAD Colombian Club of Sport Aviation
GHG Atmospheric Concentrations of Greenhouse Gases
IPCC Intergovernmental Panel on Climate Change

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