# Electric conversion of a general aviation aircraft: a case study

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**Abstract.** This study analyses the process required to convert a conventional, air-breathing, piston-powered, General Aviation (GA) airplane to fully electric propulsion. The work is configured as a feasibility study for such modifications with the intent of setting a path for similar electric conversion programs on GA airplanes. The motivation behind industries' interest in alternative propulsion is examined and a full comprehension of the characteristics of the plane in question is achieved through the acquisition of transversal knowledge, examining the aircraft both from the engineering and real-world user points of view. Electric motor, batteries, auxiliary systems and implementation considerations were all made in accordance with regulatory authorities' requirements, with the purpose of making the project to comply with EASA CS Part 23. The present work analyses the performances expected from the electric plane and compares them with the standard aircraft evaluating the project's pros and cons. Considerations regarding typical mission profiles show how the electric powerplant will allow the airplane to outperform his conventional counterpart in terms of rate of climb, pollutant emission reduction, noise levels and operating costs. Such gains are however counterbalanced by the detriment of range and endurance performances, which might be deemed acceptable considering the specific plane's intended use. The study shows how, even though close integration in electric GA aircrafts is desirable since the first stages of conceptual design, piston-to-electric conversions are possible and may indeed contribute to mitigate aviation climate impact.

## Introduction

In recent years, the themes of sustainability and low/zero-emissions propulsion have assumed great relevance in aviation. Aviation represents a crucial asset and the only way to transport people and goods across the world within a day. In 2016, the sector drove \$2.7 trillion in economic activity and supported 65.5 million jobs, which made up 3.6% of the global gross domestic product (GDP) [1]. However, the destructive environmental consequences of aviation are undeniable. Although flying makes up only 3.5% of total human-induced carbon emissions, it is one of the most challenging to decarbonize [1]. In the interest of sustaining policies like the MEA (More Electric Aircrafts) [2], a feasible path might consist in converting established, well-known, conventional airplanes to electric power via a process that makes the new project an interesting alternative with respect to the gas-powered counterpart, cutting the costs of designing a new plane from scratch. This study therefore analyzes the process needed to replace the propulsive system of a conventional internal combustion engine airplane with a state-of-the-art electric motor and the associated batteries for the new aircraft to be used *as a trainer and semi-acrobatic General Aviation plane*.

## Conversion Process

**Requirements**. Considering the current state of the technology, flight time represents one of the major limitations in electrical aircraft's capability. Therefore, the logical target market for electric

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aircraft would be identified by applications for which flight time and range are not as decisive as they are in commercial aviation. Student pilots normally train in flights of about one hour. Anything more is generally considered counterproductive according to most flight instructors, so flight training represents a perfect target application [3]. The aircraft chosen as case study is the *SOCATA Tampico TB-9*, a French-made, all-metal, low-wing, four-seater, single engine aircraft in use in numerous flight schools [4]. It is well-known for its straightforward approach, forgiving aerodynamics characteristics and robust build.

**Batteries mass**. The sizing process needs to evaluate the batteries total mass $m_b$ [kg]. Given the required run-time endurance *E* [s], the mass of the batteries can be computed as

$$m_b = \frac{P_{sh}\, E}{E_{sb}\ \eta_{b2s}} \tag{1}$$

where $P_{sh}$ is the required shaft power during run-time [kW], $E_{sb}$ is the battery specific energy [J/kg] and $\eta_{b2s}$ represents the total system efficiency from battery to motor output shaft.

A safer and more conservative approach considers the power used equal to 120 kW, the maximum rated power that the selected motor can deliver, and the required batteries mass is found to be 387 kg. However, a more detailed analysis of the mission in hand, whose features are retrieved from the aircraft flight manual [5], requires the knowledge of the expected power levels during all flight operations, which resulted in $m_b = 346.3$ kg. For the sake of the study, the more conservative value has been considered.

**Powerplant installation**. The conventional aircraft is equipped with a four-cylinders, direct drive air-cooled Lycoming O-320-D2A engine capable of producing 160 hp at 2700 rpm. It is connected to the frontal bulkhead via a steel engine support structure, easily modifiable to account for the different form factors of the two powerplants [6]. After a careful market survey, the more suitable engine for the conversion is found to be the Safran ENGINeUS™ in the 120 kW configuration.

Energy is provided by state-of-the-art lithium-sulfur batteries produced by Sion Power with a specific energy of 500 Wh/kg. The cathode is made of sulfur and a conductive material while the anode is made of lithium or a lithium-alloy. The reaction between lithium and sulfur is highly energetic, which leads to a high energy density in the battery.

In the conversion process, the main constraint is the need to the comply with the Maximum Take-Off Weight (MTOW) of the standard model. EASA's Supplemental Type Certificate specifications allow a 5% deviation from the initial MTOW of the plane after the modifications, which will therefore retained as a requirement. The weight check – Table 1 – shows how the removal of the internal combustion engine, of the tanks and fuel system, of fuel and of the rear bench and passengers leaves enough mass available for the installation of the motor, batteries, and auxiliary systems even in the most demanding configuration of 120 kW continuos $\boldsymbol{P_{sh}}$. The payload reduction is clearly another cost of the conversion, but it is deemed acceptable considering the prospective use of the converted airplane as a GA trainer.

**Centre of gravity preservation**. Trim, stability, and structural considerations require that the new powerplant is integrated preserving the allowed CG envelope. The main components placement for the considered aircraft is schematized in Fig.1. The necessary checks are performed using the aircraft standard Mass and Balance modulus [7] as a reference – Table 2 – and verifying that in even in the most demanding configuration (two people plus baggage) the Center of Gravity stays inside its nominal envelope, Fig.1.

***Table 1***: *Weight analysis for the converted aircraft.*

| **TB-9 Maximum Take-Off Weight** | | 1060 Kg | **Total of Removed items** |
|---|---|---|---|
| **Removed items** | Engine | 120 Kg | - 448.76 Kg |
| | Tanks and fuel lines | 45 Kg | |
| | AVGAS100LL | 113.76 Kg | |
| | Rear passengers | 170 Kg | |
| **Added items** | Electric motor | 45 Kg | +442 Kg |
| | Batteries | 387 Kg | |
| | Cables and Insulation | 10 Kg | |
| **Electric TB-9 Take-Off Weight** | | 1053 Kg | **Total of Added items** |

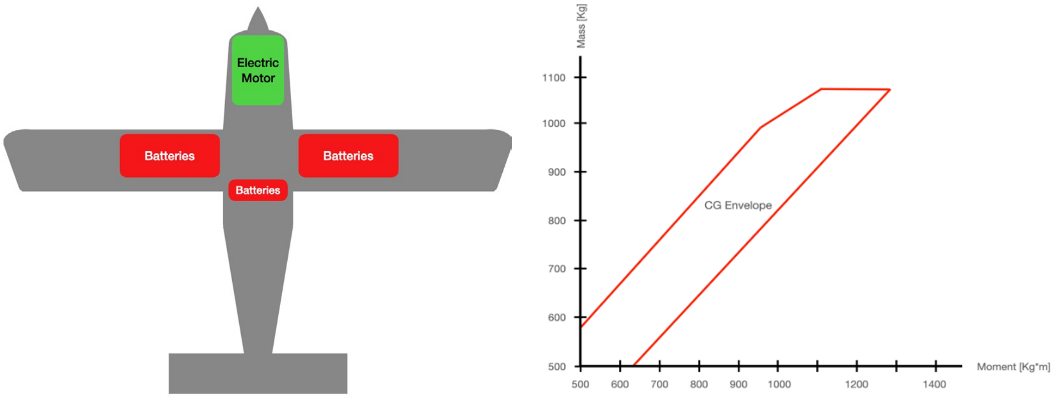

***Figure 1***: *Components placement (left) and center of gravity envelope (right) for the converted aircraft.*

***Table 2***: *mass and balance check.*

| | **Weight** [kg] | **Arm** [m] | **Moment** [Kgm] |
|---|---|---|---|
| **Aircraft** | 808 | 0.965 | 779.72 |
| **Pilot and co-pilot** | 170 | 1.155 | 196.35 |
| **Baggage** | 65 | 2.035 | 132.275 |
| **TOTAL** | 1043 | | 1108.345 |

**Performance evaluation**. In conventional engines, the volumetric efficiency decreases significantly with altitude: electric engines, on the contrary, are not susceptible to altitude variations in terms of power output. The limiting factor in terms of ceiling of the electrified airplane is related to air density decreases through propeller and lifting surfaces. With the implementation of electric technology, at 80 KIAS, the rate of climb achievable, and more importantly, sustainable for a longer time, will be given by

$$V_V = \frac{\eta_p P_{sh}}{W} - \frac{V}{(L/D)} \tag{2}$$

where $V$ is the flight speed, $\eta_p$ is the propeller efficiency, $W$ the aircraft weight [N] and $\frac{L}{D}$ is the lift-to-drag ratio. For the case in hand, Eq.(2) provides $V_V$ = 1212 ft/min.

Range is strongly affected by the limitations of the employed technology: in the case in hand the usable run-time endurance will be limited to 60 min for normal operations plus sufficient energy supply to sustain a holding pattern of 30 min. The theoretical range can be estimated as

$$R = \frac{E_{sb}\, \eta_{b2s}\, \eta_p}{g} \left(\frac{m_b}{m}\right) \left(\frac{L}{D}\right) \tag{3}$$

where $m_b/m$ is the battery mass fraction. For the considered case Eq.(3) provides $R = 353$ km. Operating costs significantly benefit from the electric conversion and, considering the price of electricity at the time of the development of the study of $€0.35/kW$h, 20% savings per flight-hour are estimated with respect to AVGAS operations, see Table 4.

***Table 4**: Performance analysis for the converted aircraft.*

| | |
|---|---|
| **Theoretical Range** | $-55.7\%$ |
| **Endurance** | $-68.75\%$ |
| **Payload** | $-43\%$ |
| **Climb rate** | $+61.6\%$ |
| **Cost per flight hour** | $-20\%$ |
| **Emissions** | $-100\%$ |

## Summary

The electric conversion of a GA trainer aircraft has been assessed. Although range and endurance are heavily affected by the limitations of the current battery technology, as expected, the other performances remain acceptable or are even enhanced and the overall platform may be profitably employed in applications where range and endurance are not the main concern, as in the considered case of training aircraft. While the platform emissions are certainly reduced, overall emission reductions depend on the *green quality* of the energy sources employed for battery recharging.

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