INVESTIGATION OF ALTERNATIVE PROPULSION CONCEPTS FOR SMALL AIRCRAFT WITH THE HYBRID ELECTRIC MOTOR GLIDER FVA 30

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Abstract

By designing and building a hybrid electric motor glider, the FVA student club aims to investigate the benefits of alternative propulsion concepts with unconventional configurations for small aircraft. The project highlights the potential of hybrid-electric powertrains in general aviation and validates the feasibility of their implementation by building a fully functional technology demonstrator, the FVA 30. The design goals comprise both performance requirements for efficient and cost-effective medium-range operation as well as ease of manufacture and maintenance. Particular attention is paid to safety to demonstrate the technology's maturity for everyday usage. The FVA 30 uses a serial hybrid power train that generates thrust via two electrically driven propellers integrated into a V-tail. A range extender provides constant power corresponding to cruise flight requirements, while temporary power peaks during take-off and climb are covered by a high-performance battery system, which additionally allows for brief battery-electric operation. The range extender employs a bivalent fuel system which may incorporate conventional gasoline as well as methane gas as primary energy sources to further reduce CO_2 emission. This paper gives insights into the general design process, aircraft properties, and preliminary conclusions. The FVA proceeds with the construction and flight-testing of the FVA 30.

Keywords
Aircraft Design, CS-22, Electric Aircraft, Hybrid Aircraft, V-Tail

1. INTRODUCTION

Fueled by the European Union's commitment to significantly reduce aircraft CO_2 emissions by 2050, electric aviation has increasingly attracted interest by both industry and academia. However, the low energy density of current battery technologies has proven to be a severe limitation for reasonable operating ranges [1]. Hybrid concepts appear to be a promising alternative in the near future as they provide the high energy density of fossil fuels while enabling more efficient and sustainable aircraft designs due to the high power density of electric motors and batteries.

Motivated to build a fast yet energy-efficient small aircraft for regional and cross-country flights, students of the *Flugwissenschaftliche Vereinigung Aachen e.V.* ("Scientific Aviation Association Aachen", short *FVA*) set out in 2017 to develop a hybrid-electric motor glider incorporating these benefits. Pursuing an exemplary mission to cover the distance from Aachen to Berlin faster and more efficient than by car, the FVA 30's design goals define a minimum range of 650 km (already including some reserve), an average speed of 140 km/h, and a maximum take-off distance of 500 m. Further, noise pollution is addressed by requiring a maximum of 60 dBA of noise emission as perceived during a fly-over at 200 m altitude.

On the basis of the e-Genius, a pre-existing electric motor glider developed at the Institute of Aircraft Design (IFB), University of Stuttgart [2], an alternative configuration is studied, which explores new benefits arising from fully electric and serial hybrid propulsion. The front section of the fuselage and the aerodynamic wing design of the FVA 30 are directly derived from the e-Genius, whereas the tailplane and the power train are newly developed.

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In addition to the technological realization, the project aims to demonstrate the readiness for an economic application by ensuring low operational, maintenance and manufacturing costs. In doing so, the prototype shall demonstrate how more sustainable flying is already a suitable option for common use cases in general aviation today.

The paper introduces the FVA 30 and its design process in five main sections. First, the concept of the motor glider and its exemplary flight profile are presented in Section 2. Certain flight-mechanical particularities that arise from the unusual propeller configuration are summarized in Section 3. In Section 4, the details of the power train are highlighted, starting with the electrical system architecture in Subsection 4.1. The propeller design and its interdependency with the propulsion system are discussed afterwards in Section 4.2, followed by the battery system design in Section 4.3. Section 5 finally describes the envisioned bivalent fuel system for the range extender before a conclusion will be provided in Section 6.

2. CONCEPT

The FVA 30 is a motor glider with a maximum take-off mass of 905 kg and a wingspan of 16.9 m, which will transport two pilots in a side-by-side configuration. Wings and ailerons are conventionally located immediately behind the cockpit. Its V-shaped tail section combines the control surfaces for the elevator and rudder. Two fixed-pitch propellers are attached to each tip of the V-tail and generate thrust in tractor configuration. Similarly to the e-Genius, the majority of the airframe's structural components are made of glass- and carbon-fiber composite materials. The configuration is illustrated in Figure 2.1.

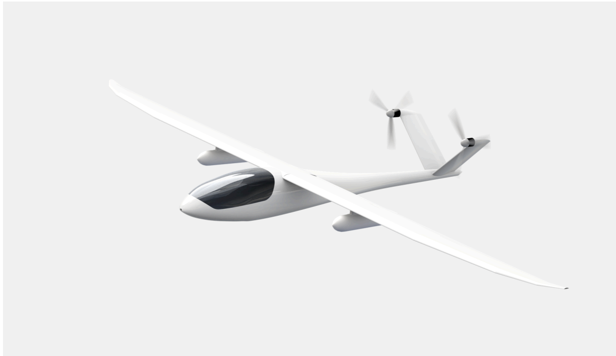

FIGURE 2.1: Concept of the motor glider FVA 30

The aircraft configuration is chosen to highlight benefits in conceptual small aircraft design, which arise from new opportunities that set electric propulsion apart from conventional piston or turbine designs. The rear placement of the propellers is motivated by the resulting long laminar airflow around the fuselage. Unlike most fossil fuel concepts that achieve a similar effect by installing a rear propeller in pusher orientation, the placement at the tips of the tail section leads to undisturbed inflow in the propeller plane and therefore reduces propeller noise and increases efficiency. Additionally, the propellers inherently comply with ground clearance requirements and, given the spatial separation from each other as well as the fuselage, large propeller blades can be implemented to further reduce rotational speed and noise emission.

Appendix 1 gives a schematic overview of the drive train integration. The propulsion system of the FVA 30 consists of two separate drive trains, thus providing a high degree of safety through complete redundancy. Two electric motors are placed behind the propellers, which they drive directly without an additional mechanical transmission. Transmission parts, typically bearing extensive loads, tend to lead to more time consuming and expensive maintenance procedures and require additional tests during certification. Omitting the transmission not only yields reduced operational costs but also reduces weight in a balance-critical position. As a consequence, the propeller blade geometry and motors' characteristic performance are strongly interdepended and were simultaneously designed in an iterative process. The procedure aimed to optimize the expected flight profile's overall efficiency and limit propeller noise emission while satisfying all minimum requirements, namely supplying sufficient power for safe take-off and climb flight phases.

The high voltage inverters, which control the synchronous machines, are located in the rear of the fuselage. A lithium-ion battery system, comprising two independent battery packs operating in parallel, is located behind the pilots. The range extender is specifically optimized for the aircraft's steady and well predictable power requirements during cruise flight and primarily operates on compressed natural gas (CNG), which is chosen to achieve lower overall carbon emission in comparison to the conventional gasoline drive trains installed in the majority of small aircraft today.

Flight Phase	Time [min]	Distance [km]	Combined Mechanical Shaft Power [kW]	Estimated Electrical Energy Demand [kWh]
Take-off	0.58	0.48	68,6	0.96
Climb	6.24	13.9	52.2	7.87
Cruise	261.1	609.2	11.2	71.7
Descent	14.7	26.9	n/A	n/A

TABLE 2.1: Flight profile covering the minimum target range of 650 km at 140 km/h cruise speed. Power values refer to the combined mechanical shaft power whereas the estimated electrical energy demands incorporate simulated motor, inverter, and cable losses.

The pressurized fuel system is stored in a pair of wing-pods, which are placed underneath each wing. Since CNG and the far more accessible standard gasoline are compatible in terms of engine requirements, an additional gasoline fuel system is implemented in the wings and fuselage. In such a serial hybrid setup, the combustion engine can operate near its ideal parameters, unrelated to the current operating condition of the aircraft.

Because of their high aerodynamical efficiency and – in comparison – low operating costs, the motor glider was selected as the adequate aircraft type for the FVA 30. The less expensive piloting license for motor gliders in German aviation further motivates a certification under the CS-22 certification specifications.

However, with two redundant drive trains, the FVA 30 represents a twin-prop configuration that is not included in the CS-22 specifications. As a result, a number of additional requirements from the CS-23 regulations must be met. These requirements specifically regard the flight mechanics and control system design of the aircraft and are selected in continuous consultation with the German Luftfahrt-Bundesamt (LBA), the German aviation authorities.

Based on the design goals presented in section 1 and flight-testing data of the e-Genius, the required flight performance was computed in a MATLAB simulation. For this purpose, a representative flight profile was used that considers the aircraft's minimum target range of 650 km with a constant cruise speed of 140 km/h. The power and energy needs are defined separately for three phases of the flight profile, namely take-off, climb, and cruise. Table 2.1 summarizes the mission flight profile and respective power and energy requirements. The power estimates in Table 2.1 denote combined mechanical motor shaft power and represent peak values in each flight phase. Energy estimates relate to electrical energy and incorporate estimated motor, inverter, and cable losses but exclude battery or range extender efficiencies.

It is to note that the efficiency estimates are derived from a simulation setup that is constantly progressing and regularly extended by new details resulting from component specifications and laboratory tests. Additional measurements taken during ground tests will allow for more precise estimates of each component's efficiency.

The motors' efficiencies are presented in Figure 4.2. The battery is regarded in detail in Section 4.3 and the fuel system together with anticipated CO_2 emissions is provided in Section 5.

3. FLIGHT MECHANICS

The tail section is equipped with the Wortmann FX 71-L-150/30 airfoil [3], a symmetric, laminar airfoil. The V-tail was sized in a two-step process that first drew on analytical analysis and later fine-tuned its dimensions numerically in a self-made tool that utilizes Athena Vortex Lattice (AVL) [4] for its aerodynamical calculations.

In this process, the tail section's dimensions and maximum deflection angles were defined in a way that ensures both stability against eigen-oscillations of the rigid aircraft and controllability of the aircraft in all conceivable flight conditions.

An analysis of the rigid aircraft's dynamic stability showed that its phygoid eigen-oscillation is not sufficiently damped and would in fact be observable during flight. However, given its miniscule frequency of less than 0.05 Hz, the phygoid can effortlessly be countered by the pilot and is therefore tolerated under CS-22 regulations. All other eigen oscillations of the aircraft were shown to be sufficiently damped.

The FVA 30's unusual propeller positioning also motivated an investigation into the ideal pitch of the propeller axes. Inflow that is misaligned with the direction of the propeller axis reduces the propeller efficiency and leads to rapidly alternating structural loads. Based on a numerical determination of the downwash in the propeller region, the ideal angle of deflection with regard to the aircraft's longitudinal axis proved to be +1,08° upwards. However, while the resulting pitch optimized cruise efficiency, it reduced the aircraft's performance during take-off and increased the nose-down pitching moment.

Because of the considerable masses of components that are located in the tail section of the aircraft, the wings need to be moved rearwards in comparison to the e-Genius. Clearly, the dimensions of the tailplane and its placement are not isolated from such a transition and reducing the distance of the rudders to the center of mass, subsequently requires increased rudders' control surfaces. To optimize this process, an algorithm compared the required tail section size with possible wing displacements along the fuselage. Additionally, constructional factors and force distribution between the landing gear parts were taken into consideration. As the ideal displacement that best satisfies the given constraints, a wing displacement of 120 mm rearwards was ultimately selected.

4. POWER TRAIN DESIGN

The central focus of the propulsion concept certainly lies on the design of the power trains. The FVA 30 is designed to operate in two different flight modes: battery electric and serial hybrid. The range extender system, consisting of the generator aggregate, the CNG fuel system in the wing-pods and the gasoline fuel system in the wings are designed to be non-essential for the safe operation of the aircraft. Therefore, its components can be selected based on weight and space optimization from a range of equipment from the automotive and transportation industry, instead of being restricted to the limited number of systems that are available to aviation due to typically extensive legal reliability standards. Circumventing the considerable costs and workload of testing the range extender system for aviation reliability standards ultimately reduces the design process's overall time and costs. This is an inherent advantage of serial hybrid configurations over their parallel-hybrid and power-split counterparts, as they must regard every component as system-relevant.
In a preliminary phase, intended for component validation and flight-testing, the FVA 30 will fly with battery electric propulsion and thus with limited range. The combustion engine, as well as the CNG and gasoline fuel systems will later be installed in the prototype in a subsequent step, once the aircraft is known to satisfy all certification requirements and is equipped with a permit-to-fly.

4.1 Electric System Architecture

The electric system is designed to provide a high degree of safety in terms of the propulsion system's reliability.
In addition to the high reliability standards of the individual components, the entire drive train is built without a single point of failure. Each component that is critical for propulsion is installed twice. The battery packs are interconnected to allow balancing during the recharging process. In addition, each battery module supplies sufficient power to shortly operate both drive units in the severe case of one unfunctional battery module. Given the significant cumulative cable length, an operating voltage of 600 V is chosen for the high voltage net to reduce weight while limiting losses.

Since the motors have to operate the propellers without additional transmissions, they need to meet a realistic propeller operating point and provide adequate torque at relatively low rotational speeds. The operation variables of the propeller are adjusted in an iterative process that takes their performance as well as the motor's efficiency into consideration. Because of their, in terms of aircraft center-of-mass, unfavorable position, the motors' weight is highly critical. Due to their power density as well as their efficiency, three-phase AC motors were prioritized and ultimately the synchronous, axial flow machine EMRAX 228 [5] in high voltage and liquid-cooled configuration was selected. Figure 4.1 shows the motors' efficiency map with the flight phases' operational points marked as take-off, climb and cruise. The operation parameters were determined in accordance with the propeller design described in section 4.2.

The motors are controlled by Unitek Bamocar [6] inverters that were selected based on their high efficiency, limited weight of 8.5 kg, and conformity with the system's high voltage.
In addition, a rectifier is required to attach the range extender (generator) to the DC-bus. A galvanically separated DC-DC buck converter is used to power the low voltage (LV) board net.
An insolation monitoring unit is implemented to observe the separation of the high voltage (HV) battery net from the fuselage. A HV discharge unit is implemented to quickly reduce the voltage to a safe level in the HV net after the batteries have been disconnected.

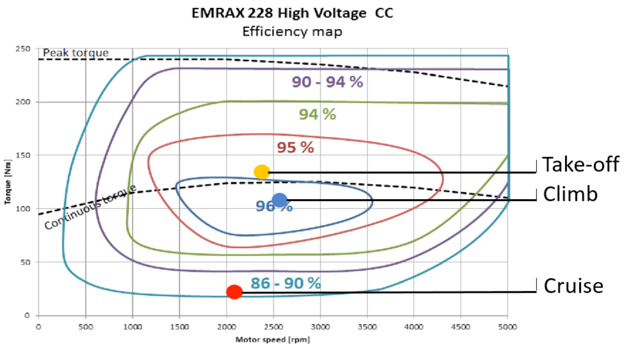

FIGURE 4.1: Efficiency map of the motors provided by the manufacturer [3]. The operating points of each phase of the flight profile are marked.

The TE Kilovac EV200 were selected as HV DC contactors. They each add 0.43 kg of mass and supply high number of reliable duty cycles.

Finally, a lithium-iron-phosphate (LiFePo4) battery is installed in the low voltage net to ensure that instrumentation and communication equipment are powered in the event of a malfunctioning DC-DC converter.
A power distribution unit (PDU) is used for the high voltage components' switching and connects the batteries with each other, with the inverters and the range extender's rectifier.
The FVA 30 uses a Speedgoat Baseline control unit [7] that regulates the pilots' power control inputs and will be used to balance power output between the range extender and the batteries. In the installed configuration the control unit weighs 1.1 kg.

The extensive cable network of the high voltage net spans from the center of the fuselage to the tail section. Because of the partially significant distance from the aircraft's center-of-mass, the cable weight has a substantial impact on the total weight and in-flight balance. To compare the significance of the additional mass with the increased efficiency of thicker cables a simulation has been performed to estimate the distribution of electrical losses throughout the cable structure. The simulation was performed for the test cycle with the highest electrical load imprinted on the cables by the batteries of the FVA 30 and determined that a 16 mm^2 copper cable set up does not lead to cable temperatures of more than 65 °C and losses were considered acceptable in contrast to the overall reduced weight when compared with 25 mm^2 cables.

4.2 Propeller Design

Based on the performance calculations of the aircraft, the propellers need to generate a required amount of thrust in each stage of the flight profile while maximizing the flight profile's overall efficiency. Because of the direct mechanical connection to the motor shafts, the motors' efficiencies had to be taken into consideration during the propeller optimization.

Based on the required performance in each stage, the software JavaProp [8] was used to generate blade geometry, geometric pitch, and number of blades. The input operating point was based on representative rotational speed and torque of the motors. The resulting preliminary propeller model was then analyzed in a self-made tool based on the Blade-Element-Momentum-Theory, which is implemented in MATLAB and uses an interface to the airfoil analysis software XFOIL [9] to generate thrust, efficiency, and torque values as well as the induced directional velocity in the propeller plane. Using XFOIL's pressure coefficient distribution an estimate on noise emittance is returned as well [10].
In an iterative process, parameters of the propeller geometry – geometric pitch, thickness, chord length – and the rotational speed are varied. The resulting trend in propeller performance is observed and the transitions in the input parameters are reduced or substantiated.

4.3 Battery Design

Battery development is subject to tough requirements regarding energy and power density and must ensure high safety standards.
The battery system is installed in the fuselage behind the pilots and is therefore predominantly volume-constrained, while its positioning helps to partially counter the rearward-shift in aircraft center-of-mass due to the tail-integrated propulsion units. According to the battery electric operation requirement, the battery has to provide the power for take-off, climb to 1000 m, and a minimum cruise flight of 15 minutes. Furthermore, a particular focus lies on a high-safety design, which is addressed on all three levels: cell-level, module-level, and system-level. Cell selection should consider inherent safety features such as

Battery Cell	Sony VTC-6
Number of cells	1440
Serial	144
Parallel	5 × 2
Operating Voltage	400 – 600 V
Total Cell Weight	68 kg

TABLE. 4.1: Battery system configuration

	Take-off	Climb	Cruise
Duration	90 s	300 s	> 900 s
Power	65.5 W	47.57 W	10.22 W

TABLE. 4.2: Power requirements on cell-level

mechanical rigidity and inbuilt protection devices (e.g. a current interrupt device triggered by internal overpressure). The modules should incorporate a thermal management system to keep the cell temperatures in a reasonable operating range and especially below the safety threshold of 60 °C. Further, it has to be ensured that cell voltages, currents and temperatures are constantly tracked and checked by a reliable battery management system. Finally, on the system level, the battery should also follow the redundant drive train design by being split into two parallel packs with separate control electronics, each of which can still ensure safe aircraft operation in case of a one-sided battery failure.

After a qualitative assessment of different cell formats, round cells were selected for their good mechanical and cooling properties, inbuilt safety features and low costs. In order to aid cell selection, an automatic cell analysis and battery configuration tool based on public measurement data from nearly 110 different cells was developed. This tool simulates the expected discharge load cycle according to the mission profile by modeling each candidate cell and identifies the best pack configuration to meet power, energy and voltage constraints. This allows to compare different cells on a profile-dependent system level. Following additional measurements of a set of pre-selected cells on an institute test bed, the Sony US18650 VTC-6 was finally selected with a configuration as shown in Table 4.1, including some performance padding considering cell aging. The resulting estimated power requirements of the target profile on cell-level are shown in Table 4.2.

The estimated heat loss obtained from the measured profile amounts to a bit less than 1 Wh per cell and is in good accordance with preceding simulations. The thermal management system must be capable of removing that amount of heat, which would lead to an excessive temperature rise beyond 60 °C, while the cells' thermal capacity can approximately absorb 0.124 Wh per 10 °C temperature increase. Furthermore, special attention must be paid to volume constraints, fail-safety and possible containment of local cell fires.

A detailed analysis compared liquid, air and phase change material (PCM)-based cooling approaches where each option was further benchmarked against a cooling-free design with corresponding space savings filled by additional cells. The need for a cooling system could be clearly demonstrated and, given the fixed load profile characteristics, a PCM-based cooling was considered a promising solution. It is inherently fail-safe without any active components involved, complies well with our volume constraints and provides additional safety by mitigating the risk of fire propagation in case of a thermal runaway. In addition, it allows the modules to be fully sealed, so that no pollutants or moisture can enter the battery and potentially hazardous gases from cell venting events can be

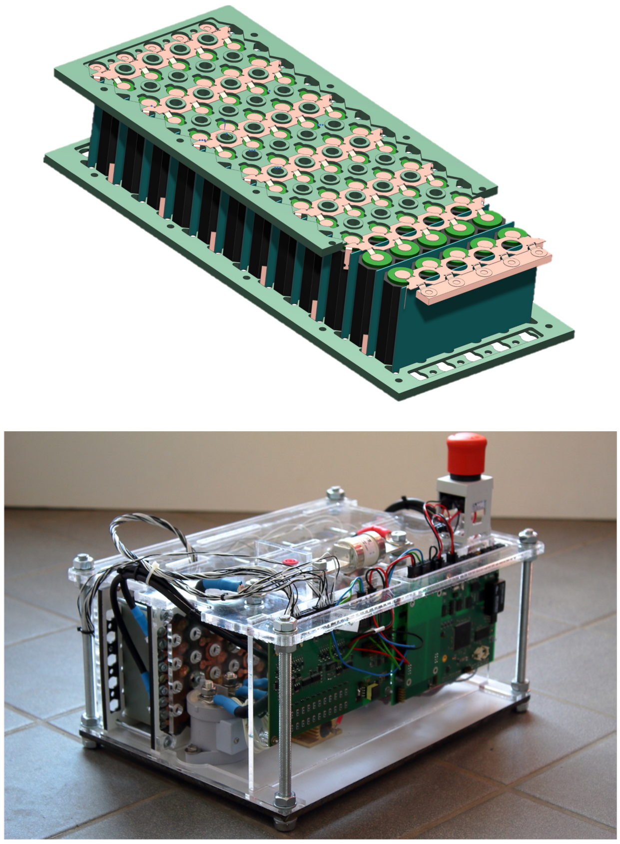

FIGURE 4.2: CAD model of the battery module embedded in a PCM cell holder (top) and the prototype for one module (bottom).

discharged on overpressure in a controlled manner. The PCM consists of paraffin, which undergoes a phase change from solid to liquid and thereby absorbs a high amount of energy. It is encapsulated in a solid host structure such as expanded graphite or polyethylene with thermally conductive additives in order to absorb heat quickly and homogeneously. By modifying the compound composition, properties such as the melting range, thermal capacity and thermal conductivity can be matched to the desired operating temperature and power loss profile.

The battery module, which is depicted in Figure 4.2, comprises 12 serial connected submodules of 5 parallel cells each, where cells are embedded into cell holders of the PCM compound. In the resulting cell matrix, the distance between cells is 3.6 mm. Submodules are separated by insulating glass fiber (GRP) panels coated with a fire-protective paint and feature small air channels for an active cool down by an external compressed air supply provided on the ground. The cells are contacted by arc-welded copper sheets.

To monitor the cells, a battery management system (BMS) is being developed based on the open-source foxbms of the Frauenhofer Institute for Integrated Systems and Device Technology IISB [11]. This is motivated by the high safety standards, component redundancy and well documented design that eases additional modifications. The foxbms follows a master-slave architecture. Each of the 12 modules of each battery pack contains one slave unit with 12 voltage and up to 16 temperature measurement channels to monitor every submodule.

In 2019, a fully functional battery module, equipped with a prototype of the PCM cooling, BMS and all relevant junction box components, compromising contactors, fuse, shunt, and pre-charge resistor, was constructed and evaluated on an institute test bed for different flight profiles. Further, preliminary battery abuse tests on submodules were performed which could demonstrate the fire propagation protection provided by the PCM structure.

5. BIVALENT FUEL SYSTEM

The limited energy density of currently available lithium-ion batteries (e.g., 237 Wh/kg for the Sony VTC-6 [12]) necessitates an additional power supply onboard the FVA 30 to enable ranges of several hundred kilometers.
With a CO_2 emission factor of 201.96 g/kWh, CNG can potentially reduce CO_2 emissions by 23.3 % in comparison to gasoline with an emission factor of 263.16 g/kWh [13]. This option is therefore selected as the primary onboard energy source to supply cruise power and recharge the aircraft's batteries.
As CNG is not as readily available as conventional gasoline, a bivalent fuel system is installed that allows both CNG and gasoline operation. This aims to ensure ease of operation and independence from logistical challenges related to the use of CNG. To sustain high ranges while limiting CO_2 emission, a balance of CNG and gasoline at the ratio of 2:1 can be used, and the range extender will conduct a seamless in-flight transition between energy carriers.
With an estimated range extender efficiency of 25.8% at 1500 m altitude, the average CO_2 emissions for the cruise flight profile presented in Table 2.1 (pessimistic conditions) amount to 92.13 g/km. Charging the batteries before each flight additionally contributes to the overall CO_2 emission. Considering average CO_2 emissions of 401 g/kWh CO_2 (German electricity grid in 2019 [14]), a full charge of the battery translates to 6.25 kg CO_2, which makes up about 10 % of overall emissions for the presented 650 km flight mission. In comparison, an aerodynamically equivalent aircraft propelled with a conventional gasoline engine with the same efficiency would have an approximate CO_2 emission of 120 g/km when following the same flight profile.

The conventional gasoline fuel system is based on known and tested fuel systems that have been implemented in other small aircraft and motor gliders. It is therefore not further regarded here. The high-pressure CNG fuel system, however, is highly unconventional in aviation and no prior certified systems can be used as a foundation. Together with the German aviation certification authorities (LBA), a guiding framework for certification of such systems is currently in development. This process is orientated towards regulations and safety standards from the automotive sector, primarily the ECE R 110 [15].
In order to determine potential hazards, a risk management study showed all foreseeable types of failure and malfunction for each of the fuel system's components. For every significant component it describes the consequences of potential unintended behavior and defines

countermeasures that the fuel system needs to undergo to preserve safe operation.

The CNG is stored in tanks that are contained in the aircraft's wing-pods and pressurized at approximately 200 bars working pressure. The gas tanks are made from resin-soaked continuous fiber. They have been specifically designed without any metal components on their innermost layer in order to prevent electrostatic discharge. As the gas is withdrawn during flight, it is depressurized to its working pressure of 5-9 bars. The wing pods are removable in order to allow modular fueling of the separated tank system and battery electric or gasoline-powered flight without CNG.

Together with the tanks, the wing pods contain a range of sensory and regulatory equipment. Two pressure release devices (PDRs), responsive to threshold temperature and threshold pressure levels respectively, regulate the pressure inside the wing-pods. Additional pressure sensors indicate the system state to the pilots. Via a manual controlled and an engine-control-unit (ECU) operated valve, the tank system is connected to a pressure regulator that reduces the pressure before the gas is funneled through the wing into the fuselage. The stiff gas pipe leading through each of the wings is mounted with loose bearings near the wing-pod valve to respond to wing flexibility and temporary deformation during flight.

6. CONCLUSION

The FVA 30 provides a promising research platform for alternative propulsion concepts in aviation. As demonstrated, taking advantage of new conceptual opportunities enabled by the electric drive train, results in a holistic aircraft optimization.

By integrating the propulsion unit in the tail section, long laminar airflow around the fuselage can be achieved, which increases efficiency and enables larger propeller diameters to reduce noise pollution. Long ranges are made possible by a serial hybrid drive train configuration with an optimized range extender running at the stable and well predictable cruise flight operating point. With an estimated engine efficiency of 25.8 % at 1500 m, the anticipated average CO_2 emissions was estimated to 92.13 g/km when operating with CNG, where performance requirements always assumed pessimistic conditions.

A particular development focus was put on high safety standards, which is reflected by the redundant drive train design, component selection, and further measures such as the PCM-based battery cooling. The drive train is designed to allow for both medium-range hybrid-electric flights with a minimum target range of 650 km, as well as shorter battery-electric flights so that the aircraft can be operated safely without the need of the range extender. This provides a considerable advantage since components for the non-essential fuel and range extender system can be selected irrespective of the strict reliability standards in aviation certification, which may lead to a significant reduction of workload and cost as well as a greater scope for optimization.

At the end of 2020, the aircraft has completed the final design review and the FVA has commenced with the manufacturing of components and subsystems in the FVA workshop in Aachen. The next milestones comprise the construction of a ground-based drive train test bed ("iron bird") as well as the manufacturing of the wings and the tail section.

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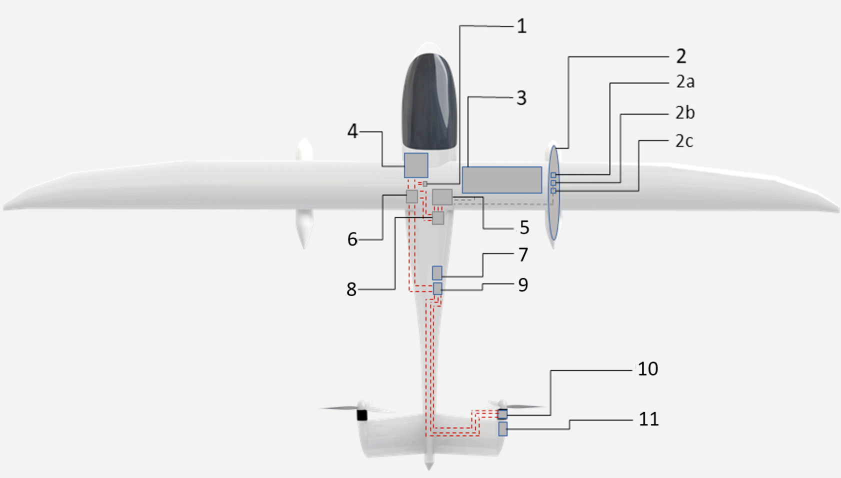
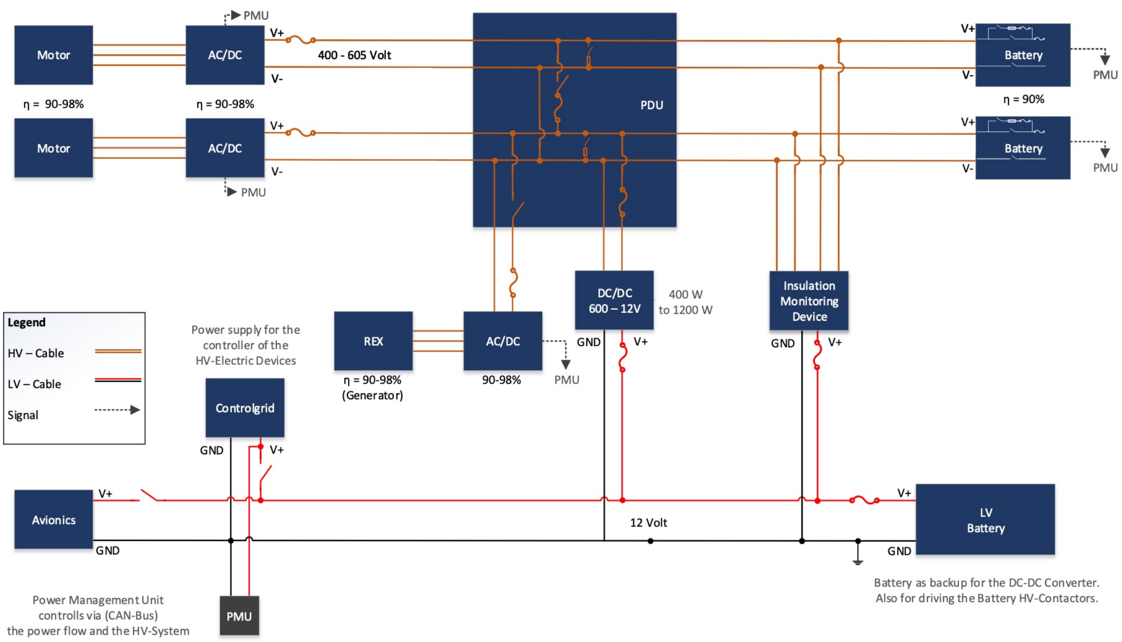


1	Insulation monitoring device
2 2a 2b 2c	CNG tank Pressure release device Manuel and ECU-controlled valve Pressure regulator
3	Gasoline tank
4	Battery
5	Range extender
6	Power distribution unit
7	Inverter cooling
8	Rectifier (AC/DC)
9	Inverter (DC/AC)
10	Motor
11	Motor cooling

APPENDIX 1: Schematic power train design of the FVA 30. Components marked blue are identically present on the opposite side but only shown once. Dotted red lines illustrate the high voltage net, whereas dotted grey lines show the fuel pipes. The low voltage net is not shown.



APPENDIX 2: Schematic system architecture comprising a HV DC net to which battery and range extender are attached as well as a LV DC that is operated by a DC/DC converter and a separate backup battery. The preliminary build phase without range extender will have two completely independent battery-driven propulsion units.