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Electric flight – history – state of the art and first applications

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Abstract

The next challenge for the electric drive trains is the third dimension, heavier than air. After an analysis of the air transport we can see a strong growth (33 million tons of kerosene in 1980 and about 600 million tons of kerosene in 2030).
In 1973 the first battery powered plane made its first flight. The technical challenge for the electric flight is the energy density of the battery. In the last 10 years a lot of new projects have been developed. This was possible with the availability of high energy Li-Ion-batteries. There are still some advantages for e-flight. The first niches are light planes as gliders, hang-gliders etc. There are two popular concepts: battery powered electric airplanes and solar powered airplanes. There is still a market for e-flight today. With hybrid planes the commercial air traffic for small regional planes could be entered in about 2030.
The Berne University of Applied Sciences (BFH-TI) is active in the field of e-flight. The university is very active in power electronics, renewable energies (mainly PV), battery technologies and automotive technology. These activities are concentrated in the "Institute for Energy and Mobility Research". The background for the e-flight was the successful technologies for racing solar cars in the 80-ties and 90-ties. This was used for the powertrain and the electronics for a first electric glider, the "Antares". Some of the actual projects are an "acrobatic plane" and a "hybrid plane" for four passengers.

Keywords: electric flight, electric gliders, solar plane, hybrid plane, market niches

1 Introduction

Electric drive trains are more and more successful in land and water transport[1]. Due to the high efficiency they can replace combustion engines and run on renewable electricity[2]. Motor powered planes however are mainly driven by fossil fuels. The weight restrictions for a plane and the high power demand for the start makes it difficult to use an electric drive train. Actually two concepts are used for the electric flight: battery powered planes and solar powered planes.
Since the first electric flight of a plane heavier than air in 1973 a lot of new concepts would be developed. Some are produced in very small numbers. The electric drive in planes heavier than air will need even more time than the automotive sector. A careful selection of market niches will help to enter the third dimension with electric drive trains. The main focus of this article is planes heavier than air, with a special look for market niches. Some projects of the Berne University of Applied Sciences BUAS will be presented too.

2 Air traffic a small part of transport energy consumption

The energy used for air traffic is part of the energy for transport, one off the biggest use of energy (other are buildings and industry). Actually 7% of the transport energy is used for air traffic (IEA). Annually 1,6 billion passenger uses the air traffic. 30 million tons are transported by the air traffic. There are strong growths: in 1980 33 million tons kerosene were used. In 2012 the consumption was 205 million tons of kerosene. The air traffic is about 3-times more relevant for CO2 emission than the traffic on earth.

The prospects for further growth are big. For 2030 a consumption of 600 million tons of kerosene are projected. 4.8 billion passenger will use the air traffic and there will be 2-time more planes in the air. The tax system does not touch international air traffic. This acts as a push for even more use of kerosene against other public transportation systems as railways, buses etc.

3 Technical challenge of e-flight

3.1 Energy needs for small planes

Planes need a lot of power for the take off. This is less a problem than the consumption during the flight. A modern small plane with four seats is as the Aerospool WT10 Advantic. He has a common internal engine combustion Rotax 914 and need about 15 l/ h fuel by a moderate cruising speed of 240 km/h[3]. This is similar to 150 kWh. Even with a very high energy density battery of 200 Wh/ kg we get a battery weight of 750 kg. This is the maximum weight of the whole airplane. The original plane WT10 Advantic can store 2x63 l fuel which is enough for a range of 1’300 km or about 5 hours of flight. This shows that we have to rethink the concept for an electric plane.

3.2 Passenger planes

Passenger planes need also a lot of energy. Modern planes needs about 2-3liter/ 100km which is quite efficient. But due to the high speed, the long distances and the number of seats of such plane we need big and heavy batteries. Such concepts are under suspicious of the group “Bauhaus Luftfahrt”, a german think tank for new possibilities in air traffic. They presented some concept plans under the assumption that in 2035-2040 much more powerful batteries could be used (up to 2’000Wh/ kg – 10-times more than now).

Figure 1: E-flight study “Claire-Liner” (Bauhaus Luftfahrt)

Figure 2: How EADS (Airbus) sees the electrified future in about 2030 (see chapter 7)

3.3 Additional energy for safety reasons

Planes need not only the fuel for the trip. They need an extra energy reserve to fly a holding if the landing has to be delayed. They also need a special reserve for an alternate airport if the planned airport can’t be used.

3.4 Niches for e-planes

E-planes can therefore not replace normal planes. Even the better energy efficiency is not enough. For one hours flight with about 60 kW we need a bigger battery than 60 kWh which has a weight of 300 kg. This is 2.5-times bigger than the gasoline tank of the WT10 Advantic.

E-planes are actually restricted to either short trips with regular charges or more realistic an exchange of the batteries. Applications could be:

- a lift off for a glider, hang gliders or paraglider
- basic training purposes around the airport

For other purposes a hybrid concept could be considered. This could be a series hybrid. Here we could have a smaller engine which is optimized for high efficiency and low consumption. The power for the propeller will be produced by a high efficiency electric motor. This motor is lighter and smaller than an ICE. This could be an advantage in the design of the plane. For commercial applications hybrid planes could be the first step. Airbus announced to build such a hybrid commuter planes in 2030.

3.5 Technical niche for small planes

Electric drives are more suitable in small light planes. If we take a glider as the DG 400 with a retractable two stroke motor of Rotax the additional weight is about 90 kg without fuel. The similar plane without motor is the DG 200/ 17C. With 20 Liter gasoline the plane can climb about 5’000 m. For a launch on an airport and a lift to the thermal upwinds 1’000 to 2’000 m are enough. With the total weight of the motor system and the gasoline of 110 kg we can use an electric drive. With 60-80 kg and an energy density of 130 Wh/ kg we get 10 kWh capacity. This is enough to use a 40 kW DC-Motor for about 15-20 minutes. Such a glider can climb about 3’000 m. Electric motor need no warm-up time. This often very long “warm-up” time of internal combustion engines (ICE’s) airplane motors, needs gasoline/ time and place. This can be saved with an electric motor.

Figure 3: Three DG 400 with retractable 2-stroke motor produced since 1982

For very light planes, powered hang-gliders and paragliders the electric propulsion is an interesting option. The market offers packages with battery, controller, motor and a special propeller. On the general aircraft faire “AERO” in Friedrichshafen in Germany the “electric flight” occupies at least one full exhibition hall.

4 History of E-flight

The first use of an electric motor in an airship was done by the French balloon pioneer Gaston Tissander in 1883. Other pioneers tried to use electric motors in airships and motor planes but weren’t very successful.

4.1 Battery powered electric planes

The first successful flight with an electric plane was done by Militky and Brditschka with the HB ME-1 on October 21st 1973. The NiCd-battery powered ME-1 motor glider flew 9 minutes in Wels (Austria).

Figure 4: The HB ME-1 from Brdlitschla and Militky on his successful first flight on a man powered e-plane on 21st october 1973 in Wels (A)

4.2 Solar electric powered planes - Solarplanes

The next remarkable electric planes had a different concept. Using the power of a battery this allows only flights for some minutes. The American aerodynamic pioneer and glider world champion from 1956 Paul McCready built human powered light weight planes. With the Gossamer Albatros I plane the American pilot and cyclist Bryan Allan accrossed the channel between England and France on June 12, 1979.

Figure 5: Gossamer Penguin (left picture) and Solar Challenger (right picture)

In 1980 Paul McCready built with his company AeronVironment several solar powered planes. With the Solar Challenger he flew 1981 from London to Paris in 5h23’. AeroVironment built several unmanned solar planes called “Pathfinder/ Pathfinder plus/ Centurion and Helios”. These planes had huge wings up to 75,3 m (Helios) and up to 14 electric motors. The idea was to reach great heights up to 30 km. This could be enough to stay several days in the air and to be an alternative to satellites etc. The latest plane, the Helios crashed in 2003 in Hawaii. He had problems with the steering and the structural problems

The next remarkable solarplane was built by Eric Raymond in 1990. Raymond was in the GM sunracer solarcar team of Paul McCready, which won the first Solar World Challenge in Australia in 1987. His solarplane "sunseeker" had thin film solar cells. He acrossed the United states in 1990 and used a small battery pack for the takeoff. From 2002 to 2006 Raymond built the *Sunseeker II*. In 2009 Eric Raymond crossed the European Alps. Actually he is working in Slovenia and builds a 2-seater electric plane.

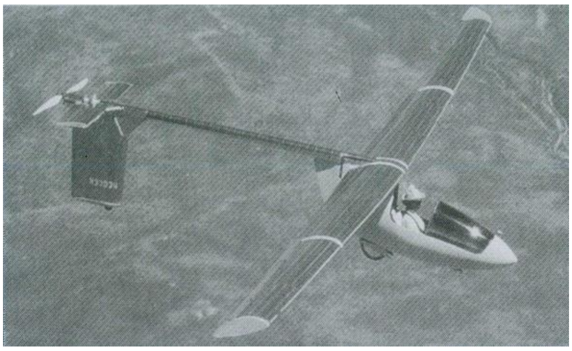

Figure 6: Eric Raymond Sunseeker I which crossed the USA in 1990

Since then many different solar planes were built. They are all prototypes. Known planes are from the german Professor Günther Rochelt, the "Solar I and II" built between 1980 and 1996.
The most successful solar plane was built by the "Institut für Flugzeugbau" from the University of Stuttgart. The "Icaré II" plane based on a fuselage of the successful glider ASW 15 and had a special wing with solar cells. This plane won the "Berblinger competition" of the city of Ulm (D) in 1996. Professor R. Voit - Nitschmann made a flight over 350 km with the plane. I presented 1998 on the "solarsaloon exhibition" in Zürich some projects from Italy and Germany. This was the first exhibition with different solar planes in the world. With the exemption of the "Icaré" from the University of Stuttgart, I assume that most of these planes never were flown.

Figure 7: The Icaré II from university of Stuttgart in 1998

Figure 8: Solar Impuls I HB-SIA

The most spectacular project actually is the "Solar Impuls" from the Swiss Bertrand Piccard and the Belgian André Boschberg. They crossed the world in a hot air balloon in 1999. As a PR-Tour for the use of solar energy in a future energy system they started the project "Solar Impuls". A first prototype, the "Solar Impuls" HB-SIA had his first flight on April 2010 in Payerne (CH). In 2011 the "Solar Impuls I" flew from Payerne to Brussel. In 2012 he flew from Payerne to Ouarzazate in Maroc. In 2013 the plane acrossed the USA. These were all world records for solar planes. Now the team builds the Solar Impuls HB-SIB which should fly around the world in different legs. The plane can fly in the night with some battery he charges during the day. The plane is huge with a span of 72 meters (Airbus 380-800: 79,75m). The trip should start in summer 2015 from Abu Dhabi.

4.3 Some technical considerations for solar planes

A solar powered plane has much more power than a human powered plane. On a surface of about $10m^2$ which is a typical for a standard class glider you can produce a maximum of 10-20 kWp. With this power a light efficient plane can fly on a constant height. In practice the full power will never be reached because of lower sunshine, wrong angels of the sun etc. Together with a storage battery for launch flights for several hours by sun shine are still possible. This very similar to a glider which normally also uses the sunshine to get the lifts.
A real commercial use will be difficult to find. Such a "solar plane" could be interesting for hobby applicants similar to gliders.

5 Battery powered Light wings with electric drives

As explained earlier light planes, "trikes", hang-gliders etc. with a small light battery powered motor are widely presented and used. In this market the production numbers are small. Even very popular gliders hardly reach a total production figure of more than 1’000. The most popular glider with a retractable 2-stroke motor, the DG 800 reached about 500 planes produced since 1990.

6 Battery powered planes with electric drives

6.1 6.1. Overview – some of the actual prototypes and series planes

There are many models, mainly prototypes. Some of the more know planes and their performances are mentioned here:

6.2 Self-launch glider with electric motor systems

The first electric glider with a retractable electric motor is the Antares 20E from Lange Flugzeugbau in Germany. Mr. Lange worked for the glider company DG Flugzeugbau (DG 400/ 800 etc.) and started his own company. He has an electric drive train from the Berne University of Applied Sciences BUAS (Prof. Dr. Andrea Vezzini). The motor has a maximum power of about 40 kW. With Saft Lithium battery the glider can climb more than 3’000 m asl. This is enough for most of the glider applications. The Antares 20E plane himself is situated in the “18 m span racing category” and has a very high performance (glider ration over 1:50). Advantages of this plane against the models with combustion engines are the high reliability, lower noise, now fuel involved and a low price in the use, especially due to the lower maintenance costs.

Figure 9: Antares 20E electric glider in Puimausson (F) – after the launch the propeller and the motors goes into the fuselage

Figure 10: View into the DC - motor of the Antares 20E

Figure 11: Small propeller beam with retractable motor and propeller system of the Antares 20E

Table 1: There are two gliders with a retractable electric motor (Antares and Silent models) and two prototype E-planes, the Yunec planes and the ElectraFlyer-C

Name	Company	Year of start production	Parameters of motor					Battery			Duration of use electric drive (data from producers)	Duration of use electric drive (from calculations capacity/nominal power of motor)
			Power [kW]	Speed [rpm]	Mass [kg]	Power density [kW/kg]	Torque density [Nm/kg]	Time of charging	Capacity [kWh]	Mass [kg]		
Silent Club	AliSport Srl	1997	13	3400	8.5	1.53	4.30	35-45 minutes at voltage 220V	1.4	40	5 minutes at maximum power and maximum climb speed	6:28 min
Silent 2 Targa Electro	AliSport Srl	2011	25	4600	9.5	2.63	5.46	150 minutes at voltage 220V	4.3	31	-	10:19 min
ElectraFlyer-C	Electra Flyer	2009	13.5	-	13.15	1.03	-	6 hours at 110V or 2 hours at 220V	5.6	22.3	1.5 hours	24:53 min
E430	Yunec International	2009	40	-	19	2.11	-	3-4 hours	13.3 133.2V/ 100Ah	83.5	2 hours	19:57 min
E-spyder	Yunec International	2009	20	-	9.8	2.04	-	3-4 hours	4.66 66.6V/ 70Ah	30	1.5 hours	13:59 min
Antares 20E	Lange Aviation	2003	42	1700	29.12	1.44	8.10	9 hours	11.6 260V/ 70Ah	77.04	13 minutes at maximum power and maximum climb speed	16:34 min
AE-1 Silent	Air Energy	1998	13	3400	8.5	1.53	4.30	5 hours – standard charge. Quick charge - 140 min at 220V or 90 min at 380V	4.1	35	-	18:55 min

Lange Flugzeugbau now builds a 23m span version the Antares E23 with even better flight performance (glider ratio 1:56 by high cruising speed). They deliver their electric motor system to competitors as Schempp - Hirt. Their double seater “Arcus E” has the similar electric drive system as the Antares 20E. The maximum lift with one charge is about 2’000m.

Lange Flugzeugbau use their expertise in electric flight for research projects as the hydrogen Antares DLR-H2 experimenal plane with a range of 750 km. The research partners for the new research project the Antares DLR-H3 is the Deutsches Zentrum für Luft- und Raumfahrt e.V. DLR. The expertise in fuel cells should be used for APU’s (auxialiary power units) for an Airbus 320.

Figure 12: Model of the Antares DLR-H3 which should make 6’000 km range with the fuel cell

The Italian light weight glider “Silent 2” from AliSport has two electric versions. The glider is a light weight glider with only 13.3 m span. The new “Silent 2 Electro” has a foldable propeller in the nose of the plane. This makes the whole construction much easier. But the propeller diameter is reduced to 1 m to get a certain distance to the ground. The motor power of 22 kW is enough to lift the small plane with a total weight of 315 kg into the air. The battery capacity (lithium polymer - LiPo) is 4,3 kWh. There are two battery packs each with 15,5 kg. The maximum lift is about 1’500 m per charge.

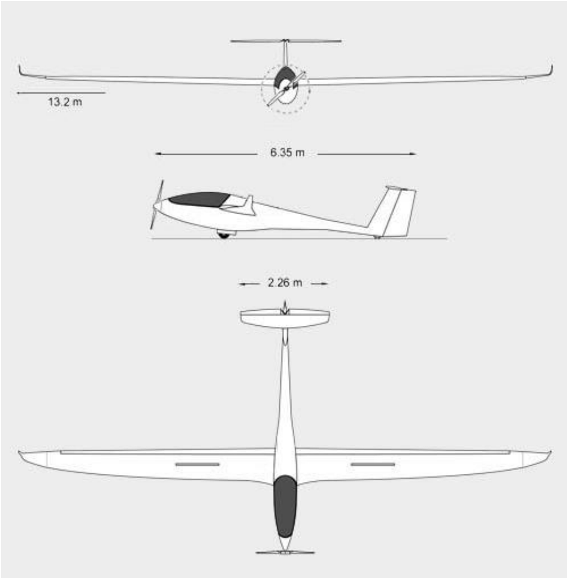

Figure 13: The Silent 2 Electro glider from Alisport Srl (Italy)

In 2014 a high performance glider “Ventus-2cxa” from Schempp-Hirt would equipped with a FES electric motor system. Similar to the Silent 2 the propeller is foldable in the nose of the glider. The use of the motor system is for additional lifts if the upwind are not enough. The glider needs still a launch by a plane or a winch. Other makes as the “HPH 304” (CZ) also offers this configuration. This demonstrates that electric propulsion systems are more and more entering the market similar to electric cars.

Figure 14: Concept electric plane E-Genius from University of Stuttgart

A new concept from the “Institut für Flugzeugbau” from the University Stuttgart is the E-Genius. The two seater plane had this first flight on mai 25th 2011 in Mindelheim (Germany). The E-Genius is a research project similar to the ICARE II. He flew the Green Flight Challenge in the USA in 2011 an won several prizes. The span is 16,86 m and the gliding ration is 1:34 at 140 km/ h. The maximum weight is 950 kg. The climbing rate of the E-Genius rate is 4,5 m/ s. His range is more than 400 km with a cruising speed of 140 - 200 km/ h. The concept looks like a big two seater - glider. The motor has a peak power of 72 kW and a constant power of 40 kW. The four battery packs have a capacity of 56 kWh. For cruising at constant height the E-Genius needs about 10-20 kW. In autumn 2014 the german glider pilot Klaus Ohlmann flew several world records for electric planes with the E-Genius from his airstrip in Serres (F).

6.3 Some technical considerations for electric gliders

For gliders an electric motor is quite attractive. The combustion engines are very costly. They run only a small number of hours. A typical glider has about 10 motor hours a year for a plane which fly’s 100-200 hours in a year. Every 25 hours or 3 years there is a special control required. After about 300 hours there is a very costly overhaul by a certified service company needed. This is mainly due to the high vibrations of the motor in use. An electric motor system could be therefore much cheaper in the service cost. The cost for energy is not a big difference due to the low use of the motor. For the electric drive the electric outlets on an airport could be a cost factor too. This is a new requirement for an airport and should be checked before.

In the use, the reliability of the internal combustion engines (IEC) is a relevant factor. If a motor system is blocked by a technical problem or the motor doesn’t start, the pilot is in serious troubles. The workload of the pilot in such a situation is very high. Especially for not very trained pilots is this a serious threat which caused some accidents in the past. In contrary the electric drive system can be totally automatically (as in the Antares 20/ 23 E).

The higher weight of an electric glider is an issue mainly for competition pilots. High performance gliders fill water in the plane to have a higher weight, which get them more speed. If the upwind conditions get worse, they can dumb the water and lose less height by a lower speed. In an electric glider the additional weight leads to a higher speed but can’t be changed.

An advantage is the lower noise level of the electric motors system. The motors with internal combustion engines are very noisy even if they pass all the tests. On some air strips starts over noon are forbidden because of the noise. On the airport of the town of Olten (CH) planes with fuels are forbidden because of the groundwater

reservoir under the small airstrip. The gliders are normally towed by a winch. Now some pilots bought an Antares 20E and can fly now from the airstrip without all the handling for the winch.
For gliders electric drive systems offers some advantages. We can expect that in this small market the electric drive goes on.

7 Battery powered general aviation planes with electric drives

As explained before for planes it is very difficult to find an application outside some concept planes. But in the last year I could easily identify more than 10 projects. First commercial e-planes will be delivered in 2015.

One of this planes is the ultralight plan, the "Elektra One". On the Aero 2014 exhibition the company PC-Aero GmbH (D) presented the "Elektra One UAS". This plane is based on the "Elektra One Solar". With batteries the Elektra One UAS has a weight of only 130 kg. The wing has a span of 13 m (optional 15 m). High efficient solar cells are on the wing. This gives a maximal power of 2,4 kWp. For cruising speed the plane needs 2 kW. The range could be very long on a sunny day, up to 1'000km. The company PC-Aero GmbH works on a two seated version, the "Elektra Two". They work also on a unmanned version "SolarStratos" for research and flight in the stratosphere. All planes are prototypes.

Figure 15: The "Elektra" planes from PC-Aero and the overview of all the models:

In the last 10 years many new electric planes made their first flight. One of them is the French Electravia "BL1E Electra" which started first in Aspres-sur-bueches on December 2007. It was the first licenced plane in the world. He had a "Kokam" LiPo-battery and an 18 kW motor.
The airplane company Boeing presented in 2008 a double seater "Dimona" with fuel-cells and an electric drive.

The Chinese company "Yunec" announced the E-430, a two-seater presented 2009. The plane should be cheaper than conventional planes. The E430 was announced as the first commercial electric plane in the world. The plane will be marketed by the US-company Greenwing, which accept now first orders.

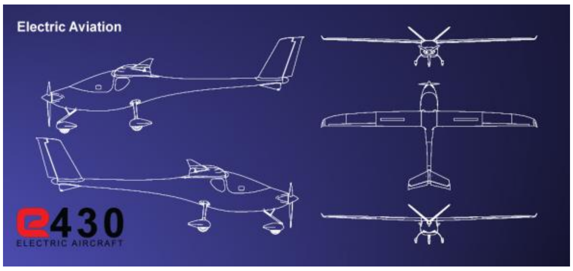

Figure 16: Two seater Yuntec E-430

In 2013 the same companies announced a ultra-light plane the E-spider. He got the certification by the german DULV in 2013 as first plane in the world. The full price is about 35'000 US$ in Europe. With a 24kW motor and a 13 kWh battery he can fly 1-1,5 hours.

Figure 17: E-spider from Yuntec and marketed by GreenWind International (USA)

Table 2: some electric airplanes of today

Specifications	Elektra One	Elektra One Solar	Elektra Two Record	Elektra Two Standard
MTOW	300 kg	300 kg	350 kg	472 kg
Empty weight (without batteries)	100 kg	100 kg	140 kg	200 kg
Battery weight	100 kg	100 kg	80 kg	up to 100 kg
Payload	100 kg	100 kg	150 kg	180 kg
Wing span	8,6 m	11 m	17 m	14 m / 17 m
Wing surface	6,4 m²	8,2 m²	19 m²	15 m² / 19 m²
Max. engine power	16 kW	16 kW	16 kW	40 kW
Max. range	more than 400 km	up to 1000 km	more than 2000 km	14 m wing span: 500 km 17 m wing span: 700 km
Max. endurance	more than 3 hours	more than 8 hours	over 20 hours	14 m wing span: 5 hours 17 m wing span: 8 hours
Cruise	160 km/h	140 km/h	80 km/h	14 m wing span: 140 km/h 17 m wing span: 120 km/h
Aspect ratio	11,65	14,7	15	14 m wing span: 13 17 m wing span: 15
Best glide ratio	25	30	34	14 m wing span: 28 17 m wing span: 34
Certification	Ultralight class Germany (LTF-UL)	Ultralight class Germany (LTF-UL); in future also in the FAR 103 ultralight class	LTF-UL Germany	LTF-UL germany

Advantages for electric planes are the low noise level. The high efficiency of the electric drive leads to much lower cost per hours. Together with the lower maintenance costs this could be an important point for users. If the recharge problem could be solved, it could be interesting for training purposes to start with electric 2-seaters. Instead of a fast charge, a battery exchange could be a solution. It would need more than one battery pack per training plane, but the charger could be smaller and the needed grid power too.
The commercial plane producer Airbus is also active in the field. They started their own company for electric planes called VoltAir. The first plane "E-Fan" has an interesting configuration for the motors and the propellers in a fan-construction on the rear of the plane. This saves energy through the lower air drag resistance. Actually the E-Fan can fly about 30 minutes. Airbus could see the production of a hybrid electric commuter plane in 2030.

Figure 18: Airbus VoltAir "E-Fan" first flown in 2014

There is a small step for electric planes to unmanned planes and drones. Here a broad range of observation up to military applications is quite common. From here it's a small step to helicopter and multicopter designs. Here low noise is an important point. Such a concept is the german "volocopter" a 2-seater multicopter with electric drive.

Figure 19: German project Volocopter a 2-seated multicopter with E-drive

8 Projects of the Berne University of Applied Sciences BUAS

The Berne University of Applied Sciences BUAS in Biel was very active in solar car racing in the 80- and 90-ties. This know-how was transferred into the aircraft technology. So the electric system of the Antares 20E (Lange Flugzeugbau) was developed at the BUAS in Biel. The motor system is similar to high efficiency solar racing cars.

Since then, other concepts were supported by the team of Prof. Dr. Andrea Vezzini.

Figure 20: Project for an electric acrobatic plane – here the conventional model

Actually we are working on a concept for an electric acrobatic plane. The concept and first studies are ready. The budget is about 1 million US$ for the prototype and we are working on the financial support for the project together with a producer of such planes. The plane should be as competitive as electric acrobatic models. The motor power of 200 kW is a big challenge for the batteries. Here we are looking for high density high power batteries over 200 Wh/ kg in a 10-15 minute discharge.

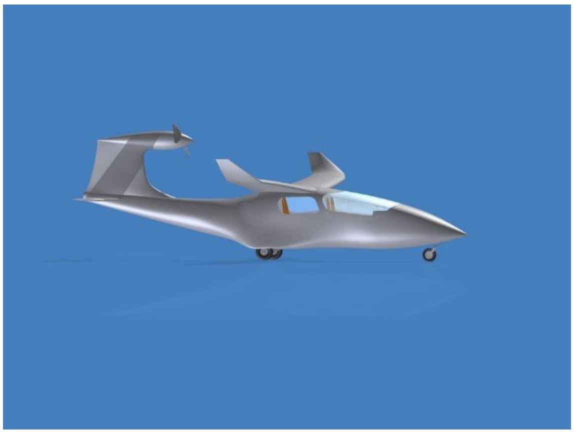
Figure 21: Smartflyer picture – four seater with hybrid configuration

Another project we will support, is the "Smartflyer" from the Swiss aircraft captain Rolf Stuber (CH). This 4-seater hybrid electric plane should have an electric drive for the launch. For longer distances an optimized internal combustion engine works as range extender and produce the energy for the generator. The concept is similar to a Chevrolet Volt.

9 Conclusion

E-flight is the next step for electrification. First applications are still on the market. It starts with electrified gliders, E-trikes and -hanggliders. Then electrified lightweight planes will be the next step. Hybrid planes could expand the possibilities of the E-drive. If we consider that each plane destroys a lot of energy with his air brakes for landing, we could also imagine that we could use the propeller for this purpose and recuperate the energy into the battery. For commercial planes fuel-cell "APU's" and electric drives for the ground movement could be the next step. In contrary to cars the production numbers will be all ways very small. This offers another opportunity to tackle the market.

Author

Urs Muntwyler is the co-founder and manager of the „Tour de Sol, 1985-92" in Switzerland, the first solar mobile race in the world. Since 1999, he is the Chair of the "Implementing Agreement Hybrid & Electric Vehicle Technologies and Programs" of the International Energy Agency. Urs Muntwyler is professor at BUAS and a passionate glider pilot since 1978, flying now a high power DG 808C.

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