DOI: 10.13009/EUCASS2017-676

Advances, Challenges and Future of All-Electric Aircraft

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Abstract
All-electric aircraft have higher efficiencies and produces less noise, greenhouse gases, and pollution than conventional aircraft. Thirty-four all-electric and hybrid aircraft were analysed. Results show that most have one or two seats, use DC brushless motors with a power between 10 and 250 kW, MTOW is between 170 and 2 494 kg, maximum speed is between 40 and 339 knots, and endurance is between 0.3 and 117 hours. $LiFePO_4$ batteries provide the highest cycles and energy density, while the highest specific energy is obtained with $LiCoO_2$ batteries. Battery technology is improving and will be a key in the future.

1. Introduction

Population growth, resource depletion, pollution, and climate change are the World´s biggest threats and are having a great impact on air transportation. Aviation consumed about 17 billion gallons of fuel in 2016 (US carriers) [1]; emitted 781 million tons of CO_2 in 2015 [2]; generated noise which disturbs sleeping, produces health effects, and decreases home value [3]; and general aviation uses Tetraethyl Lead which damages the central nervous system, kidneys, red blood cells, immune and cardiovascular system, reduce learning, and seems to be carcinogen [4]. Many developments have been done in biofuels, improving propulsion system, and others. But limits in the supply of biofuels and efficiencies of current engines makes necessary to look for new technologies. All-electric aircraft have higher efficiencies; are more reliable; and produces less noise, greenhouse gases, and pollution; but the low specific energy of the available batteries makes it necessary to find new battery technologies and improve aircraft design. This paper aims to evaluate the state of art of all-electric aircraft and evaluate the different battery technologies available.

Several authors have investigated all-electric aircraft. Riboldi and Gualdoni [5] stablished a standard procedure for the preliminary sizing of electric aircraft. They used a database of eight small electrical aircraft already flying in 2016 to obtain some correlations for the take-off and empty weight, and for the weight and power of the electric motor. The weight of the battery is estimated by computing the energy required for the various flight phases. This procedure is validated by the possible design of two aircraft: a motor-glider and an acrobatic, bearing realistic results.

Gohardani, Doulgeris and Singh [6] pointed out that air transport of the 21st century is no longer limited only to technological constraints, but also to environmental restrains. They considered an all-electric aircraft combined with distributed propulsion (three engines or more) as one environmental propulsion option for future commercial aircraft. Distributed propulsion decreases noise, take-off and landing distance, and specific fuel consumption [6]. NASA´s distributed electric propulsion experiments with 18 electric motors along the wing span and powered by $LiFePO_4$ batteries have shown high lift coefficients at low velocities without the pitching moments present in high-lift devices [7]. Rajagopalan [8] designed a four-seat general aviation electric aircraft, and performed a parametric study of the effect of lift-to-drag ratio, flight speed, and cruise altitude on required power and battery capacity.

2. Materials and Methods

Thirty-four aircraft were analysed. Most of them were all-electric aircraft, but there were also some solar and fuel cell aircraft. Most of the technical information was obtained from the manufacturer´s website, but other online sources were also assessed. There was an incoherence in the reported empty weight. Some of the manufacturers or authors included the weight of the motor and the batteries in the empty weight. According to Raymer [9], the empty weight in a conventional aircraft does not include payload, crew and fuel. In all-electric aircraft, the fuel is the battery. Riboldi & Gualdoni [5] considered the empty weight as everything except for the payload, battery and motor. In this work, the empty weight does not include the payload, crew, battery, and motor. Whenever the payload is not reported, it is assumed as the number of seats times 70 kg.

DOI: 10.13009/EUCASS2017-676

3. Results

Table 1 shows the main specifications of some all-electric aircraft and some hybrid aircraft.

Table 1: Main specifications of some all-electric and hybrid aircraft.

		Units	**Electraflyer Trike** [10]	**Electric Lazair** [11], [12], [13], [14]	**MC30 Firefly** [15], [16], [17], [18], [19]	**EADS Cri-Cri** [20], [21], [22], [8]	**E-Cristaline Cri-Cri** [23], [24]	**Electraflyer-C** [25], [26], [27]	**PC Aero- Electra One** [28], [29], [30], [31]
Category			VLA[a]	VLA	VLA	VLA	VLA	VLA	VLA
Energy Source			Battery	Battery	Battery	Battery	Battery	Battery	Battery
Seats			1	1	1	1	1	1	1
Motor	Type		DC Brushless	Turnigy CA120 150 kv Brushless Outrunner		Brushless	E-MOTOR GMPE 104		HPD 13.5
	Power	kW	13	10	19	11	25.6	13.41	16
	Weight	kg	11.7	15.9	5.4	10	10		4.7
	Number		1	2	1	4	2	1	1
	RPM	RPM	1 800	4 500				2 800	
	Voltage	V	100	30-70		100			
	Current	A	200	250		5			
Propeller	Length	m	1.35						
Battery	Capacity	kWh	5.6		4.7		3	5.6	5.8
	Specific Energy	Wh/kg	0.16				125	0.16	
	Specific Power	W/kg							
	Weight	kg	35		53	26.1	24	35.3	100
	Life Cycles								
	Type and name			Zippy Li-Po[b]	Kokam	Li-Po	Li-Po	Li-Po	Li-Ion

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		Units	**Electraflyer Trike** [10]	**Electric Lazair** [11], [12], [13], [14]	**MC30 Firefly** [15], [16], [17], [18], [19]	**EADS Cri-Cri** [20], [21], [22], [8]	**E-Cristaline Cri-Cri** [23], [24]	**Electraflyer-C** [25], [26], [27]	**PC Aero- Electra One** [28], [29], [30], [31]
Weight	Empty	kg	65		44	80	76	172	100
	Payload	kg	70	70	70	70	70	70	100
	MTOW	kg	182	170	183	176	170	284	300
Wing	Span	m	10	11	6.8	4.9	4.9	10.08	8.6
	Area	m^2	16-17		4.6	33.4		14,6	6.4
	Aspect Ratio				10.35			18	11.65
Fuselage	Length	m		4.3		3.9	3.9	13.4	
Maximum Wing Loading		kg/m^2			44		54		
Speed	Stall	knots	18	19					
	Stall	m/s	9	10					
	Cruise	knots	32	35	87	100		61	86
	Cruise	m/s	17	18	45	51		31	44
	Maximum	knots			118	122	141	78	
	Maximum	m/s			61	63	72	40	
Endurance		h	1.5	1.3	4.6	0.5	1.7	1.5	3
Range		km	77		800	463	462	169	400
Controller				JetiSpin OPTO 300 controllers	Lynch-type motor, controller and battery from Electravia			Pulse width modulation electronic control speed	

[a]Very Light Aircraft, [b]Lithium-polymer

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Table 1 (cont.): Main specifications of some all-electric and hybrid aircraft.

		Units	**Silent 2** [32], [33]	**Yuneec E-spyder** [34], [35], [36], [37]	**Yuneec E430** [38], [39], [40]	**Yuneec Eviva** [41], [42]	**Pipistrel Taurus Electro G2** [43], [44], [45]	**Pipistrel Alpha Electro-WattsUP** [46]	**Pipistrel Panthera Electro** [47]	**E-genius** [48], [49]
Category			Motor glider	VLA	VLA	Motor glider	Motor glider	VLA	General	Motor glider
Energy Source			Battery	Battery	Battery	Battery	Battery	Battery	Battery	Battery
Seats			2	1	2	2	2		4	2
Motor	Type							Siemens AG		
	Power	kW	22	20	40	40	40	85	145	59
	Weight	kg	7	7	19	23	11	14		45
	Number		1	1	1	1	1	1		1
	RPM	RPM	4 500	1 800 - 2 200				2 200		
	Voltage	V	116	74	230					
	Current	A		70			30-40			
Propeller	Length	m	1	1.65	1.65	1.60				
Battery	Capacity	kWh	4.4	31.2			4	17		56
	Specific Energy	Wh/kg	270	2.4	153.7		113.1			205
	Specific Power	W/kg			801		925.4			
	Weight	kg	33	26	110	67	42	126		272
	Life Cycles				1500					
	Type and name		Li-Po Kokam	18 Li-Po	36 Li-Po	36 Li-Po	Li-Po			
Weight	Empty	kg	138	179	207	225	253	237		485
	Payload	kg	100	70	220	140	197	173		140
	MTOW	kg	300	282	476	455	450	550	1 315	938
Wing	Span	m	13.5	10.13	13.8	17	14.97	10.5	10.86	16.8

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		Units	**Silent 2** [32], [33]	**Yuneec E-spyder** [34], [35], [36], [37]	**Yuneec E430** [38], [39], [40]	**Yuneec Eviva** [41], [42]	**Pipistrel Taurus Electro G2** [43], [44], [45]	**Pipistrel Alpha Electro-WattsUP** [46]	**Pipistrel Panthera Electro** [47]	**E-genius** [48], [49]
	Area	m^2	9	14.6	11.4	14.2	12.3	9.51	11.2	12.3
	Aspect Ratio		20				18.6	11.3		24
Fuselage	Length	m	6.34	5.91	6.98	7	7.27	6.5	8.07	
Maximum Wing Loading		kg/m^2								
Speed	Stall	knots	35	24	35	35		37	60	45
	Stall	m/s	18	13	18	18		19	30	23
	Cruise	knots		32	52	86	59	85		
	Cruise	m/s		17	27	44	30	43		
	Maximum	knots	118	59	82	123	80	135	220	
	Maximum	m/s	61	30	42	63	41	69	113	
Endurance		h		1	2	1.3	0.5	1		2.5
Range		km		60	225	206	200	200	400	322
Controller					Yuneec Power Drive 40					

Table 1 (cont.): Main specifications of some all-electric and hybrid aircraft.

		Units	**Bye Cessna 172** [50], [51], [52], [53], [48], [54], [55]	**Antares 20E** [56]	**Alatus**	**Sonex E-Flight** [57], [58], [59], [60], [61]	**Pipistrel Taurus G4** [62], [63], [64]	**Arcus E**	**San José State University Designed Aircraft** [8]	**TriFan 600** [65], [66]
Category			General	Motor glider		General	Motor glider	Motor glider	General	
Energy Source			Battery	Battery	Battery	Battery	Battery	Battery	Battery	
Seats			2		1	1	4	2	4	6
Motor	Type		UQM 125	DC brushless	GMP102	DC brushless		DC brushless	DC brushless	HTS900
	Power	kW	125	42		54	150	42	160	250

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		Units	**Bye Cessna 172** [50], [51], [52], [53], [48], [54], [55]	**Antares 20E** [56]	**Alatus**	**Sonex E-Flight** [57], [58], [59], [60], [61]	**Pipistrel Taurus G4** [62], [63], [64]	**Arcus E**	**San José State University Designed Aircraft** [8]	**TriFan 600** [65], [66]
	Weight	kg	19	70		22.6	90			153
	Number		1	1		1	1	1		
	RPM	RPM		1 500			5 500	1 500		
	Voltage	V		212-288		220	325	190-288		
	Current	A				200		160		
Propeller	Length	m					1.00	2.00	1.58	1.83
Battery	Capacity	kWh			3	14.5	90		135	
	Specific Energy	Wh/kg		136			180		270	
	Specific Power	W/kg		794						
	Weight	kg	47	80	24	90	500		504	
	Life Cycles							3 000		
	Type and name		Li-Po	Li-ion Saft VL41M	Li-Po	17 Li-ion cells	Li-Po	Li-ion Saft VL41M	Li-Po	
Weight	Empty	kg	543	441		418	632		1 166	
	Payload	kg	140	0	70	70	280	140	364	1 000
	MTOW	kg	679	661		600	680	812	1 750	2 494
Wing	Span	m	11	20		10.87	21.36	20	13	11.6
	Area	m^2	16	12.6		12	12.33	15.6	17	
	Aspect Ratio		7.5	31.7			18.6	25.6	10	
Fuselage	Length	m	8.3	7.4		6.2	7.40	8.73	8.2	12
Maximum	Wing Loading	kg/m^2			52			52		103
Speed	Stall	knots	52	40		43	45		61	
	Stall	m/s	27	20		22	23		31	

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		Units	**Bye Cessna 172** [50], [51], [52], [53], [48], [54], [55]	**Antares 20E** [56]	**Alatus**	**Sonex E-Flight** [57], [58], [59], [60], [61]	**Pipistrel Taurus G4** [62], [63], [64]	**Arcus E**	**San José State University Designed Aircraft** [8]	**TriFan 600** [65], [66]
	Cruise	knots	129				99		108	339
	Cruise	m/s	66				51		55	174
	Maximum	knots	163			112	116		135	
	Maximum	m/s	84			58	60		69	
Endurance		h	2			1.1	2.75		4	4.4
Range		km	177			264	400		800	2 779
Controller										

Table 1 (cont.): Main specifications of some all-electric and hybrid aircraft.

		Units	**Eco-Eagle ERAU (Stemme S10)** [48], [67], [68], [69]	**Diamond, Siemens & EADS (HK36 Dimona)** [70]	**Antares H3** [8], [71]	**Sky-Spark** [72]	**Boeing´s Fuel Cell Plane (Dimona)** [73]	**E-Fan 2.0** [74], [75], [76]
Category			Motor glider	Motor glider	Motor glider	General	Motor glider	General
Energy Source			Battery and gas	Battery and gas	Fuel cell	Fuel cell	Fuel cell (PEM[c])	Fuel cell
Seats			2	2	0	2	2	2
Motor	Type		Rotax 912 ULS & electric			SKP-VAL2	Brushless DC UQM Power Phase 75	
	Power	kW	29 (electric)	70	36	64	48	60
	Weight	kg				33		
	Number		2		1	1	1	2
	RPM	RPM					8 000	
	Voltage	V						
	Current	A						
Propeller	Length	m						

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		Units	**Eco-Eagle ERAU (Stemme S10)** [48], [67], [68], [69]	**Diamond, Siemens & EADS (HK36 Dimona)** [70]	**Antares H3** [8], [71]	**Sky-Spark** [72]	**Boeing´s Fuel Cell Plane (Dimona)** [73]	**E-Fan 2.0** [74], [75], [76]
Battery	Capacity	kWh	150			7.5		29
	Specific Energy	Wh/kg						174
	Specific Power	W/kg						
	Weight	kg	90					167
	Life Cycles							
	Type and name		Li-Po				Li-ion	2 982 Li-ion
Weight	Empty	kg	753					293
	Payload	kg	140		200	409		140
	MTOW	kg	1 075		1 255	530	770	600
Wing	Span	m	22.9		23	24.7	16.3	11
	Area	m^2				10		
	Aspect Ratio							
Fuselage	Length	m	8.22		8.73	6.25		5.67
Maximum Wing Loading		kg/m^2						
Speed	Stall	knots	45					
	Stall	m/s	23					
	Cruise	knots	86		64	135	54	149
	Cruise	m/s	44		33	69	27	77
	Maximum	knots			134	160		
	Maximum	m/s			69	82		
Endurance		h	2		50	2	0.33	1.1
Range		km	322		5 998	499		304
Controller								

[c]Proton Exchange Membrane

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Table 1 (cont.): Main specifications of some all-electric and hybrid aircraft.

		Units	**Solar Impulse 2** [77], [78], [79], [80], [81], [82]	**PC Aero-Electra One Solar** [83]	**PC Aero-Electra Two Record** [84]	**PC Aero-Electra Two Standard 14 m wing span** [84]	**PC Aero-Electra Two Standard 17 m wing span** [84]
Category				VLA	VLA	VLA	VLA
Energy Source			Solar	Solar	Solar	Solar	Solar
Seats			1	1			
Motor	Type			HPD 13.5			
	Power	kW	52	16	16	40	40
	Weight	kg		4.7			
	Number		4	1			
	RPM	RPM	525				
	Voltage	V	300				
	Current	A					
Propeller	Length	m	4.00				
Battery	Capacity	kWh	154	5.8			
	Specific Energy	Wh/kg	260				
	Specific Power	W/kg					
	Weight	kg	633	100	80	100	100
	Life Cycles						
	Type and name		Kokam Li-Po	Li-Ion			
Weight	Empty	kg	894	100	140	200	200
	Payload	kg	70	100	150	180	180
	MTOW	kg	2 300	300	350	350	350
Wing	Span	m	72	11	17	14	17
	Area	m^2		8.2	19	15	19

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		Units	**Solar Impulse 2** [77], [78], [79], [80], [81], [82]	**PC Aero-Electra One Solar** [83]	**PC Aero-Electra Two Record** [84]	**PC Aero-Electra Two Standard 14 m wing span** [84]	**PC Aero-Electra Two Standard 17 m wing span** [84]
	Aspect Ratio			14.7	15	13	15
Fuselage	Length	m					
Maximum Wing Loading		kg/m^2					
Speed	Stall	knots					
	Stall	m/s					
	Cruise	knots	37	75	43	75	64
	Cruise	m/s	19	38	22	38	33
	Maximum	knots	40				
	Maximum	m/s	21				
Endurance		h	117	8	20	5	8
Range		km	8 095	1 000	2 000	500	700
Controller							

Table 2 shows the specifications of commercially available battery chemistries.

Table 2: Specifications of commercially available battery chemistries.

	Pb	**NiMH**	**$LiCoO_2$**	**$LiMn_2O_4$**	**$LiFePO_4$**	**Zinc-air**	**Li_2S/Si**
Specific energy (Wh/kg)	40	90	170	120	110	442	630
Energy density (Wh/L)	80	260	250	250	320		
Cycles (80% discharge)	250	400	800	800	1 500		

DOI: 10.13009/EUCASS2017-676

4. Discussion

Results show that most of all-electric aircraft have one or two seats, except for the Pipistrel Taurus G4 (4 seats), the San José State University designed aircraft (4 seats), the Trifan 600 (6 seats), and the Pipistrel Panthera (4 seats). The Pipistrel Taurus G4 has a specific fuel consumption of 649 km-passenger per equivalent gallon of fuel. Most of them use DC brushless motors due to their higher efficiency and lower maintenance [48]. Their power is between 10 kW (Electric Lazair) and 250 kW (Trifan 600). The Trifan 600 and the San José State University are still conceptual designs. The aircraft with the most power motor flying is the Pipistrel Taurus G4, with a single 150 kW motor.

Most of them use Li-ion and Li-Po batteries. Li-Po batteries are Li-ion batteries with a dry or gel polymeric ionic membrane which serves both as electrolyte and membrane [85]. Li-Po can be built on many battery chemistries, like $LiCoO_2$, $LiMn_2O_4$, and others. Li-ion batteries are the systems of choice in electrical mobility due to their high energy density, lightweight, and longer lifespan than comparable technologies [86]. The highest battery specific energy was obtained in the Silent 2 aircraft with the Li-Po batteries manufactured by Kokam (270 Wh/kg). The next highest specific energy battery was obtained in the Solar Impulse 2 with the same type of batteries and manufacturer (260 Wh/kg). The highest specific power battery was obtained in the Pipistrel Taurus Electro G2 with 925 W/kg.

The SkySpark, Antares H3, Boeing´s fuel cell demonstrator, and Airbus E-Fan 2 use fuel cell, which allows them to increase their endurance and range. The Solar Impulse uses solar cells on the wing to capture energy and store it in batteries, which allowed it to stay day and night in the air and fly across the world without fossil fuels. For example, the SkySpark can be in the air for 2 hours and 499 km, the Antares H3 for 50 hours and 5 998 km, and Solar Impulse 2 for 117 hours and 8 095 km. The endurance of the other aircraft is between 0.33 hours (Boeing´s Fuel cell plane) and 8 hours (PC Aero-Electra One), while the range is between 60 km (Yuneec E-spyder) and 2 779 km (TriFan 600).

The empty weight is between 44 kg (MC30 Firefly) and 1 166 kg (San José State University). While the MTOW is between 170 kg (Electric Lazair & E-Cristaline Cri-Cri) and 2 494 kg (TriFan 600). The fastest electric aircraft is going to be the TriFan 600 with a cruising speed of 339 knots (174 m/s).

With respect to battery chemistries, $LiFePO_4$ batteries are the ones which provide the biggest number of cycles (1 500) while $LiCoO_2$ and $LiMn_2O_4$ batteries give around 800 cycles and NiMH batteries provide around 400 cycles. The highest specific energy is obtained with $LiCoO_2$ batteries, around 170 Wh/kg, while the $LiFePO_4$, $LiMn_2O_4$ and NiMH batteries give 110, 120, and 90 Wh/kg, respectively. Lithium batteries are around 40% more expensive than NiMH batteries. The energy density of the $LiFePO_4$ batteries (320 Wh/L) is higher than the one for $LiCoO_2$ (250 Wh/L), $LiMn_2O_4$ (250 Wh/L), and NiMH (260 Wh/L) batteries. Zinc-air and Li_2S/Si have not been used yet in electric vehicles.

5. Conclusions

The main specifications of thirty-four aircraft were analysed. Most of them were all-electric aircraft, but there were also some hybrid aircraft. This work serves as a baseline for the design of new all-electric aircraft, and to develop correlations that help to estimate the weights and the power required for an all-electric aircraft. Right now only 4 passengers can be carried out, but as the battery capacity increases more passengers can be transported. The design of all-electric aircraft has been more toward very light aircraft and motor gliders, because of the low specific energy of the batteries and the high efficiency of the gliders. Additionally, the gliders design allows them to stay aloft longer by capturing the energy from rising air produced by thermals or hills. The best technologies so far for a new all-electric aircraft design are the DC brushless motors and $LiFePO_4$ batteries. The highest specific energy obtained in an aircraft is 270 Wh/kg with Li-Po batteries from Kokam. Battery technology is improving and will be a key in the future of all-electric aircraft. While the light weight, small volume, and high power and efficiency of DC brushless electric motors are making possible new aircraft designs with higher efficiencies.

Acknowledgments

The author wants to thank especially to the student Richard Quintero who helped to get some of the data; to Felipe Correa and Julian Sierra for their initial contributions to this work; the Semillero de Investigación Ambiental-SIA and Grupo de Investigación e Innovación Ambiental-GIIAM for their help in this project; and to the Dirección Operativa de Investigación, Facultad de Ingeniería, and Juan Mazo, Director of International Relations, from Institución Universitaria Pascual Bravo for their financial support.

DOI: 10.13009/EUCASS2017-676

References

[1] U.S. Department of Transportation. 2017. Airline Fuel Cost and Consumption (U.S. Carriers - Scheduled) January 2000 - March 2017, 5 may 2017. [Online]. Available: https://www.transtats.bts.gov/fuel.asp?pn=1. [Accessed 5 may 2017].

[2] Air Transpor Action Group. 2016. Facts and Figures, 1 may 2016. [Online]. Available: http://www.atag.org/facts-and-figures.html. [Accessed 5 may 2017].

[3] Maurice, L. 2013. Session III: Technology & Operations: Aviation Environmental Impacts, in *ICAO Sympossium on Aviation and Climate Change "Destination Green"*.

[4] Scheer, R. and D. Moss. 2017. Does the Continued Use of Lead in Aviation Fuel Endanger Public Health and the Environment?, 22 may 2017. [Online]. Available: https://www.scientificamerican.com/article/lead-in-aviation-fuel/. [Accessed 22 may 2017].

[5] Riboldi, C. and F. Gualdoni. 2016. An integrated approach to the preliminary weight sizing of small electric aircraft," *Aerospace Science and Technology*. 58:134-149.

[6] Gohardani, A. S., G. Doulgeris and R. Singh. 2011. Challenges of future aircraft propulsion: A review of distributed propulsion technology and its potential application for the all-electric commercial aircraft, *Progress in Aerospace Sciences*. 47:369-391.

[7] Stoll, A. M., J. Bevirt, M. Moore, W. Fredericks and N. Borer. 2014. Drag Reduction Through Distributed Electric Propulsion. In: *14th AIAA Aviation Technology, Integration, and Operations Conference*.

[8] Rajagopalan Srilatha, A. 2012. Design of a 4-Seat, General Aviation, Electric Aircraft. MSc Thesis. San José State University, Department of Mechanical and Aerospace Engineering.

[9] Raymer, D. 1992. Aircraft Desing: A Conceptual Approach. Washington DC: American Institute of Aeronautics and Astronautics.

[10] Electric Aircraft Corporation. 2017. Electraflyer Trike [Online]. Available: http://www.electraflyer.com/trike.php. [Accessed 2017 may 31].

[11] RC Groups. 2011. 100% scale, Electric Lazair [Online]. Available: https://www.rcgroups.com/forums/showthread.php?1412424-100-scale-Electric-Lazair. [Accessed 2017 may 31].

[12] Sigler, D. 2011. Dale Kramer and his Electric Lazair. *Kitplanes*. 28(12):31-35.

[13] HobbyKing.com. 2017. Turnigy CA120 150kV sin escobillas Outrunner (100cc equiv)," [Online]. Available: https://hobbyking.com/es_es/turnigy-ca120-150kv-brushless-outrunner-100cc-equiv.html?___store=es_es. [Accessed 2017 may 31].

[14] Smithsonian Air and Space Museum. 2017. Ultralight Lazair SS EC [Online]. Available: https://airandspace.si.edu/collection-objects/ultralight-lazair-ss-ec. [Accessed 2017 may 31].

[15] Electravia. 2011. MC30E Firefly with Electravia Propulsion System [Online]. Available: http://www.electravia.fr/mc30eEng.php. [Accessed 25 october 2011].

[16] Wikipedia. 2017. Colomban MC-30 Luciole [Online]. Available: https://en.wikipedia.org/wiki/Colomban_MC-30_Luciole. [Accessed 2017 may 31].

[17] The Electric Motorcycle Forum. 2011. Electric MC30E Firefly airplane [Online]. Available: http://elmoto.net/showthread.php?t=1773. [Accessed 31 may 2017].

[18] Sigler, D. 2011. The Electric Firefly Sets Two World Records [Online]. Available: http://cafe.foundation/blog/the-electric-firefly-sets-two-world-records/. [Accessed 2017 may 31].

[19] Sigler, D. 2012. The Little Firefly That Could [Online]. Available: http://cafe.foundation/blog/the-little-firefly-that-could/. [Accessed 1 june 2017].

[20] Aerokurier. 2010. EADS fliegt viermotorige Cri-Cri mit Elektroantrieb [Online]. Available: http://www.aerokurier.de/general-aviation/motorflug/eads-fliegt-viermotorige-cri-cri-mit-elektroantrieb/492463. [Accessed 2017 may 31].

[21] Wikipedia. 2017. Colomban Cri-Cri [Online]. Available: https://en.wikipedia.org/wiki/Colomban_Cri-cri. [Accessed 2017 may 31].

[22] La Razón. 2010. El avión eléctrico Cri-Cri de EADS despega con éxito en su vuelo inaugural en París [Online]. Available: http://www.larazon.es/historico/3252-el-avion-electrico-cri-cri-de-eads-despega-con-exito-en-su-vuelo-inaugural-en-paris-SLLA_RAZON_310088. [Accessed 2017 may 31].

DOI: 10.13009/EUCASS2017-676

[23] Anne. 2015. Le MC15E Cri-Cri de Hugues Duval, le 1er avion électrique ayant traversé la Manche [Online]. Available: http://www.blog.electravia.fr/archives/5068. [Accessed 2017 may 31].

[24] Wikipedia. 2017. Colomban MC-15 [Online]. Available: https://es.wikipedia.org/wiki/Colomban_MC-15. [Accessed 2017 may 31].

[25] Green Car Congress. 2008. ElectraFlyer C Debuts at Oskhosh AirVenture [Online]. Available: http://www.greencarcongress.com/2008/08/electraflyer-c.html. [Accessed 31 may 2017].

[26] Wikipedia. 2017. Electric Aircraft Corporation ElectraFlyer-C [Online]. Available: https://en.wikipedia.org/wiki/Electric_Aircraft_Corporation_ElectraFlyer-C. [Accessed 31 may 2017].

[27] Pew, G. 2017. Electric Aircraft [Online]. Available: http://www.glennpew.com/electricairplane.html. [Accessed 31 may 2017].

[28] PC-Aero. 2011. PC-Aero: Official First Flight successful [Online]. Available: http://www.pc-aero.de. [Accessed 25 october 2011].

[29] Wikipedia. 2017. PC-Aero Elektra One [Online]. Available: https://de.wikipedia.org/wiki/PC-Aero_Elektra_One. [Accessed 31 may 2017].

[30] Elektra UAS and PC-Aero. 2017. Elektroflugzeug Elektra One [Online]. Available: http://www.aircraft-certification.de/index.php/elektra-one-27.html. [Accessed 31 may 2017].

[31] Kreisel, M. 2014. Electric Aeroplane Elektra One with Kreisel Battery Technology [Online]. Available: http://www.kreiselelectric.com/en/blog/electric-aeroplane-elektra-one-kreisel-battery-technology/. [Accessed 31 may 2017].

[32] AliSport.2017. Silent 2 Electro [Online]. Available: http://www.alisport.com/?product=silent-2-electro-2. [Accessed 31 may 2017].

[33] Wikipedia. 2017. Alisport Silent 2 [Online]. Available: https://en.wikipedia.org/wiki/Alisport_Silent_2. [Accessed 31 may 2017].

[34] Paur, J. 2010. Exclusive: We Fly An Electric Airplane [Online]. Available: https://www.wired.com/2010/10/wired-flys-e-spyder-electric-plane/. [Accessed 31 may 2017].

[35] Wikipedia. 2017. Yuneec Power Drive 20 [Online]. Available: https://en.wikipedia.org/wiki/Yuneec_Power_Drive_20. [Accessed 31 may 2017].

[36] Wikipedia. 2017. Flightstar [Online]. Available: https://en.wikipedia.org/wiki/Flightstar. [Accessed 31 may 2017].

[37] Lee, K. 2013. GreenWing International's eSpyder Electric Airplane is Finally Here and It Costs Just Under $40K [Online]. Available: http://inhabitat.com/greenwing-internationals-espyder-electric-airplane-is-finally-here-and-it-costs-just-under-40k/. [Accessed 1 june 2017].

[38] Wikipedia. 2017. Yuneec International E430 [Online]. Available: https://en.wikipedia.org/wiki/Yuneec_International_E430. [Accessed 1 june 2017].

[39] Avia.pro. 2015. Yuneec Internacional E430 - avioneta doble en China, fabricado por aeronaves "Yuneec Internacional" [Online]. Available: http://es.avia.pro/blog/yuneec-international-e430-tehnicheskie-harakteristiki-foto. [Accessed 1 june 2017].

[40] Castro, A. 2009. Avión eléctrico E430 de Yuneec llega al mercado [Online]. Available: http://www.fierasdelaingenieria.com/avion-electrico-e430-de-yuneec-llega-al-mercado/. [Accessed 1 june 2017].

[41] Wikipedia. 2017. Yuneec International EViva [Online]. Available: https://en.wikipedia.org/wiki/Yuneec_International_EViva. [Accessed 1 june 2017].

[42] Revolvy. 2017. Yuneec International EViva [Online]. Available: https://www.revolvy.com/main/index.php?s=Yuneec%20International%20EViva. [Accessed 1 june 2017].

[43] Pipistrel. 2017. Taurus Electro [Online]. Available: http://www.pipistrel.si/plane/taurus-electro/overview. [Accessed 1 june 2017].

[44] Pipistrel. 2017. Taurus Electro G2 [Online]. Available: https://www.pipistrel.ad/es/planear/taurus-electro-g2. [Accessed 1 june 2017].

[45] Pipistrel. 2017. Taurus Electro Technical Data [Online]. Available: http://www.pipistrel.si/plane/taurus-electro/technical-data. [Accessed 1 june 2017].

[46] Pipistrel. 2017. Alpha Electro - (prototype name WATTsUP) [Online]. Available: http://www.pipistrel.si/plane/alpha-electro/overview. [Accessed 6 june 2017].

DOI: 10.13009/EUCASS2017-676

[47] Pipistrel. 2017. Panthera [Online]. Available: http://www.pipistrel.si/plane/panthera/technical-data. [Accessed 6 june 2017].

[48] Costello, L. A. 2011. State of the Art of Piloted Electric Airplanes, NASA's Centennial Challenge Data and Fundamental Design Implications. MSc Thesis. Embry-Riddle Aeronautical University.

[49] Wikipedia. 2017. E-Genius [Online]. Available: https://en.wikipedia.org/wiki/E-Genius. [Accessed 1 june 2017].

[50] Phelps, M. 2010. Two-Place Electric Cessna 172 Skyhawk [Online]. Available: http://www.flyingmag.com/news/two-place-electric-cessna-172-skyhawk. [Accessed 1 june 2017].

[51] Dean, S. 2010. Bye Energy, Cessna Move Toward the Electric 172 [Online]. Available: http://sustainableskies.org/bye-energy-cessna-move-toward-the-electric-172/. [Accessed 1 june 2017].

[52] Goyer, N. 2012. The "Electric Cessna" What is Happening? [Online]. Available: http://www.acmp.com/blog/the-electric-cessna-what-is-happening.html. [Accessed 1 june 2017].

[53] Wikipedia. 2017. Cessna 172 [Online]. Available: https://es.wikipedia.org/wiki/Cessna_172. [Accessed 1 june 2017].

[54] Karsten, P. 2017. Cessna 172 [Online]. Available: http://www.flugzeuginfo.net/acdata_php/acdata_cessna172_en.php. [Accessed 1 june 2017].

[55] Croft, J. 2010. Bye readies for electric 172 first flight [Online]. Available: https://www.flightglobal.com/news/articles/bye-readies-for-electric-172-first-flight-349208/. [Accessed 1 june 2017].

[56] Saft. 2009. Series Production Restarts for Antares 20e Self-Launching Sailplane Powered by a Saft Lithium-Ion Battery System [Online]. Available: http://www.saftbatteries.com/press/press-releases/series-production-restarts-antares-20e-self-launching-sailplane-powered-a-saft. [Accessed 1 june 2017].

[57] Wikipedia. 2017. Sonex Electric Sport Aircraft [Online]. Available: https://en.wikipedia.org/wiki/Sonex_Electric_Sport_Aircraft. [Accessed 1 june 2017].

[58] Sonex Aircraft. 2017. Electric Power [Online]. Available: http://www.sonexaircraft.com/research/e-flight/electric.html. [Accessed 1 june 2017].

[59] Quick, D. 2010. Sonex Aircraft's electric sports plane makes successful maiden flight [Online]. Available: http://newatlas.com/sonex-aircraft-electric-sports-plane-maiden-flight/17341/. [Accessed 1 june 2017].

[60] Goldston, B. 2010. Sonex E-Flight Electric Waiex Aircraft Achieves First Flight [Online]. Available: http://avstop.com/news_december_2010/sonex_e_flight_electric_waiex_aircraft_achieves_first_flight.htm. [Accessed 1 june 2017].

[61] Sonex Aircraft. 2017. E-Flight [Online]. Available: http://www.sonexaircraft.com/research/e-flight.html. [Accessed 1 june 2017].

[62] Wikipedia. 2017. Pipistrel Taurus [Online]. Available: https://es.wikipedia.org/wiki/Pipistrel_Taurus. [Accessed 1 june 2017].

[63] Paur, J. 2011. Electric Airplane Has 4 Seats, Two Fuselages, One Big Motor [Online]. Available: https://www.wired.com/2011/08/pipistrel-taurus-g4-electric/. [Accessed 1 june 2017].

[64] Tomazic, T., V. Plevnik, G. Veble, J. Tomazic, F. Popit, S. Kolar, R. Kikelj, J. Langelaan, and K. Miles. 2011. Pipistrel Taurus G4: on Creation and Evolution of the Winning Aeroplane of NASA Green Flight Challenge 2011. *Journal of Mechanical Engineering*. 57(12):869-878.

[65] XTI Aircraft. 2017. Introducing a new type of aircraft [Online]. Available: http://www.xtiaircraft.com/trifan-600/. [Accessed 1 june 2017].

[66] Start Engine. 2017. XTI Aircraft Company [Online]. Available: https://www.startengine.com/startup/xti. [Accessed 1 june 2017].

[67] Embry-Riddle Aeronautical University. 2017. Worldwide Campus Expands Relationship With Microsoft for Veterans' Cybersecurity Program," [Online]. Available: http://alumni.erau.edu/s/867/social.aspx?sid=867&gid=1&pgid=252&cid=2426&ecid=2426&ciid=5536&crid=0. [Accessed 1 june 2017].

[68] Tehcnologic Vehicles. 2011. Green Flight Challenge 2011: Eco Eagle the hybrid airplane from Embry Riddle's University [Online]. Available: https://www.technologicvehicles.com/en/green-transportation-news/1069/green-flight-challenge-2011-eco-eagle-the-hyb#.WTAjxWg1-70. [Accessed 1 june 2017].

[69] Swift Enterprises. 2017. Stemme S10 [Online]. Available: http://swiftenterprises.com/evia-liquid-battery-system/stemme-s10/. [Accessed 1 june 2017].

DOI: 10.13009/EUCASS2017-676

[70] Siemens, Diamond Aircraft and EADS. 2011. World's first serial hybrid electric aircraft to fly at Le Bourget [Online]. Available: https://www.siemens.com/press/en/pressrelease/?press=/en/pressrelease/2011/corporate_communication/axx20110666.htm. [Accessed 1 june 2017].

[71] Technologic Vehicles. 2017. Lange Aviation Antares H3 [Online]. Available: https://www.technologicvehicles.com/en/details/689/lange-aviation-antares-h3-prix-et-fiche-technique. [Accessed 1 june 2017].

[72] Wikipedia. 2017. SkySpark [Online]. Available: https://it.wikipedia.org/wiki/SkySpark. [Accessed 1 june 2017].

[73] Lapeña-Rey, N., J. Mosquera, E. Bataller and F. Ortí. 2017. The Boeing Fuel Cell Demonstrator Airplane. In *Aerotech Congress and Exhibition*.

[74] Wikipedia. 2017. Airbus E-Fan [Online]. Available: https://es.wikipedia.org/wiki/Airbus_E-Fan. [Accessed 1 june 2017].

[75] Airbus. 2017. E-fan: Toward more electric planes [Online]. Available: http://www.airbusgroup.com/int/en/corporate-social-responsibility/airbus-e-fan-the-future-of-electric-aircraft/Programme.html. [Accessed 1 june 2017].

[76] Ridden, P. 2015. E-Fan 2.0 makes podium appearance at Le Bourget [Online]. Available: http://newatlas.com/airbus-e-fan-2-paris-air-show-2015/38068/. [Accessed 1 june 2017].

[77] Solar Impulse. 2017. 4 high voltage batteries power Si2 through the night until the sun is powerful enough to start recharging again [Online]. Available: http://www.solarimpulse.com/infocard-Batteries. [Accessed 1 june 2017].

[78] Solar Impulse. 2017. There are four 17.4hp motors spaced along the wing [Online]. Available: http://www.solarimpulse.com/infocards/view/37. [Accessed 1 june 2017].

[79] Aerospace-Technology.com. 2017. Solar Impulse HB-SIA Solar Airplane, Switzerland [Online]. Available: http://www.aerospace-technology.com/projects/solar-impluse/. [Accessed 1 june 2017].

[80] Jian, J. 2015. Solar cell-powered Solar Impulse 2 flies on Kokam´s lithium polymer battery using no single drop of petroleum [Online]. Available: http://kokam.com/solar-cell-powered-solar-impulse-2-flies-on-kokams-lithium-polymer-battery-using-no-single-drop-of-petroleum/. [Accessed 1 june 2017].

[81] Abudhabi2. 2016. Solar impulse 2 plane completes historic round-the-world trip [Online]. Available: http://www.abudhabi2.com/solar-impulse-2-plane-completes-historic-round-the-world-trip/. [Accessed 1 june 2017].

[82] El País. 2016. Así es el Solar Impulse II y su vuelta al mundo [Online]. Available: http://economia.elpais.com/economia/2016/06/23/actualidad/1466678049_614291.html. [Accessed 1 june 2017].

[83] PC-Aero. 2017. Electric- and Solaraircraft Elektra One Solar [Online]. Available: http://www.aircraft-certification.de/index.php/elektra-one-solar.html. [Accessed 6 june 2017].

[84] PC-Aero. 2017. Elektra Two (2-seater) [Online]. Available: http://www.aircraft-certification.de/index.php/elektra-two-standard-record.html. [Accessed 6 june 2017].

[85] Scrosati B., and R. Neat. 1993. Applications of Electroactive Polymers. Springer Netherlands.

[86] Tarascon, J., and M. Armand. 2001. Issues and challenges facing rechargeable lithium batteries. *Nature*. 414:359-367.