



Electric Aerospace Primer

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1. Executive Summary

MARKET DYNAMICS

- The market for electric aviation is already worth in excess of \$10 billion and forecasts indicate rapid market growth up to \$20-30 billion by 2030.
- The market is made up of:
 - An existing but fast growing More Electric Aircraft (MEA) sector which consists of replacement of non-propulsion hydraulic, mechanical with electric parts.
 - Manned Electric Aircraft: full electric for small aircraft, helicopters, leisure craft, microlights etc
 - Hybrid-electric systems for larger aircraft and jets.
 - Unmanned Aircraft Systems (UAS) including autonomous Vertical Take-Off and Landing (VTOL) and drones.
- Active industry participants consist of:
 - Traditional aviation and aerospace OEM (Airbus, Boeing, Siemens etc), especially in the MEA sector
 - Start-ups in the air-taxis, VTOL and full or hybrid electric systems sector
 - Automotive OEMS looking to transfer electric vehicles technology straight into the aviation sector along the lines of the “flying car” model
 - Tech giants (Google, Facebook etc.) looking to leverage their expertise in unmanned aircraft (drones)

RECOMMENDATIONS

- Target early adopters of small electric aircraft and VTOL. Pursue tie-ups with flying car and air taxi developers and establish location and ownership of landing sites for VTOL e.g. in city centres. Less regulatory hurdles for this sector.
- Form partnerships with key academic centres of excellence in the UK to commercialise research.
- Look at innovations in the More Electric Aircraft (MEA) sector to serve existing, fossil-fuel powered aircraft.
- Identify projects for full Electric Propulsion systems to serve small aircraft, helicopters, microlights etc and further along the roadmap, larger commercial aircrafts and jets. Hybrid systems are nearer term for commercial aircraft.

2. Electrification Technologies

2.1. More Electric Aircraft (MEA)

There are many systems on an aircraft which historically were operated by sources of energy which were hydraulic, mechanical or pneumatic in nature and over time these have been partially or fully replaced with electrically powered parts. Essentially the replacement of all non-propulsive systems on an aircraft is known as “More Electric Aircraft” (MEA).

The Boeing 737 heralded the introduction of MEA into mainstream commercial aviation in the late 1960s with its electrical cabin equipment and avionics. Later in the 1980s Airbus followed by Boeing introduced computer regulated control of flight information known as “Fly by Wire” (FBW) which eliminated mechanical linkages in the transmission of flight information from the cockpit to flight control surfaces thus saving weight and space and improving aircraft safety. Innovations continued with introduction of electrically-powered thrust reversers, electro-hydraulic actuators and pumps, air-conditioning, brake systems and de-icing. In military fighter jets, the level of electric innovation is even higher with electrically powered distribution, sensors and other systems.

2.2. Electric Propulsion

Compared with MEA, electric propulsion has been a more elusive technology to implement and to date has been limited to prototypes although the pace of development is increasing. In the 1970s some progress was made in the use of nickel cadmium (NiCad)-battery to power a manned aircraft (an HB ME-1). Many prototypes have since been developed which run on solar or solar-hybrid power.

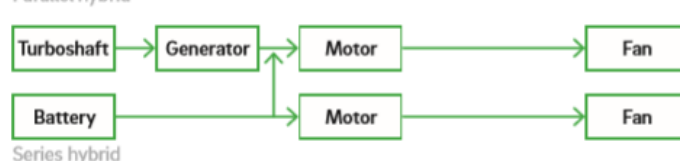
Currently there is a choice of three architectures: hybrid-electric (electric motor in parallel with turbo-fan or battery-assisted generators for fans in series with a turbo-shaft), turbo-electric (fans powered by a generator using kinetic energy from a turbo-shaft) or full-electric propulsion (complete elimination of gas turbine or fuel).

Electrical Propulsion Architectures

Source: Roland Berger

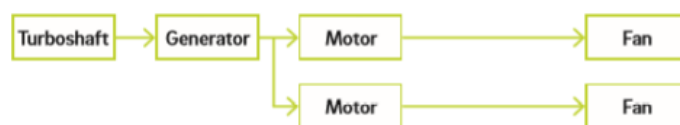
Hybrid-electric

Hybrid-electric is one of two architectures – Parallel or Series hybrid. Additional electric energy can be used for acceleration and in times of high power demand, and bi-directional flow of power is possible between the generator and battery.



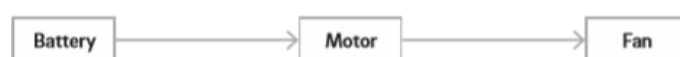
Turbo-electric

The kinetic energy of a turbo shaft is transformed into electric energy via a generator to drive multiple, distributed fans, with the fans driven by electric motors.



All electric

One, or multiple, fans are driven by electric motors with energy stored in a battery.



Source: NASA, Roland Berger

2.3. UK Centres of Excellence

2.3.1. Advanced Propulsion Centre, Warwick

The Advanced Propulsion Centre (APC) in Warwick is a global centre of excellence for low carbon propulsion development and production. It was formed as a private limited company in 2013 with a £1 billion commitment from the UK government and industry participants. The APC aims to help bring parties together to commercialise relevant research. While the APC's activities are primarily intended for automotive research, there are considerable synergies with the aviation sector including battery performance, motors and range extenders to name a few. The APC would be a good organisation to approach to commercialise an electric aircraft innovation.

2.3.2. The Institute for Advanced Automotive Propulsion Systems (IAAPS)

The Institute for Advanced Automotive Propulsion Systems (IAAPS) based in the Bristol and Bath Science Park, UK is intended to be a global centre of excellence, for delivering transformational research and innovation into advanced propulsion systems. It is intended as a hub for research on ultra-low emission vehicles around which new businesses can be located. It is due to open in early 2020 and will stimulate some £67 m in research investment by 2025. It has a target to increase the turnover in the UK's automotive sector by creating an additional £800 m turnover and to create 1,900 new jobs.

IAAPS has been allotted a capital investment of £28.9 million from the Higher Education Funding Council for England's (HEFCE) UK Research Partnership Investment Fund (UKRPIF) to enable construction of the IAAPS facility (£60 m total CAPEX) with work to start in the summer of 2018. As with the APC, there is considerable overlap with the aviation sector in terms of the research focus.

2.3.3. Hybrid Electric Aerospace Research Group, University of Newcastle

The Hybrid Electric Aerospace Research Group at the University of Newcastle houses research groups focusing on:

- Smart, connected More Electric Aircraft (MEA) and developing UK advanced systems technologies to capture high-value opportunities in current and future aircraft.
- Future propulsion concepts: to investigate and evaluate the potential of large scale hybrid turbo-electric propulsion systems, including electrical and integration aspects

The group was funded by an EPSRC / ATI Institutional Support Grant provided in July 2016 to create a wide community of researchers across the UK working together to decrease aircraft emissions. Specific projects are being carried out within a consortium of universities housed under the group's activities. Currently underway are:

- Advanced Motors designs for Hybrid Aircraft
- Superconducting Power networks
- Medium Voltage Power Networks
- Feasibility study on a large aircraft using tail mounted BLI systems

3. Market Overview

3.1. Market Segments

3.1.1. More Electric Aircraft (MEA)

More Electric Aircraft (MEA) is not a new market area, and as discussed in section 2.1, the earliest products were introduced in the 1960s. MEA is more dominated by traditional OEM's such as Airbus, Boeing and Siemens than with start-ups. However, the push for electrification of aviation and aerospace has given this sector renewed vigour. Market forecasts for MEA vary between analysts. Markets and Markets predicts that the 2016 level of \$7.7bn will rise to \$10.9 bn by 2021. This equates to a Compound Annual Growth Rate (CAGR) of 7.3%. Power electronics which increase the aircraft's energy and reduce the aircraft's weight are the largest segment. The largest regional market is North America with over 35% of the total (according to Market Research Future - MRFR) but is expected to be overtaken by Asia-Pacific by 2022. MRFR value the market at \$22.8 bn in 2016 rising at a CAGR of 4.3% until 2021. Around 70% of the market is for commercial flights with the remainder in military and Unmanned Aerial Vehicle (UAV) sectors.

3.1.2. Manned Electric Aircraft

A report from IDTechEx predicts that the market for Manned Electric Aircraft will reach \$7 billion by 2028. This is made up of small work aircraft, planes, helicopters, airships and microlights. The electric and hybrid-electric powertrains are made up of electric motors, range extenders, energy storage, energy harvesting & regeneration systems. Small aircraft are pure electric whereas larger mainstream aircraft require hybrid powertrains to cope with the range, duty cycles and regulatory requirements.

Much like with cars, technology is being developed by start-ups with considerable funding from traditional OEM such as Airbus and Boeing as well as other investors. Vehicle OEM including BMW, Honda and Toyota are leveraging technology from their EV programmes and are also entering the electric aviation space. Even tech giants such as Google and Facebook are getting in on the act. Most innovation is happening in the USA and Europe, with Japan and China further behind.

3.1.3. Unmanned Aerial Vehicles

Unmanned Aerial Vehicles (UAV) also known as Unmanned Aircraft Systems (UAS) include developments such as Boeing's VTOL for cargo, Airbus' Vahanna and Facebook's solar-powered drone. The market estimates are very high but there is likely overlap with those of MEA and sales of both propulsion and non-propulsion components are included in the figures. Shipments of commercial enterprise drones (excluding the smaller personal drones) is estimated to reach over 800,000 units by 2021 according to Business Insider (the market value is not disclosed). Several Chinese companies account for a large percentage - DJI (Dajiang) Innovations based in Shenzhen has around 70% of the commercial drone market. There is also 3D Robotics (a start-up in Berkeley California) and a French quadcopter manufacturer Parrot SA. The same analysts also highlight the US government's Department of Defense budget for military drones of \$2.9 billion for 50 planned UAV

4. Drivers and Challenges for Electrification of Aerospace

Aircraft electrification is not a new concept in fact the French Chemist Tissandier achieved the first electric flight in 1883 when he powered a dirigible propeller by attaching it to an electric motor. However, the techno-economics of fossil fuel powered jet engines surpassed those of electric motors and became the prevailing choice of technology for aviation and aerospace.

Fortunes change, and electrification is expected to be a major disruptor in the aerospace sector; many leading authorities believe that we are currently on the cusp of this revolution. Electrification has a great deal to offer including:

- Cheaper, lighter and quieter aircraft with less heat pollution
- Less dependence on fossil fuel prices, leverage renewable power and smart grid
- Improved performance in terms of climb speed and reduce take-off time
- Enables new modes of transport – e.g. VTOL for air taxis, personal transport
- Ability to meet future legislative targets on fuel efficiency, greenhouse gas (GHG) emissions and tail gas emissions (e.g. nitrogen oxides (NO_x), carbon monoxide (CO), particulates (PM) and hydrocarbons (HC) and others).
- Cheaper total lifecycle costs
- Ease of maintenance
- Higher reliability.

The electrification of aircraft has a number of key challenges to address namely:

- Battery performance
- Battery safety
- Lightweight high-power density
- Power electronics
- Safe and light high voltage distribution
- Flight range
- Autonomous flight
- Boundary Layer Ingestion
- Regulation

5. Regulatory Developments

The regulatory environment is the single biggest issue facing the commercial aviation and aerospace sector. As with on-road transportation, regulators have set tough targets on emissions for the aviation and aerospace sectors to meet.

The International Air Transport Association (IATA) set out a vision for the aviation industry to achieve “carbon-neutral growth” between 2020-2050 so that emissions are capped at 2020 levels and by 2050, GHG emissions see a 50% reduction over 2005 levels. This can only be realised using electrification technology or a replacement of fossil fuels with biofuels.

The European Commission’s FlightPath 2050 initiative has targets for 2050 of a 75% reduction in CO₂ emissions per passenger kilometre, a 90% reduction in NO_x emissions and a 65% reduction in perceived noise emission of flying aircraft over 2000 levels for new aircraft.

In terms of regulation on the actual electrical components that will be installed onto aircraft, currently it is still work in progress. As an initial measure, development of performance-based industry standards is underway to assist the regulatory authorities in developing legislation. Industry is keen that the pace of regulatory development is such that it does not hold products back from the marketplace once they have been developed. In Europe, the European Aviation Safety Authority (EASA) is liaising with industry participants to keep up with the technical and commercial developments.

It is normal for authorities to ask for new written standards to be developed. For instance, the US Federal Aviation Administration (FAA) requested that a new technical committee be set up by the international standards developers SAE International on additive manufacturing to help to regulate the use of 3D Printed parts on board aircraft. In the same vein, SAE has set up the Electric Aircraft Steering Group (EASG) in response to requests from these organisations. EASG meets twice a month with industry and is working on the standardisation landscape and a roadmap for new standards introduction to serve the electric aviation sector.

Another influential organisation is The International Civil Aviation Organization (ICAO), a United Nations (UN) specialized agency. The ICAO works with stakeholders to help develop Standards and Recommended Practices (SARPs) in such a manner to be economically and environmentally sustainable. The SARPs are then handed down to member nations for them to ensure that the local aviation policies conform.

In Europe, key organisations with roles in aviation regulation include the European Commission, the Advisory Council for Aeronautics Research in Europe (ACARE) and more locally in the UK, the Civil Aviation Authority (CAA) is responsible for the regulation of aviation safety.

6. Key Industry Participants

6.1. The Boeing Company

The Boeing Company (Boeing) is headquartered in Chicago, Illinois and makes aircraft for the aerospace and defence sectors. Boeing has a revenue of £69 bn and is the world's largest aerospace company. Dennis A. Muilenburg is the company's Chairman, President and Chief Executive Officer. Boeing's traditional products and services include commercial and military aircraft, satellites, weapons, electronic and defence systems, launch systems, advanced information and communication systems, and performance-based logistics and training.

Boeing has a long history of development with More Electric Aircraft (MEA) systems. Its newest 787 aircraft has a "no-bleed system" which replaces most of the pneumatics, saving three percent fuel, reducing maintenance costs and improving aircraft range and reliability.

Boeing has more recently moved to invest in electric propulsion for aviation. Its venture capital arm, HorizonX together with JetBlue Airways Corp and Zunum Aero have invested in a hybrid electric aircraft technology with the intention of a market launch of a 12-seater aircraft powered by two electric engines in 2022.

In October 2017, Boeing announced its intention to acquire aviation research partner, Aurora Flight Sciences. The intention is leverage Aurora's unmanned aerial vehicles (UAV) capabilities for a future autonomous aircraft.

6.2. AirBus

Airbus, headquartered in Toulouse, France is a designer and manufacturer of aerospace products, solutions and services to its global marketplace. Denis Ranque is the Chairman of the Board of Directors and Thomas Enders is the CEO. Its key products include commercial aircraft, helicopters, unmanned aerial vehicles (UAV) and solar-powered High Altitude Pseudo-Satellite (HAPS) for defence applications, space satellites, launchers and other space exploration products. To date the company

has delivered almost 11,000 aircraft and 12,000 helicopters. Airbus recorded a revenue of €66.7 bn (£58.7 bn) in FY 2017 and is the second largest aircraft manufacturer globally behind Boeing.

Airbus innovations include unmanned aircraft and hybrid and electric propulsion systems for cleaner aviation. Airbus had a plan to introduce an electric two-seater with two 30 kW fans (its E-FAN programme) but in 2017 it announced that the plans were abandoned because the rate of development in the industry had already rendered them obsolete. It now has a joint-programme with Siemens with 300 kW motors.

Airbus collaborates with Rolls Royce and Siemens pooling resources to overcome hurdles to commercialisation of electric aircraft technology. The companies launched the E-Fan X hybrid-electric flight demonstrator to study hybrid-electric propulsion.

6.3. Other Players

Company Name	Location	Activities
Ampaire	Los Angeles, CA, USA	Full electric zero-emissions airplanes
Bell Helicopter	Fort Worth, TX, USA	Urban Electric Taxis "BellAirTaxi"
Bombardier Aerospace	Belfast, N. Ireland	e-APU, MEA
Boom Supersonic	Denver, Colorado, USA	XB-1 Supersonic Demonstrator, Virgin partnership. Japan Airlines \$10 m investment
Bye Aerospace	Denver, Colorado, USA	Medium and high altitude long endurance UAVs
DeLorean Aerospace	Laguna Beach California, USA	DR7 VTOL Flying Car U.S. patent 9,085,355
DigiSky Avionics Solutions	Torino, Italy	SkySpark demonstrator
Ehang	Guangdong, China	Ghostdrone 2.0 Drones, UAV
Eviation	Kadima-Zoran, Israel	Alice Project – commercial aviation
French Cleantech	Lyon, France	Electric Urban Cargo
Geely (Terrafugia)	Boston, MA	TF-X "flying car"
Honeywell Aerospace	NJ, USA	MEA, Airbus 380
Jet Blue	Long Island, NY, USA	Funding Zunum Aero
Joby Aviation	Santa Cruz CA, USA	Air-Taxis
Lange Aviation	Zweibrücken, Germany	Antares 20E Sailplanes
Lilium	Munich, Germany	Full electric VTOL jet
Lockheed Martin	Bethesda, MD, USA	"Power-by-wire" flight controls,
Mooney Aircraft	Kerrville, TX, USA	Uber partner for electric VTOL
NASA	Washington DC, USA	LEAPTech project, X-57 Maxwell Electric Research Plane
Pipistrel	Ajdovščina, Slovenia	Alpha Electro, Taurus Electro G2 2-seater,
Raytheon	Harlow, Essex, UK	MEA
Rolls-Royce	London, UK	Electrical non-propulsion. Partners with Airbus and Siemens
Safran	Paris, France	MEA, Commercial and military, digital battlefield solutions
Siemens	Munich, Germany	Partners with Airbus. Long-range hybrid-electric aircraft
Solar Impulse	Lausanne, Switzerland	World Alliance for Efficient Solutions
Sun Flyer	Englewood, CO, TX	Electric Flight Trainer
Thales	La Défense, France	MEA, TopStart™ starter generator, TopStart™ starter
United Technologies	Farmington, CT, USA	Owns Pratt & Whitney and UTC Aerospace. Electric power generation
Wright Electric	Los Angeles, CA, USA	150-seat electrically-propelled aircraft
XTI Aviation	Denver, CO, USA	Trifan 600 hybrid VTOL "Flying Taxi"
Zodiac Aerospace	Plaisir Cedex, France	Electric Power Systems
Zee Aero	MountainView, CA	Flying cars
Zunum Aero	Kirkland, WA, USA	Partners with Boeing, hybrid powertrain, electric Jet, quiet fans

FURTHER READING

Roland Berger: Aircraft Electrical Propulsion – The Next Chapter of Aviation?

https://www.rolandberger.com/publications/publication_pdf/roland_berger_aircraft_electrical_propulsion.pdf.

More Electric Aircraft (www.moreelectricaircraft.com)

Galea, Michael (2013) High performance, direct drive machines for aerospace applications. PhD thesis, University of Nottingham.

<http://eprints.nottingham.ac.uk/14431/1/601768.pdf>

Airbus abandons E-Fan as electric tech moves on

<https://www.flyer.co.uk/airbus-abandons-e-fan-as-electric-tech-moves-on/>

The Lilium Jet – The world's first all-electric VTOL jet

<https://www.youtube.com/watch?v=ohig71bwRUE>

More Electric Aircraft Market Worth 10.94 Billion USD by 2021

<https://www.prnewswire.com/news-releases/more-electric-aircraft-market-worth-1094-billion-usd-by-2021-602883166.html>

More Electric Aircraft Market Research Report- Global Forecast to 2021

<https://www.marketresearchfuture.com/reports/more-electric-aircraft-market-1245>

Preparing for electric flight

<https://www.aerosociety.com/news/preparing-for-electric-flight/>

Race to build first electric passenger aircraft takes to skies

<https://www.ft.com/content/f7f56adc-a96a-11e7-ab55-27219df83c97>

787 No Bleed Systems

http://www.boeing.com/commercial/aeromagazine/articles/qtr_4_07/article_02_1.html

Advanced Propulsion Centre, (APC) UK

<http://www.apcuk.co.uk/about-apc/what-will-apc-do/>

New £60 million automotive facility to propel UK jobs and investment

www.bath.ac.uk/research/news/2017/07/10/new-60m-automotive-facility-to-propel-uk-jobs-and-investment-2

Hybrid Electric Aerospace Research Group

<http://www.ncl.ac.uk/engineering/research/eee/power/centresofexpertise/#ati/aerospace>

Airbus, Rolls-Royce, and Siemens team up for electric future Partnership launches E-Fan X hybrid-electric flight demonstrator

www.airbus.com/newsroom/press-releases/en/2017/11/airbus--rolls-royce--and-siemens-team-up-for-electric-future-par.html