

Emerging Aircraft Technologies and their potential noise impacts

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Chapter 1

Introduction

DfT is developing a new Aviation Strategy¹ to look at aviation's challenges with the aim "to achieve a safe, secure and sustainable aviation sector that meets the needs of consumers and of a global, outward-looking Britain" and will set out the long-term direction for aviation policy making to 2050. As part of the preparation of the Aviation Strategy consultations, DfT has requested that CAA undertakes the noise analysis for this work.

In view of the new Aviation Strategy, the objective of this report is to review the potential noise impacts of future technologies in the Aviation Strategy. This includes a literature review of the noise associated with the development of electric aircraft (Chapter 2), supersonic aircraft (Chapter 3), drones (Chapter 4) and spaceplanes (Chapter 5). It discusses and proposes an interim approach to the management of their noise impacts in the early years of their operations.

The work includes:

- Literature review of potential technology designs;
- Literature review of noise modelling and noise measurements related to the future technologies;
- Recommendation of interim approach/regulation to address early days of technology update;
- Overview of other environmental impacts that may need further consideration.

Appendix A covers a description of the noise sources discussed in this report.

¹ "Aviation Strategy - Developing an aviation strategy to support industry in delivering improvements for passengers, the environment and our country.", Department for transport, 2018.

Chapter 2

Electric Aircraft

Background

Electric aircraft form an important component of achieving greenhouse gas emissions, air quality and noise exposure targets for aviation as they can reduce dependence on fossil fuels and allow for independent use of aircraft power generator and power propulsion, which could facilitate different aircraft designs such as Blended Wing Body (BWB) and Distributed Electric Power (DEP) that may also contribute towards reducing aviation noise.

At the international level, one of ICAO's main priorities and one of the Organization's key environmental goals is to limit or reduce the number of people affected by significant aircraft noise². The main overarching policy on aircraft noise is the Balanced Approach to Aircraft Noise Management and includes four main elements: reduction of noise at source, land-use planning and management; noise abatement operational procedures; and operating restrictions. As part of noise reduction as a source, ICAO sets noise limits for new aircraft and currently distinguishes between different aircraft types (e.g. light and heavy propeller aeroplanes, helicopters) and power plants (propeller and jet aeroplanes). Historic fleet evolution has achieved great progress over the years using conventional aircraft designs and gas-turbine (jet) engines. Electric powered aircraft are considered as part of the effort to reduce noise and would potentially need to go through the same aeroplane noise certification procedures as jet and propeller powered aeroplanes and comply with the same noise certification limits. Although only small electric powered aircraft are available at present, ICAO is monitoring and promoting the certification of electric flight concepts. Unmanned Aircraft Systems are covered in Chapter 5. Manned air taxis in the electric aeroplane category (i.e. not capable of vertical take-off) that would be expected to comply with ICAO propeller aeroplane noise certification requirements are covered in this chapter.

In Europe, the European Commission's Flight Path 2050 vision aims to achieve a reduction in carbon dioxide emissions of 60%, nitrogen oxide pollution of 90% and noise reduction of 75% by 2050 and this has been, in part, the motivation for some manufactures to embark on electric aircraft development programmes³.

In the UK, cleaner, greener flight is being encouraged through industry and government investment and as part of that the government announced investments in support of

² "On Board – A Sustainable Future", Environmental Report, ICAO, 2016.

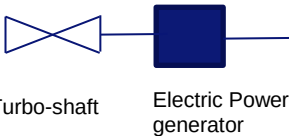
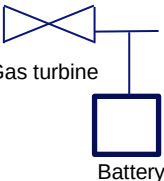
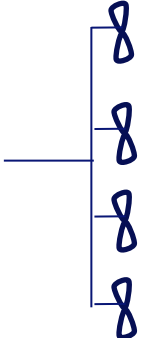
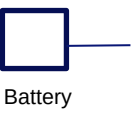
³ "Flightpath 2050 Europe's Vision for Aviation", ISBN 978-92-79-19724-6, European Union, 2011.

cleaner and greener hybrid aircraft during the 2018 Farnborough International Airshow⁴. A major beneficiary of the latest research and development funding is the demonstrator project E-Fan X (partnership between Siemens, Airbus and Rolls-Royce). The E-Fan X project aims to test a hybrid-electric propulsion system in a medium aircraft and expected to be ready by 2020.

Technologies designs

There are three main technology types being considered as future electric aircraft from a power generation perspective, including turbo-electric, hybrid-electric and electric aircraft, as presented in Figure 1. Noise from air taxis is covered in this report as part of a Fully Electric design if take-off is horizontal and under Unmanned Aircraft Systems (Chapter 4) if vertical take-off.

Figure 1: Main Electric Aircraft technology types

Technology Type	Power	Propulsion
(a) Turbo-electric	 Turbo-shaft Electric Power generator	 Conventional combined propulsion system
(b) Hybrid-electric	 Gas turbine Battery	 Distributed propulsion system
(c) Fully Electric	 Battery	

Turbo-electric aircraft: In a Turbo-electric aircraft, turboshaft engines are used to drive an electrical power generator to provide electricity to motors, driving the propulsors that in

⁴ <https://www.gov.uk/government/news/lift-off-for-electric-planes-new-funding-for-green-revolution-in-uk-civil-aerospace>

turn drive the fan⁵. This arrangement provides flexibility of design and can be used for BWB and DEP.

Hybrid-electric aircraft: In a hybrid electric aircraft there are two power sources, a gas turbine and a battery (or fuel cell) and both can be used to provide power to the fan⁶. In this report, this technology type is considered to have similar designs as conventional aircraft, although in the literature sometimes the term Hybrid-electric includes Turbo-electrics.

Fully electric aircraft: In a fully electric aircraft the power is provided only by batteries, fuel cells or energy collectors. The power is distributed to electric motors that drive the fans⁷.

From a propulsion perspective, there are different solutions varying from single fan and ducted fan to distributed propulsion (multiple fans). They can be used with different types of power generation, but overall full electrification will bring flexibility in design to allow for improved aerodynamics by distributing the motors into many locations on the aircraft, enabling multiple smaller motors and further integration between airframe and propulsion systems.

For comparison with the electric technologies, a conventional aircraft with turbo-fan engines is considered for qualitative analysis.

Weight

Considerations about weight are important on aircraft, as they determine other characteristics of a design, such as wing size (area), propulsion thrust/power and the weight of the power supply itself. The power supply weight will also impact range, cost of operation and available payload. Weight considerations are taken into consideration in this work, as the weight of the power supply in electric planes differs from conventional planes.

Turbo-electric aircraft are in general designed to be lighter than conventional aircraft and lighter than fully electric aircraft as the turbo generator is optimised to produce electrical power rather than propulsive thrust. In a hybrid-electric aircraft, fuel burn will allow for fuel mass reduction during flight. The weight of this configuration is comparable with the weight of an equivalent conventional aircraft. In a fully electric aircraft, the weight is a function of batteries and propulsion system. Due to use of batteries, the weight of the batteries

⁵ J.L. Felder, "Turboelectric Distributed Propulsion Engine Cycle Analysis for Hybrid-Wing Body Aircraft", NASA.

⁶ B.J. Brelje, "Electric, Hybrid, and Turboelectric Fixed-Wing Aircraft: A Review of Concepts, Models, and Design Approaches", Progress in Aerospace Sciences, 2018.

⁷ B. Łukasik and W. Wiśniowski, "FULL-ELECTRIC, HYBRID AND TURBO-ELECTRIC TECHNOLOGIES FOR FUTURE AIRCRAFT PROPULSION SYSTEMS", Journal of Powertrain and transport, Vol, 23, no. 4, 2016.

remains the same throughout the flight. A recent study⁸ showed that the weight of fully electric aircraft is higher than for conventional turbofan aircraft and higher than hybrid-electric or turbo electric aircraft due to current battery technology. Battery technology is continuously improving and hence the weight difference is likely to diminish in the future. Technology needs and progress⁹, on energy density of batteries compared with kerosene is presented.

Beyond the weight of the power system, the weight of the aircraft is also influenced by the weight of the propulsion system. Therefore, turbo-electric and fully electric aircraft have wider opportunities for the reduction of weight of their propulsion systems given that their configuration facilitate the use of multiple electric motors for DEP configurations.

Thrust & Power

The thrust requirements are a function of drag, mass and number of propulsors. The requirements for thrust and power for hybrid-electric aircraft in general will be like the requirements for conventional aircraft, i.e. take-off runway length, ability to operate with one engine inoperative and time to cruise altitude. Given the higher weight, a fully electric aircraft would require higher thrust and power than hybrid-electrics and conventional aircraft or may have poorer climb performance, with potential adverse noise implications.

Power supply weight

In hybrid-electric configurations, kerosene will be consumed during the flight and therefore the landing mass will be less than the take-off mass. In contrast, for a fully electric aircraft the landing mass will be the same as the take-off mass and it will be higher than for other propulsions configurations. Higher mass during the landing approach will lead to higher thrust requirements and potentially lead to higher noise emission.

⁸ A.P. Synodinos et al, "Preliminary noise assessment of aircraft with distributed electric propulsion", 2018 AIAA/CEAS Aeroacoustics Conference, 2018.

⁹ Andreas W. Schäfer et al, "Technological, economic and environmental prospects of all-electric aircraft", Nature Energy, 10 December 2018. <https://doi.org/10.1038/s41560-018-0294-x>

Noise sources, modelling and measurement

Noise at Source

In a turbo-electric aircraft, the main sources of noise are the turbo-shaft engine, the electric generator and the propulsors¹⁰ (motor and fan). The motor noise contribution is considered small compared to the other sources.

In a hybrid-electric aircraft, the main sources of noise are from the gas turbine, fan, electric motor and airframe.

In a fully electric aircraft, the main noise sources come from battery systems, the electric propulsors (motor and fan) and the airframe. The battery systems noise is considered negligible. During take-off, propulsion noise is dominant and although the electric aircraft weight is higher, the noise is expected to be reduced because of the higher mass flow and lower exhaust speed of the electric propulsors compared with conventional turbofan engines. The larger electric propulsors, could however, lead to increased fan inlet noise. During landing approach, higher aircraft mass will drive a larger wing and/or higher lift flap system that may increase airframe noise. The increase in drag associated with heavier aircraft and higher lift flap system will also require extra power which will increase electric propulsors noise. Preliminary research on electric motor noise for aircraft propulsion applications have been made and are predicted to be low compared to other propulsion noise sources¹¹. This research also shows that the electric propulsors' weight is reduced when the number of propulsors increases, as the weight increases in a quadratic way with the fan diameter.

Noise Modelling and Measurements

From a noise modelling perspective, current modelling tools are expected to be able to consider electric aircraft, however adjustments will be required to reflect the aircraft performance and noise characteristics of electric aircraft. A framework for predicting noise characteristics of electric aircraft has been created¹² and could be used once tested to decompose the noise characteristics from each aircraft component.

Initial noise measurements are being undertaken for small electric aircraft and for scale models of commercial aircraft types. There is still a clear need to undertake noise

¹⁰ A.P. Synodinos et al, "Noise Assessment of Aircraft with Distributed electric propulsion using a new noise estimation framework", 24th International Congress on Sound and Vibration, 2017.

¹¹ D. Huff et al, "Motor Noise for Electric Powered Aircraft, 22nd AIAA/CEAS Aeroacoustics Conference, 2016.

¹² A. Synodinos et al, "Framework for Predicting Noise–Power–Distance Curves for Novel Aircraft Designs", Journal of Aircraft, Vol. 55, No. 2, March–April, 2018.

measurements of the full scale commercial electric planes once they are available to fully understand their noise characteristics and any different source noise directivity considerations that may need to be used for noise modelling.

Noise exposure and annoyance

Work is progressing to determine the noise exposure from electric aircraft. It is still unknown whether the noise exposure from electric aircraft will be an improvement from conventional turbofan powered aircraft. According to Synodinos¹³ preliminary modelling results, electric aircraft are likely to reduce residential noise exposure around airports at take-off (for the same thrust the jet velocity and jet noise are lower due to higher airflow through propulsors) and increase noise levels during approach (due to the energy density of current batteries). Noise exposure will vary depending on the number of propulsors (motors and fans), decreasing as the number of propulsors increases, as propulsion weight varies with fan diameter. Also, because electric planes are predicted to be heavier, they are expected to climb at a slower rate after take-off compared with conventional aircraft and this may have an additional effect on noise exposure on the ground, offsetting some of the benefits of reduced source noise emission.

Electric propulsion is expected to alter the frequency spectrum of the sound emission. Fan noise emission, which is made of both broadband (a wide range of frequencies) and pure tone noise will likely dominate the sound emission. According to NASA¹⁴, the combination of multiple propellers has the potential to alter the relationships currently being used between noise exposure and annoyance due to their combined amplitude and phase modulation.

Qualitative analysis

Range of potential noise impacts identified

Some predictions¹⁵ show that medium commercial aircraft operating short-haul flights could be electrified in the early 2030s, whereas long-haul aircraft are not anticipated to be electrified until at least 2050. Noise levels of electric commercial aircraft may be higher than their kerosene fuelled equivalents if battery technology improvements driving reduction of weight in fully electric aircraft are not realised. The main improvements driving

¹³ A.P. Synodinos et al, "Preliminary noise assessment of aircraft with distributed electric propulsion", 2018 AIAA/CEAS Aeroacoustics Conference, 2018.

¹⁴ S. Rizzi et al, "Annoyance to Noise Produced by a Distributed Electric Propulsion High-Lift System", NASA, 2018.

¹⁵ "Aircraft Electrical Propulsion – Onwards and Upwards", Think:Act, Roland Berger, July 2018