An Overview of Low-Noise Approach and Departure Procedures for an Electrified Aircraft

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Introduction

The European Commission has set the goals to achieve climate neutral aviation and a reduction in perceived noise of 65 % compared to the year 2000 by the year of 2050. To accomplish climate neutrality, propulsion technology has to be advanced considerably [1]. One possibility is the electrification of the propulsion system. The integration of electrified propulsion systems (EPS) into civil aviation could lead to reductions in carbon emissions. To thereby successfully reduce aircraft noise, it is necessary to assess the noise reduction potential of electrified aircraft. A preliminary conceptual study, comparing the noise generation of electrified and conventional aircraft under the simplifying assumptions of constant aircraft weight and constant number and size of the propulsors revealed no distinctive differences [2], as the dominant noise source in modern gas turbine-driven engines is the fan or the propeller. This will not change significantly through the process of electrification, unless other approaches like distributed electric propulsion (DEP) are considered. Yet, the operational characteristics of electric machines offer a greater variability in take-off and approach procedures, providing potential for noise reduction during these flight phases, as presented in [3]. The current study represents an initial and qualitative overview of operational noise reduction means during approach and departure enabled by the electrification of the propulsion system. Distinct properties of the EPS, that enable certain low-noise approach and departure procedures (LNADP), as well as selected noise reduction measures are discussed.

Noise Sources in EPS

One can distinguish between three main electric aircraft architectures. In so-called turbo-electric aircraft, gas turbines drive electric power generators, which in turn supply electricity to the electric motors driving the fans [4]. The fan of so-called hybrid-electric aircraft is powered by two sources – a gas turbine and a battery or fuel cell, respectively [5]. Lastly, a fully electrified aircraft is solely driven by batteries or fuel cells [6].

The main noise sources of a turbo-electric propulsion system are considered to be the turbo-shaft engine and the fan. For a hybrid-electric propulsion system, gas turbine and fan constitute the main noise sources. For a fully electric propulsion system, the fan is considered to be the dominant noise source. In general, the noise resulting from the electric motor is currently considered to be low in comparison to the fan noise, although further research is necessary to verify this statement. Furthermore, when using an electric motor to drive the fan to achieve the same thrust as for the conventional turbofan engines, the jet velocity and consequently the jet noise are reduced considerably [7,8]. Yet, it has to be assumed that increased fan speed might be a result of compensating the missing thrust of the core engine. In the current initial study, the missing jet thrust is not accounted for.

Overview of Low-Noise Approach and Departure Measures

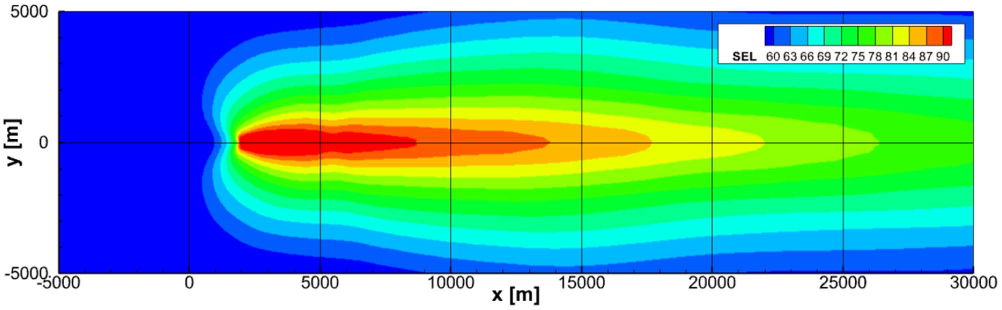
In the following sections, the effect of an electrification of the propulsion system on the noise impact as well as selected LNADP are discussed. First, the noise reduction potential at departure is assessed before the noise reduction potential at approach is analysed.

Noise Reduction Measures at Departure

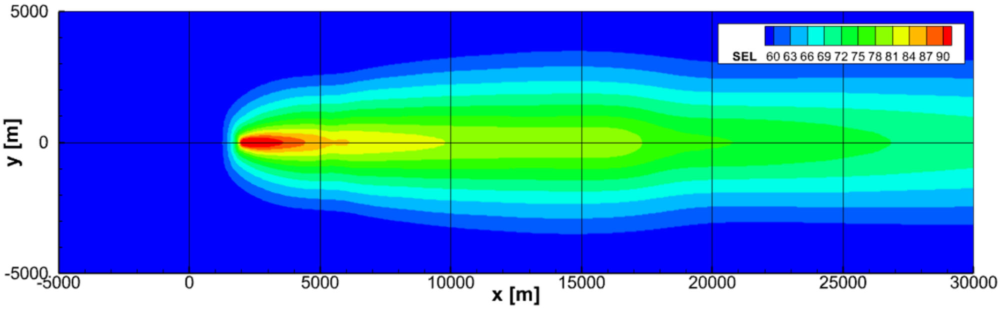
In this section, the effects of a reduced jet velocity and the application of higher take-off thrust, without increasing engines stress, on the noise impact of an electrified aircraft during departure are discussed.

Effect of Reduced Jet Velocity

As mentioned, the electrification of the propulsion system results in significantly lower jet velocities and, consequently, lower jet noise. Since, besides the fan, the jet constitutes one of the main noise sources at take-off for aircraft with conventional engines [10], a notable noise reduction might be accomplished. In order to illustrate the potential noise reduction inherent to EPS, a simulation was conducted with the DLR software tool PANAM (Parametric Aircraft Noise Analysis Module) [9]. In the simulation, the noise impact of an Airbus A320 with a V2500 engine at departure is compared to that of a simplified electrified version of the aircraft for the same flight trajectory. Combustion chamber and turbine were generally omitted as noise sources for both versions of the aircraft. Hence, the only noise sources present in the example are airframe noise as well as jet and fan noise. All these noise sources were considered for the conventional aircraft, while for the electrified A320, jet noise was neglected as a simplified first attempt. Of course, omitting jet noise completely is a rather crude assumption, because the accompanying loss of thrust would in



(a) Conventional turbofan engine



(b) Electrified turbofan engine

Figure 1: Effects of jet noise reduction in an electrified aircraft on the noise impact during departure, calculated using PANAM [9].

reality require compensation by an enhanced fan speed or fan diameter, and therefore can lead to an increase in fan noise. Thus, the results should be understood as an initial estimate of the full reduction potential. In reality, less noise reduction is expected. Figures 1a and 1b depict the noise maps in terms of sound exposure level (SEL) for a standard departure trajectory of a conventional A320 and its electrified version, respectively. As can be seen, the area as well as the SEL directly below the trajectory of the plane are decreased considerably.

Increase of Take-Off Thrust utilising an Electric Motor

A common operational practice is to reduce take-off thrust (i.e., flex-thrust) if the available runway field length allows a safe departure using a thrust setting smaller than the maximum take-off thrust rating. This operational measure mainly reduces engine stress and therefore maintenance costs. At the same time, a lower take-off thrust reduces the acceleration and climb capabilities, which leads to a longer take-off run distance and a lower altitude profile. This, in turn, might result in increased noise levels on ground and in increased fuel consumption. Utilising an electrified engine, the thrust could potentially be compensated or increased by engaging the electric motor of comparably low noise signature, while keeping the benefit of less engine stress to the turbofan engine. Thereby, even steeper take-off angles might be realised, increasing the distance between source and observer and, consequently, reducing the noise impact directly along the flight path. Fig. 2 displays this method schematically. Thereby, $P_{\mathrm{ICE,reduced}}$ and P_{electric} represent the resulting power from the reduced thrust of the internal combustion engine (ICE) and the power resulting from the electric motor, respectively.

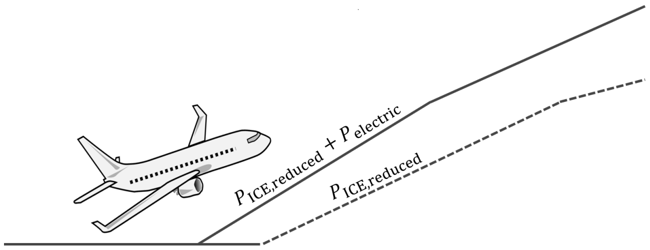
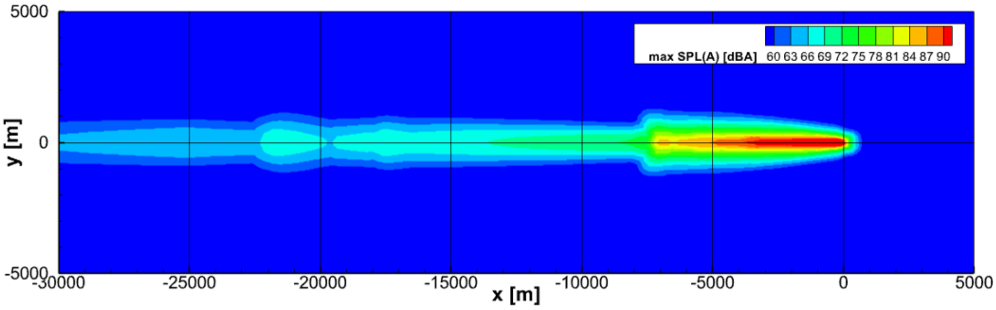


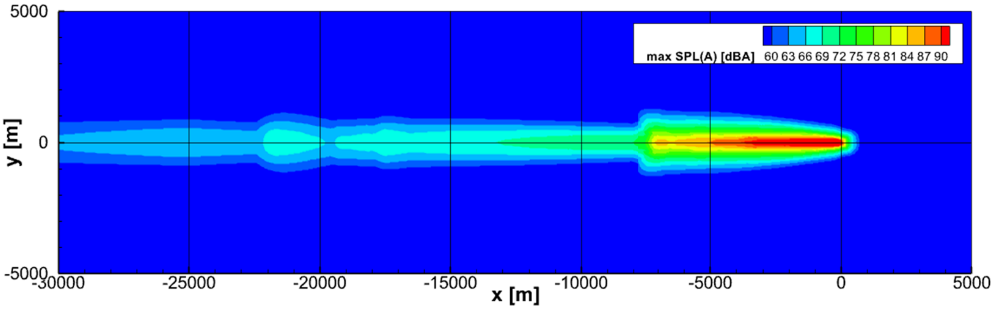
Figure 2: Increase of take-off thrust by means of an electric motor in a hybrid-electric or fully electric engine.

Noise Reduction Measures at Approach

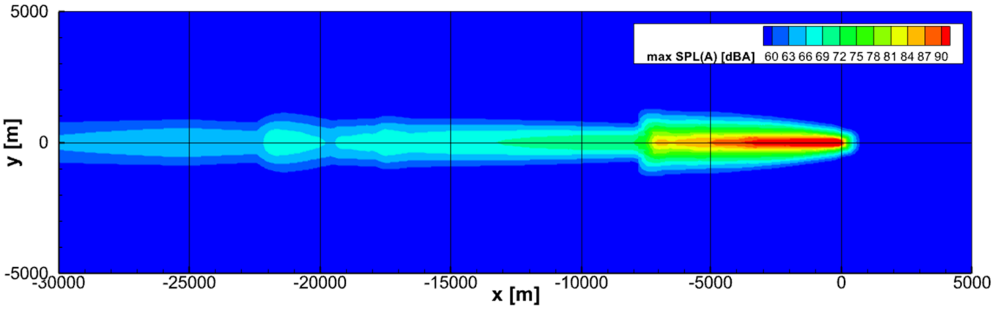
Low-noise approach procedures are enabled by two distinct properties of EPS. Firstly, EPS allow for the employment of an additional drag mechanism called windmilling, that must be avoided with turbofan engines due to the risk of a compressor stall. In the process of windmilling, the fan rotates with a speed smaller than the inflow velocity of the fluid into the engine, automatically creating additional drag. Besides the rotational speed of the fan, the amount of drag generated is, amongst others, dependent on the properties of the fan blades, the fan area, and the duct geometry [3]. Secondly, compared to combustion engines, EPS allow for a reduced amount of idle thrust during approach, as they restore the rotational speed for go-around thrust faster. Approach idle thrust is the minimum thrust that is necessary as safety measure in case of a missed approach.



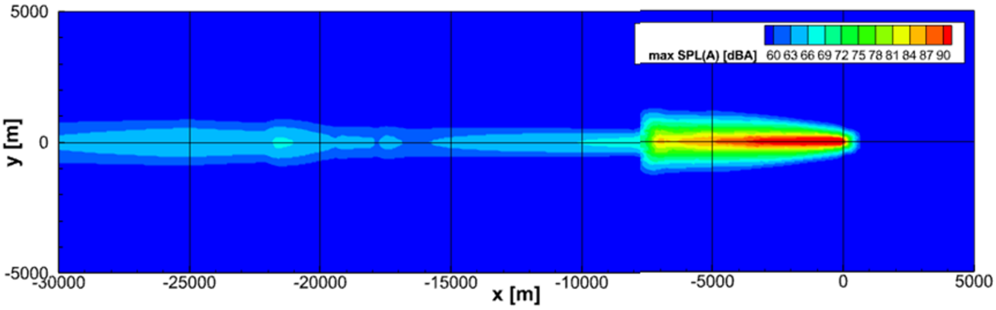
(a) Reference high-lift design and reference approach idle thrust



(b) Reference high-lift design and reduced approach idle thrust



(c) Low-noise high-lift design and reference approach idle thrust



(d) Low-noise high-lift design and low approach idle thrust

Figure 3: Effects of reduced approach idle in an electrified aircraft on the noise impact during approach.

Effect of the Reduction of Approach Idle thrust on the Noise Emission

For an EPS, reducing the idle thrust during approach leads to a decrease of the rotational speed of the fan and, hence, fan noise. The noise impact at approach is again analysed with the help of the PANAM software for the electrified A320 considered before. The reduced idle thrust is included in the simulation by the corresponding reduction of fan noise. First, Figs. 3a and 3b compare the overall A-weighted noise impact at ground level for the A320 under different idle settings. The results confirm the dominance of the airframe during typical approaches. A relevant difference can only be achieved, if additional measures to reduce the airframe contribution are applied in combination with the reduced engine idle setting. Following this, the identical analysis is conducted for a low-noise high-lift retro fit design. Figs. 3c and 3d depict the results. It can be seen that the benefits of reducing the idle thrust now affect the overall noise. Therefore, if the airframe can be optimised regarding its noise emission properties, a reduction of idle thrust might be beneficial to the overall noise signature of the aircraft. At $x \approx -7500\,\mathrm{m}$ the engines spool up and no more advantage is observable.

Steeper Angle of Approach and Delayed Deceleration Approach

Lastly, by the use of windmilling and the reduction of idle thrust, either a steeper angle of approach, a delayed deceleration procedure or a combination of both measures might be realised in electrified aircraft. A steeper angle of approach leads to a faster increase of the distance between noise source and observer and, theoretically, to a decrease of the noise impact at the observer point. Since the airframe noise increases with air speed in a greater manner than the overall noise decreases with an increased distance between source and observer [11], the advantage of an increased distance might even be reversed, if the aircraft accelerates faster due to insufficient drag.

The so-called delayed deceleration approach describes the procedure of delaying the employment of high-lift devices and landing gear, thus avoiding additional airframe noise until a distance closer to the landing point. Similar to the case of an approach with steeper angles, the amount of noise mitigation depends on the additional drag that can be created as well as the amount of approach idle thrust reduction that can be realised.

Conclusion

This paper describes selected low-noise approach and departure methods that are enabled by distinct properties of electrified aircraft engines in a qualitative manner. Simulations indicate that, due to the reduced jet velocity and therefore reduced jet noise of electrified aircraft, the noise emissions at departure might be reduced considerably. Furthermore, by the assistance of an electric motor, the take-off thrust could be increased without significant noise penalty. This enables steeper climbing angles at take-off, thereby decreasing noise impact at ground level due to increasing the distance between noise source and observer. Low-noise approach procedures for electrified aircraft are enabled by the additional drag generation through windmilling and the reduced demand of approach idle thrust compared to a conventional aircraft. Due to the dominance of airframe noise at approach, the reduction of idle thrust produces a notable reduction of overall noise only for the case of noise optimised high-lift devices. In addition, windmilling and reduced idle thrust enable steeper angles of approach as well as the delay of the deceleration process to a distance closer to the landing point, thus providing potential further noise reduction. The results of this study will serve as a starting point for a quantitative analysis of low-noise approach and departure measures enabled by the electrification of aircraft. Furthermore, the most promising measures will be combined and applied to exploit the full potential, e.g., including non-conventional low-noise approach procedures [12].

Acknowledgements

This preliminary study is part of the project *LU(FT)^2 2030* by the German Aerospace Center DLR.

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