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Experimental Acoustic Characterisation of the Propeller BLI Configuration for Zero and Adverse Pressure Gradient Boundary Layers

Ismaeel Zaman[a,1], Michele Falsi[b,2], Feroz Ahmed[a,3], Bin Zang[a,4], Mahdi Azarpeyvand[a,5]

[a]Faculty of Engineering, University of Bristol, Bristol, UK

[b]Department of Civil, Computer Science and Aeronautical Technologies Engineering, Università degli Studi Roma Tre, Via Vito Volterra, 62, 00146 Rome, Italy

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Introduction

The boundary layer ingestion (BLI) configuration is commonly featured on future flight aircraft concepts due to its compactness and potential for increased energy efficiency [1-3]. The BLI concept is based on positioning a propulsion system, be it a propeller, turbofan or similar, such that it is partially or totally ingesting the airframe boundary layer. Thus, reenergising the wake and reducing skin friction drag which results in increasing efficiency. However, since the inflow to the propulsor is now non-uniform and highly turbulent, this leads to concerns of a significant noise penalty. Therefore, acoustic analysis of the BLI configuration is an area of great research interest [2, 4-7]. To date, a comprehensive experimental study has not been reported to evaluate the impact of several operational parameters (e.g. propeller speed, tip gap, incoming boundary layer properties) on the emitted noise of a propeller ingesting a zero-pressure gradient (ZPG) boundary layer and an adverse pressure gradient (APG) boundary layer for partially buried arrangements. Therefore, the current study seeks to carry out such a comprehensive aeroacoustic experimental assessment of both BLI configurations across several operational parameters using a wide array of instrumentation.

Methodology

To achieve this, two experimental setups were constructed, the first to study the ZPG BLI (Config. A1) and the second to study the APG BLI (Config. A2). Experiments were conducted at the Aeroacoustic Wind Tunnel Facility at the University of Bristol, which is a closed-loop, open-jet wind tunnel where the exit nozzle and test section are located within an anechoic chamber [1]. The propeller and purpose-built propeller rig is common to both setups and used a Mejzlik 12x18” 2-bladed propeller mounted to a 3.2kW BLDC motor. For Config A1, an instrumented flat plate was built and mounted adjacent to the exit of the nozzle. To examine the effect of boundary layer thickness and turbulence contents to the radiated BLI noise, three different tripping devices were placed upstream. The propeller rotational velocity was also swept as well as varying the tip-plate displacement. Config. A2 replaced the flat plate with an instrumented curved S-plate, the curved section is defined using a cubic Bezier function to ensure smooth gradient transitions. This setup is designed to mimic the arrangement of a partially buried installation configuration. In this case, the investigated parameters were: the streamwise position of the propeller along the curve, the rotational speed of the propeller and the tip-plate displacement. Far-field acoustic information were collected by two microphone arcs populated with GRAS 40PL microphones placed parallel and orthogonal to the plates as depicted in figures 1 and 2. This allows detailed directivity and spectral analysis of the emitted noise. The plates were instrumented with surface static pressure taps and surface pressure transducers to characterise flow development. Flow and boundary layer characterisation was performed though hotwire constant-temperature-anemometry surveys.

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[1] i.zaman@bristol.ac.uk
[2] michele.falsi@uniroma3.it
[3] feroz.ahmed@bristol.ac.uk
[4] nick.zang@bristol.ac.uk
[5] m.azarpeyvand@bristol.ac.uk

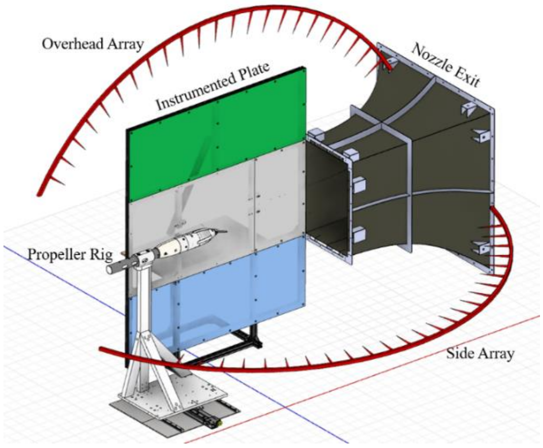

Figure 1 Config A1 ZPG BL Experimental setup

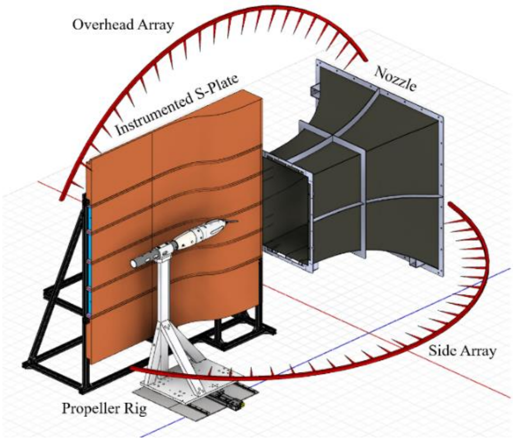

Figure 2 Config A2 APG BL Experimental setup

Results and Discussion

Acoustic results for Config A1 reveal strong sensitivity to the incoming boundary layer properties in regards to broadband emissions and stronger tonal harmonics, see figure 3. Increased noise is strongly directed towards the downstream portion parallel to the plate, additionally, distinct noise characteristics were observed between the two arcs, see figure 4. Both observations indicate that propeller turbulence ingestion noise (TIN) is primarily directed along the blade normals. Increasing the RPM of the propeller was seen to reduce the strong acoustic influence of the incoming boundary layer properties, as alternate noise generation mechanisms become dominant.

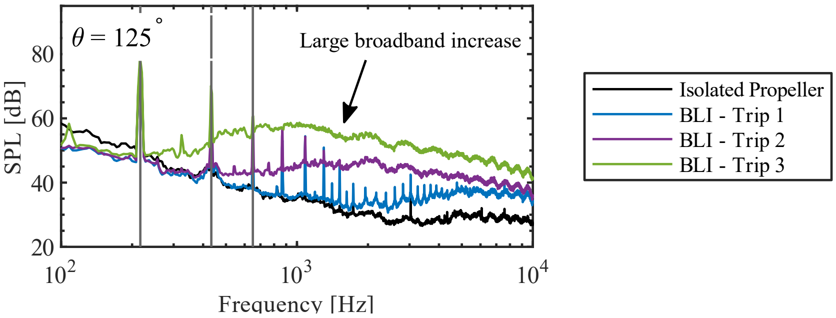

Figure 3 Acoustic Spectra from downstream θ=125° microphone in Overhead array for increasing BL thickness- Config A1.

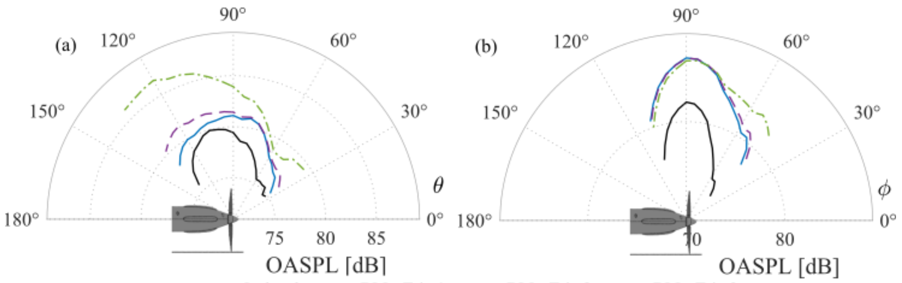

Figure 4 OASPL Directivity Patterns for Overhead (left) and Side (right) arrays - Config A1

Results for Config A2 show a clear adverse pressure gradient BL is generated with turbulence levels that far exceed those of the flat plate. This translates to a significant level of noise generation, which also exhibits strong acoustic haystacking, as seen in figure 5. This haystacking phenomena is accentuated when operating at higher RPMs. Noise is also strongly influenced by positioning the propeller at different streamwise positions along the curve, with far upstream locations presenting significantly reduced noise, as shown in figure 6, the different noise levels observed can be primarily attributed to the turbulence contents present in the propeller inflow at the respective locations.

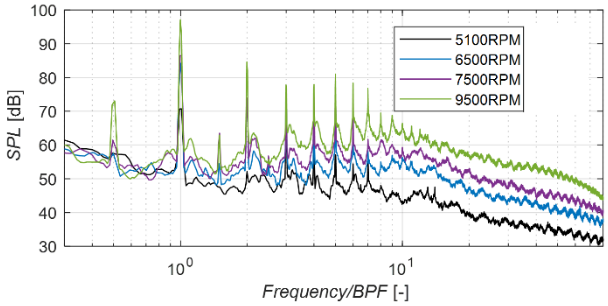

Figure 5 Acoustic spectra with increasing RPM in the Overhead array, strong haystacking - Config A2

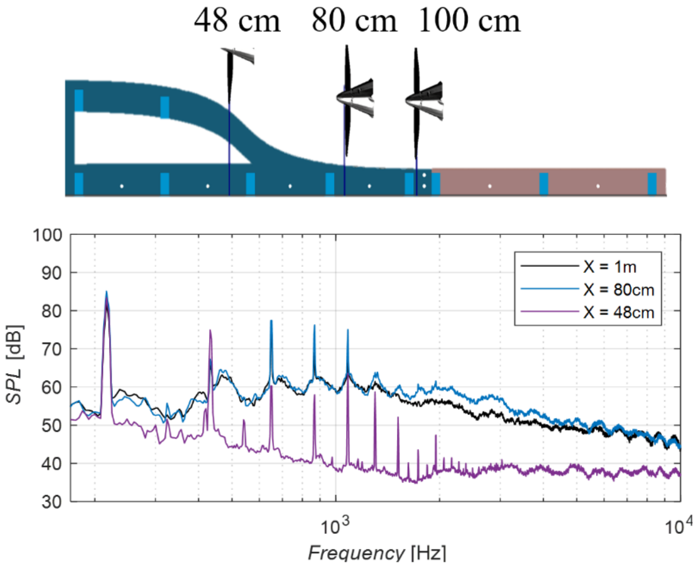

Figure 6 Acoustic spectra for different streamwise positions – Config A2

References

[1] Y. D. Mayer, H. K. Jawahar, M. . Szoke and M. . Azarpeyvand, "Design of an Aeroacoustic Wind Tunnel Facility at the University of Bristol," , 2018. [Online]. Available: https://arc.aiaa.org/doi/pdf/10.2514/6.2018-3138. [Accessed 4 10 2023].

[2] A. P. Plas, M. A. Sargeant, V. . Madani, D. . Crichton, E. M. Greitzer, T. . Hynes and C. A. Hall, "Performance of a Boundary Layer Ingesting (BLI) propulsion system," , 2007. [Online]. Available: http://silentaircraft.org/object/download/1922/doc/aiaa-2007-450-464.pdf. [Accessed 2 10 2023].

[3] D. K. Hall, A. C. Huang, A. . Uranga, E. M. Greitzer, M. . Drela and S. . Sato, "Boundary Layer Ingestion Propulsion Benefit for Transport Aircraft," *Journal of Propulsion and Power,* vol. 33, no. 5, pp. 1118-1129, 2017.

[4] A. . Voogd, "Experimental investigation of boundary layer ingestion in integrated propulsion systems," , 2020. [Online]. Available: https://repository.tudelft.nl/islandora/object/uuid:02ce639b-5ef8-495d-b09a-f9bf1e311e2d?collection=education. [Accessed 2 10 2023].

[5] G. . Romani, Q. . Ye, F. . Avallone, D. . Ragni and D. . Casalino, "Fan Noise Boundary Layer Ingestion Installation Effects for NOVA Aircraft Configuration," , 2019. [Online]. Available: https://narcis.nl/publication/recordid/oai:tudelft.nl:uuid:7431c316-1511-4d8f-95e7-20a392e310fe. [Accessed 2 10 2023].

[6] G. . Romani, Q. . Ye, F. . Avallone, D. . Ragni and D. . Casalino, "Numerical analysis of fan noise for the NOVA boundary-layer ingestion configuration," *Aerospace Science and Technology,* vol. 96, no. , p. 105532, 2020.

[7] H. . Murray, W. J. Devenport, W. N. Alexander, S. A. L. Glegg and D. M. Wisda, "Aeroacoustics of a rotor ingesting a planar boundary layer at high thrust," *Journal of Fluid Mechanics,* vol. 850, no. , pp. 212-245, 2018.

[8] I. Zaman, M. Falsi, B. Zang, M. Azarpeyvand and R. Camussi, "Effect of Tip Gap on Nearfield and Farfield Acoustics of Propeller Boundary Layer Ingestion," in *AIAA AVIATION 2023 Forum*, San Diego, 2023.

[9] I. Zaman, M. Falsi, B. Zang, M. Azarpeyvand and R. Camussi, "Experimental Parametric Investigation of the Haystacking Phenomenon for Propeller Boundary Layer Ingestion," in *AIAA AVIATION 2023 Forum*, San Diego, 2023.

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