AEROELASTIC OPTIMISATION OF FLEXIBLE AIRCRAFT WINGS WITH DISTRIBUTED ELECTRIC PROPELLERS

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ABSTRACT

Recent advancements in electric drives have fuelled a growing interest in distributed electric propulsion (DEP) wings, featuring multiple small propellers spaced across the wingspan. These novel wing configurations enable zero-emission propulsion using multiple electric motors. One such configuration is used in the NASA X-57 Maxwell and the Electra EL9 eSTOL aircraft, as shown in Figure 1. Many of the recent research studies [1–4] have examined the aeroelastic instabilities of DEP wing configurations. However, the structural sizing of DEP wings, particularly incorporating the effects of propeller whirl flutter and propeller mounting stiffness, remains largely unexplored. Moreover, the lack of computationally efficient frameworks capable of capturing these coupled aeroelastic–structural interactions has limited the application of optimisation-based structural sizing approaches, motivating the use of low-order aeroelastic models combined with global optimization techniques such as Genetic Algorithms.

Figure 1: Novel aircraft configurations with Distributed Electric Propulsion. a) NASA X-57 Maxwell [7] and b) Electra EL9 eSTOL [8].

The aim of this paper is to investigate how minimising the structural weight of the wing in DEP configurations by optimising the wing box thickness distribution can be achieved within the design constraints using a Genetic Algorithm (GA) method. To this end, a low-order coupled aeroelastic model was developed in MATLAB to investigate the aeroelastic behaviour of a flexible cantilever wing equipped with varying numbers of flexibly mounted inboard and wingtip propellers, see Figure 2. The propeller dynamics are captured using Houbolt-Reed's method [5], while the structural model of the wing is obtained through the Rayleigh-Ritz method in conjunction with Lagrange's equations [6]. The aerodynamic loading on the wing is characterized using a combination of a modified strip theory and Theodorsen's unsteady aerodynamic formulation. The developed coupled aeroelastic model was demonstrated to accurately predict both wing flutter and whirl flutter in DEP-configured wings through validation against existing literature. Furthermore, in the extended framework of the proposed

aeroelastic model, the preliminary wing structural sizing of DEP wings is optimised for minimal wing mass by identifying the optimal thickness distribution of the wing box. The effects of propeller whirl flutter and propeller mounting stiffness are incorporated as design constraints within the developed aeroelastic optimisation framework.

The initial results indicate that the optimisation can lead to a significant reduction in the optimised wing mass while still meeting the whirl flutter and structure stress constraints, as depicted in Figure 3. The final version of the paper will present the definition of the optimization problem for the design of DEP wings through an extension of the proposed aeroelastic model of coupled propeller–wing system. The Genetic Algorithm (GA)–based optimization framework will be applied to various case studies to assess the effects of whirl flutter and propeller mounting stiffness. Furthermore, the paper will discuss the benefit of combining low order modelling with GA methods for use in structural sizing of the DEP wings aimed at achieving minimal wing mass while satisfying the prescribed design constraints.

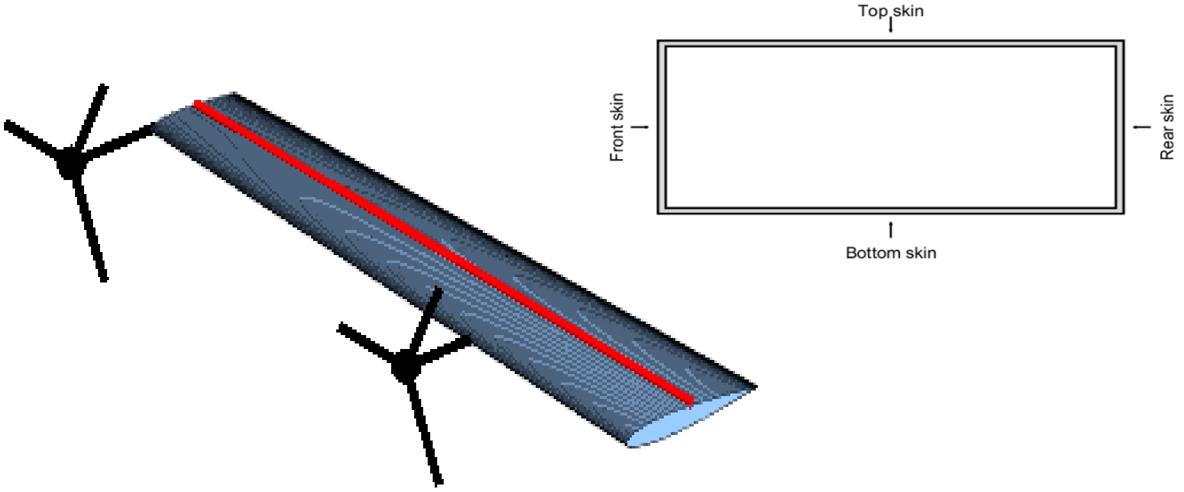

Figure 2: A schematic of the coupled wing-propeller model with illustration of the wing-box thickness parameters used in the optimisation.

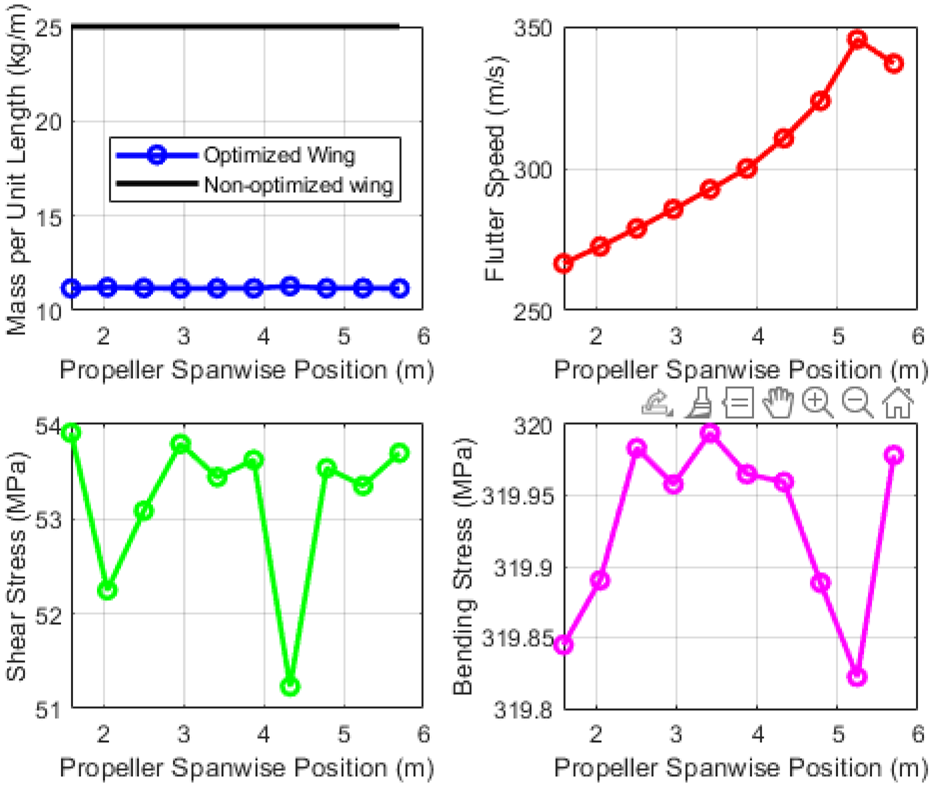

Figure 3: Initial results of optimised coupled wing-propeller model

REFERENCES

[1]. Amoozgar, M., Friswell, M. I., Fazelzadeh, S. A., et al. (2021). Aeroelastic stability analysis of electric aircraft wings with distributed electric propulsors. *Aerospace*, 8(4),100.

[2]. Xu, V. L., (2020). Propeller-Wing Whirl Flutter: an analytical study. *Delft University of Technology*.

[3]. Böhnisch, N., Braun, C., Koschel, S., et al. (2022). Whirl flutter for distributed propulsion systems on a flexible wing. In *AIAA SCITECH 2022 Forum*. p. 1755.

[4]. Dede, S. T., Tatar, A., Rezgui, D., and Cooper, J. E., (2024). Aeroelastic analysis of distributed electric propulsion flexible wings. In *International Forum on Aeroelasticity and Structural Dynamics*. p.129

[5]. Houbolt, J. C. and Reed, W. H. (1962). Propeller-nacelle whirl flutter. *Journal of the Aerospace Sciences*, 29(3), 333–346.

[6]. Wright, J. R. and Cooper, J. E. (2007). *Introduction to Aircraft Aeroelasticity and Loads*. CBS Publishers & Distributers.

[7]. NASA. https://www.nasa.gov/image-detail/x-57_maxwell_city_0/, (accessed January15, 2026).

[8]. Electra.aero. https://www.electra.aero/, (accessed January15, 2026).