Thesis subject proposition

Title: Phenomenological Aerodynamic Force Breakdown on Propellers and Open-Fan Configurations Using the Kutta-Joukowski-Maskell-Betz Formulation

Reference: **MFE-DAAA-2026-12**
(To be mentioned in all correspondence)

Beginning of the thesis: October 2026	**Application deadline: April 30th 2026**

Key words

Drag, Thrust, Torque, Far-field Analysis, Propeller, Aerodynamics, CFD, FFD

Profile and desired skills

Graduate school of Engineering or University (Master 2).

Good knowledge of aerodynamics and fluid mechanics, appetency for theoretical work and research, programming skills (mainly Python, perhaps Fortran), good level of oral/written English.

Presentation of the project, context and objectives

For the last thirty years, ONERA has been developing several formulations aiming at decomposing drag, thrust and torque into their phenomenological contributions [1-4]. Those formulations allow for a near-field/far-field balance in terms of pressure and friction components (near-field approach) or lift-induced, viscous and wave components (far-field approach) [1, 2]. Using the near-field approach consists in computing the aerodynamic force by considering the effect of the airflow on the aircraft, whereas using the far-field approach comes down to studying the effect of the presence of the aircraft on the surrounding airflow. With the information provided by the far-field breakdown (lift-induced, viscous and wave contributions), aerodynamicists and aeronautical engineers may then improve the design of airplanes, engines and propeller blades. ONERA in particular develops a series of scientific software allowing to assess all those contributions starting from the analysis of a Computational Fluid Dynamics (CFD) solution.

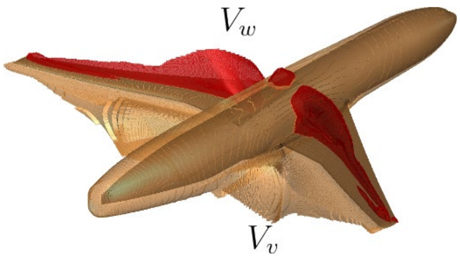

Figure 1: Physical volumes for viscous and wave drag extraction around the NASA CRM aircraft

Together with his colleague van der Vooren, Destarac laid down the first foundations [1] and developed a thermodynamic formulation taking over the concept of entropy drag introduced by Oswatitsch several decades earlier. Over the years, this formulation has demonstrated its robustness and accuracy on many academic and industrial cases (airfoils, wings and aircraft) and is now a reference method for far-field drag breakdown. This motivated the development of two additional formulations, based on the same underlying model, aiming either at decomposing drag in unsteady flows [5] or thrust and resisting torque on propellers and counter-rotating open rotor configurations [4].

In spite of those fruitful developments, a lingering question of the definition of lift-induced drag remained. Indeed, van der Vooren and Destarac's model is based on assumptions that allow to directly define the profile drag (viscous and wave drag), but the lift-induced drag is defined indirectly. Consequently, the physical mechanisms of lift-induced drag cannot be straightforwardly analysed with this kind of model.

That is why additional research was carried out on far-field formulations based on the Lamb vector [6-8]. Thus, a novel far-field force formulation was developed at ONERA, referred to as the Kutta-Joukowski-Maskell-Betz (KJMB) formulation, allowing to directly define the lift-induced drag as well as to evaluate the far-field lift. This formulation is promising since it gathers in a single expression a viscous compressible extension of the theories from classical incompressible aerodynamics: the Kutta-Joukowski circulation theorem [9, 10], Maskell's lift-induced drag formula [11] and Betz's profile drag formula [12].

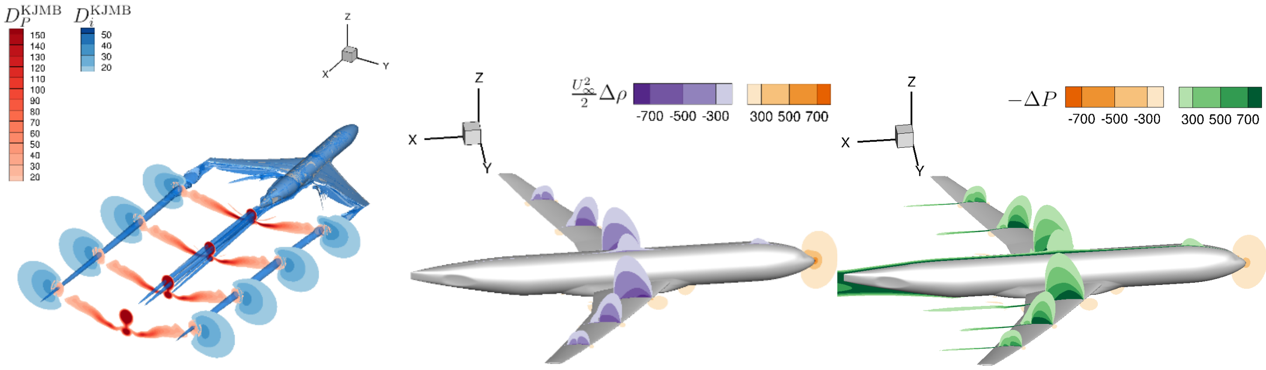

Figure 2: Contours of lift-induced and profile drag contributions around the NASA CRM aircraft [13]

So far, the KJMB formulation has been applied to steady flows around airfoils, wings and aircraft configurations and has shown promising results. The aim of this thesis is to develop a KJMB formulation able to extract the thrust and the torque exerted on propeller configurations, and to decompose them into lift-induced and profile contributions. This formulation intends to be applicable to flows being steady in the rotating frame attached to the propeller blades.

First, the work will take over the improvements recently made on the KJMB formulation regarding the evaluation of lift-induced drag, in order to revisit the definitions of viscous and wave drag proposed in [13] by conducting numerical analyses on airfoils, wings and aircraft. The purpose of this task is to achieve a good level of robustness for the KJMB formulation in the inertial frame before extending the approach to the rotating frame.

Then, the balance of momentum and torque will be written in the rotating frame in order to identify the terms related to thrust and torque. The goal is to be able to isolate the terms purely contributing to thrust and those related to induced and irreversible losses. For this purpose, a blade-section thrust-drag breakdown approach will have to be developed, inspired from the works of Méheut [4] in order to distinguish the induced losses from the actual thrust.

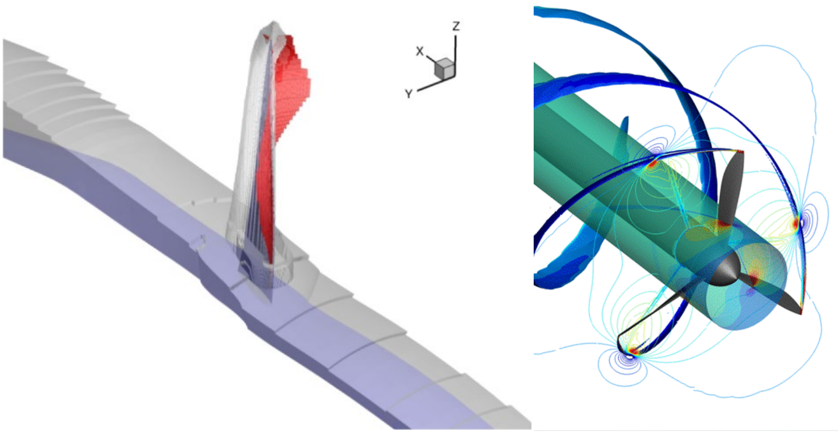

Figure 3: Integration volumes for far-field thrust and torque breakdown [4] (left). Isosurfaces of axial vorticity coloured by relative Mach number (right).

Later on, this theoretical work will be tested and validated on practical CFD cases of increasing complexity, first on a single propeller, then on an open-fan configuration. The results obtained with the novel KJMB formulation will be compared to those obtained with that developed by Méheut [4]. These developments will be implemented in a dedicated analysis software developed at ONERA.

References

[1] van der Vooren, J., and Destarac, D., "Drag/thrust analysis of jet-propelled transonic transport aircraft; definition of physical drag components," Aerospace Science and Technology, Vol. 8, No. 6, 2004, pp. 545–556. doi: https://doi.org/10.1016/j.ast.2004.03.004.

[2] Arntz, A., "Civil aircraft aero-thermo-propulsive performance assessment by an exergy analysis of high-fidelity CFD-RANS flow solutions," Ph.D. thesis, Lille 1 Université - Sciences et Technologies, Lille, France, 2014, https://theses.hal.science/tel-01113135v1.

[3] Méheut, M., and Bailly, D., "Drag breakdown methods from wake measurements." AIAA Journal, Vol. 46, No. 4, 2008, pp. 847–862. doi: 10.2514/1.29051, https://arc.aiaa.org/doi/10.2514/1.29051.

[4] Méheut, M., “Thrust and torque far-field analysis of propeller and counter rotating open rotor configurations,” 31st AIAA Applied Aerodynamics Conference, Fluid Dynamics and Co-located Conferences, AIAA Paper 2013-2803, American Institute of Aeronautics and Astronautics, 2013. doi: https://doi.org/10.2514/6.2013-2803.

[5] Toubin, H., “Prediction and phenomenological breakdown of drag for unsteady flows,” Ph.D. thesis, Université Pierre et Marie Curie de Paris VI, 2015, https://theses.hal.science/tel-01343976v1.

[6] Wu, J. Z., Liu, L. Q., and Liu, T. S., “Fundamental theories of aerodynamic force in viscous and compressible complex flows,” Progress in Aerospace Sciences, Vol. 99, May 2018, pp. 27–63. doi: https://doi.org/10.1016/j.paerosci.2018.04.002.

[7] Mele, B., Ostieri, M., and Tognaccini, R., “Aircraft lift and drag decomposition in transonic flows,” Journal of Aircraft, Vol. 54, No. 5, 2017, pp. 1933–1944. doi: https://doi.org/10.2514/1.C034288.

[8] Fournis, C., Bailly, D., and Tognaccini, R., “Invariant vortex-force theory extending classical aerodynamic theories to transonic flows,” AIAA Journal, Vol. 60, No. 9, 2022, pp. 5070–5082. doi: https://doi.org/10.2514/1.J061278.

[9] W. M. Kutta, “Auftriebskräfte in strömenden flüssigkeiten,” Illustrierte Aeronautische Mitteilungen, Vol. 6, No. 133, pp. 133–135, 1902.

[10] N. Joukowski, “On annexed vortices,” Proc. Phys. Section of the Natural Science Society, Vol. 13, No. 2, pp. 12–25, 1906.

[11] E. Maskell, “Progress towards a method for the measurement of the components of the drag of a wing of finite span,” Tech. Rep. 72232, Procurement Executive, Ministry of Defence, Royal Aircraft Establishment, 1972.

[12] A. Betz, “A method for the direct determination of wing-section drag,” Tech. Rep. NACA TM37, National Advisory Committee for Aeronautics, 1925.

[13] Fournis, C., “Aerodynamic force prediction and breakdown using the lamb vector in steady compressible flows,” Ph.D. Thesis, Sorbonne Univ., Paris, France, 2021, https://tel.archives-ouvertes.fr/tel-03514103.

Potential collaborations

Exchanges with key players in the civil aviation industry in France as part of joint research activities.

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