BEYOND THE CLEAN AEROFOIL: THEORETICAL DEFINITION OF AN AERO-PROPULSIVE ELEMENT

DESCRIPTION:

Traditionally (in very simple terms) in preliminary aeroplane design one considers two distinct elements which provide the two forces needed for sustained flight:

- Wing/aerofoil: providing lift (at a drag penalty),
- Engine/propulsor: providing thrust/motive power (with its own associated drag penalty).

At the most basic level, the two elements work separately on an aeroplane, with very limited mutual influence/interference. (Fig.1, left) Contemporary research motivated by perspectives of dramatic fuel burn reduction looks more and more at "synergetic" configurations (*wake-filling* and/or *Boundary Layer Ingestion (BLI)* configurations[1]), **where thrust and lift production mechanisms are designed to be functionally and structurally correlated** in order to yield a smaller overall drag penalty for the same functional i.e. lift and thrust benefit (Fig.1, right).

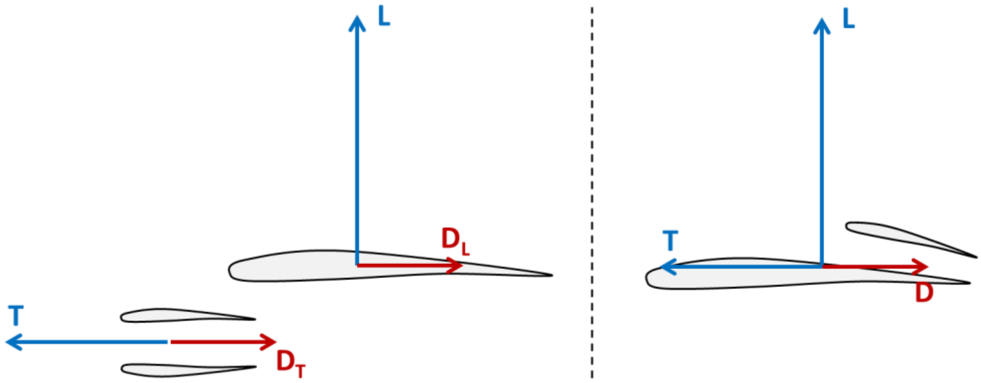

Figure 1: Traditional segregated generation of forces through separate employment of potential effect and active energy addition to the flow (left) and innovative synergetic approach where the two phenomena are functionally correlated (right).

PROBLEM AT HAND:

If we want to undertake design, optimisation and analysis of aerofoils (and later transpose these to 3D solutions) for exploring this new aeroplane concept space, the problem at hand becomes much more complicated than what it used to be: the aerofoil under consideration is no longer a simple geometry exposed to a free stream, but it must also intrinsically contain discrete energy source(s) somewhere inside the flow to emulate a propulsive element that works in unison with the airframe. This means that a traditional clean aerofoil would represent a special case of this element, so we are looking at a prospect of **generalising the theoretical aerofoil descriptions to enable design of aero-propulsive concepts**.

[1] https://www1.grc.nasa.gov/aeronautics/bli/

OBJECTIVES:

To the knowledge of the tutors, the work will provide a first step in this theoretical exploration. The preliminary detailed literature review will enable further insights. Nevertheless, the first objectives can be defined at this point:

- Extend the basic traditional aerofoil theoretical analysis methods (stream function, velocity potential, etc.) for including the discrete energy addition to the flow, and define an "aero-propulsive" element characterised not only by C_L, C_D and C_M, but also by a C_T (thrust coefficient);
- The work can be initiated with manipulation of the elementary flows (uniform, source, sink, doublet, vortex, etc. see Fig.2) in order to construct a first fundamental aero-propulsive element and use this as baseline for further work.

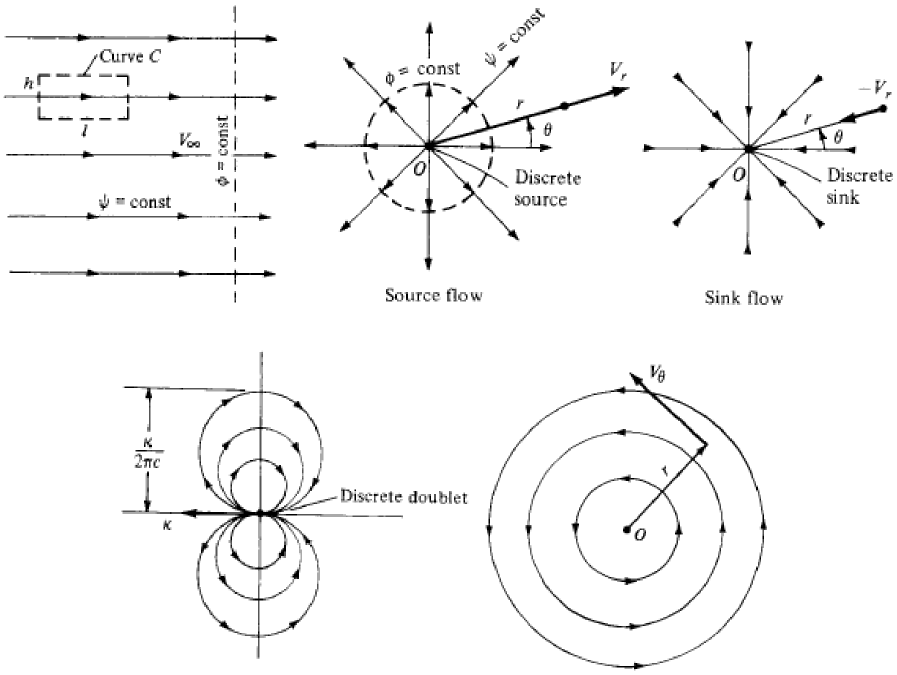

Figure 2: Stream functions of 'elementary flows' – uniform, source, sink, doublet, vortex.[2]

Depending on the progress of the project, the following actions can be envisioned:

- Thin aerofoil extension with uniform flow source additions,
- Vortex sheet extension, lifting line theory extension, and so on…

The idea is to construct theoretical framework for basic prediction of performance characteristics like lift, drag and propulsive force, for dealing with stagnation point problems when the clean aerofoil description is complemented with an *active* sub-element and the flow field at hand becomes non-conservative. It is equally possible that the formalism not be based on force breakdown (i.e. lift and drag); e.g. formalism based on exergy analysis is gaining more attention from the community[3]. Whatever the formalism adopted at the end of the project – the goal is to have an element for flow

[2] From Anderson, J., 1984, *Fundamentals of Aerodynamics*.
[3] See the following PhD dissertation for more details: https://hal.archives-ouvertes.fr/tel-01113135/document

analysis and configuration definition which is not characterised by purely "aerodynamic" effect (force) as it has been the case so far, but by an "aero-propulsive" effect.

Such low order theoretical methods will be directly applicable to early preliminary sizing of aeroplanes with strong structural and functional integration between the airframe and the propulsive system. While extensive efforts have been dedicated in recent years at DAEP to understand this disciplinary coupling by used of various CFD models (see Fig.3 for an example of explored aeroplane configuration), this type of modelling is too resource costly to be extensively employed in preliminary explorations of aeroplane design space. On the other hand, expertise and results gathered throughout these CFD campaigns can be put to use by the candidates working on this research project to guide the intuition and decision making.

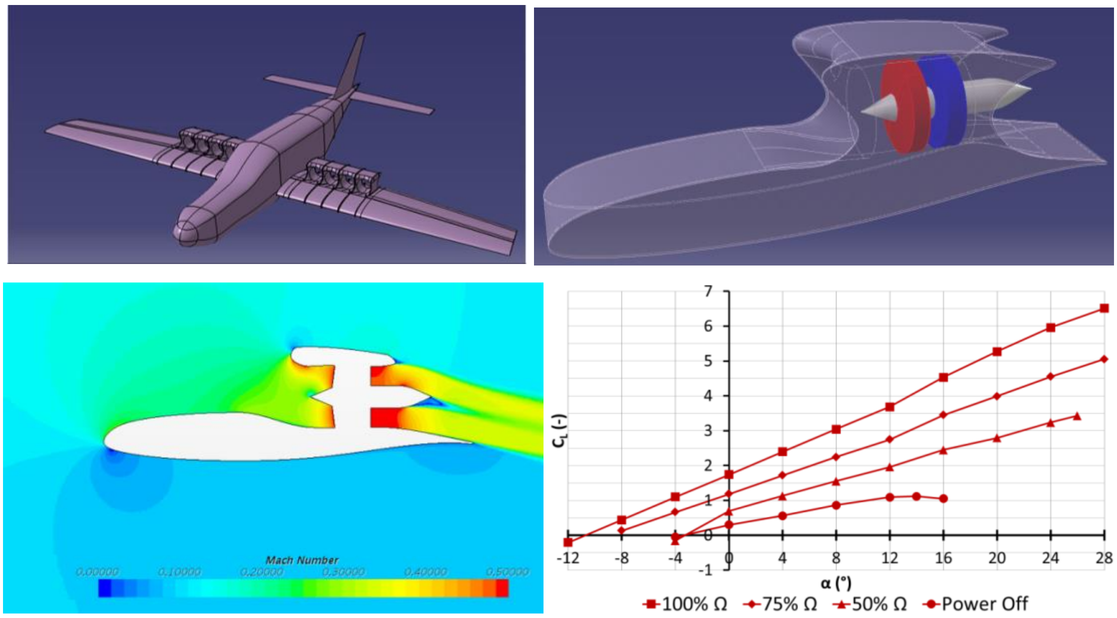

Figure 3: Example aeroplane concept with innovative propulsive system (hybrid-electric distributed propulsion) and the constituent aero-propulsive assembly explored at DAEP through extensive CFD campaigns.[4]

REQUIRED SKILLS:

Theoretical knowledge: strong background and interest in fundamental aerodynamics and mathematical analysis.

Technical and personal skills: coding, preferably in Python; research-oriented candidate profile.

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[4] Benichou, E. et al, 2019, *Numerical Low-Fidelity Method for Improved Analysis of Breakthrough Aero-Propulsive Systems*, AEC_2020_484