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Distributed Electric Propulsion : a Technology requiring Multi-Disciplinary Aircraft Design

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Benefits of Distributed Electric Propulsion

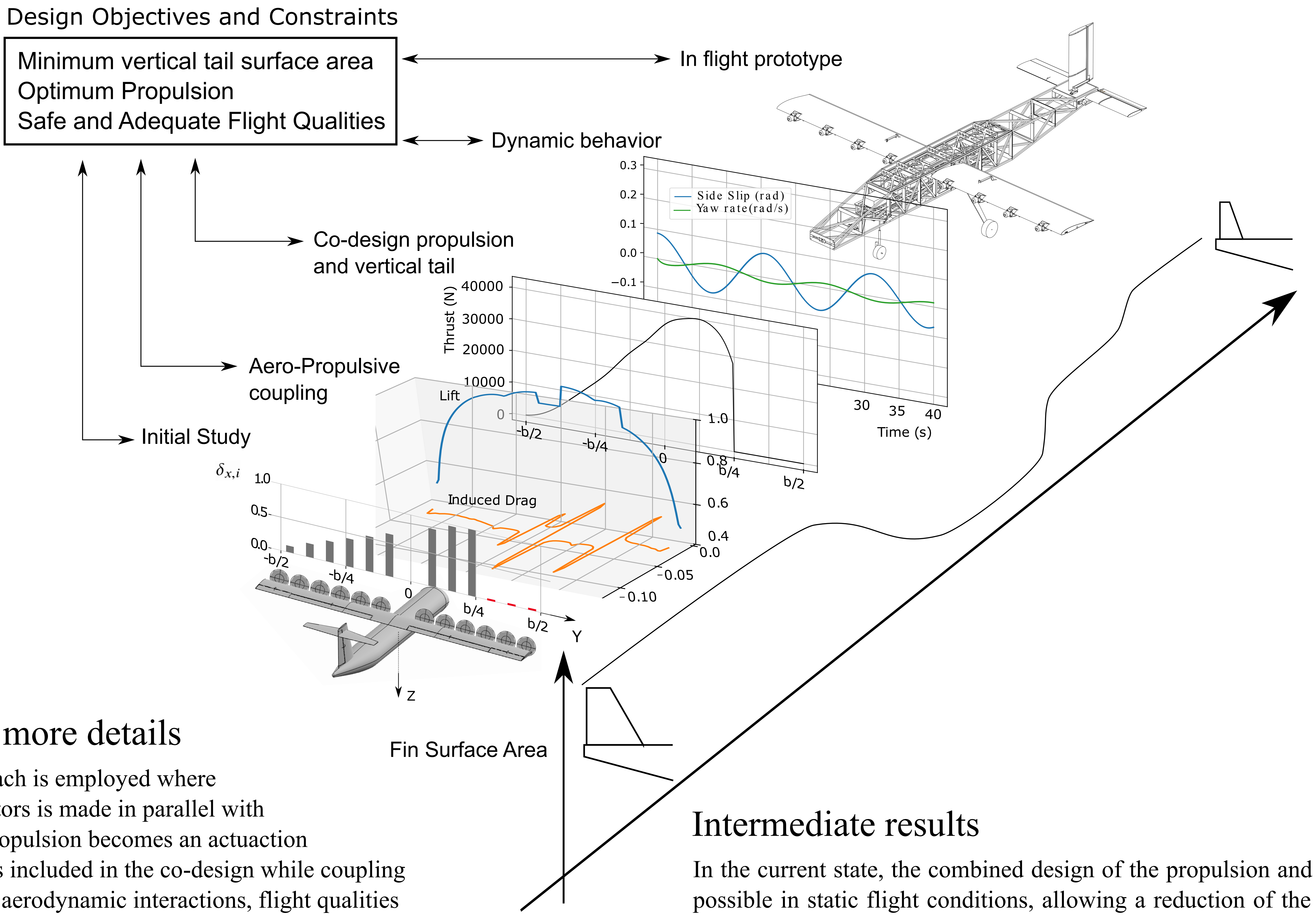
Distributed electric propulsion offers opportunities to enhance aircraft performances through three main leverages: wing blowing to increase maximum lift [1], boundary layer ingestion to lower parasitic drag [2] and additional directional control authority [3]. Using one of these means often implies that the propulsion is distributed on the wing. Therefore the structural design can also be positively impacted by relieving the bending stress[4].

Reason for a different approach

The exploitation of one of the previously mentioned benefits results in the coupling of two or more disciplines. Because the optimum of each discipline often does not correspond to the optimum of the coupled disciplines, design tools or methodologies such as cascade design and statistic models can become inefficient for the sizing of a non traditional aircraft. Rather, multi-disciplinary optimisation technics appear as a toolbox for the designer to explore a possibly large solution space emerging from the coupling of multiple disciplines.

Case study : Vertical Tail Reduction using Differential Thrust

At ISAE-SUPAERO and ONERA, design of distributed electric aircraft is tackled in researches focusing on the use of differential thrust to increase directional control authority [3][6]. In this study three types of coupling appear; 1. The size of the vertical tail depending on flight safety rules in case of engine failure, 2. The dual function of propulsion, generation of forward thrust and yaw moment, 3. The aerodynamic interaction between propeller slipstream and wing.



Design Objectives and Constraints

Minimum vertical tail surface area
Optimum Propulsion
Safe and Adequate Flight Qualities

In flight prototype

Dynamic behavior

Co-design propulsion
and vertical tail

Aero-Propulsive
coupling

Initial Study

Fin Surface Area

Approach in more details

A co-design approach is employed where the design of effectors is made in parallel with control laws. As propulsion becomes an actuaction system, its sizing is included in the co-design while coupling disciplines such as aerodynamic interactions, flight qualities (climb rate, cruise velocity,...) and safety rules bring either physical complexity or design constraints.

Flight safety is evaluated by studying equilibrium and gradually integrating additional physical complexities, captured by analytic or semi-empirical models. This allows the deduction of new design constraints to comply with high level safety objectives of aircraft regulation.

Flight qualities are ensured using robust control approach in which the surface area of the vertical tail is an uncertain parameter to minimize similarly as [7]. Remains the sizing and placement of the propulsion system that is treated as a continuous function rather than force points.

Intermediate results

In the current state, the combined design of the propulsion and the vertical tail is possible in static flight conditions, allowing a reduction of the vertical tail of up to 30% [3-5]. The co-design of control law and vertical tail surface area with a fix number of engine allows a reduction of up to 40% at low velocity while ensuring flight qualities.

Concluding remarques

This study is an example of use of a multi-disciplinary approach as a solution to manage the important couplings and physical complexity accompanying the design of distributed electric propulsion aircraft. The focus is on the co-design of control laws and effectors where preliminary results encourage the reduction of stability surfaces while assuring similar flight qualities and safety.

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