# Numerical and experimental studies on BLI propulsor architectures

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**Keywords:** Boundary Layer Ingestion, Jet Propulsion, Aerodynamics, Optimization, Computational Fluid Dynamics

**Abstract.** An increasing awareness about the impact of civil air transportation emissions is currently driving a low-carbon technology transition, towards more sustainable propulsion strategies. Boundary layer ingesting systems are one of the most promising solutions, as a closer integration between fuselage and propulsors is considered a key in the achievement of more sustainable architectures. Such architecture is characterized by a high level of integration between the airframe and propulsors, making the design process become a major challenge. The present work deals with a complete CFD based design and optimization of a propulsive fuselage concept, both in terms of airframe shape and fan design.

## Introduction

The present work deals with the activities carried out in the Clean Sky 2 project SUBLIME. The aim of this project was to advance the state of art in BLI studies by means of wind tunnel activities supported by high fidelity CFD simulations to consistently predict the behavior of BLI architectures that minimize inlet flow distortion and maximize the power saving. The design activity has been separately carried out for the wind tunnel test model (WTT) – subjected to geometrical constraints – and an unconstrained full scale (FS) model, using for both cases a momentum-based approach for the definition of a proper performance metric, a surrogate of the propulsive power defined starting from the aircraft net assembly force (NAF): starting from the Net Assembly Force, a surrogate of the net propulsive thrust is introduced by subtracting to the NAF a reference airframe drag:

$$\Delta NAF = NAF - D_{ref} \tag{1}$$

ΔNAF takes into account the installation effects of the BLI nacelle and the variations in the fuselage shape with reference to a non-BLI configuration. The surrogate of the propulsive efficiency is then defined as:

$$\eta_{\Delta NAF} = \frac{-\Delta NAF\ V_{\infty}}{W_{fan}} \tag{2}$$

This performance metric has been used during the CFD-based design optimization of the propulsors. For both the WTT and the FS cases, a sequential approach has been followed : (a) geometric parametrization of the propulsor and its connection to the airframe ; (b) design space investigation aimed at determining the most influential design variables and the research space ; (c) shape optimization carried out using GeDEA-II[2-8], a proprietary genetic algorithm. A CFD approach has been considered at each step for the BLI propulsor performance evaluation.

## BLI360 Design Optimization

The BLI360 design has been carried out for both the WTT and FS cases. In particular, the WTT configuration was subject to a high degree of geometrical constraints, thus reducing the design variables space and therefore limiting the optimization process. As stated in the previous section, the design process followed a similar approach for each case, starting with a 2D axisymmetric design space investigation. The results of the WTT design space investigation suggested that geometries with low hub radii and short nacelles feature higher values of the ΔNAF efficiency. Furthermore, this metric has a maximum for a certain range of fan pressure ratio, between 1.3 and 1.5, as seen in Fig. 1. The FS Design of Experiments led to an analogue result.

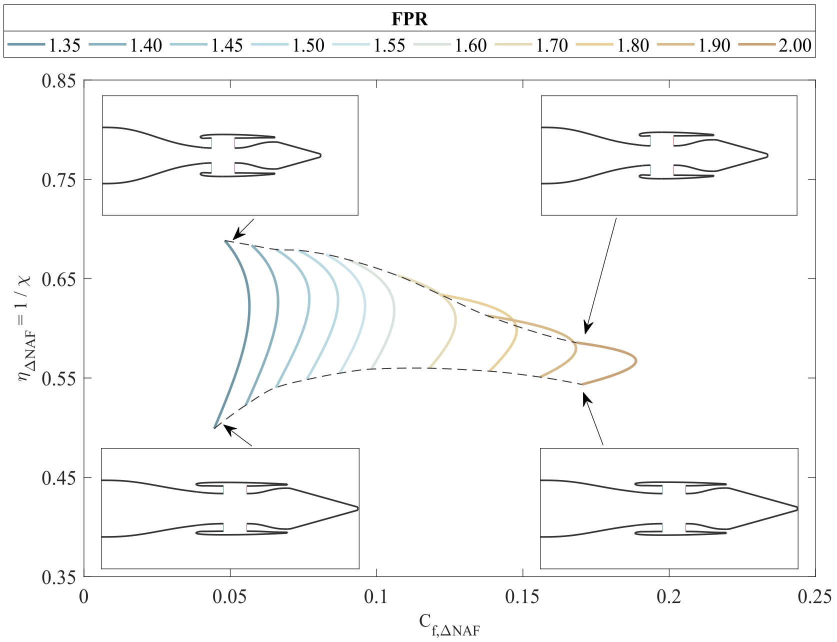

*Figure 1: WTT design space investigation results.*

A 2D optimization has been conducted to obtain a starting geometry for the 3D design. The objective was the maximization of the ΔNAF efficiency for an arbitrary set of NAF values. The three-dimensional design has therefore been set up by considering three different azimuth profiles of the propulsor: such profiles have been parametrized in terms of highlight height and axial displacement of the cowl maximum radius point (points “A”). Furthermore, interpolation laws between the highlight points and the points “A” of each profile have been defined. Given the high set of constraints of the WTT model, a design space investigation between the design variables defining the interpolation laws and profiles shapes has been conducted, leading to a population of individual with slight variations in terms of performance. Being the FS model geometrically unconstrained, an optimization has been produced. Fig. 2 shows the optimization results in the objectives space. The lack of a Pareto front has been justified by having fixed the fan pressure ratio and the nozzle contraction ratio to the 2D optimum values. The previous design space investigations suggested that these parameters were the main performance drivers. Therefore, any increase in the efficiency is due to a decrease in the drag-components of the axial force.

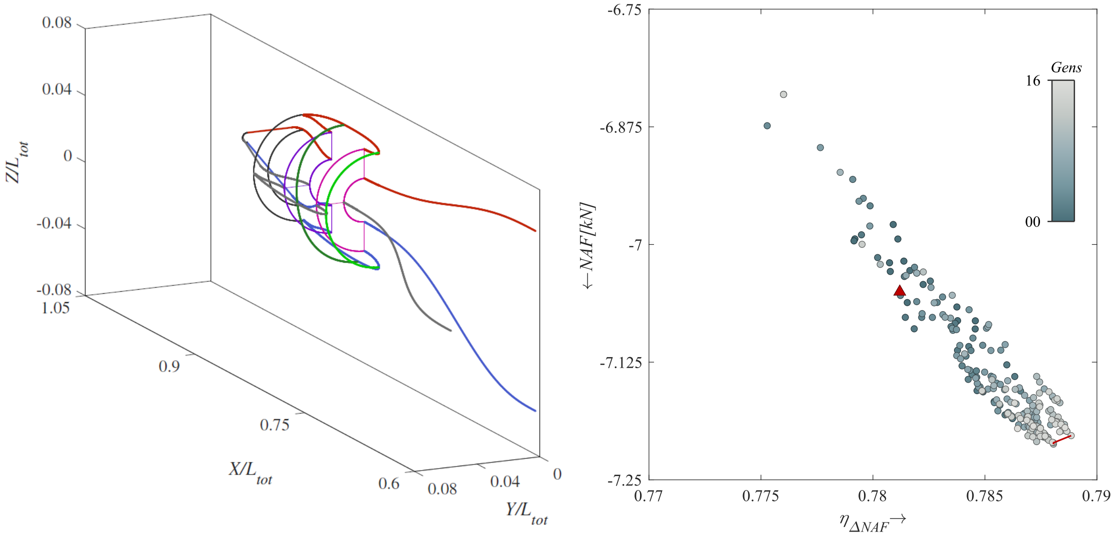

*Figure 2: BLI360 FS Model Parametrization and Optimization Results.*

## SUBLIME Experimental campaigns

The SUBLIME project involved two wind tunnel test campaigns. The first was un-powered where three main configurations were tested which included a reference (without a propulsor), BLI360 and BLI180 boundary layer ingesting propulsor configurations which included exhaust plug changes for intake mass flow variation. The second test campaign concerned only the BLI360 configuration but the nacelle pressurized with an ejector system to simulate the exhaust flow. The test campaigns were carried out in the 9'x8' ARA Transonic wind tunnel at Mach = 0.2 to 0.8 with variation in α and β. Figure 3 shows the model in the wind tunnel & with center cover removed showing the high pressure air manifold for the ejector.

The model instrumentation included a rear fuselage balance, fuselage static pressures and provision for boundary layer rakes. The configurations with propulsors were equipped with AIP rakes for assessment of intake mass flow & distortion characteristics. The wake of the model was measured via a motorized traversing rake system mounted between the support booms to provide high-resolution wake plane data for all configurations.

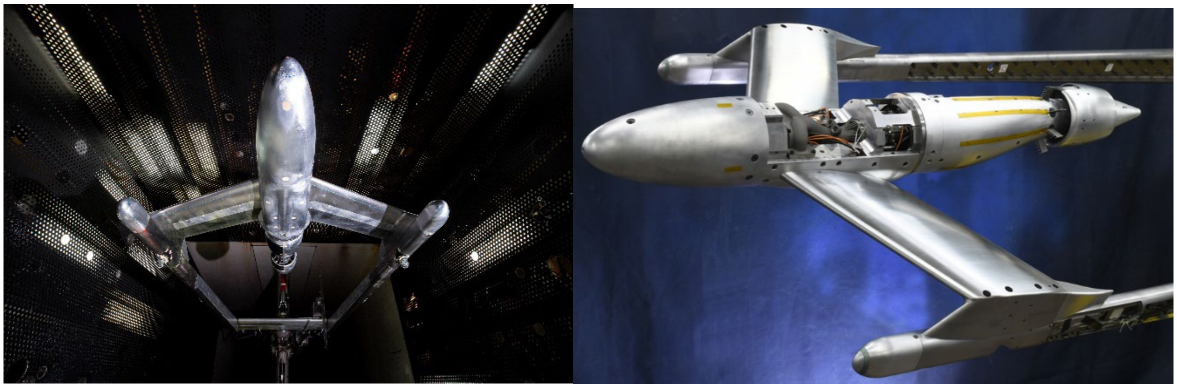

*Figure 3: SUBLIME BLI360 configuration in wind tunnel*

## Acknowledgments

This study is financed by the Clean Sky 2 project SUBLIME (Supporting Understanding of Boundary Layer Ingestion Model Experiment). The project has received funding from the

European Union’s Horizon 2020 research and innovation program under grant agreement number 864803.

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