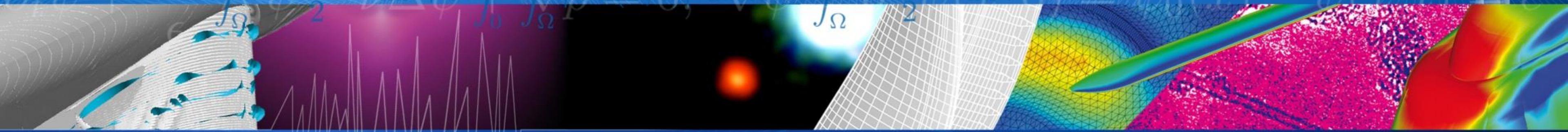

Innovative Engine Integration Solutions for Transport Aircraft : Current Research and Future Challenges

EUCASS 2017, Milano, 6 July 2017

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*With contributions of : O. Atinault, R. Grenon, L. Wiart, J.-L. Godard, M. Méheut, B. Ortun, J. Hermetz**

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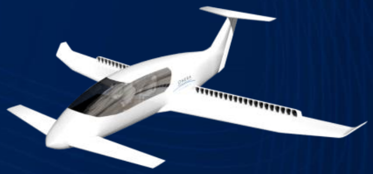

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Outline

1. Introduction

   Context, why new engine integration concepts?

2. Boundary Layer Ingestion

3. Towards Distributed Hybrid Electric Propulsion

4. Conclusions

Introduction (1)

- Evolution of major transport aircraft products:

  - No revolution in aircraft architecture!
  - More a continous evolution through incremental improvements and optimisation of components with frozen architecture:
    - tube-and-wing architecture,
    - under-wing mounted engines (>100 pax),
    - from 4-engines to 2-engines

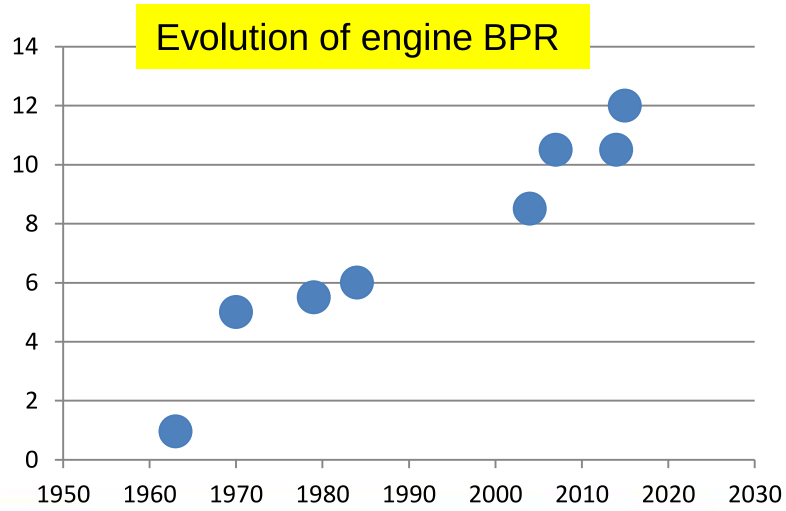
- Advantages of under-wing, podded engines architectures:
  - Engine ingesting unperturbed flow (better from the engine perspective)
  - Clear separation between engine and airframe:
    - Independent design & manufacturing
    - Clear industrial breakdown, responsibilities between engine and airframe manufacturers

Introduction (2)

- Overall A/C performance (Breguet-Leduc) formula :

$$Range = c.\boxed{M\frac{L}{D}}\boxed{\frac{1}{g.TSFC}}\boxed{\ln\left(\frac{W_{empty}+W_{fuel}}{W_{empty}}\right)}$$

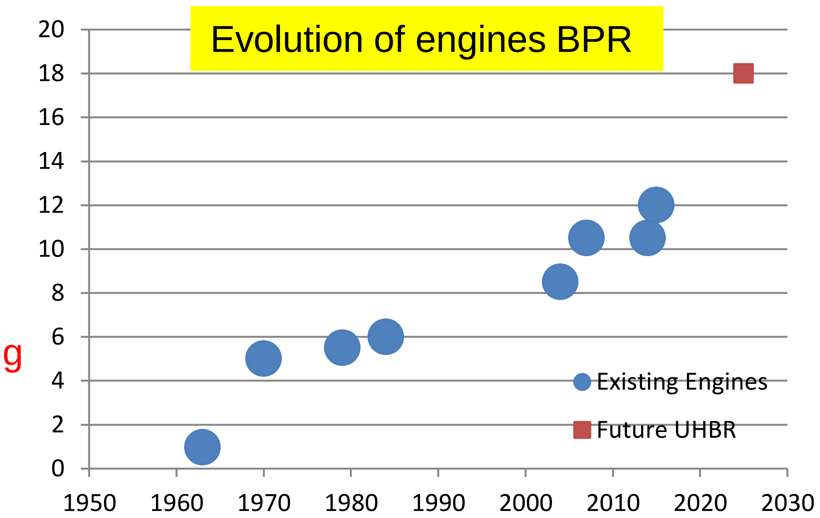
- Major trends (from an aircraft architecture point of view) :
  - Better aerodynamics (L/D): higher wing aspect ratio, winglet, …
  - Better engines (TSFC): higher bypass ratio (bigger engine), thermodynamic cycle,…
  - Lighter structures (W_{TO}/W_{empty})



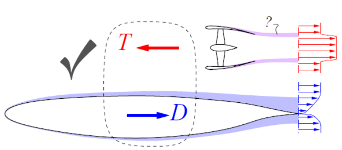
Introduction (3)

Why investigating new engine integration solutions?

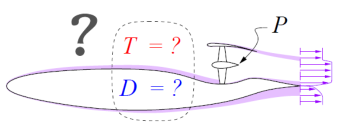
1. Limits of under-wing, podded engines architectures:
   - Current BPR of 10-12
   - Envisaged UHBR of 15-20 for N+1 A/C generation
   - Integrating such big engines under the wing raises intricate issues:
     - Longer landing gear needed
     - Stronger engine-airframe aerodynamics coupling
     - Nacelle weight/drag



2. Maximising overall aero-propulsive efficiency of the aircraft+engine as a whole can push us away from podded engine architectures



(Drela, 2009)



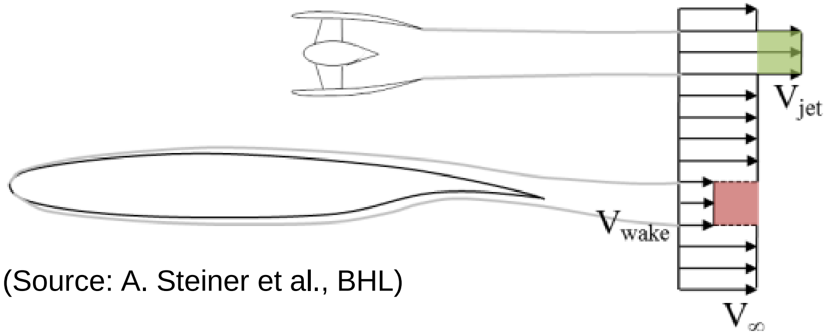
$$Range = c\,\boxed{M\,\frac{L}{D}\,\frac{1}{g.TSFC}}\,\ln\left(\frac{W_{empty}+W_{fuel}}{W_{empty}}\right)$$

Outline

Basic principles/physics of Boundary Layer Ingestion gains

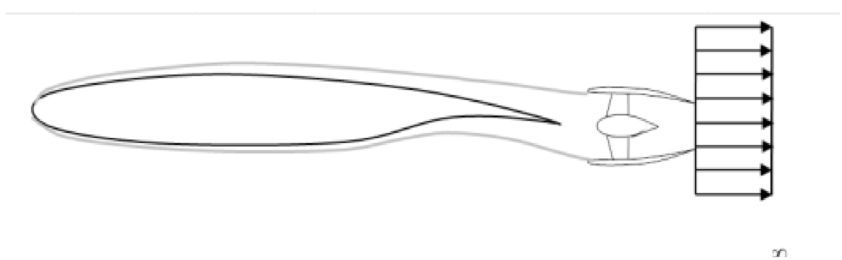
- How can we expect to gain with BLI :

Non-BLI



(Source: A. Steiner et al., BHL)

BLI



- For the same net longitudinal force («thrust=drag»)
- Less mechanical power is required in the case of BLI to produce the same thrust (ΔV) :
  - the fan accelerates a slower flow ($V_0^{BLI} < V_0^{non-BLI}$) and power scale as V_0^2

Experimental BLI investigation in ONERA-L1 WT

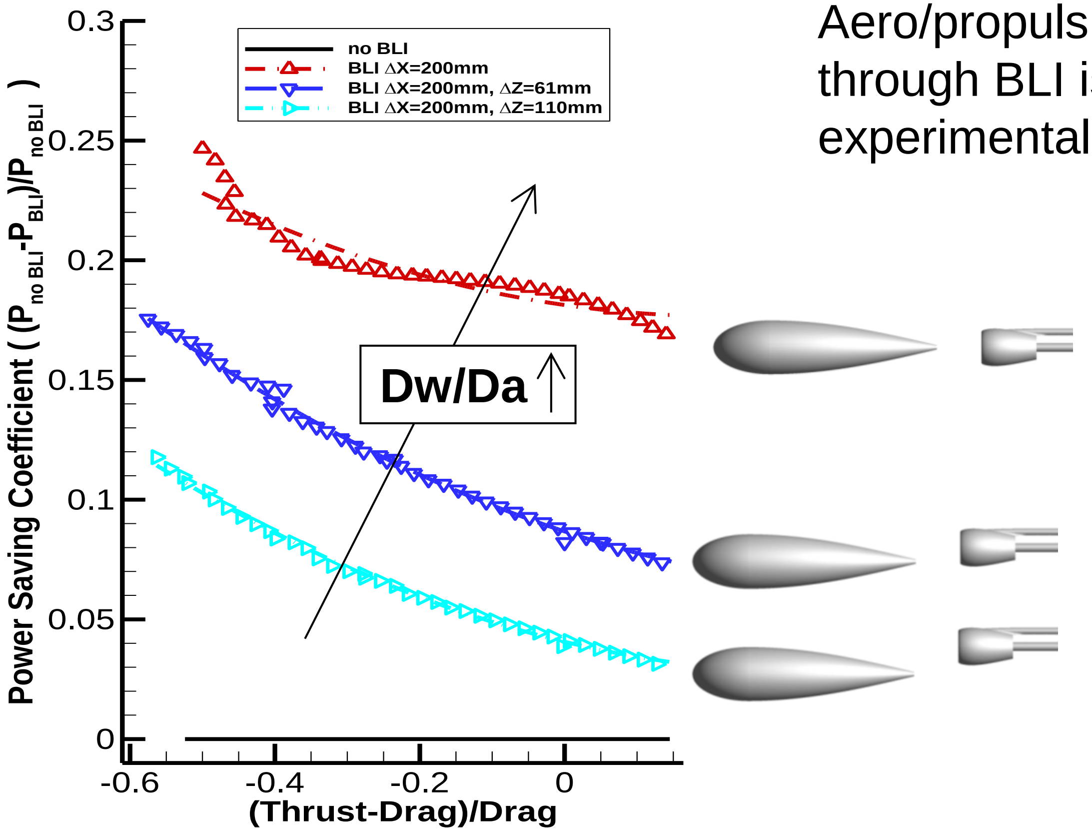
- Objectives of the RAPRO2 L1-WT tests:
  - to acquire accurate and detailed aerodynamic data for validation of CFD-based BLI evaluation methodology
  - to confirm BLI concept potential (Mach 0.2)

RAPRO2 test in ONERA L1 WT (Mach 0.2)

Electric powered nacelle (Schübeler EDF)

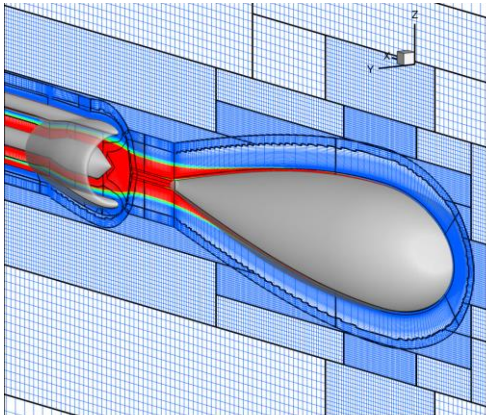
Experimental BLI investigation in ONERA-L1 WT

Analysis of the BLI efficiency: $PSC = \frac{P_{non\ BLI} - P_{BLI}}{P_{non\ BLI}}$ as a function of net axial force

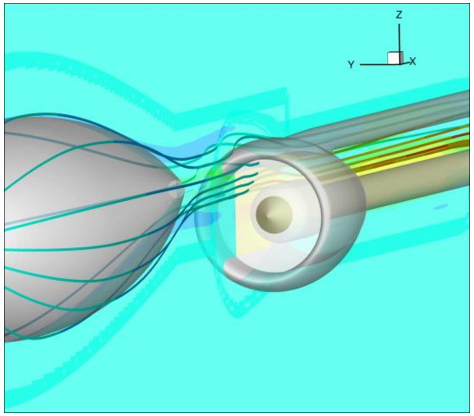


Aero/propulsive efficiency improvement through BLI is confirmed experimentally @ M 0.2 : ~ 20% (D_W/D_A =1)

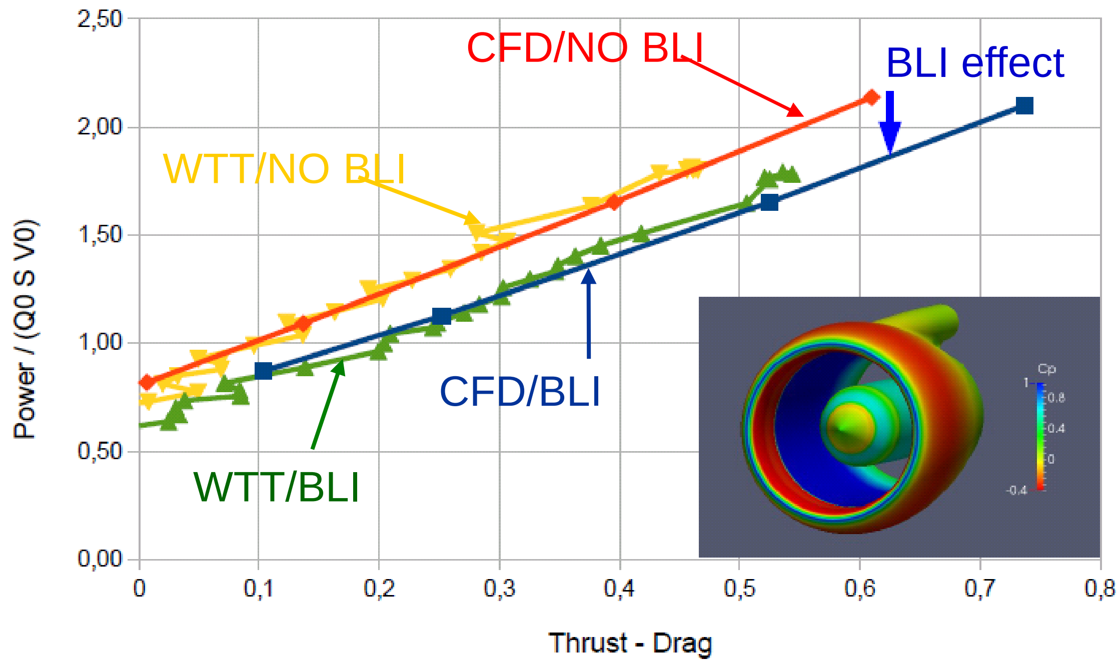
Validation of numerical methods for BLI investigations



Use of overset and Cartesian grids techniques (elsA)



CFD simulation of the powered nacelle using Actuator Disk (elsA)



- Importance of CFD-based simulation for the design of efficient BLI aircraft
- Require careful validations of the capability of CFD-based process to capture all the flow physics involved by BLI:
  - BL development and wake advection
  - Fan/BL interaction

Development of NOVA Aircraft Configurations for Large Engine Integration Studies

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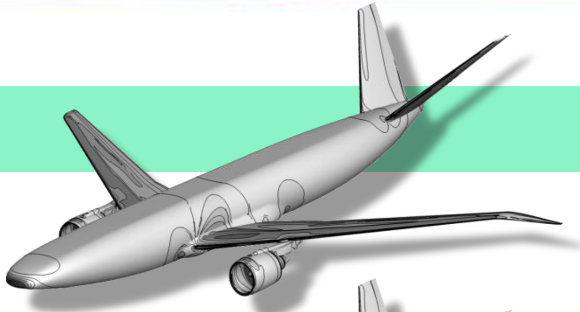
return on innovation

NOVA
Targeted architectures for UHBR

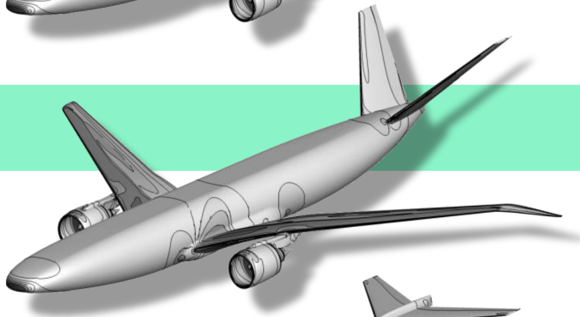
✓Baseline

- ✓ UHBR engine
- ✓ Wide lifting fuselage
- ✓ High AR wing
- ✓ Downward oriented winglets



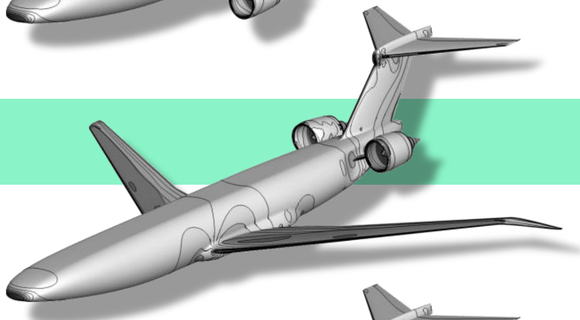
✓Gull wing

- ✓ Increased inner wing dihedral to limit landing gear length



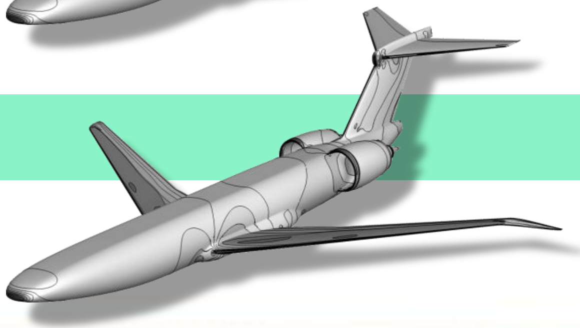
✓Podded

- ✓ Engines mounted on aft fuselage side



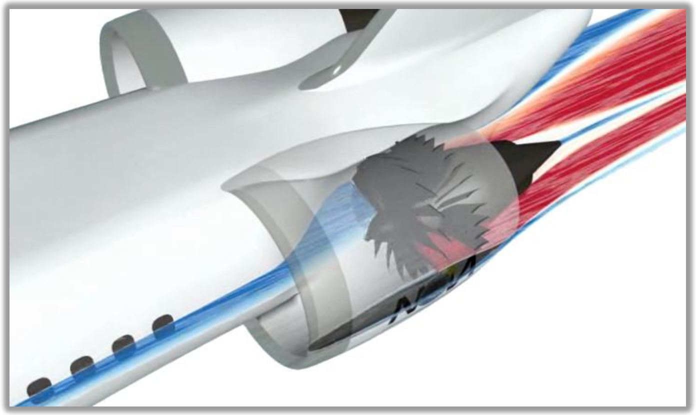
✓BLI

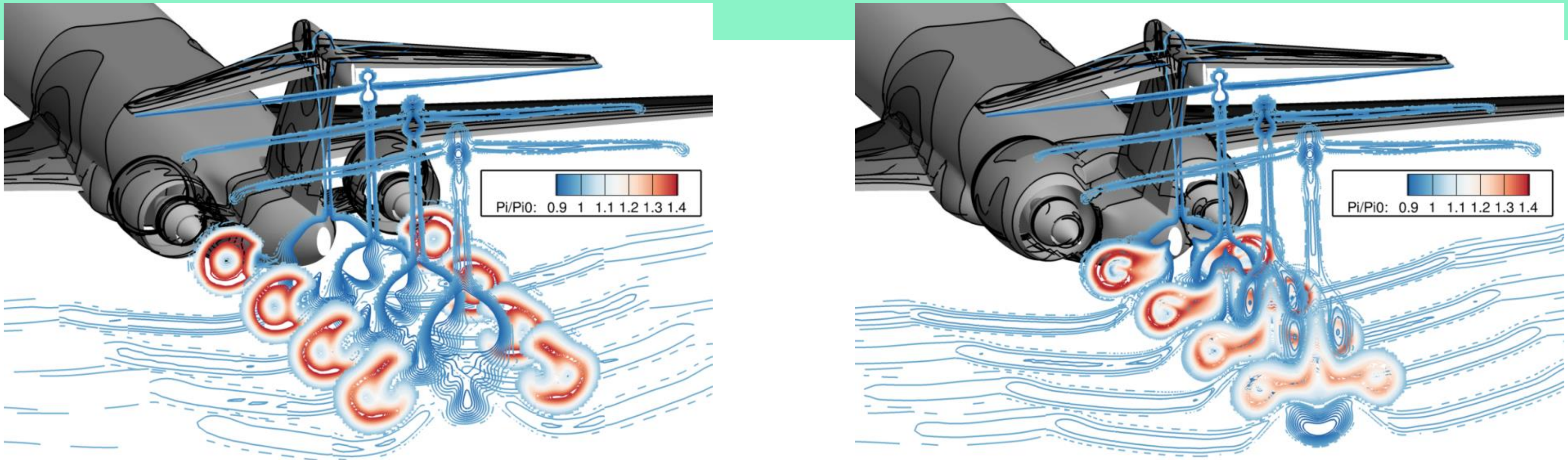
- ✓ Engine inlet ingesting the fuselage boundary layer



NOVA
BLI configuration

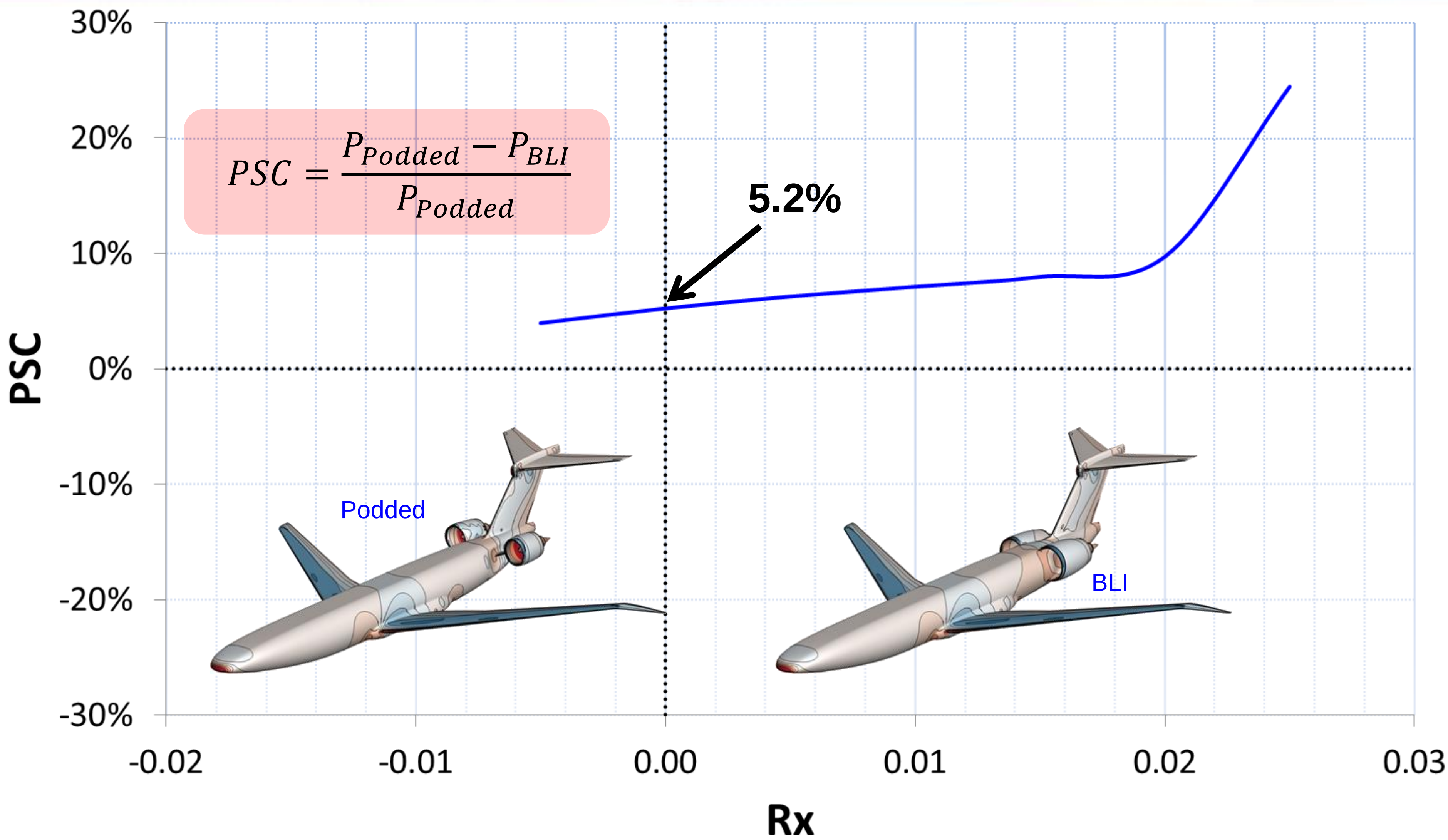
- ✓ By embedding the engine into the fuselage, savings in fuel (due to reduced wetted area and jet/wake losses) and mass are expected
- ✓ **Deliberately « agressive » design:**
  - ✓ engine~40% burried
  - ✓ short inlet (inlet length/fan diameter ratio~1)





When ingesting the fuselage boundary layer, the engines tend to minimize the aircraft footprint in the surrounding airflow, indicating better thrust-drag balance

NOVA
Power saving VS stream-wise force



$$PSC = \frac{P_{Podded} - P_{BLI}}{P_{Podded}}$$

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1. Introduction
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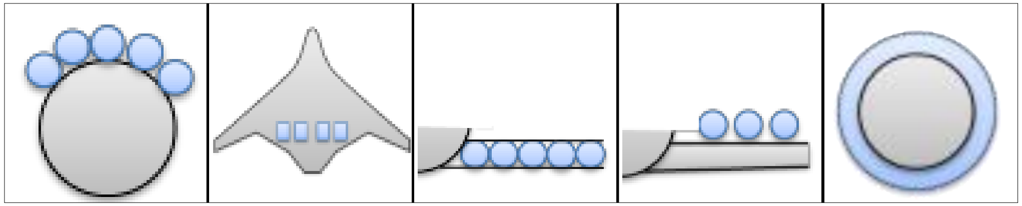
4. Conclusions

BLI →Distributed propulsion →Electric propulsion

- Links between BLI and Distributed Propulsion :
  - Efficiency ↑ with fraction of BL ingested (**D_W/D_A**)
  - Many architectures can be envisaged:



(Source: A. Steiner et al., BHL, ICASE2012)

  - Distributed propulsion has additional advantages:
    - Redundancy/reconfiguration (safety)
    - Use differential thrust for control

- Links between Distributed Propulsion and (Hybrid) Electric:
  - Electric ducted fan is a enabling technology for multifan and “massively” Distributed Propulsion architectures
  - Distributed propulsion calls for <u>separation of thrust and power production functions</u>, making the use of hybrid energy source more natural.

Distributed Electric Propulsion studies

in the AMPERE Project

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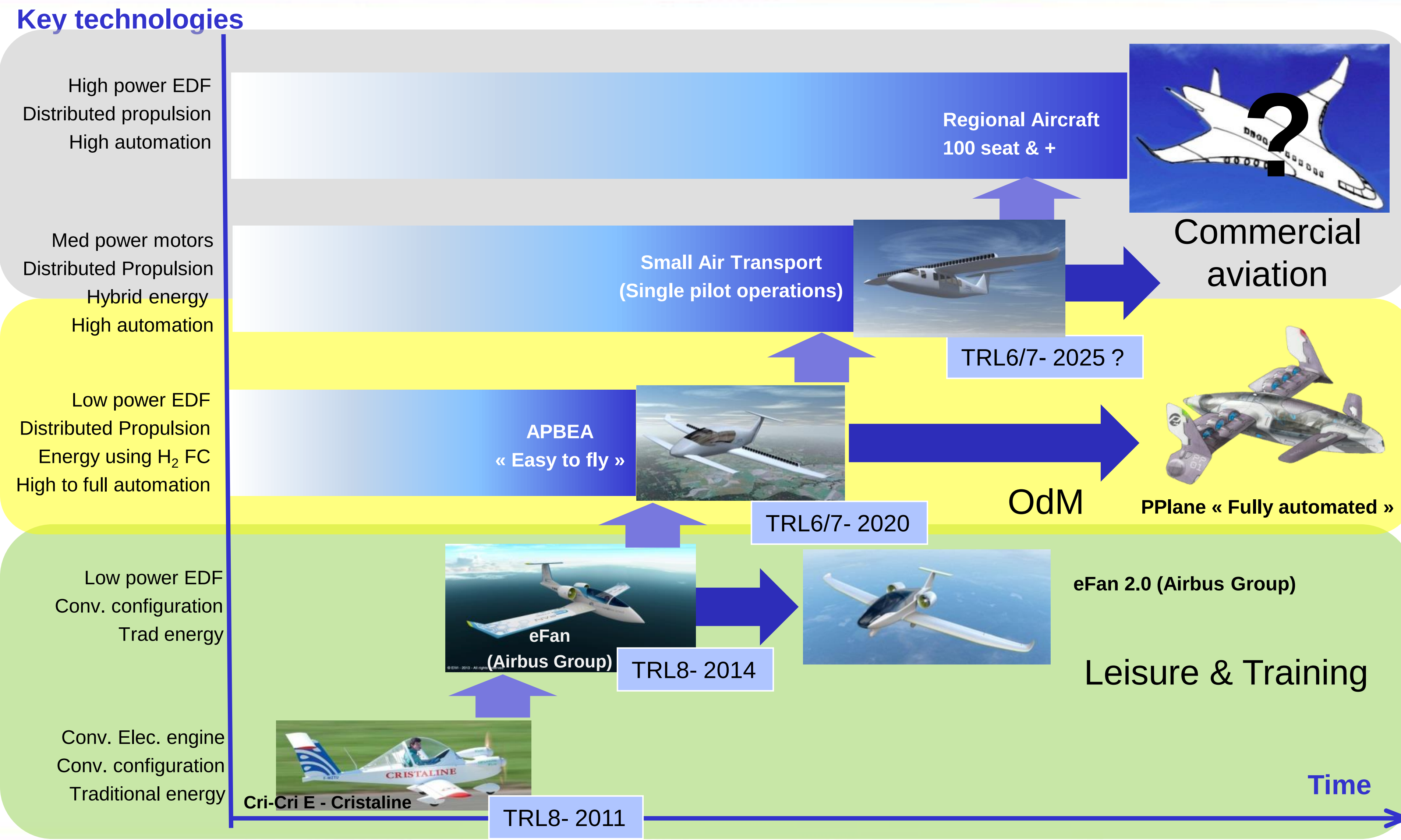
Technologies and associated A/C concepts roadmap



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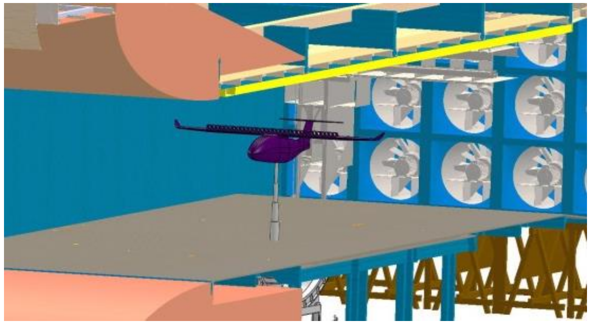
AMPERE
Overview

✓**Objective:** Increase maturity of DEP technology

- ✓ Aerodynamics of Electric Ducted Fan (EDF) integration
- ✓ A/C Control/command through EDF and conventional moving surfaces (considering potential resizing)

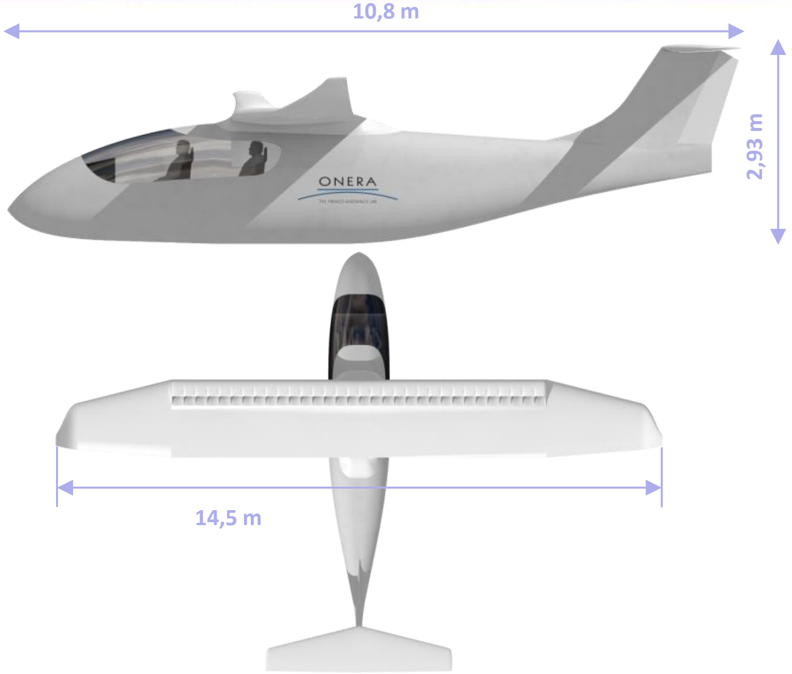
✓***Means:*** Numerical and experimental approaches

- ✓ Aerodynamic design of EDF integration
- ✓ Wind tunnel experiments
  - ✓L2 very low speed WT (Lille, France)
  - ✓Powered 1:5 scale Mock-up with on the shelf components

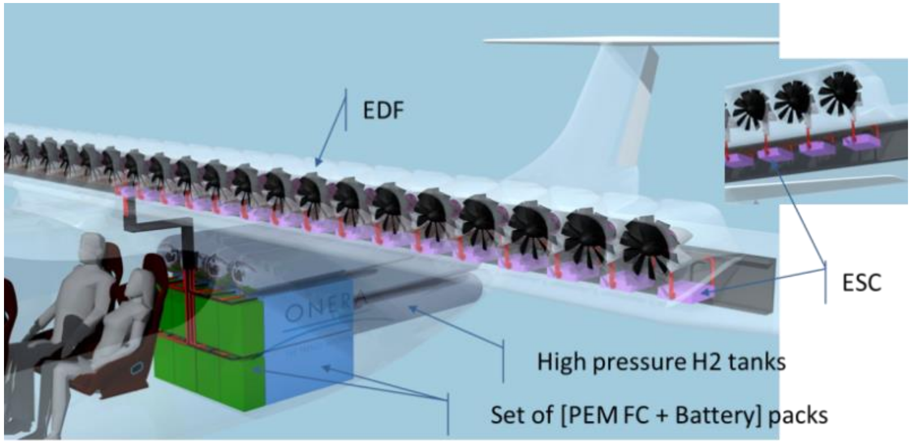


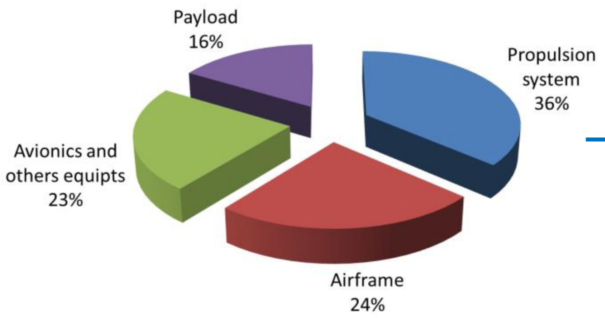
- ✓ Control Law definition using both control surfaces and EDF
- ✓ 6DoF Simulation tool using aerodynamic model and Control law for robustness analysis and demonstration

AMPERE
Aircraft Pre-design

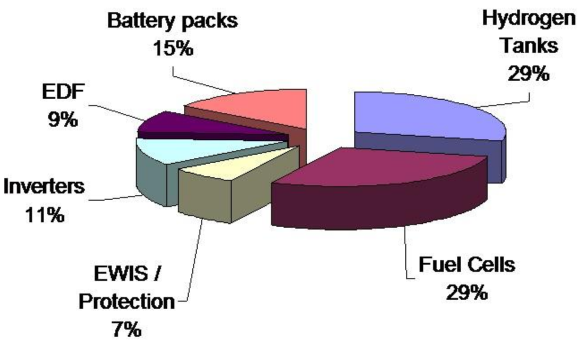


Example of arrangement of electrical propulsion architecture





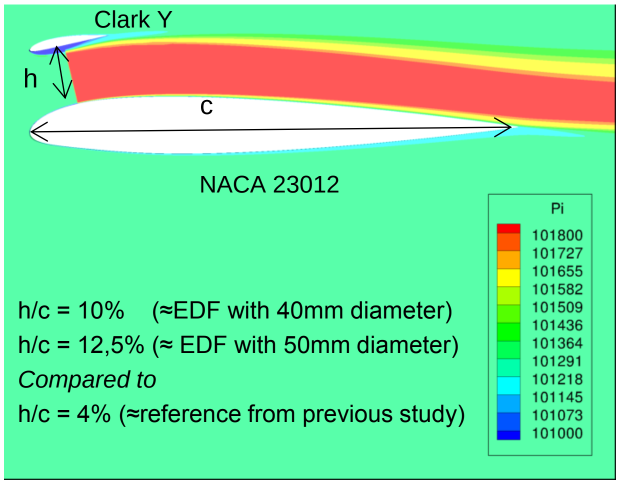
Estimated MTOW ~2400 kg

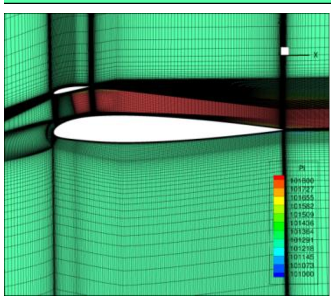


Estimated weight of advanced power architecture (Propulsion) ~890 kg

Numerical investigation of DEP with blowing effect (2D)

Preliminary investigations



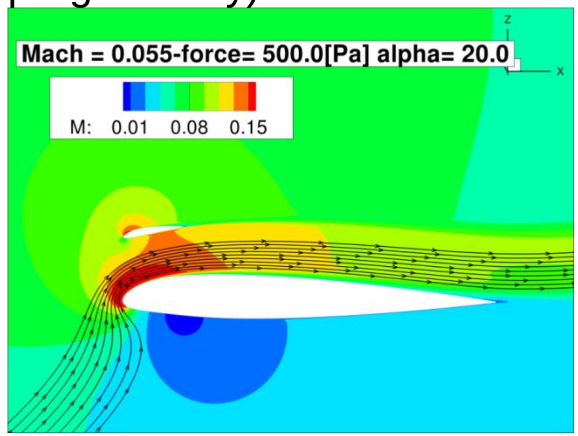


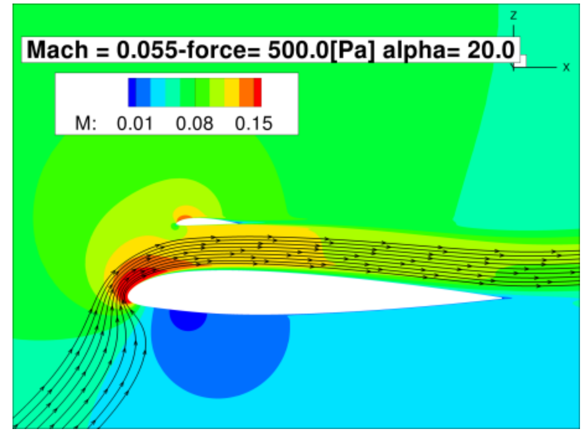
Actuator disk →

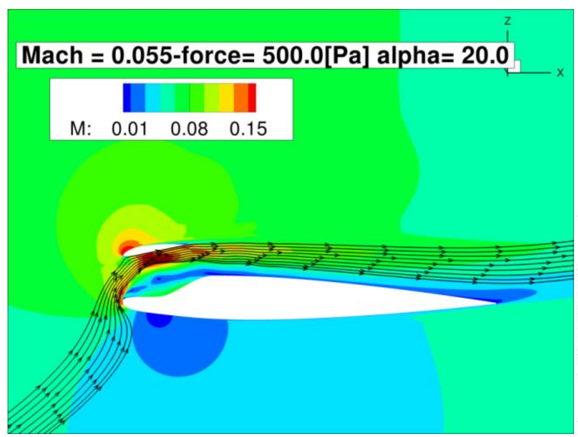
Imposed pressure variation

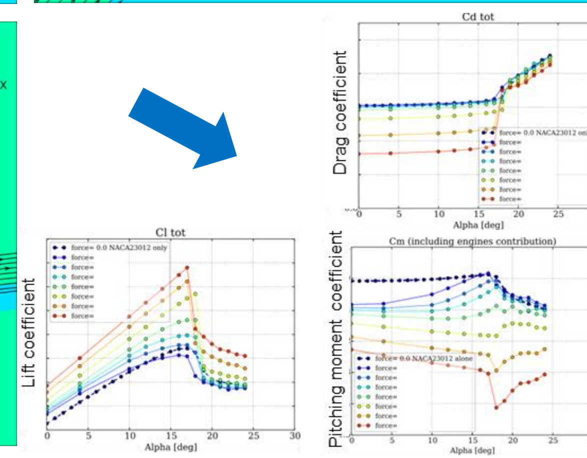
Engine location sensitivity analysis

Selection criteria upon Cz_{max}, stall behavior (stability and progressivity)



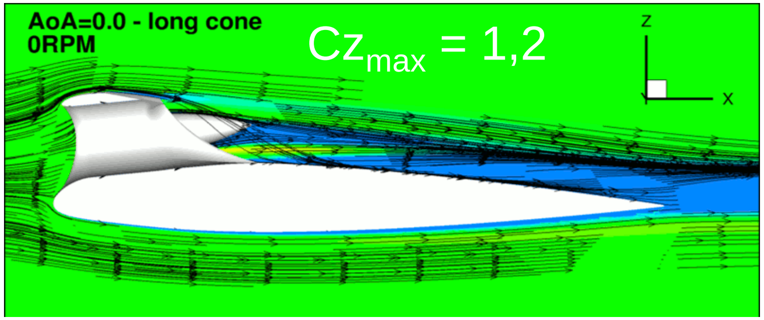


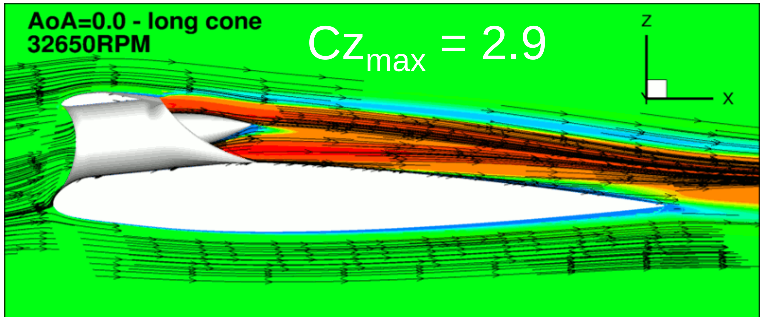


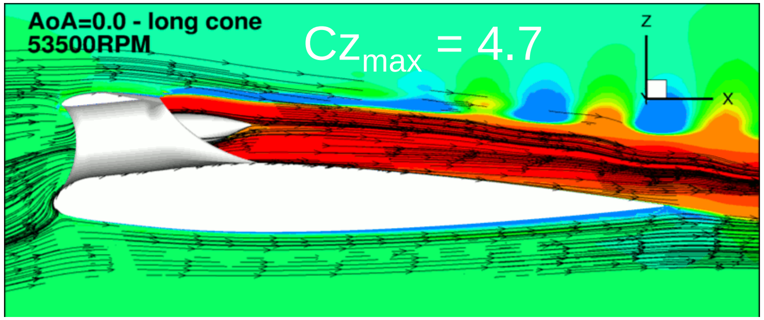


CFD RANS 2D

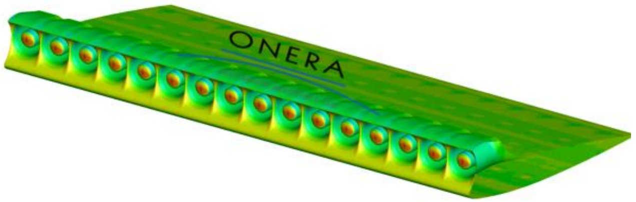
Numerical investigation of DEP with blowing effect (3D)

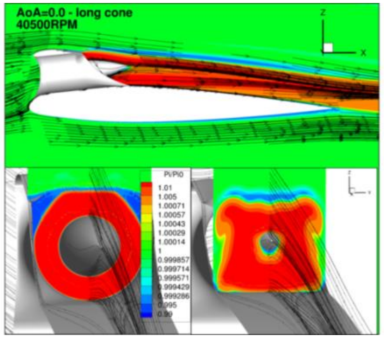






- CFD 3D computations, viscous, stationnary (RANS), on a wing section with 1 EDF (which models a wing with an infinity of EDF)





- Fan modelled by an actuator disk (pressure gap)
- Guide vanes integrated into computations
- 3D effects integrated to handle «squaring the circle» issue (to go from a circle section to an square one)

➡ Cz_{max} in 3D close to 4.7 instead of 5.7 with 2D CFD assessment

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Testing in ONERA L2 WT

- ✓ Tests were ended early 2017
- ✓ Analysis on going

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1. Introduction

   Context; why new engine integration concepts?

2. Boundary Layer Ingestion

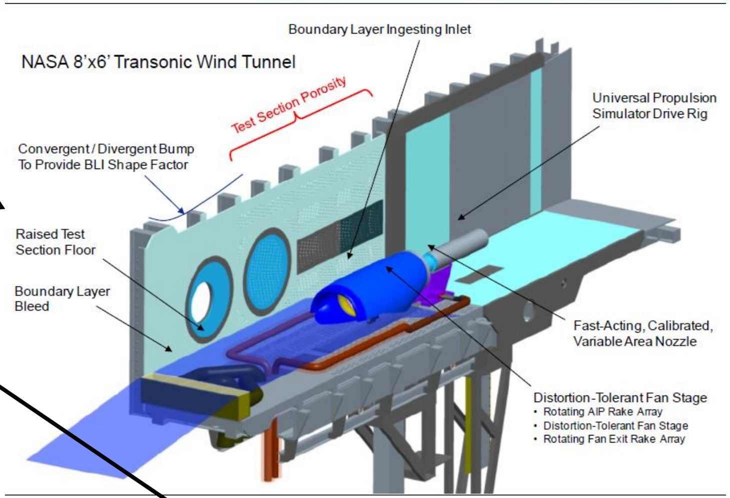
3. Towards Distributed, Hybrid Electric Propulsion

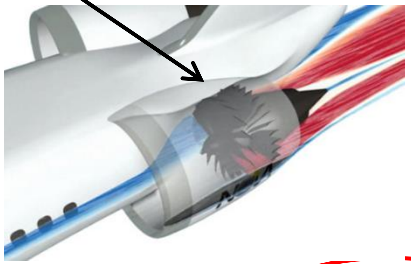
4. Conclusions:

   Future challenges of BLI and DEP

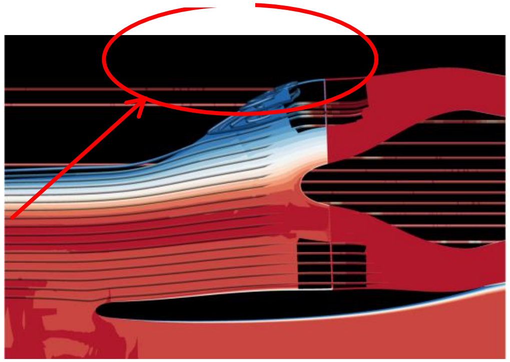
Conclusions:
Main challenges of BLI

- ✓ *Experimental proof of benefits in transonic conditions*
- ✓ *Design fan/OGV tolerant to distortion*
- ✓ *Aero-elastic behaviour of the fan with distortion*
- ✓ *Design air inlet suitable for all operating conditions (Active Flow Control)*
- ✓ *Impact of BLI engine integration architecture on structure and mass*
- ✓ *Aero-acoustic characterisation of BLI configuration*



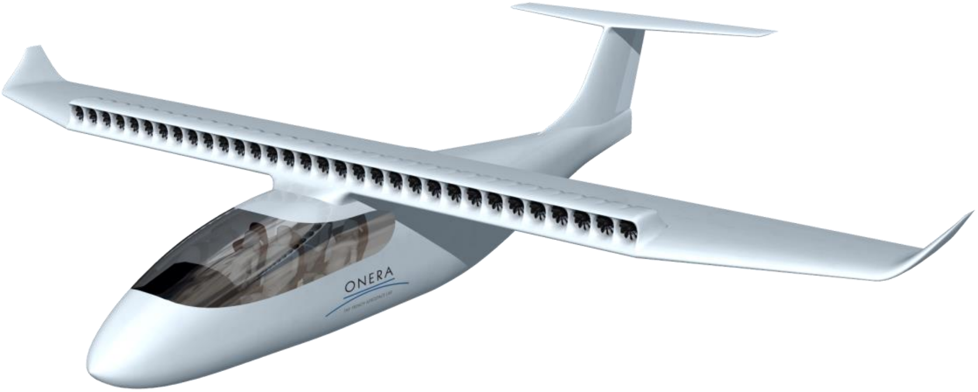


Flow separation with short inlet



Conclusions:
Main challenges of Distributed Propulsion

- ✓*Performance in transonic conditions*
- ✓*Experimental proof of benefits at Low-Speed (Take-off and Landing)*
- ✓*Impact of DP architecture on structure and mass*



- ✓*Engine integration issues*
  - ✓*Thermal aspects for large passenger Aircraft*
  - ✓*Electromagnetic compatibility*

Thanks for your attention.
Any questions?

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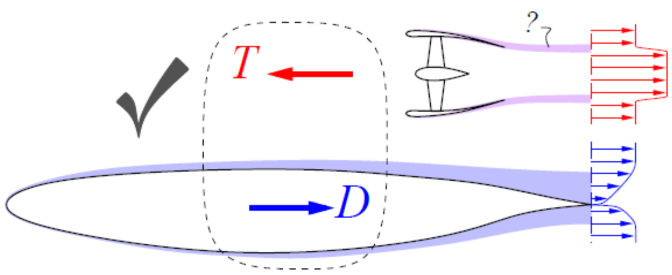
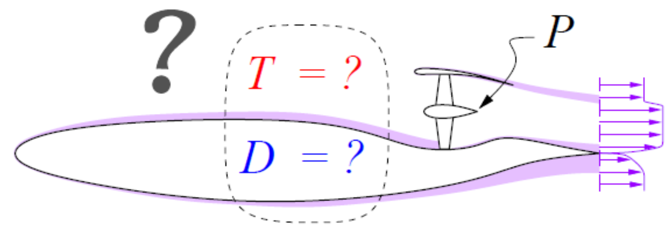
Far-field exergy based breakdown
Rationale

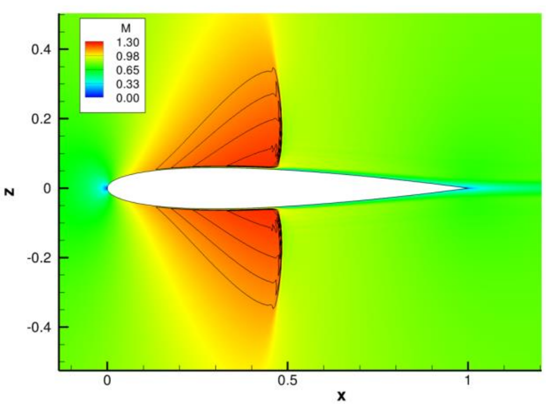
✓ <u>Context</u>

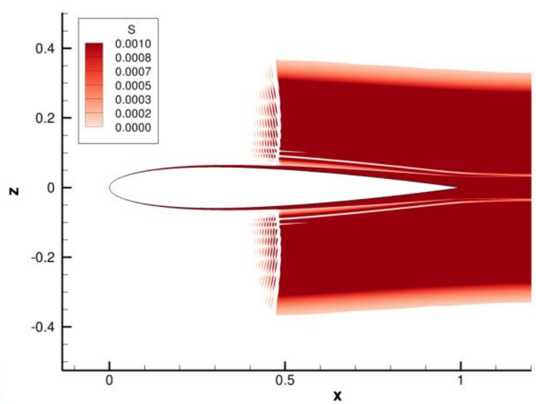


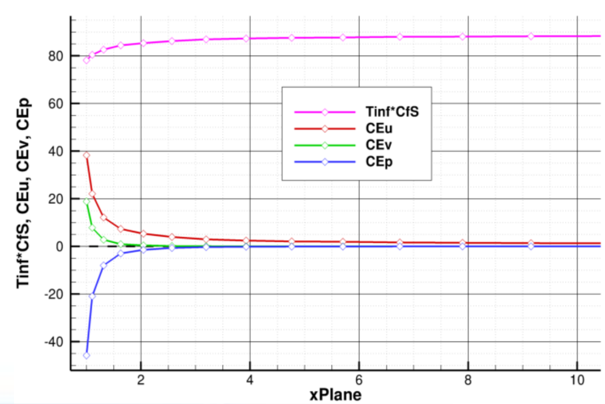
(Drela, 2009)



- <u>Design tool: post-processing code</u>

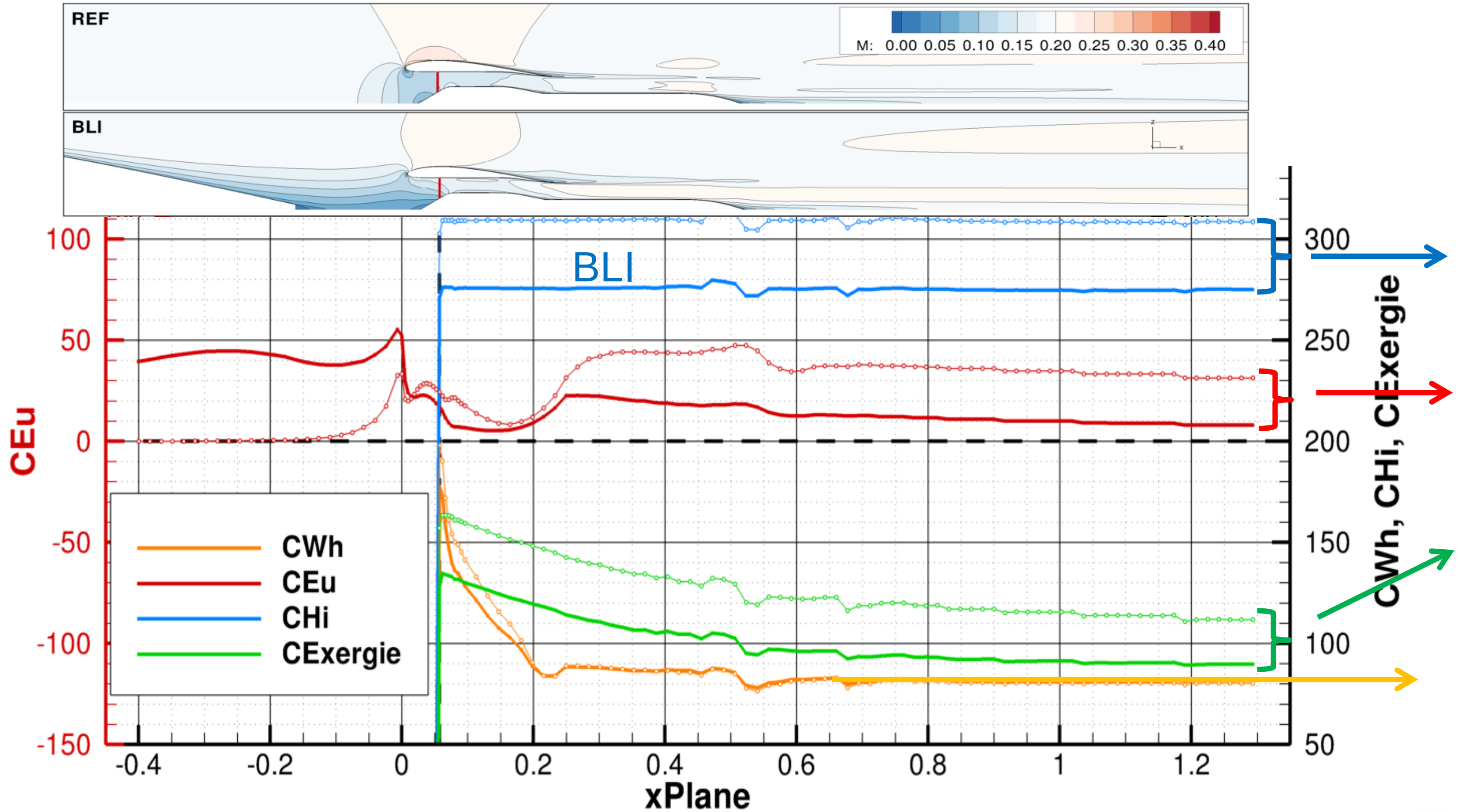






Far-field exergy based breakdown
Application to BLI

$$\underbrace{\text{Exergy}}_{\text{Energy convertible in mechanical work}} = \underbrace{\text{Stagnation enthalpy}}_{\text{Energy provided to the system (Engine)}} - \underbrace{T_{ambiant} \times \text{Entropy}}_{\text{Dissipations (viscosity + thermal losses + shock waves)}}$$



-10% of required energy

Less losses in wake (jet)

Less required exergy

Same axial force

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