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THE FRENCH AEROSPACE LAB

High Fidelity* Aerodynamic Analysis and Design for the Investigation of New Transport Aircraft Concepts

(* Hi-Fi: CFD, CSM, CAA)

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20 May 2021

7th UTIAS International Workshop on Aviation and Climate Change

Outline

1. Introduction
2. Hi-Fi simulations in concepts studies: motivations, needs, associated challenges
3. Experiences of Hi-Fi based aircraft concepts investigations
4. Efficient geometry handling for new aircraft concept aerodynamic design
5. Aerodynamic and aero-structural design using adjoint optimization
6. Concluding remarks

Introduction

- Context

  Goals for civil transport (EC "Flightpath *2050*") :
  - 75% reduction in C02
  - 90% reduction of NOx
  - and 65% reduction noise (2000→2050)

- Radical changes needed :
  - new aircraft architectures
  - new technologies (especially new propulsion & energy systems)

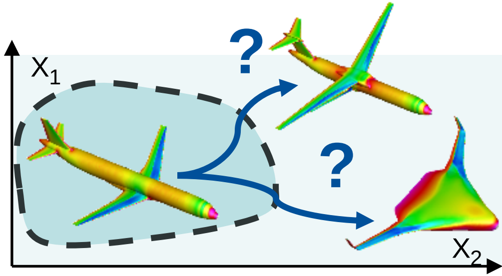
- Aerodynamics is a key discipline to enable such radical changes:
  - Direct contribution to overall aircraft performance improvement
  - Remains a central piece in the flight physics, rules handling qualities, therefore essential for safe/certifiable final product

Outline

Why introducing Hi-Fi simulations in A/C concepts studies

1. Lack of physical data and knowledge away from "tube-and-wing" designs
   - Empirical, statistical methods are limited

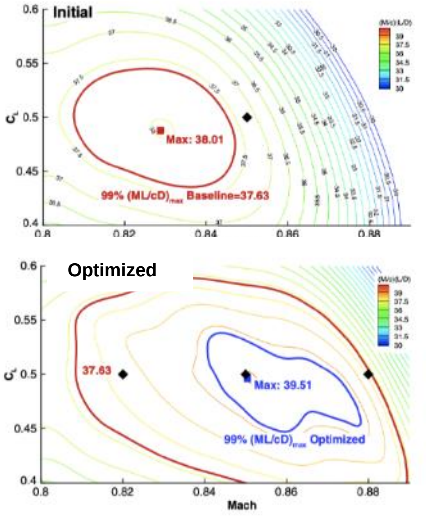
   → Hi-Fi simulations (CFD, CSM, CAA…) for conceptual design studies of disruptive A/C architectures



Source: Joaquim Martins,& Al., 2020

2. Inherently non-linear behavior of transonic aerodynamics
   - Simple (linear) aerodynamic methods, conventional in conceptual design, are limited

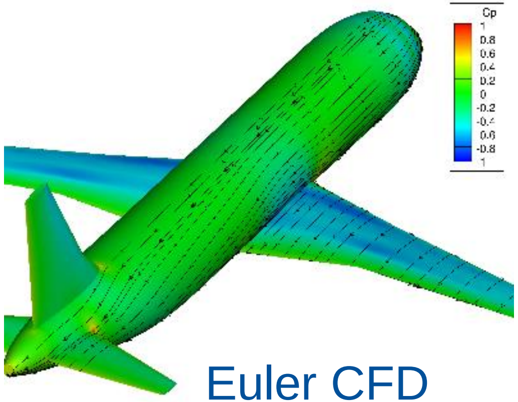
   → CFD brings a physics-based answer and captures the complex non-linear effects



Challenges with Hi-Fi simulations in A/C concepts design

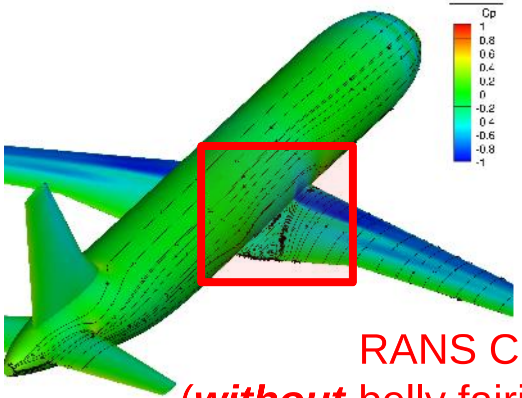
- Versatile and fast turn-around time process *“from geometry to post-processed results”*
  - *Current HPC, grid generation and CFD technologies enable CFD for cruise conditions on a complete A/C to be evaluated in few minutes (Euler) to few tens of minutes (RANS)*
- Robust & Fast CFD solvers
  - Systematic, good convergence (RANS) robust to grid quality deterioration
- Parametric geometry modelling
  - Enabling topological changes in aircraft architecture AND providing control on the aerodynamic shape for aerodynamic design
  - Consistent geometry representations throughout conceptual→preliminary(→detailed) design stages
  - Including the level of details required by the type of simulations: VLM, Euler, RANS have different needs in term of geometry
- CFD post-processing tools to extract all meaningful physical information from the CFD solutions
- Robust adjoint-based sensitivities calculation capability for efficient aerodynamic shape design (high dimension design space)

Needs for consistent Hi-Fi geometry modeling



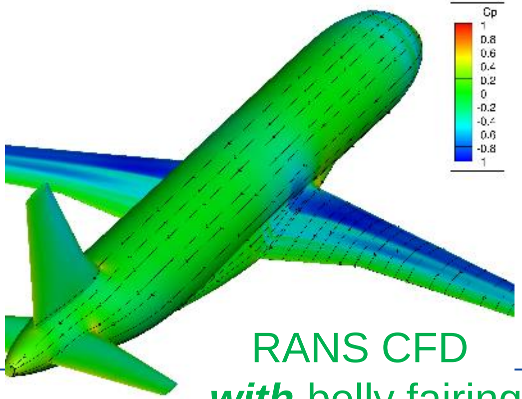
Euler CFD

KO



RANS CFD
(***without*** belly fairing)

OK



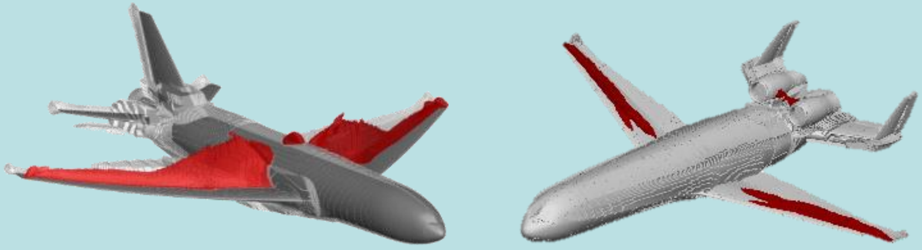
RANS CFD
with belly fairing

Geometries suitable for aerodynamic analyses based on Euler equations may be insufficient for viscous RANS analyses, yielding separated viscous flow (i.e. corner flows)
→ More design efforts to shape a proper aerodynamic junction is required for performance evaluation with RANS analysis

Needs for physics-based aerodynamic post-processing tools

Far-Field Drag (FFD) analysis

- **FFD software developped by ONERA since 1990**
- **Used in industry since 2000**
- **Direct diagnostic of drag sources for the designer : where and how much**

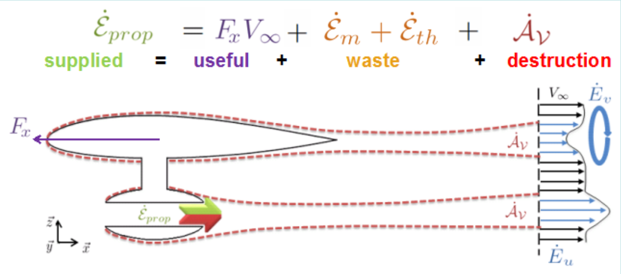


Wave (red) and viscous (gray) drag integration volumes calculated by *ffd72*

Destarac, D., and van der Vooren, J.,
“Drag/Thrust Analysis of Jet-Propelled Transonic Transport Aircraft: Definition of Physical DragComponents,” Aerospace Science and Technology, Vol. 8, No. 6, 2004,pp. 545–556

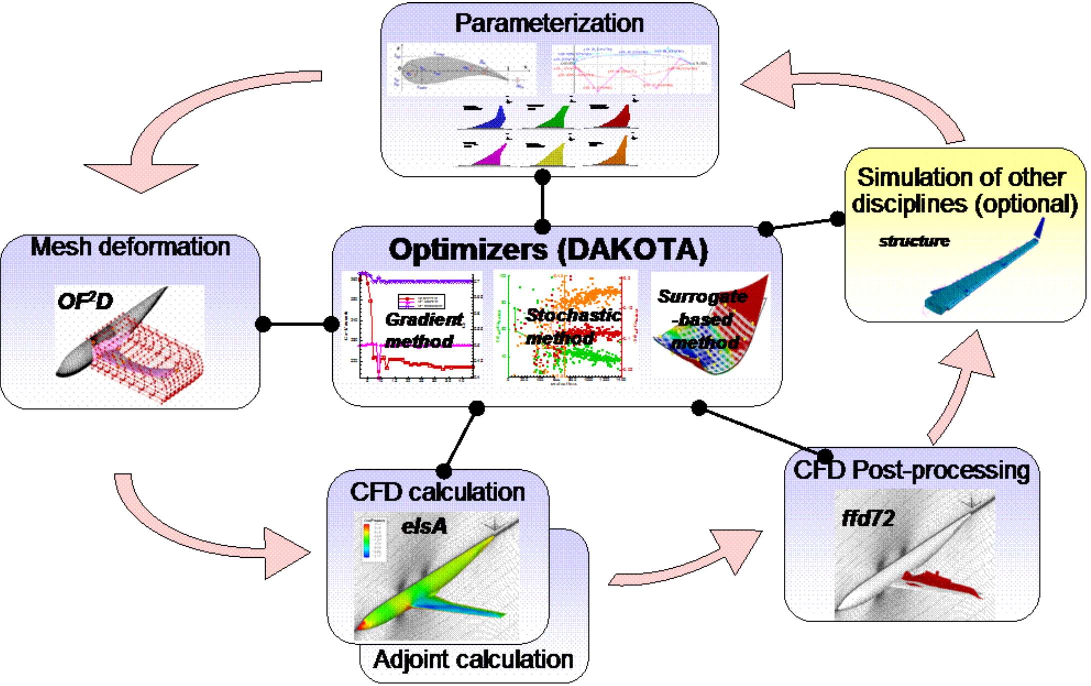
Exergy analysis

- **Implemented at ONERA in the FFX software since 2015**
- **Real interest for closely-coupled airframe/propulsion system when drag/thrust breakdown does not make sense anymore**



A. Arntz, O. Atinault, D. Destarac, A. Merlen
“Exergy-based Aircraft Aeropropulsive Performance Assessment: CFD Application to Boundary Layer Ingestion“ ,
HAL Id: hal-01068957https://hal-onera.archives-ouvertes.fr/hal-01068957

Needs for numerical optimization



Requisites for numerical optimization:

1. Efficient & flexible geometry handling
2. Automated meshing (or mesh deformation)
3. Robust & fast CFD
4. Numerical sensitivities by adjoint technique
5. Numerical optimization algorithms (high number of variables, constrained problems, non-linear functions)

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3. *Experiences of with Hi-Fi based aircraft concepts investigations*
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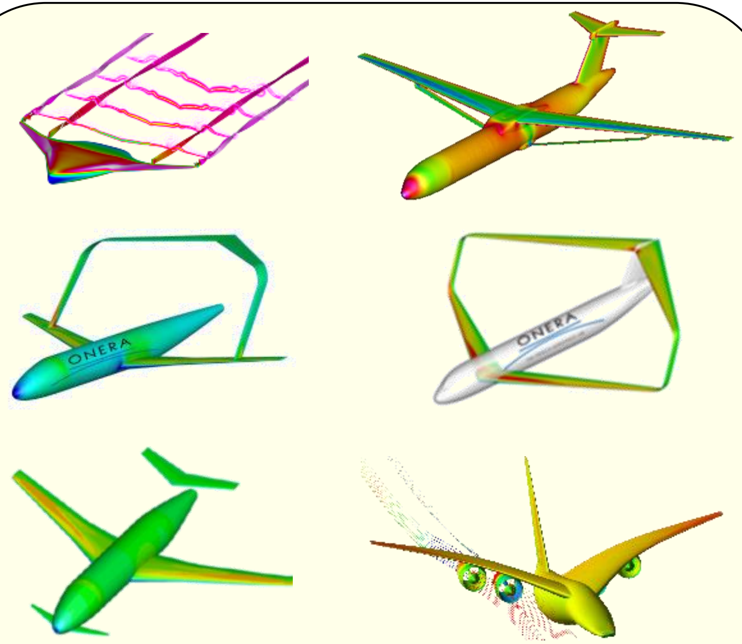
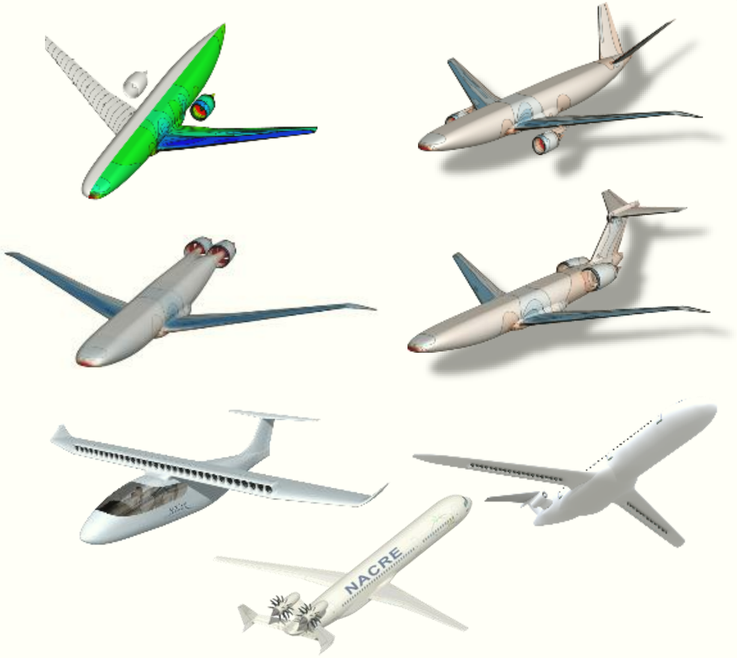
Scope of Civil Transport Aircraft Concepts & Technologies

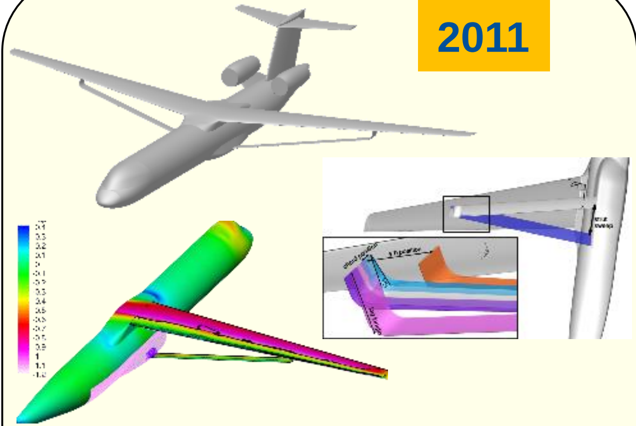


Airframe architecture



Propulsion system integration

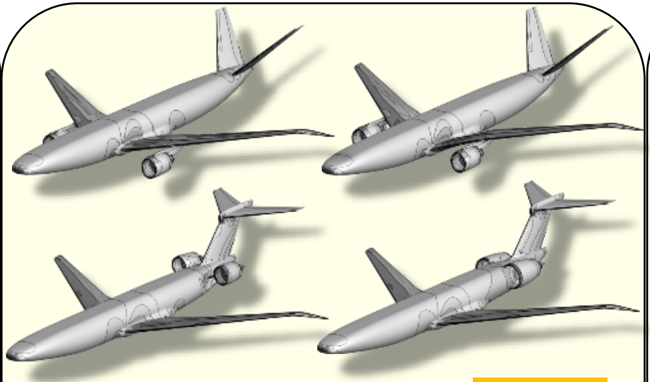
Some examples of concepts studies using Hi-Fi Aerodynamics



2011

G. Carrier, O. Atinault, S. Dequand, J. -L. Hantrais-Gervois, C. Liauzun, P. Paluch, A. -M. Rodde, C. Toussaint, «Investigation Of A Strut-braced Wing Configuration For Future Commercial Transport», 28th Congress of the International Council of the Aeronautical Sciences, 23 - 28 September 2012, Brisbane, Australia, Paper ICAS 2012-1.10.2

ALBATROS concept



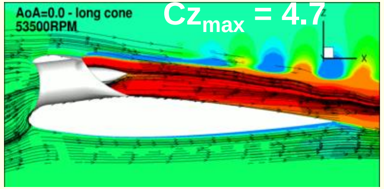
NOVA

2015

L Wiart, O. Atinault, J.-C. Boniface, R. Barrier, «Development of NOVA Aircraft Configurations for Large Engine Integration Studies», EUCASS 2017 Conference

NOVA concepts

2015

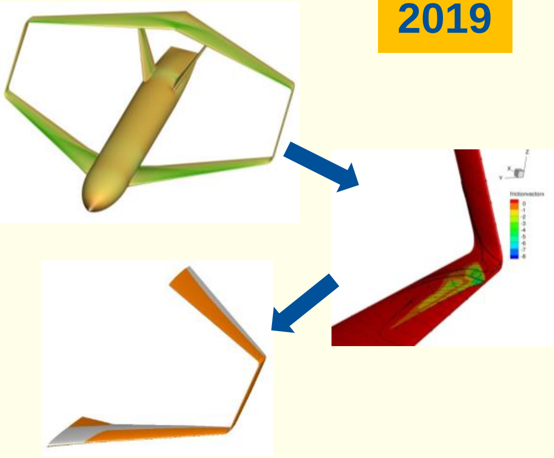


J. Hermetz, M. Ridel, C. Döll, «Distributed Electric propulsion For Small business Aircraft: A Concept-plane For Key-technologies Investigations», 30th Congress of the International Council of the Aeronautical Sciences (ICAS), September 2016, Daejeon, Korea

AMPERE concept

Some examples of concepts studies using Hi-Fi Aerodynamics

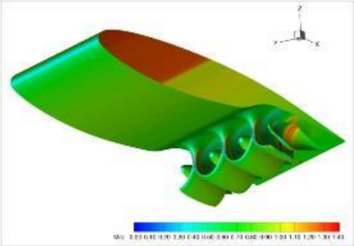
2019



M.Carini, M. Meheut, S. Kanellopoulos, V. Cipolla and K.Abu Salem
«Aerodynamic analysis and optimization of a boxwing architecture for commercial airplanes», AIAA Paper 10.2514/6.2020-1285

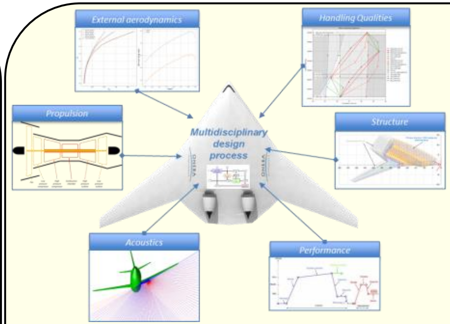
PARSIFAL* concept

2019



P. Schmollgruber, C. Döll, J. Hermetz, R. Liaboeuf, M. Ridel, I. Cafarelli, O. Atinault, C. François, B. Paluch, «IMultidisciplinary Exploration of DRAGON: an ONERA Hybrid Electric Distributed Propulsion Concept», AIAA Paper 10.2514/6.2019-1585

DRAGON concept



2019

OAD process

Multifidelity applied to aerodynamic (left : LoFi, right: HiFi)

A, Tremolet, J. Gauvrit-Ledogar, L. Brevault, S. Defoort and F. Morel, Multidisciplinary Overall Aircraft Design and Optimisation of Blended Wing Body Configurations, CEAS 2019, 1 - 4 July 2019, Madrid, Spain

BWB concept

* H2020 project PARSIFAL: https://cordis.europa.eu/project/id/723149/fr

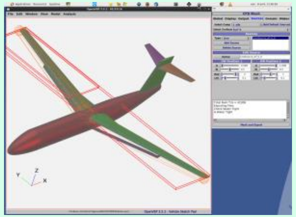
Outline

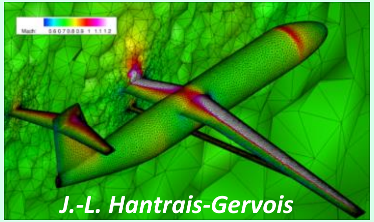
Geometry handling for concept studies: needs and solutions

Objectives:

– To enable consistent/continuous geometry representation from ***conceptual*** to ***preliminary (even detailed***) design stages
– Fully parametric
– With high level of control on the shapes
– Providing ready-to-mesh geometry for flawless "CAD -> analysis" link

► First capability developed at ONERA: ***CANOE tool-suite*** based on OpenVSP, tetgen (2014)





► Ongoing evaluation of the EGADS, EngineeringSketchPad and CAPS tool suite (MIT/Syracuse)

esp caps

Bob Haimes haimes@mit.edu
Marshall Galbraith galbramc@mit.edu
Massachusetts Institute of Technology
John F. Dannenhoffer, III jfdannen@syr.edu
Syracuse University

CAPS (Computational Analysis Prototype Syntheses)
- Python
- Interface to ***analysis modules***:
  - Mesh generator
  - VLM, CFD, …
  - CSM, …

EngineeringSketchPad
- CSM Langage
- ***Boolean ope.***
- ***Geometry*** parameterisation

EGADS

Open CASCADE TECHNOLOGY

- Use of **script capability of Pointwise®** to **automate unstructured CFD grids generation for Euler or RANS** simulations from (almost) any geometry

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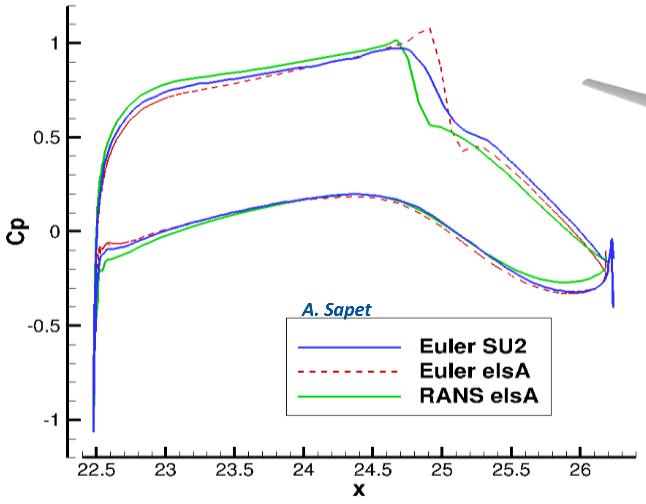
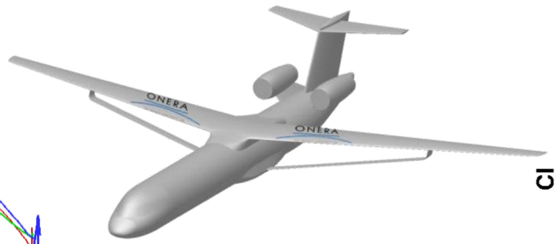
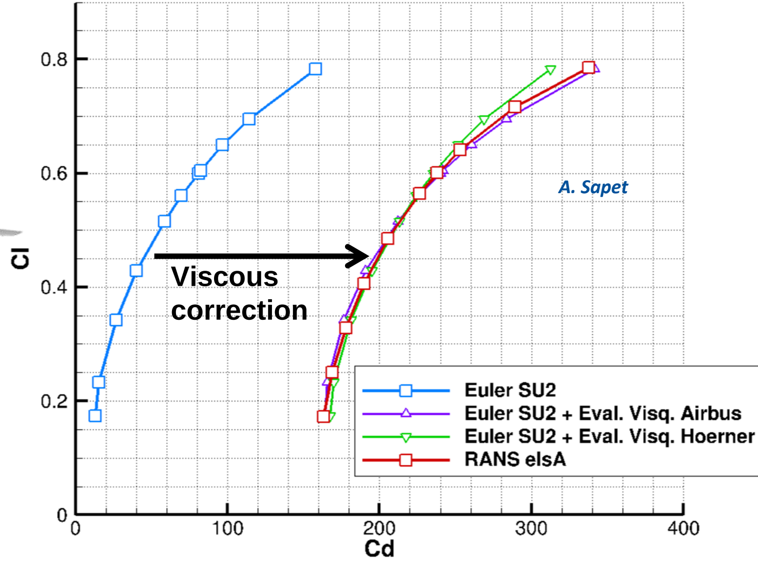
CANOE: First approach to (Euler) CFD automation for concept studies

- How accurate can we be with such an approach (Euler + analytical viscous correction)
    - Comparaison with RANS analysis:
    - ⇨ OK if mesh is fine enough



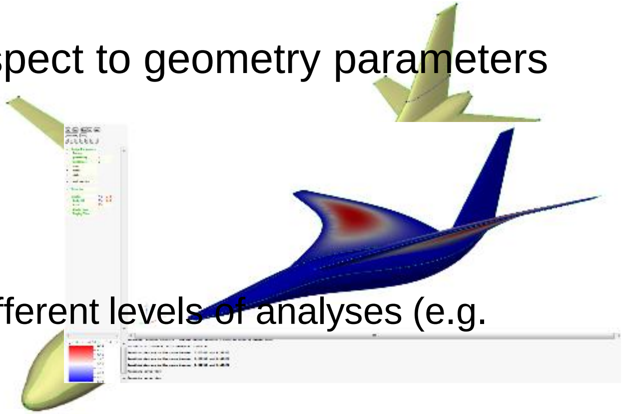




ESP/EGADS: Assembly of different parameterised geometry components

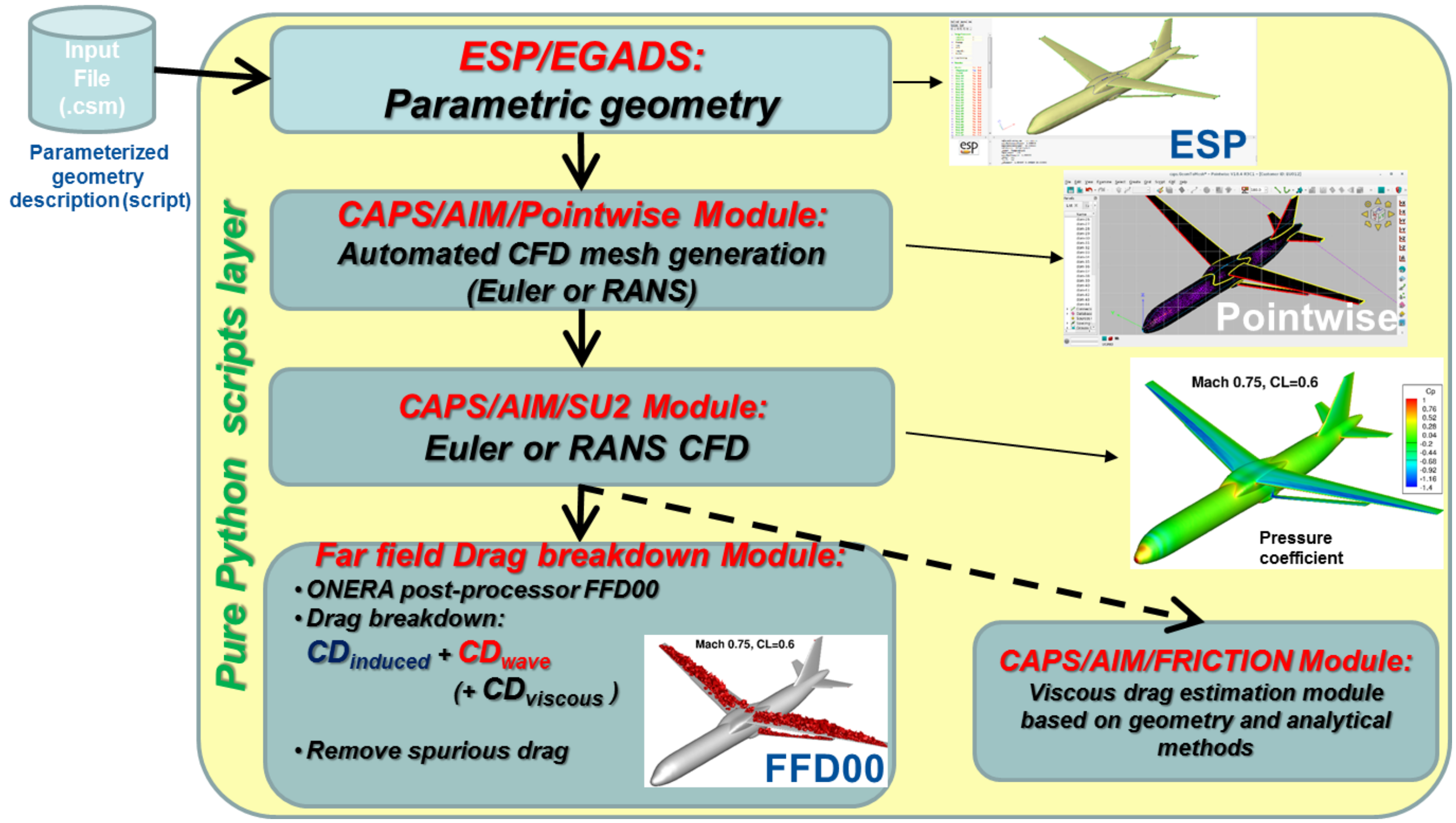
- Underlying surfacic B-Rep NURBS (OpenCascade)
- Parametric geometry models implemented through openCSM scripts

- Analytic sensitivities calculation of the final geometry with respect to geometry parameters
  → compatible with adjoint sensitivities analysis



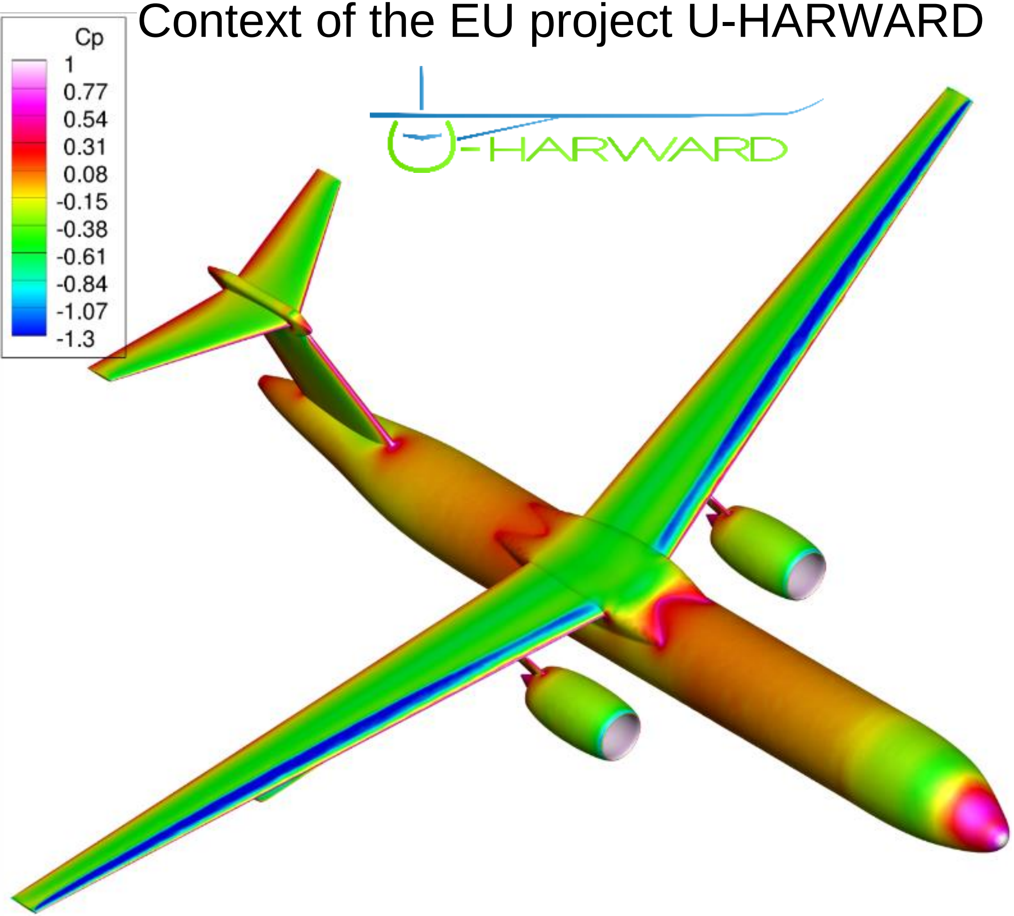
- Enables to derive
  - different levels of geometry models of the same object to feed different levels of analyses (e.g. VLM → Euler → RANS)
  - multiple geometrical representation for multiphysics analyses

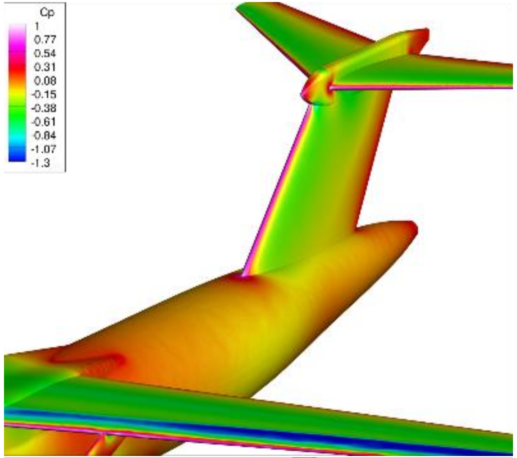
CAPS: Geometry-centric process for geometry ↔ Hi-Fi analysis

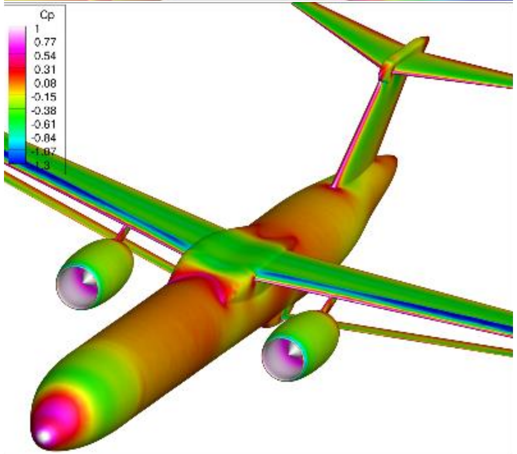


Exemple of use of CAPS/ESP/EGADS for SBW design

Context of the EU project U-HARWARD







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MADELEINE H2020 project

***M**ultidisciplinary **AD**joint-based **E**nablers for **L**arg**E**-scale**I**ndustrial desig**N** in a**E**ronautics*

Forthcoming contribution to AVIATION 2021

Towards industrial aero-structural aircraft optimization via coupled-adjoint derivatives

M. Carini[1], C. Blondeau[2], N. Fabbiane[3] and M. Méheut[4]
ONERA The French Aerospace Lab, Meudon, F-92140, France

M. Abu-Zurayk[5], J. Feldwisch[6], C. Ilic[7] and A. Merle[8]
German Aerospace Center (DLR), Germany

R. Olivanti[9] and J. Brézillon[10]
Airbus Operations SAS, Toulouse, 31060, France

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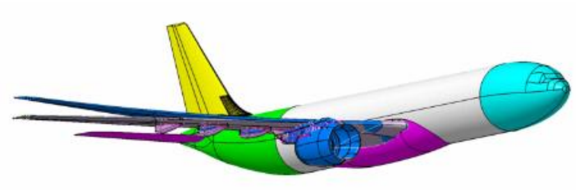
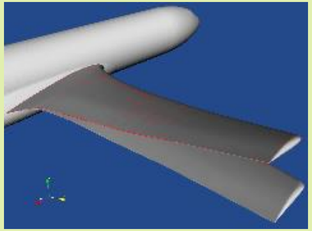
Aero-structure optimisation: AIRBUS XRF-1 test case

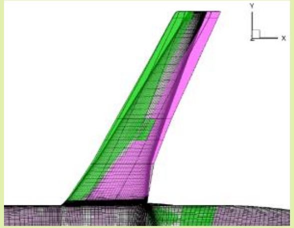


XRF-1 long range transonic transport

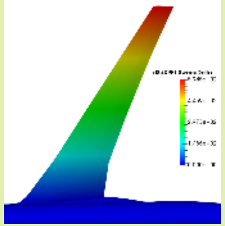
PADGE CAD to MESH SHAPE PARAMETERISATION



Flight Shape Fitting

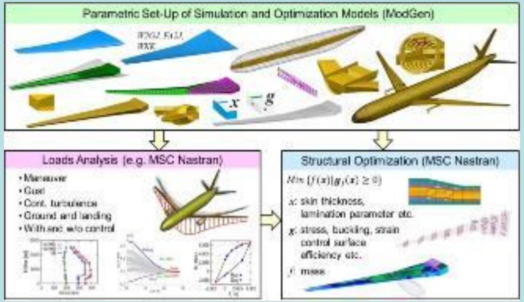


Surface Mesh deformation

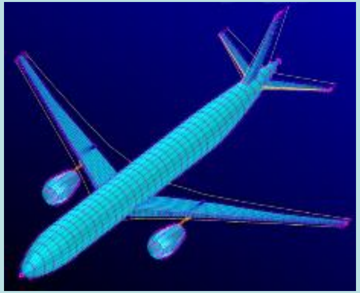


Surface mesh sensitivity

STRUCTURE SIZING



DLR CPACS-MoNa process



XRF-1 FEM model

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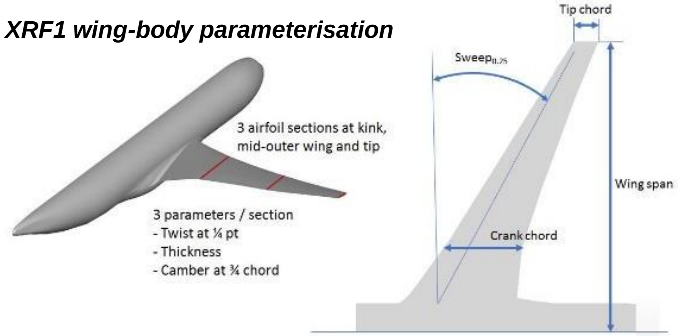
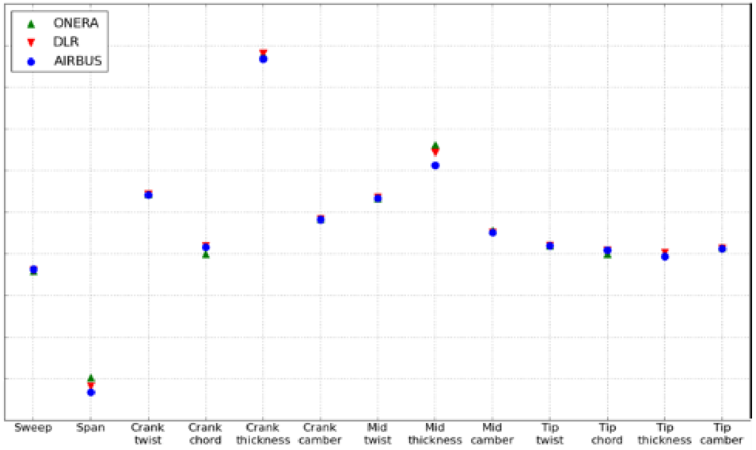
Rigid and Flexible gradient verification (ONERA, DLR & AIRBUS)

- ***Common CAD (PADGE) template** (13 design variables):*
  - *Wing planform parameters*
  - *Local airfoil parameters*
- ***Common FEM model***
- ***CFD (aeroelastic)solver:***
  - *Structured (ONERA) and unstructured (AIRBUS & DLR) approaches*
  - *Frozen & linearised turbulence model (SA)*

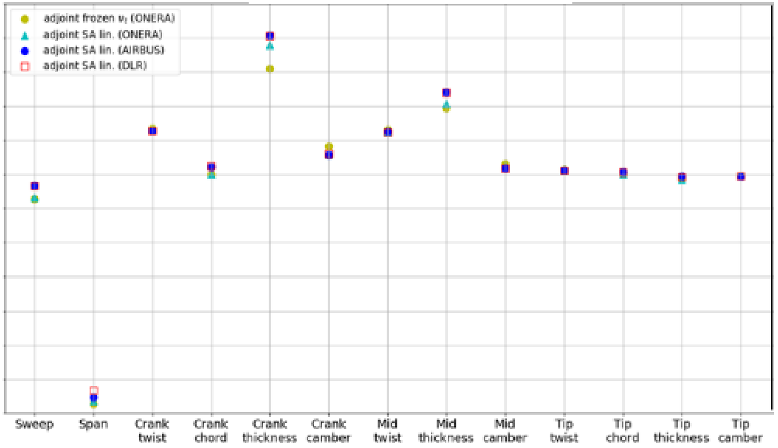
XRF1 wing-body parameterisation



CDp Rigid Gradients



CDp Flexible Gradients



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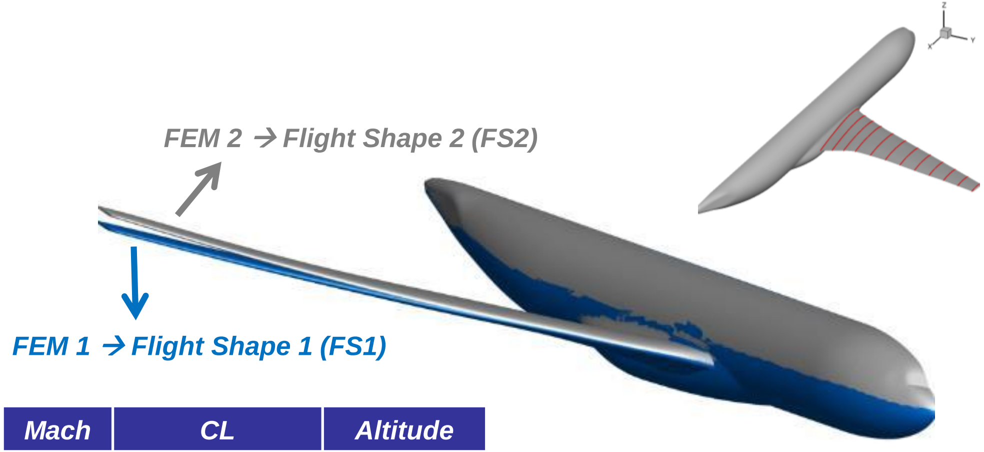
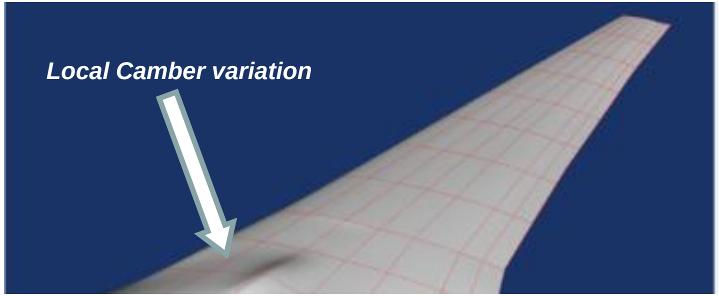
XRF-1 Enriched PADGE template & FEM models

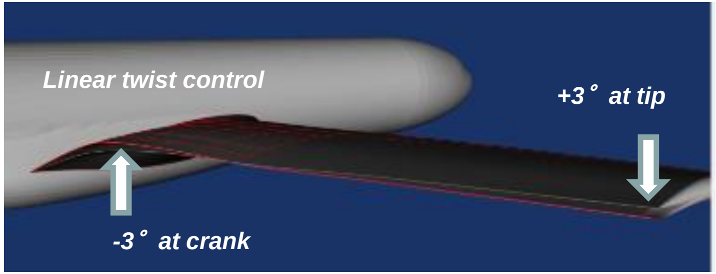
73 Camber and twist design variables:

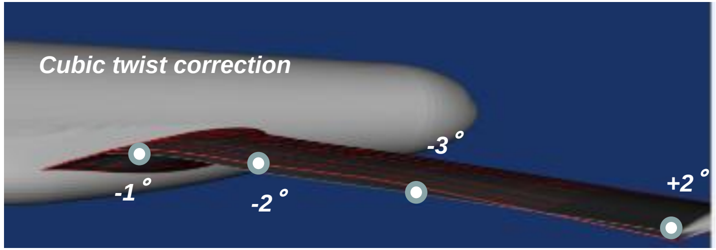
- *12 control sections (one frozen)*
- *6 camber control points/section (15., 30., 45., 60., 80., 90.) % chord*
- *Twist control:*
    - *Linear interpolation between crank and tip sections*
    - *B-spline additive corrections*



Mach	CL	Altitude
0.83	0.5	10.39 km







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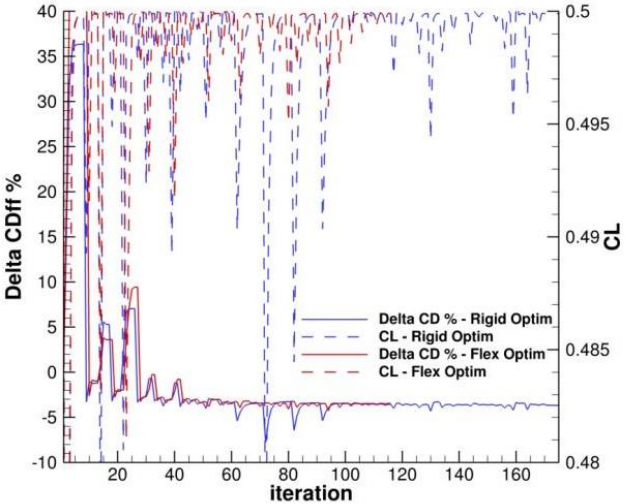
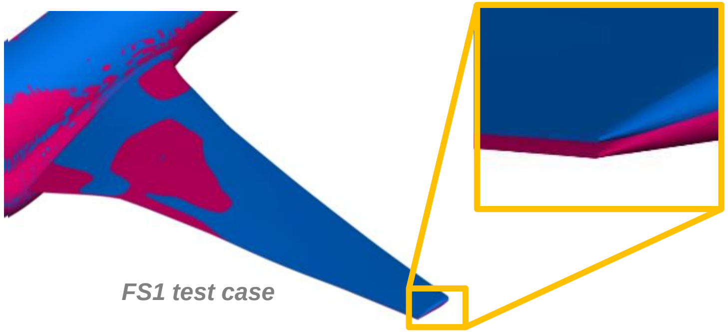
Rigid vs Flexible shape optimisation (CD minimization under CL constraint)

Optimisation history for FS1 test case



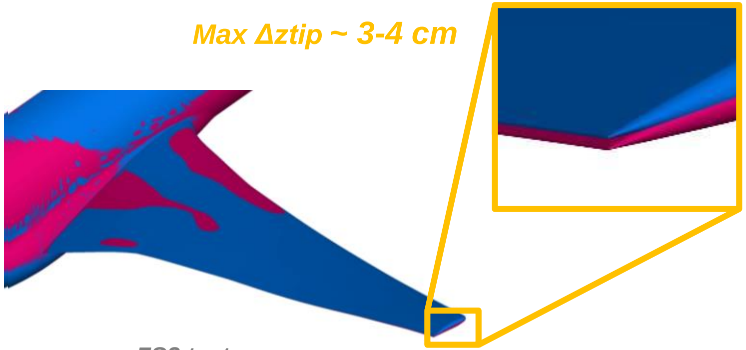
FS	Optim	ΔCdi	ΔCdw	ΔCdvp	ΔCdf	ΔCdff
FS1	Rigid	+1.00%	-90.44%	-6.66%	+0.38%	-3.68%
	Flex	+0.70%	-84.81%	-6.08%	+0.49%	-3.47%
FS2	Rigid	+0.80%	-92.45%	-7.83%	+0.29%	-4.95%
	Flex	+1.04%	-93.17%	-7.15%	+0.57%	-4.68%

Rigid vs Flexible Optimised Shapes



FS1 test case

Max Δztip ~ 3-4 cm



FS2 test case

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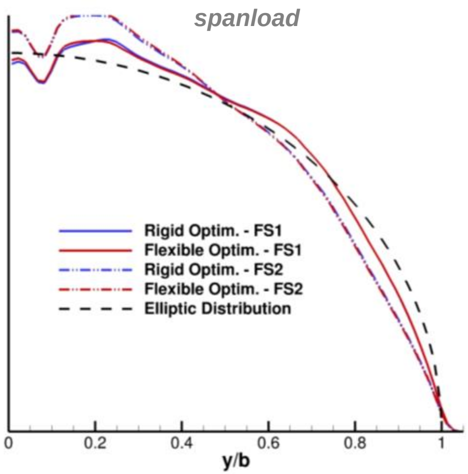
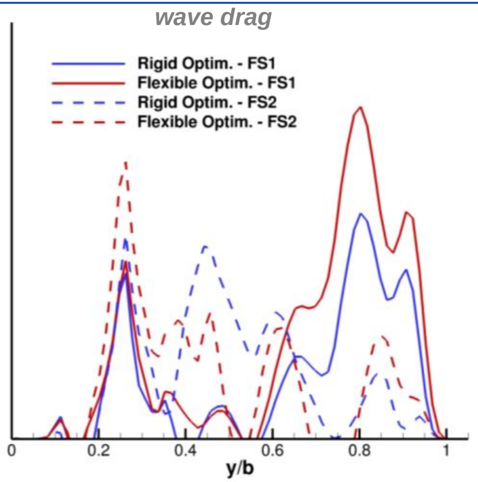
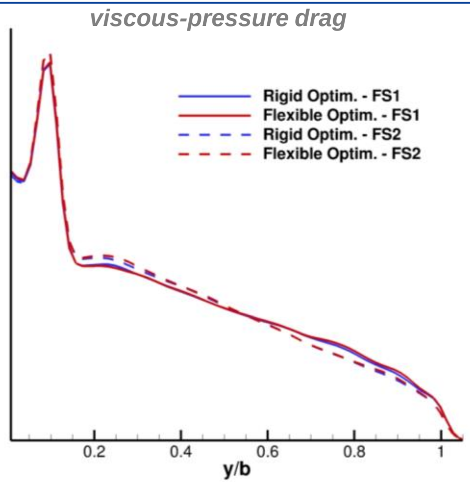
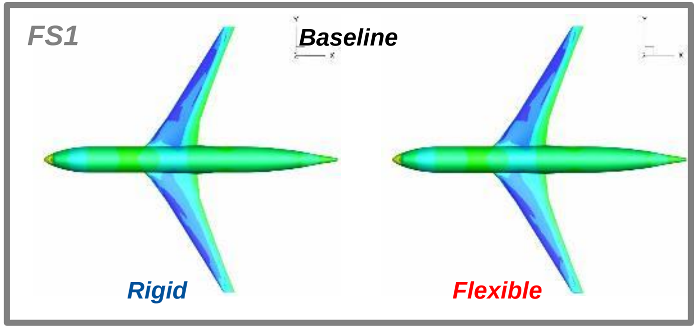
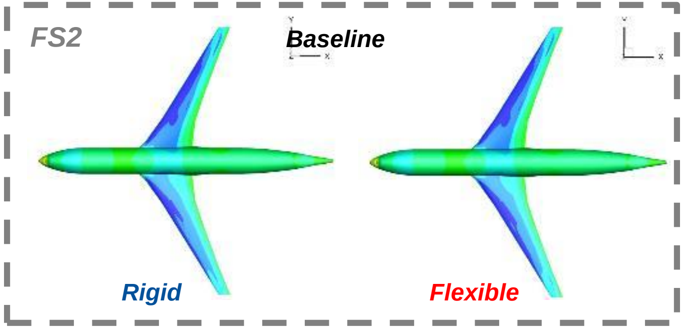
Rigid vs Flexible shape optimisation (preliminary results)











Concluding remarks & perspectives

- Introduction of CFD analysis in the conceptual exploration & design of novel aircraft concept is considered as a way-to-take
  - Not necessarily as the unique level of modelling
  - But surely as much as possible in order to alleviate the bias and limitations of empirical & statistical models or simplified aerodynamic methods
- Significant improvements achieved over the last decade(s) :
  - RANS-based analysis is now conceivable in conceptual design
- Ways forward:
  - Flawless geometry modeling compatible with downstream numerical analyses (ready for tessellation)
  - Automated grid generation for RANS simulation as one of the main current bottle neck: robustness and efficiency improvements needed
  - Robust adjoint based optimization capability for both aerodynamic and aerostructural design
    - Target application: equilibrated free-flying aircraft accounting for geometrical non-linearities (large displacement when flexible HARW)

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Thanks for your attention