How the Digital Twin Defined the Wind Tunnel Arrangement for high lift systems:

the Clean Sky 2 MOTHIF project

Paolo D'Alesio[1], Giorgio Travostino[1]

[1] Piaggio Aerospace, Flight Technology Aerodynamics, Villanova d'Albenga (SV), Italy

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Chapter 1: Introduction

MOTHIF in SAT Frame

SAT: Small Air Transport

European Research Project main goal is to improve the overall European air mobility to meet the FlightPath 2050 target "d2d 4h"(door to door within 4 hours).

To reach the target it is mandatory to improve the link between the remote areas far from main airports or with limited or absent road and railway connection to major cities.

The improvement can be realized through the use of small transport aircraft (19 PAX) capable to use the available ground infrastructures for small airport, realizing small aircrafts, offering a greener and more economic alternative to commercial flights and offloading surface transport.

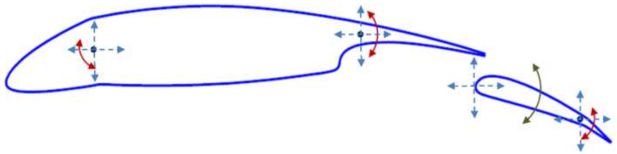
Considering the smaller airports implies the dealing with short take off runaway, then the aircrafts must have effective STOL capabilities which have to be obtained with an accurate aerodynamic design of the high lift system

The Aerodynamic Solutions

The high lift architecture considered for its high effectiveness with respect to its simplicity and low cost was the **fowler flap**.

Two different approaches has been proposed to comply with the target of an extra lift performance:

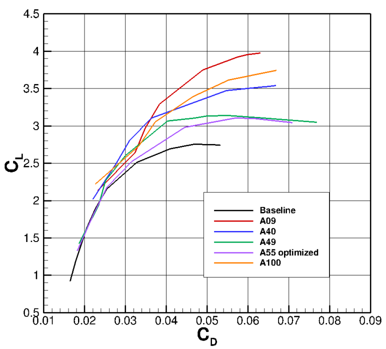
1) A traditional optimization process
2) To brush up an well known solution considered in the past for experimental jets and very high speed aircraft: the blown flap

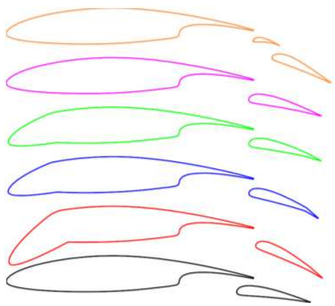


The solution down selection

CIRA (pure fowler flap optimization on Piaggio Aerospace Avanti aircraft airfoil) and the Poland Institute of Aviation ILOT (blown fowler flap on PZL MIELEC M28 aircraft airfoil) studied the identified solutions showing a maximum coefficient value respectively equal to 3.1 and 4.47.
Considering the results the blown flap has been down selected.

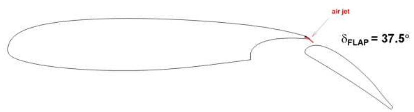
CIRA





ILOT

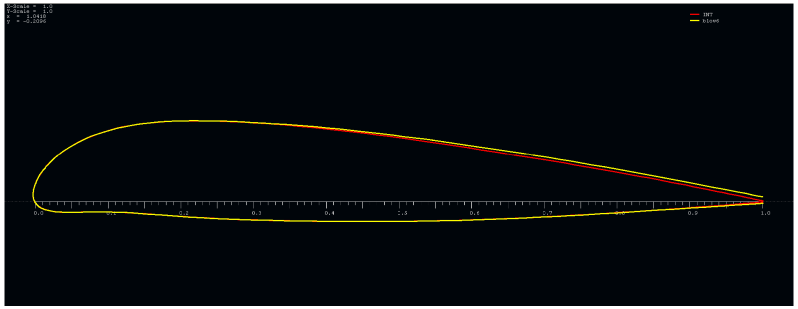
Pressure Ratio	CLmax	Power
1.000	3,80	0,00
1,097	3,90	0,80
1,194	4,05	4,08
1,292	4,17	10,51
1,389	4,27	20,16
1,486	4,35	32,89
1,584	4,42	48,63
1,681	4,47	66,94

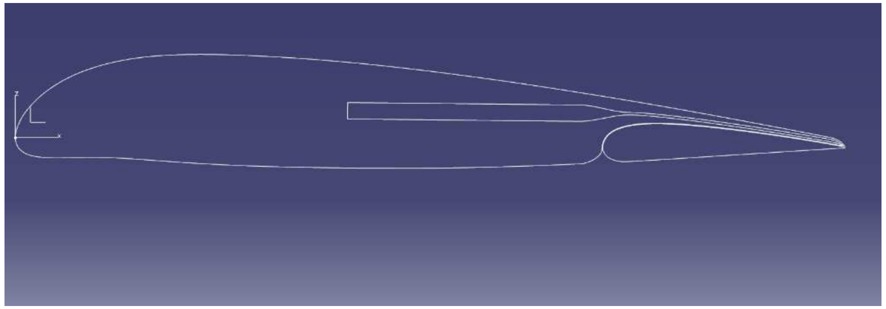


Airfoil: Piaggio redesign

To apply the blown flap concept to the 19 PAX STOL aircraft conceptual design a new airfoil have to be defined. The target was to have a thickness to chord ratio equal to 0.13 and a 3,5 2D max take-off lift coefficient in blow off condition to avoid aerodynamic lift crisis in case of blow failure.

The following airfoil have been proposed after an optimization of NACA 43013 airfoil (+10% in max lift coefficient) and adapted to adress the blown duct





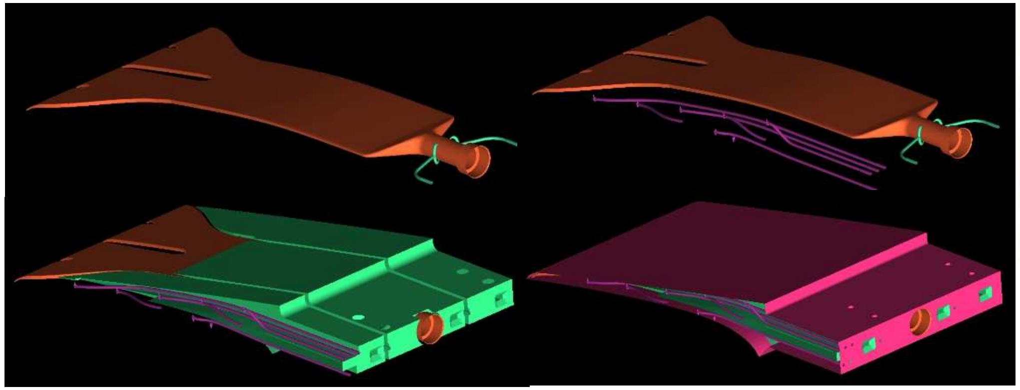
A gap-overlap optimization have been performed assuring a blow on 4.25 Take-Off max lift coefficient with an air pressure feeding equal to P/P_0=1.48, to reach a compromise between high lift performance, installed blower system dimension and acoustic impact.

Implementation in wind tunnel model

The concept implementation in the wind tunnel model showed immediately the need of a large model, due to the minimum dimensions of blown air feeding system allocation.

From the start it was clear that the model cannot be entirely machined by SONACA which was in charge of model manufacturing and assembly.

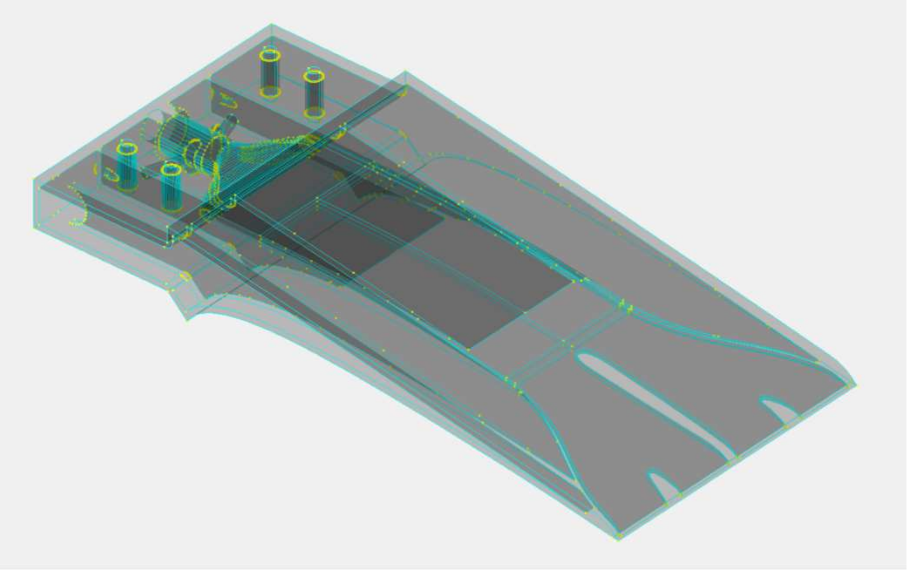
The trailing edge part had to be realized using the Stereolithography technique with Accura Bluestone material (3D-Systems S.R.L). The model chord was 1.35 m flap retracted.



Implementation in wind tunnel model – material saving

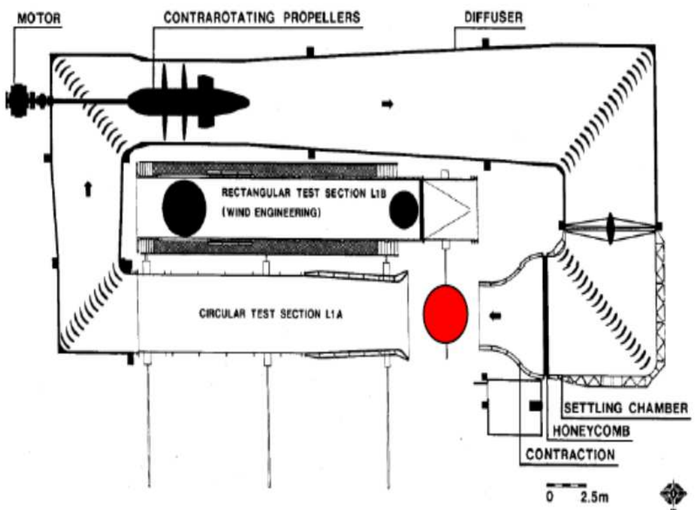
Thanks to the coupling fluidodynamic and structural analysis two main goal has been reached:

- Wind tunnel model safety load factor reduction (accepted by VKI) from 5 to 3.5
- Accura Blue Stone employed quantity reduction nearly 49% with acceptable local deformation



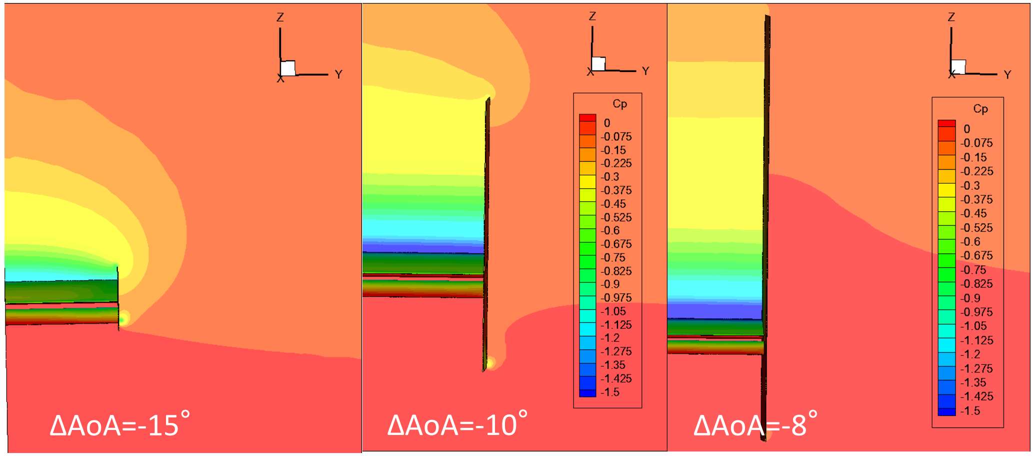
The Wind Tunnel

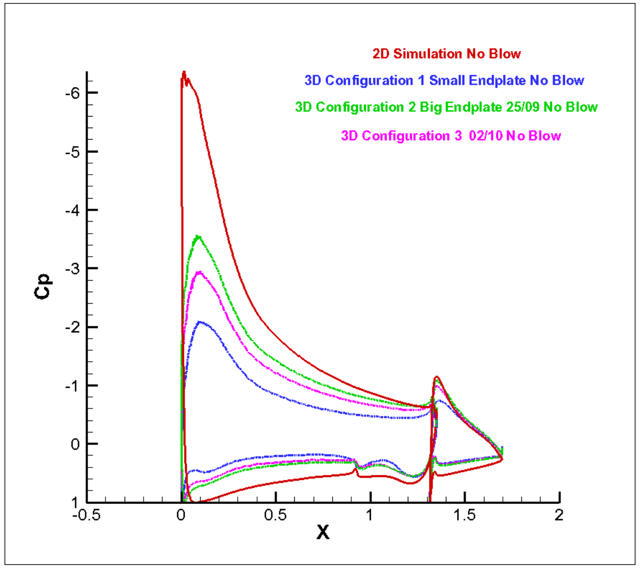
The selected wind tunnel was the VKI low speed wind tunnel L1-A, which has an open jet test section of 3m diameter and 4.5m length. Its maximum speed can vary continuously from 0 to 60 m/s. The contraction ratio is 4 with a typical turbulence level of 0.3%.
The wind tunnel freestream tests speeds were 20ms, 30ms, 35ms and 42,5ms, to evaluate blockage and speed influence on aerodynamic behaviour. Different jet blowing pressure (and so blowing speeds) are also tested.



The Aerodynamic Issue

The first identified aerodynamic issue for the Wind tunnel test has been the generation of a proper 2D flow field on the model. To have a representation of the problem we do facing with, a CFD model has been generated considering side walls with different dimensions:





Side walls reduced but not cured the problem. This was well expected but these tests quantified an 8° reduction in Angle of Attack for the larger endplate

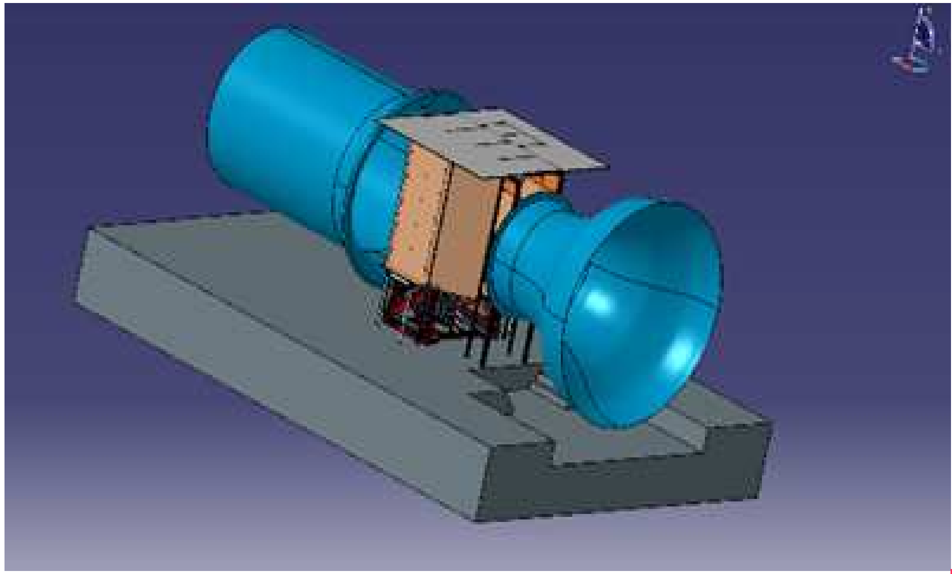
Considerations

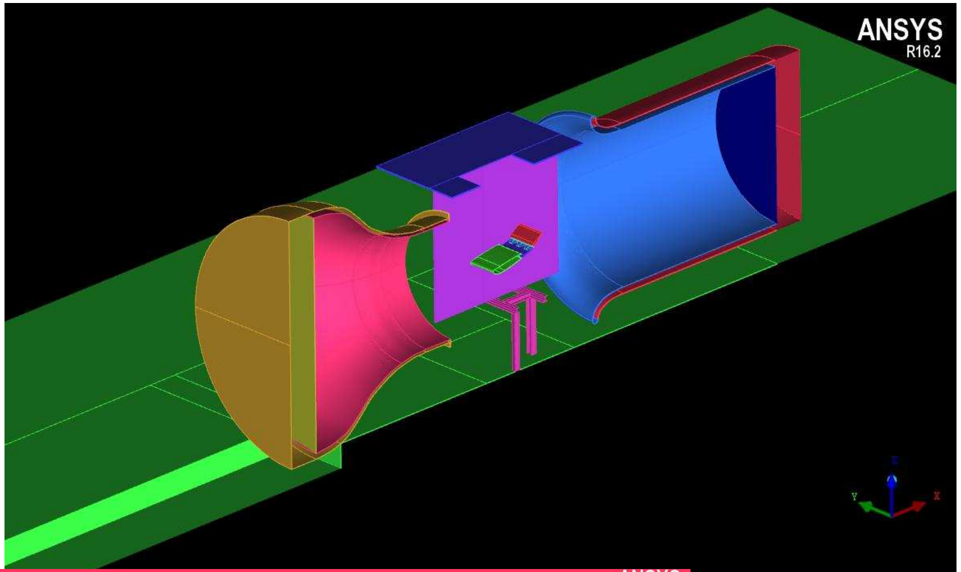
The preliminary CFD model simulation cleared that the wind tunnel cannot provide the needed data to evaluate our aeropneumatic design and it was clear also that the only viable approach was to resort to a **Digital Twin** .

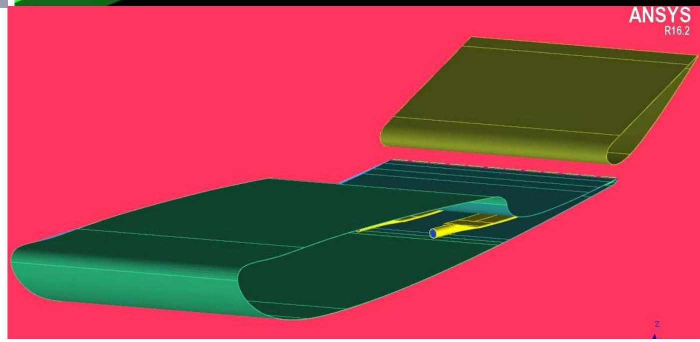
The basic idea was to exactly simulate the wind tunnel and validate our CFD computational skill to induce the validity of the 3D simulation of the aircraft installed blowing system.

Chapter 2: The MOTHIF Blowing Flap & Wind Tunnel Digital Twin

The Digital Twin



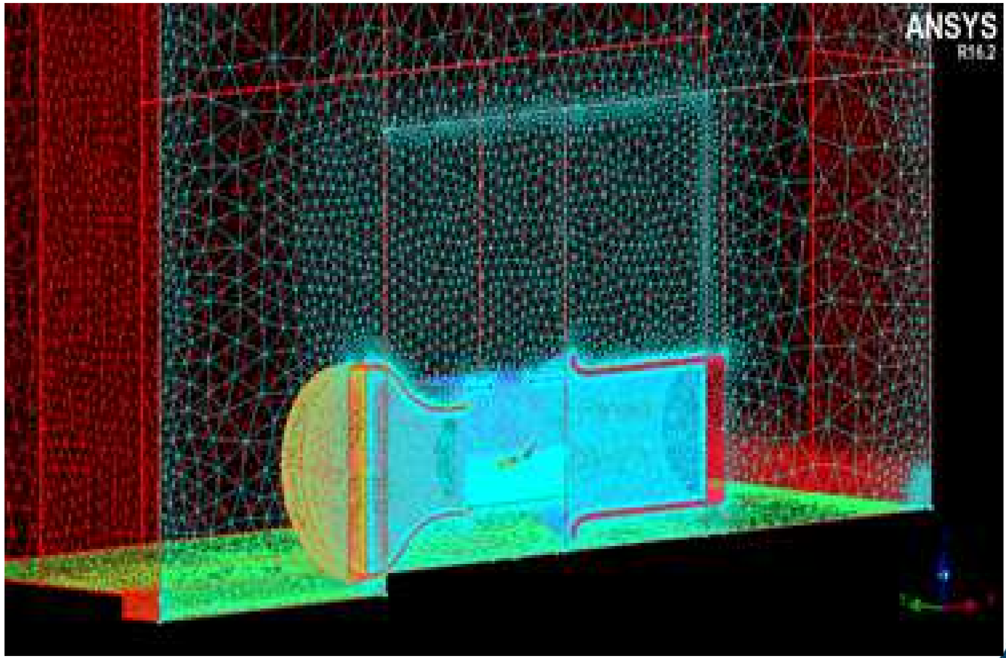




Kindly VKI gave to Piaggio Aerospace the L1-A CAD file. The represented geometry took in account all the features that can have an impact on the flowfield

The Digital Twin Mesh

The computational domain considered the Wind Tunnel Hangar, the upstream and downstream WT ducts, the floor with a longitudinal long step, the beams of the model support, the upper and side walls proposed by VKI and the airfoil model. The entire mesh counts 67 e6 Tetra-Prism cells.



The Simulation Setup

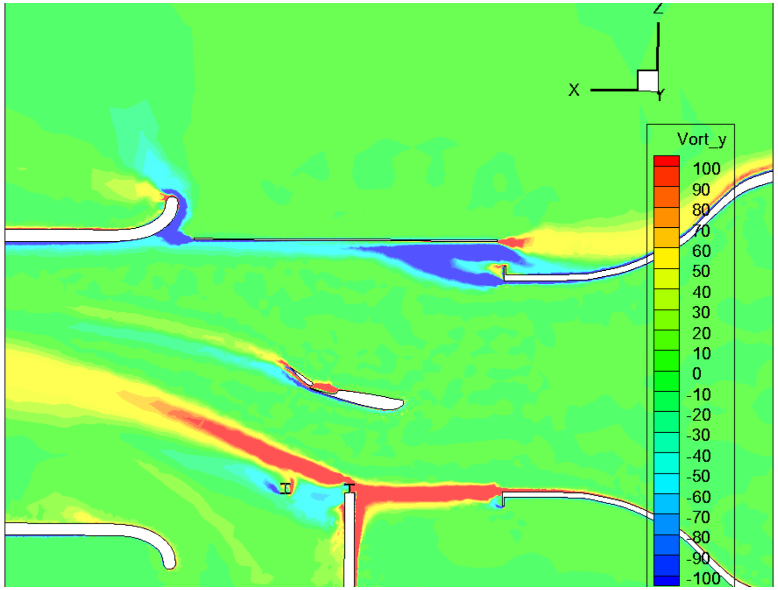
- **Software** : Metacomp CFD++
- **Solver**: Preconditioned/Compressible Pressure based equations
- **Turbulence Model**: Both k-ω SST and k-ε
- **Discretization**: Second Order, both flow and turbulence equations
- **Wind Tunnel Speed**: 42,5 ms, imposed via Reservoir delta pressure with respect to ambient
- **Blowing Jet Boundary Condition**: Mass Flow imposition
- **External Ambient**: Characteristic based Inflow Outflow (Free Stream data as virtual state outside the domain for solving a Riemann problem at the boundary)
- **Symmetry**

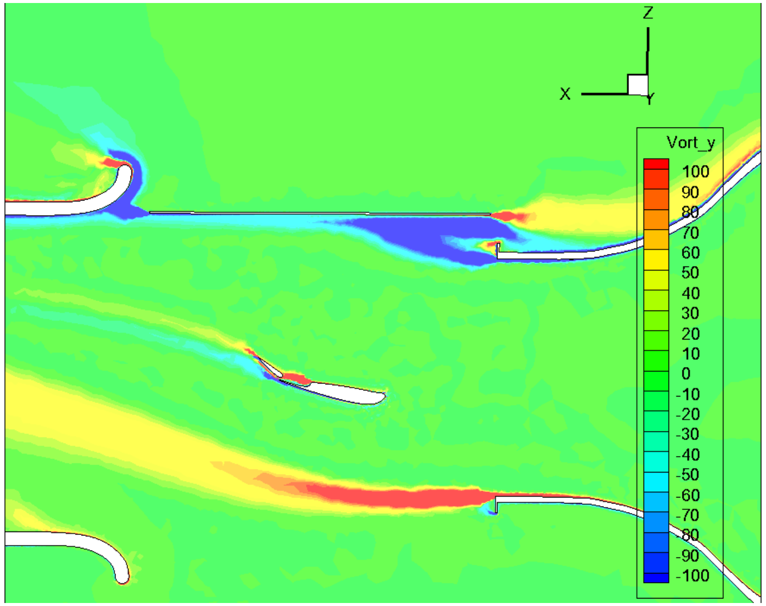
Chapter 4: Wind Tunnel Digital Twin Results

The Wind Tunnel Test Chamber Arrangement Improvements

The Digital Twin process allowed for the improvement of the Wind Tunnel flow quality.

The proposed wind tunnel arrangement caused upward flow shift causing a loss of the specimen aerodynamic angle of attack and consequently a loss in lift. The shift was enforced by the pillars structure of the specimen, but it still arose excluding the pillar structures.

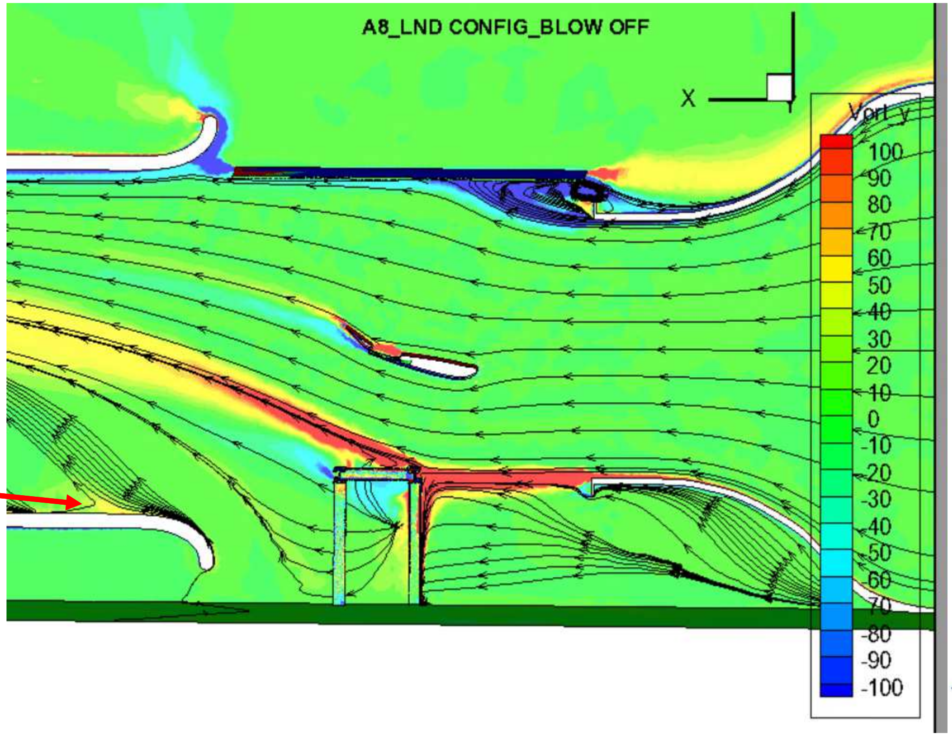




The Wind Tunnel Test Chamber Arrangement Improvements

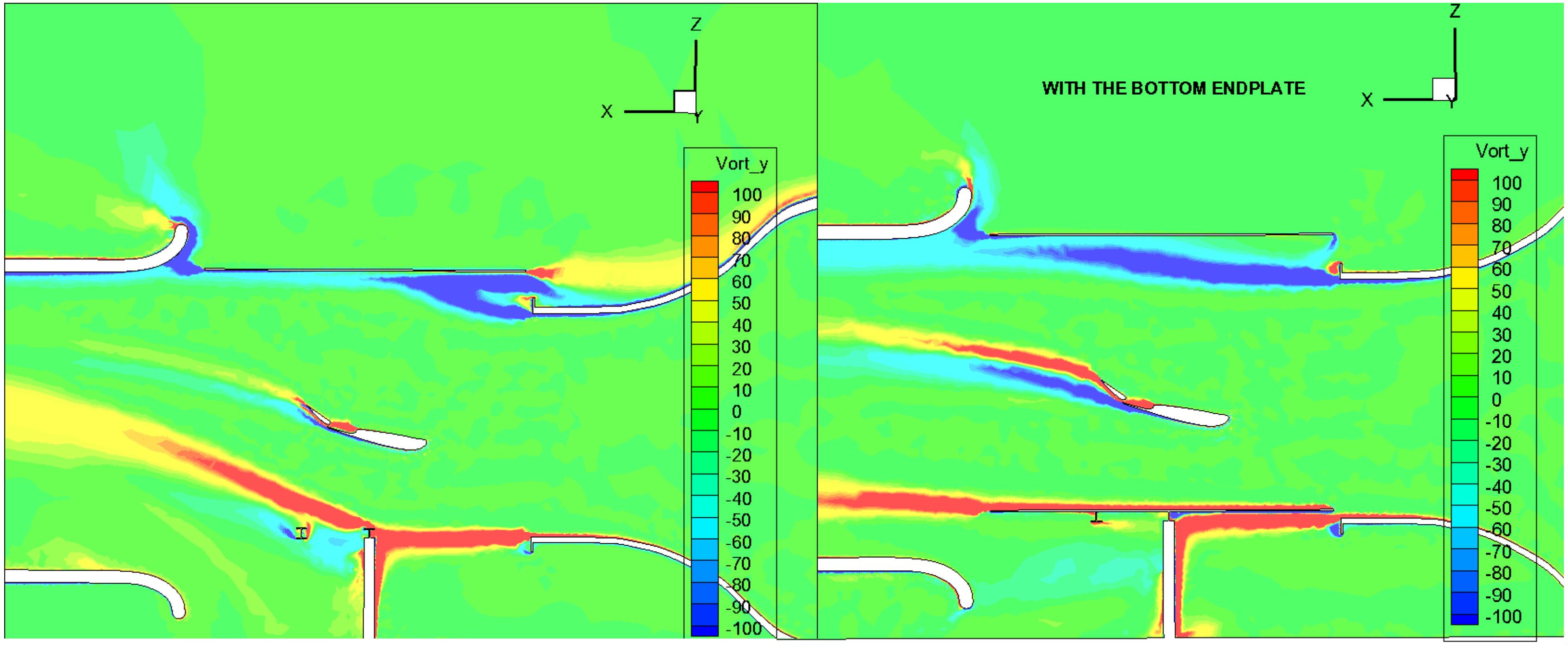
The proposed wind tunnel arrangement:

Caused a flow velocity reduction in the wind tunnel outlet axis zone, with also a small recirculation on the outlet bottom lip (counterchecked by tufts in the wind tunnel)



The Wind Tunnel Test Chamber Arrangement Improvements

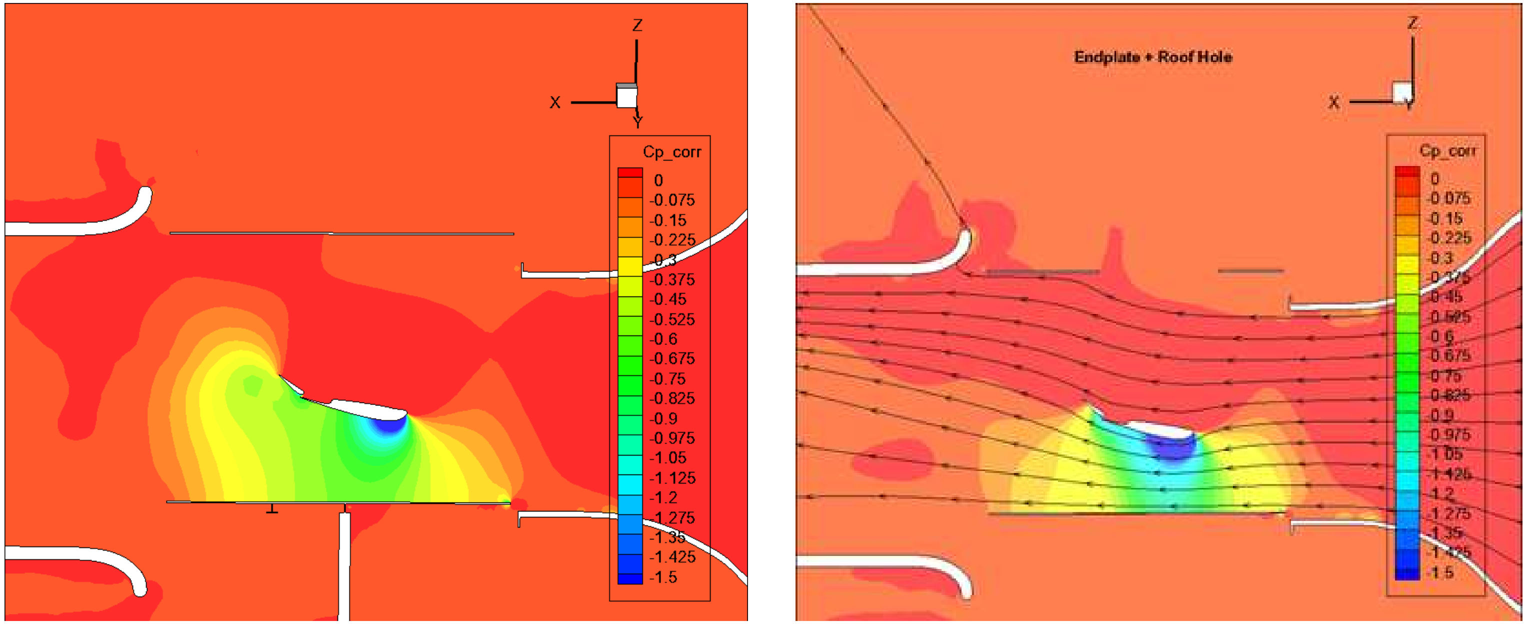
To eliminate the issue a bottom endplate has been added



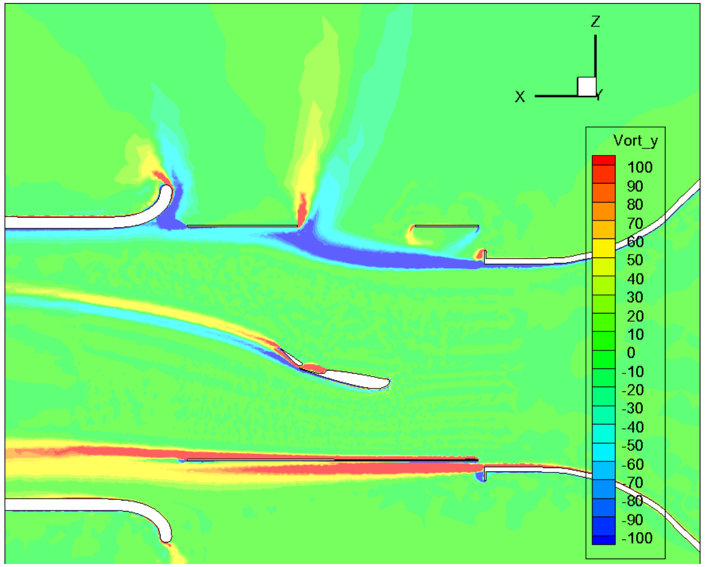
The Wind Tunnel Test Chamber Arrangement Improvements

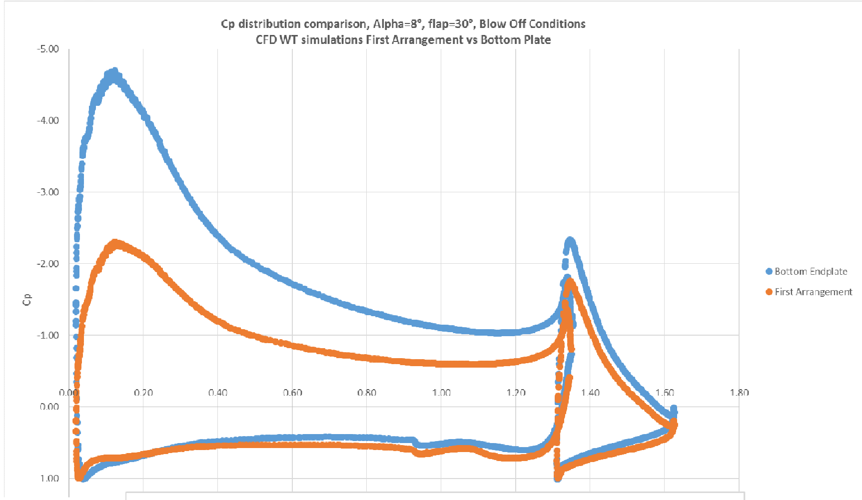
A further stepforward was the addition of an opening on the top endplate, to increase the angle of attack of the airfoil, by reducing the flow acceleration in the test chamber on the upper side.

This last solution was proposed by VKI and counterchecked by Piaggio Aerospace via the Digital Twin



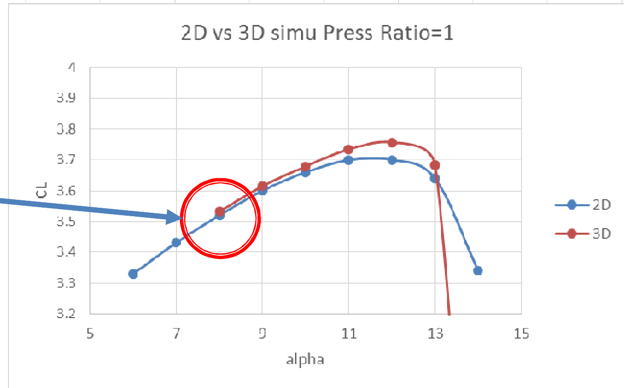
The Wind Tunnel Test Chamber Arrangement Improvements





Flap=30°, alpha=8°	C_L
No bottom plate, rooftop closed	1.87
Bottom Plate, Rooftop closed	2.63
Bottom Plate and Hole on Rooftop	2.86

3D free air (infinite tip endplates) CL > 3.5



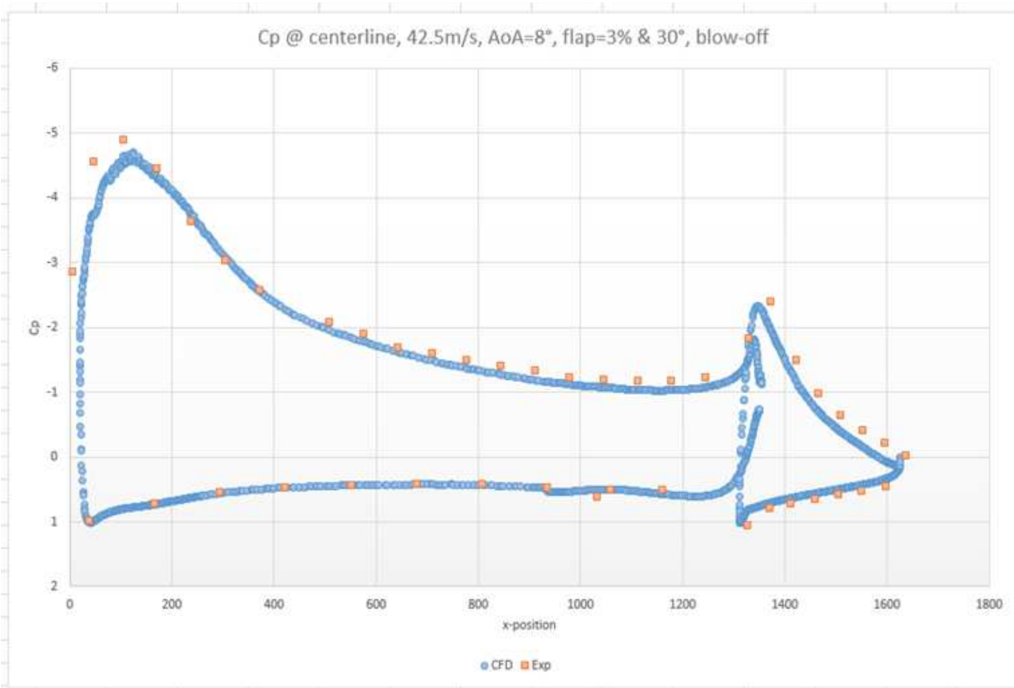
The Wind Tunnel Test Chamber Arrangement Improvement

Rear view

Front view

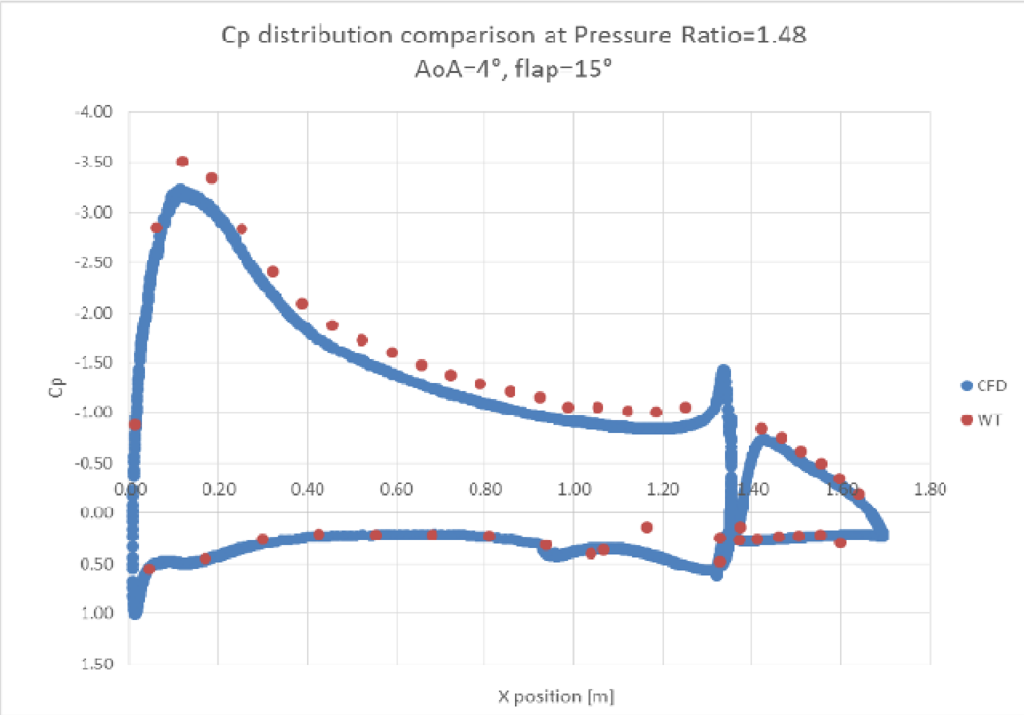
Bottom view

The Wind Tunnel Test Pressure distribution vs CFD prediction: Blow Off



	CFD simulations		WTT		Δ CFD vs WTT [%]	
AoA	C_L	C_{my}	C_L	C_{my}	Δ C_L %	Δ C_m %
4°	2.68	-0.75	2.626	-0.7	+2%	+7%
8°	2.86	-0.625	2.892	-0.66	-1.2%	-4.3%

The Wind Tunnel Test Pressure distribution vs CFD prediction: Blow On

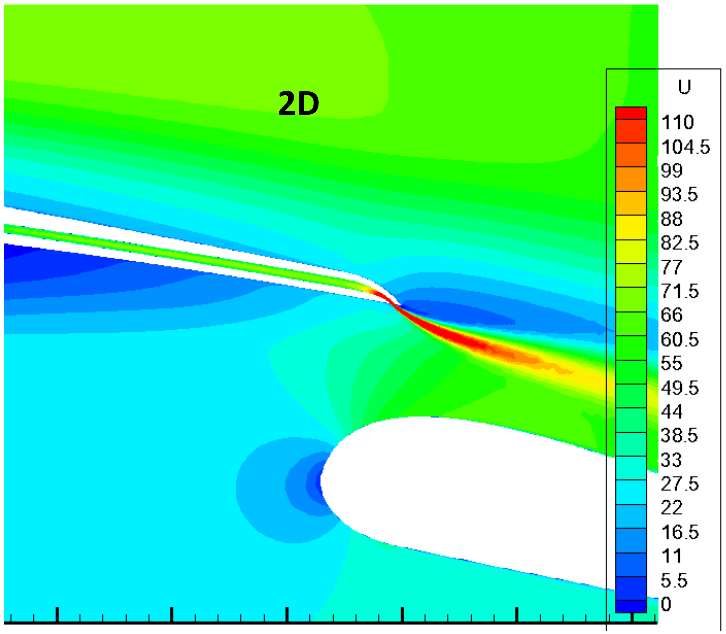


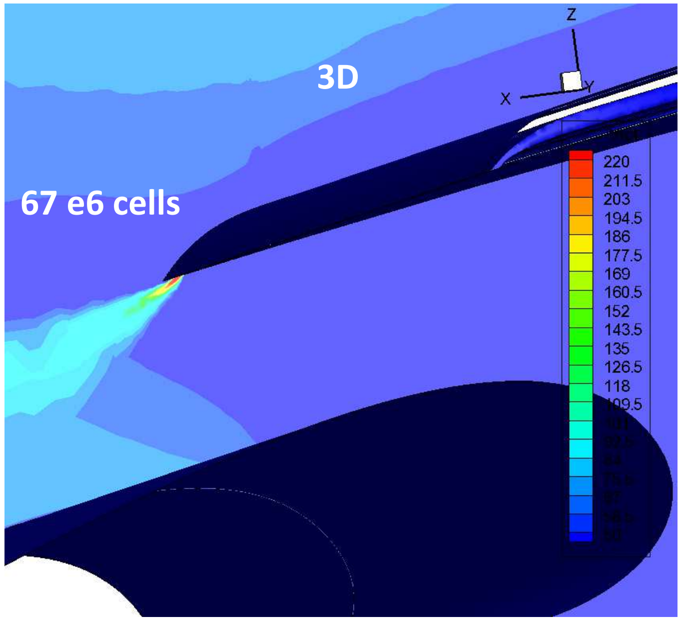
For the blow on case the difference between CFD and WT grows .

AoA=4°, flap=15°, Press Ratio=1.48	
WT CL	2.25
CFD CL	2.03
Δ%	10

The Wind Tunnel Test Pressure distribution vs CFD prediction: Blow On

For the blow on case the difference between CFD and WT grows. The cause has been identified in a worse blow jet gradient definition due to mesh poorness as can be seen by comparison 2D vs 3D simulations. Unfortunately the max number of Piaggio Aerospace available cells was reached for 3D Wind Tunnel case.



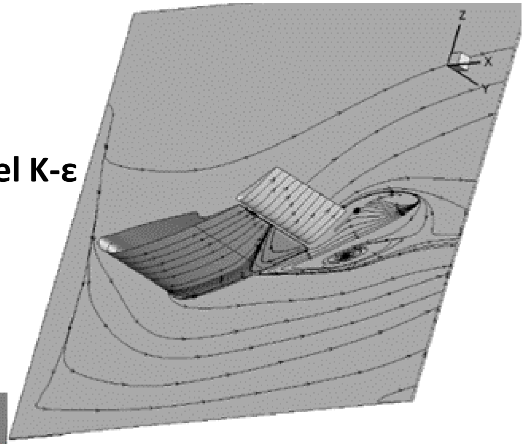


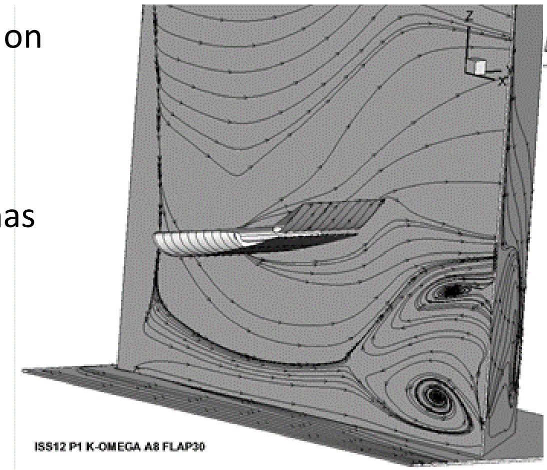
Turbulence Model: K-ω SST or k-ε?

At the start of the activity a check on the effect of the turbulence model has been made. The check took in consideration K-ω SST and K-ε relizable turbulence models applied k-ε at the same mesh and boundary conditions. The computation showed that the adverse pressure gradient rearward the airfoil cannot be sustained by k-ε causing separation on the trailing edge.
K- ω SST, instead, can deal better with the adverse pressure gradient and results in a large recirculation on the lower rear section of the side enplate, whilst the flow on the airfoil remains attached.

The separation on the bottom of the side endplate has been experienced also in WT, visualized using tufts.

Turbulence Model K-ε





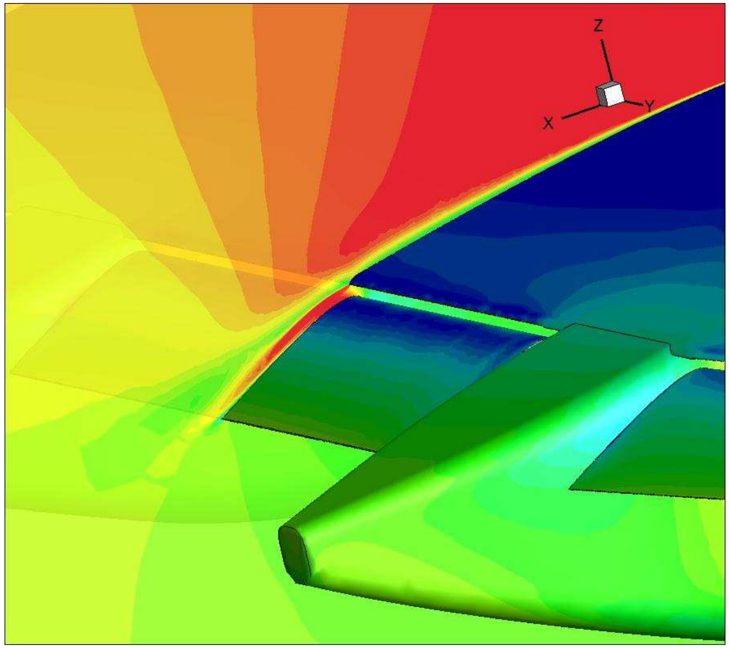
Turbulence Model K-ω SST

Conclusions

Digital Twin outcomes

The Digital Twin approach allows for a successful use of the experimental results for an indirect validation of the CFD design predictions. This outcome overcomes the problem of a model too large to have a wind tunnel that represents the immersion in free air, taking in account of wall interference and blockage.

To reach the above mentioned goal the flow quality have to be assured. In this case also the Digital Twin assumed a very important role.



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DISCLAIMER

The present paper reflects only the author's view and JU is not responsible for any use that may be made of the information it contains.

DATA AVAILABILITY STATEMENT

Data that support the findings of this study are available from the corresponding author upon reasonable request.

Thanks for the attention