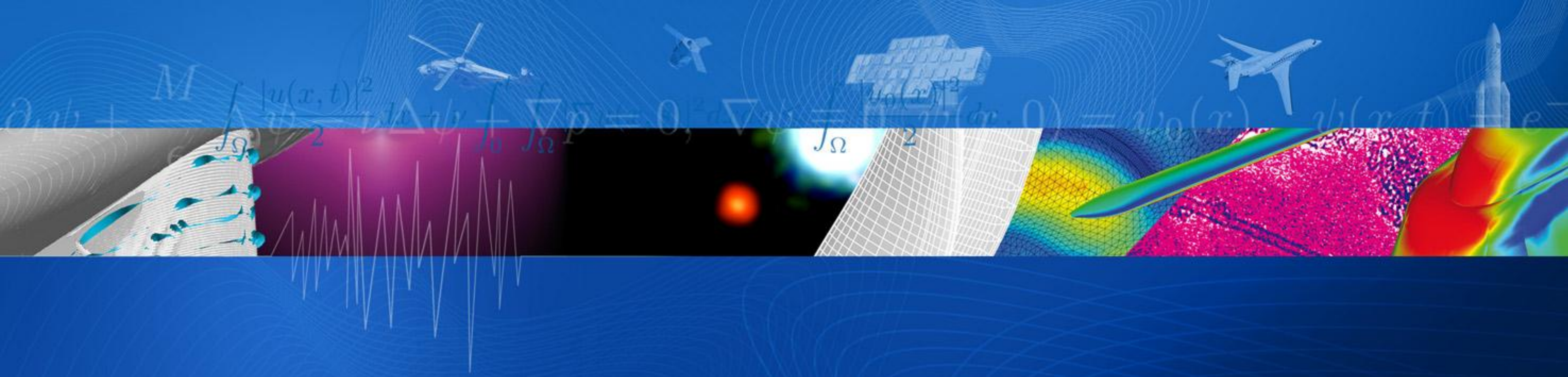

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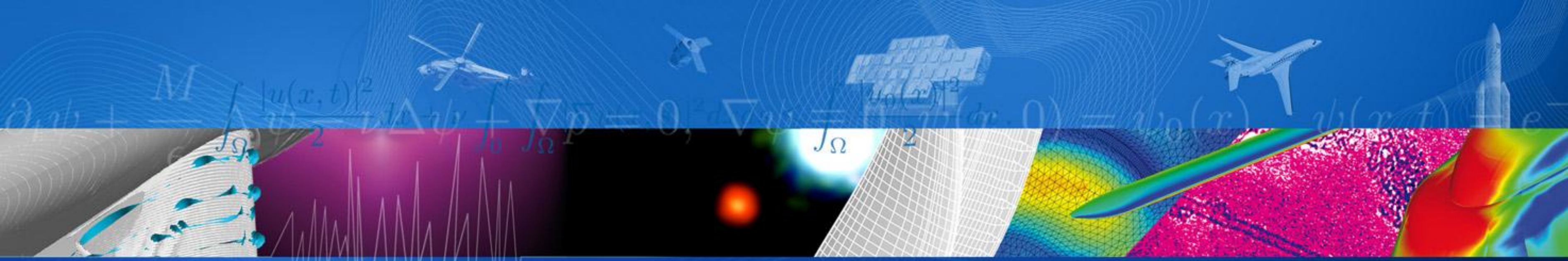

MULTI-DISIPLINARY NUMERICAL OPTIMISATION OF THE SLAT POSITION FOR A REALISTIC 2D HIGH LIFT AIRFOIL

Thomas Le GARREC, Jean-Luc GODARD, Eric MANOHA, Fréderic MOENS, Daniel-Ciprian MINCU, Onera (DSNA/ACOU, DAAP/ACI)

September 24th, 2014

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Context of the study

- Green Regional Aircraft ITD (JTI-GRA)
- “Low-Noise Configuration” Project
- WP 2.2.1 “High-Lift Devices Technologies”
  - *2.2.1.1: To evaluate the capabilities of acoustic liners to reduce the noise generated by 2D high lift airfoils, using high fidelity codes (RANS + ZDES + FW-H methods)*
  - 2.2.1.2: Perform an aeroacoustic optimization (MDO) for a 2D high lift airfoil, aiming at minimizing the airframe noise (downward acoustic power) while maintaining as much as possible the aerodynamic low speed performance (lift)
- Study focused on the Alenia JTI-GRA 3D high lift configuration and generic RA16SC1 HLD profile (EUROPIV configuration)
- Aerodynamic RANS simulations
- Aeroacoustic simulations

Multidisciplinay Optimization Design (MDO) Methodology

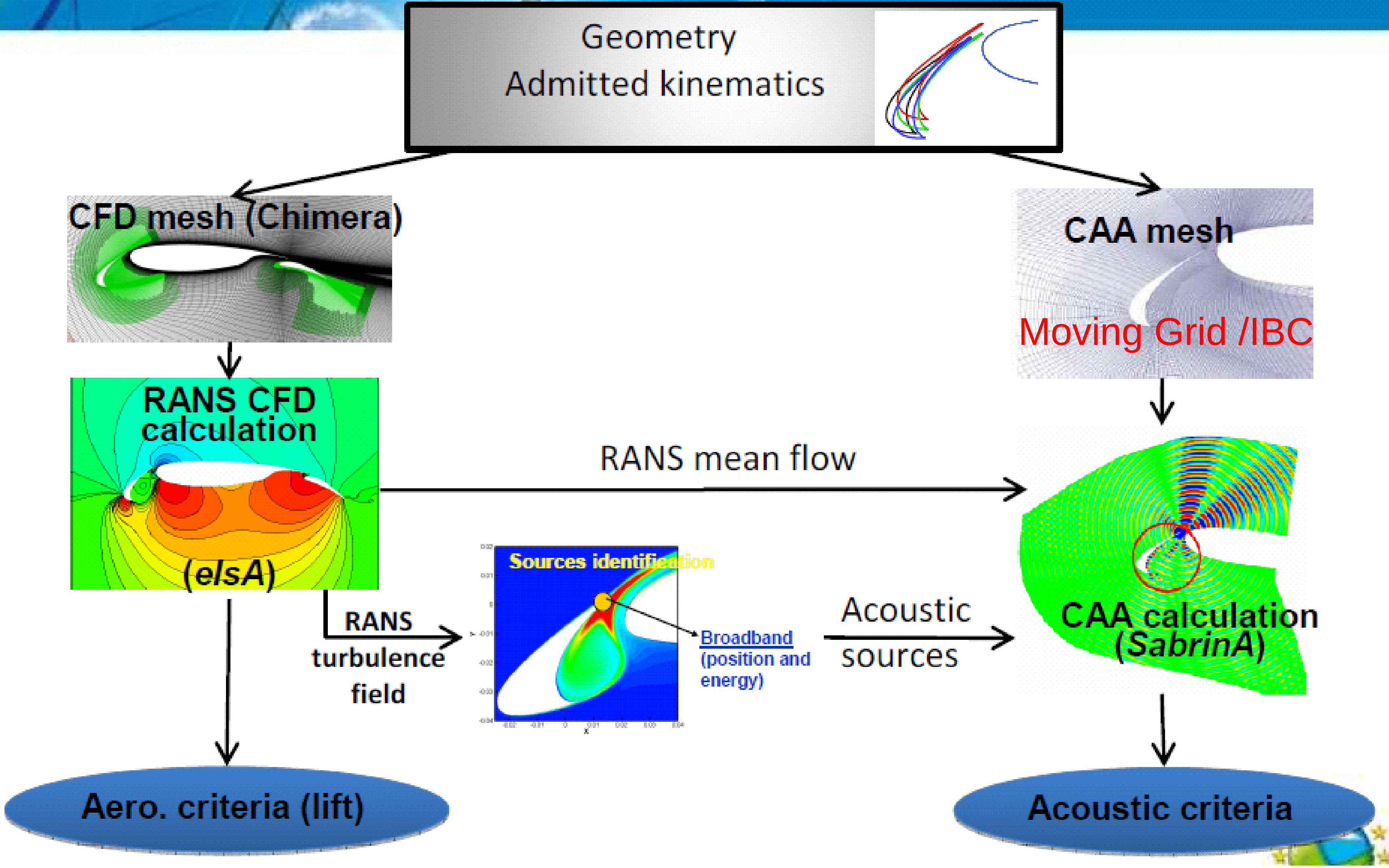
➢ <u>Different steps for each loop of aeroacoustic computation</u>:

- Define design space based on realistic assumptions and mechanical constraints
- Generate aerodynamic mesh
- Perform aerodynamic RANS computation
- Extract aerodynamic data for optimisation
- Generate acoustic mesh
- Interpolate aerodynamic solution on acoustic mesh
- Define noise sources characteristics from aerodynamic flow
- Perform acoustic propagation computation
- Extract acoustic data for optimisation

➢ <u>Different steps for optimisation process</u>:

- Generation of a database of different shapes
- Construction of two surrogate model (aerodynamic, acoustic)
- Optimisation on the surrogate models
- A second optimisation was performed after local enrichment of the surrogate model around the first solution

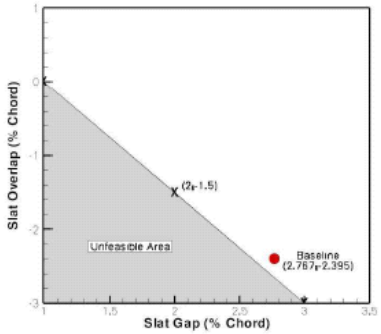
Multidisciplinay Optimization Design (MDO) Methodology

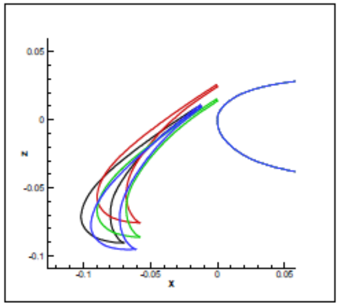


Multidisciplinay Optimization Design (MDO) Methodology

➢ Design space / parameters:

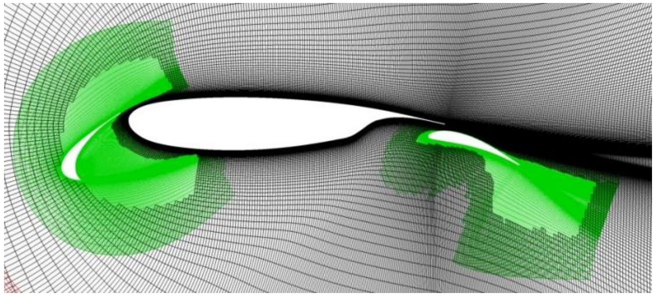
- ➢ Gap and overlap
- ➢ Deflection angles: 30 deg slat +/-5 deg, flap -5/+10 deg





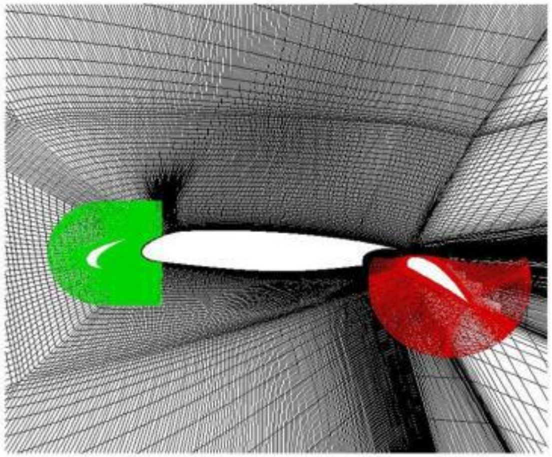
➢ Aerodynamic mesh generation:

- ➢ Automatic remeshing using an overset approach (chimera technique)



➢ Aerodynamic calculation:

- ➢ 2D CFD RANS (elsA software) with Wilcox k-ω or Spalart-Allmaras TM

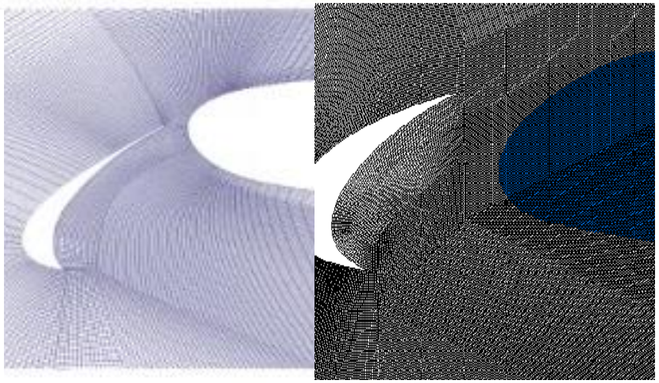


➢ Data extraction for optimisation:

- ➢ CL in landing condition (optimisation parameter)
- ➢ Aerodynamic mesh and flow as inputs for acoustic computation

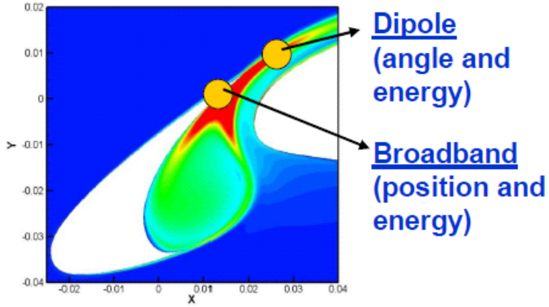
Multidisciplinay Optimization Design (MDO) Methodology

- **<u>Acoustic mesh generation</u>:**
  - Automatic remeshing using a journalized module
  - Mesh refurbishing (Gambit) and mesh filtering (external filtering module)
  - IBC mesh creation



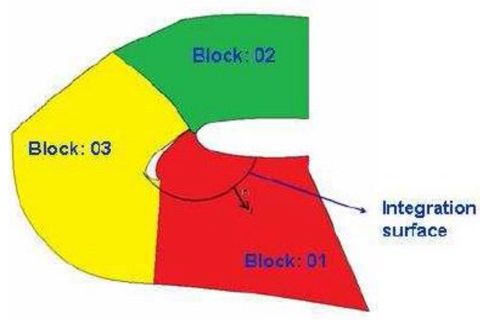
- **<u>Aerodynamic flow interpolation</u>:**
  - Tecplot software

- **<u>Noise sources identification</u>:**
  - Dipole and broadband noise sources determined from turbulent kinetic energy and second turbulent variable



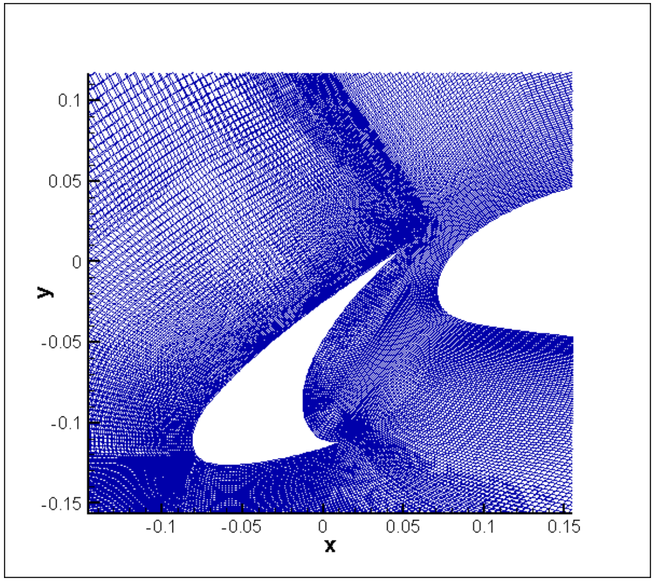
Turbulent kinetic energy

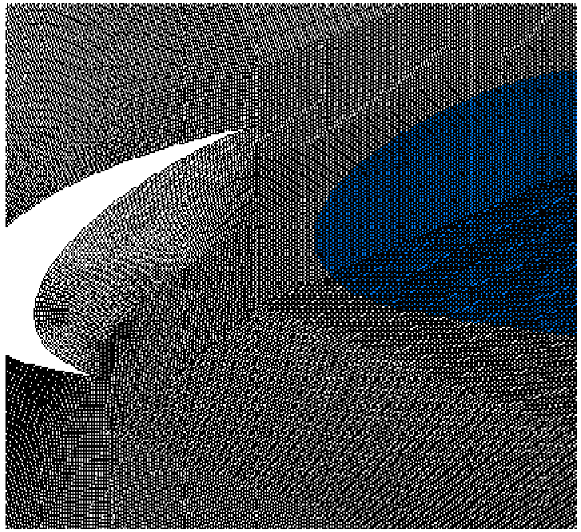
- **<u>Noise propagation calculation</u>:**
  - 2D CAA Euler computation (sAbrinA_v0 software)



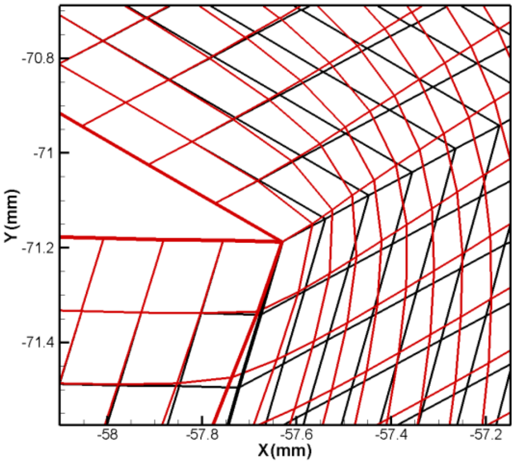
- **<u>Data extraction for optimisation</u>:**
  - Downward acoustic power (optimisation parameter)

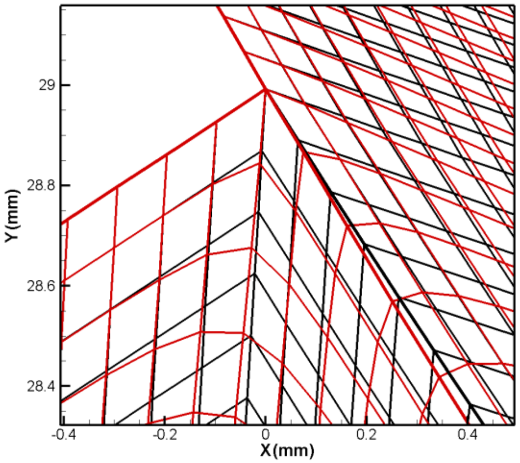
Multidisciplinay Optimization Design (MDO) Methodology – Mesh creation



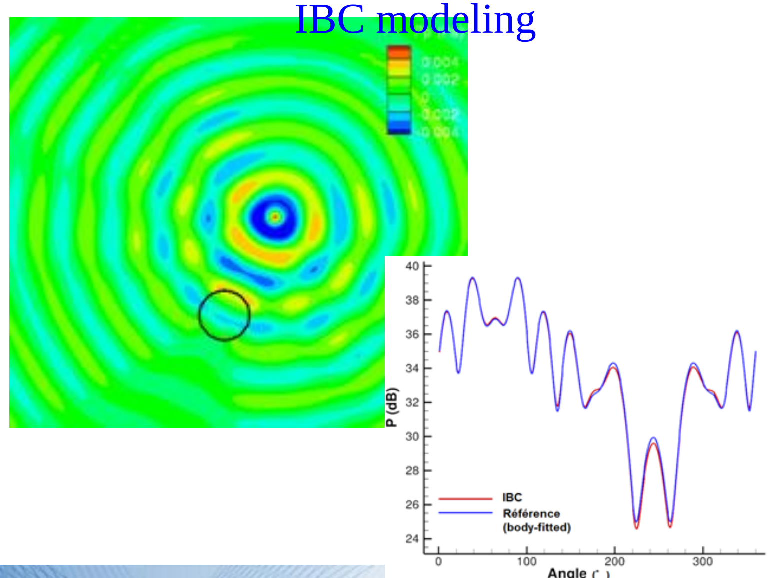


Dynamic body fitted



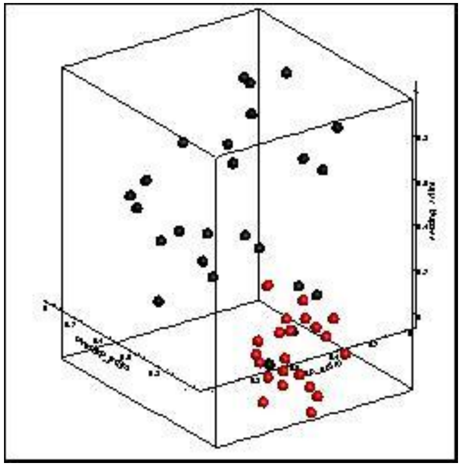


IBC modeling

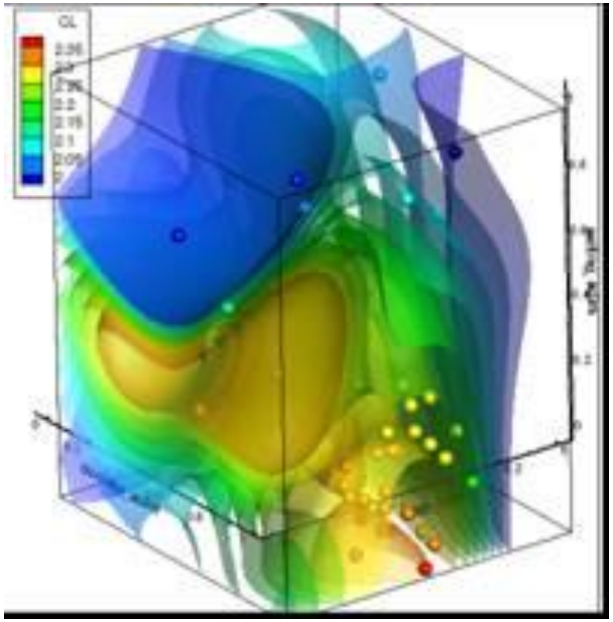


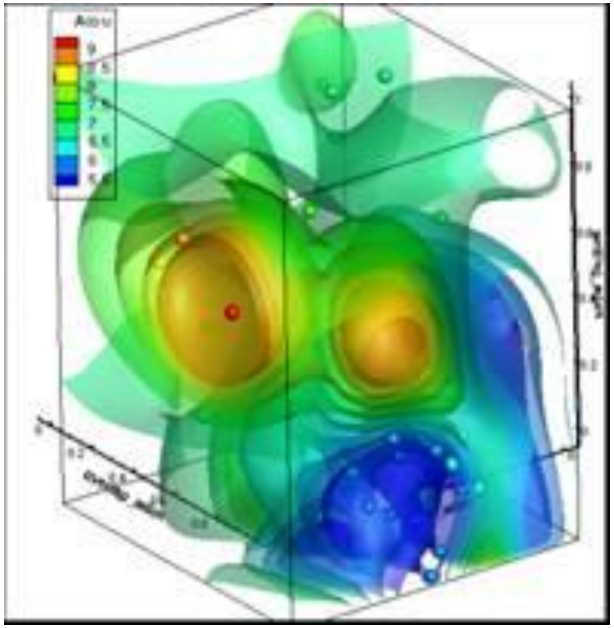
Multidisciplinary Optimization Design (MDO)
Results on RA16SC1

- Generation of a database of shapes: selection of a sampling of 24 shapes
- Optimization process: multi objective genetic algorithm -> Pareto front
- Second step of optimization: enrichment of the Kriging models in the region of best designs, followed by optimization



First and second samplings in the design space (overlap, gap, setting)





Final kriging models for the lift (left) and acoustic power (right)

Optimum for aerodynamic and acoustic seems to be in the same region of the space domain

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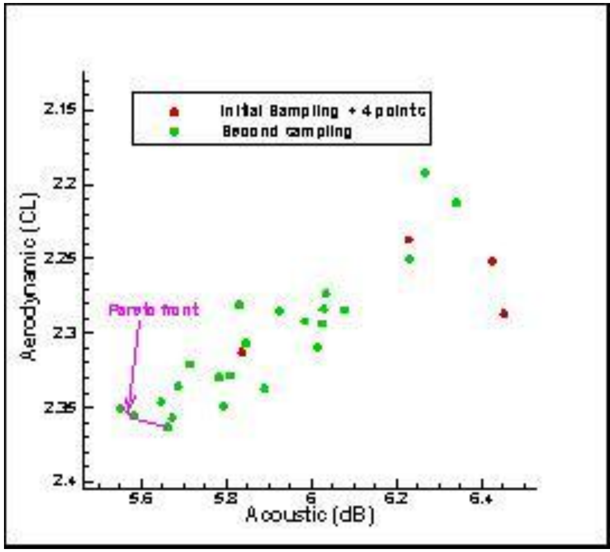
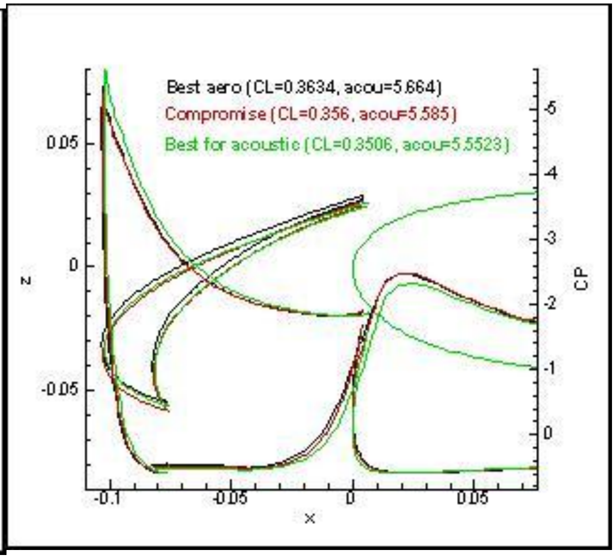
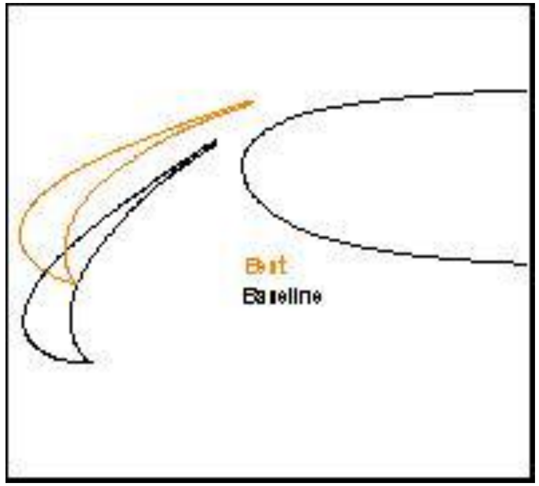
Multidisciplinary Optimization Design (MDO) Results on RA16SC1

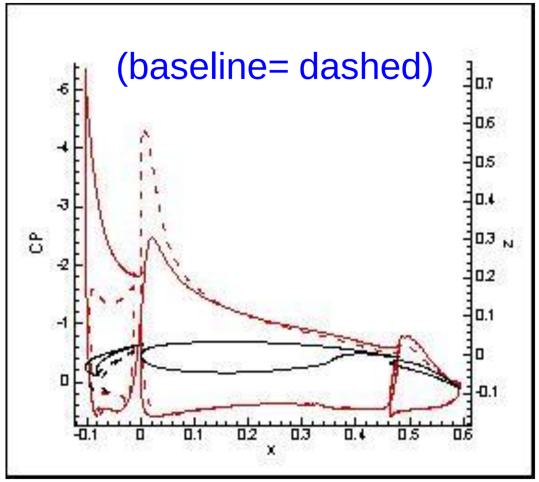
Comparison of geometry and pressure of three Pareto optimum designs





Comparison of best and baseline geometries (shape and Cp distribution)





- Baseline: CL≈ 2.15
- Best shape (for aerodynamics): CL≈ 2.35

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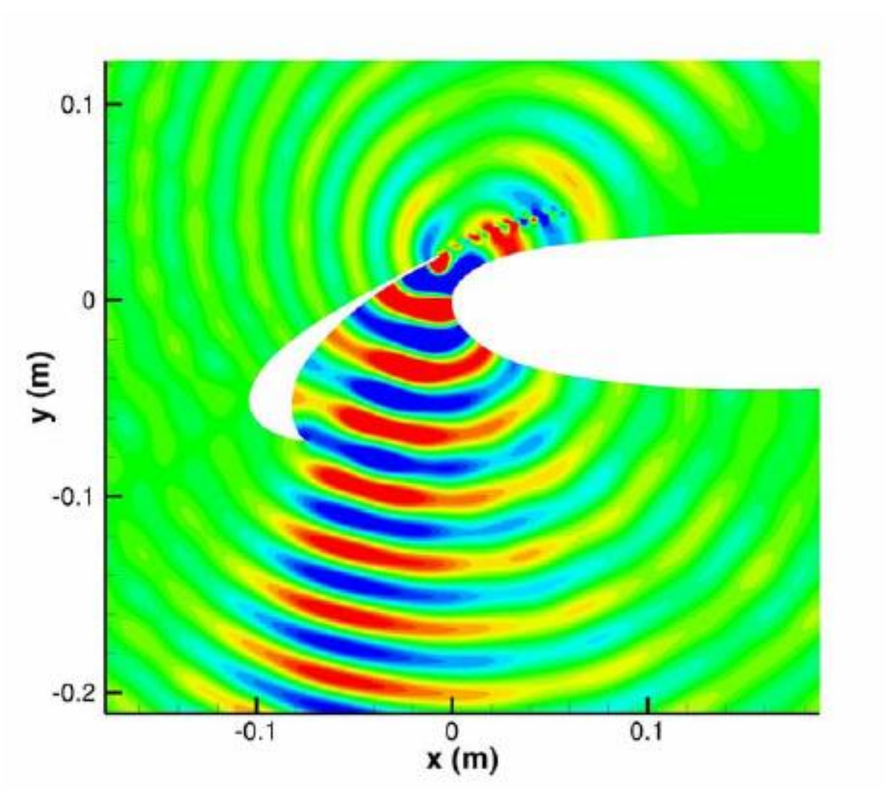
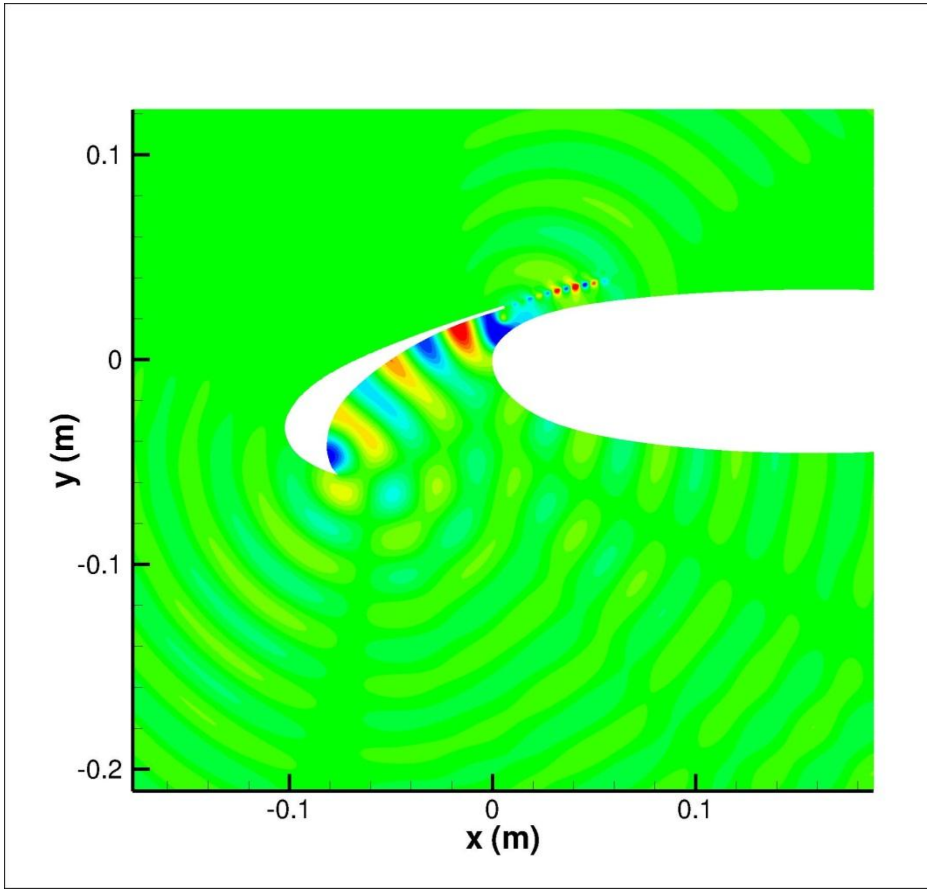
Multidisciplinary Optimization Design (MDO) Results on RA16SC1

Comparison between the best and the baseline configurations
Acoustic instantaneous pressure field

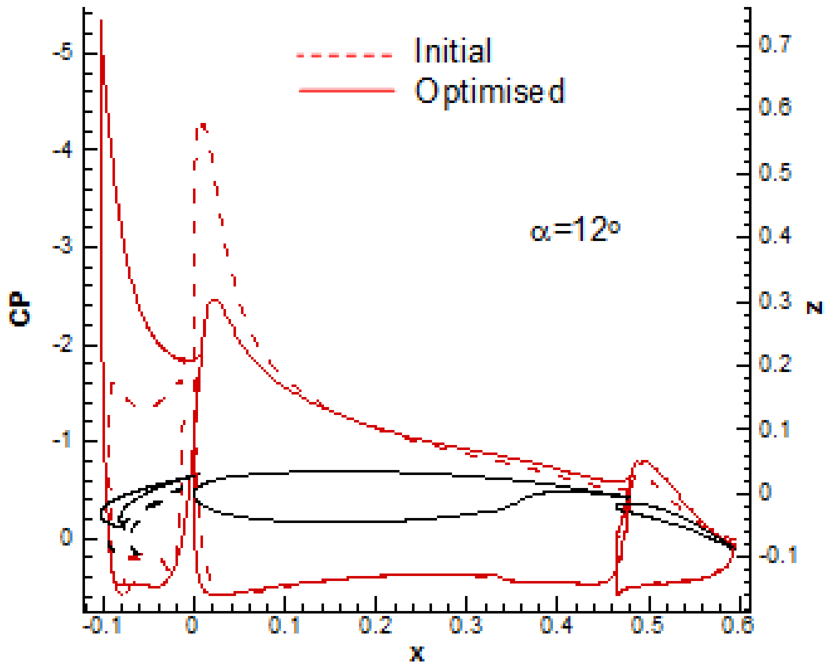




➢ About 50% downward noise reduction

Multidisciplinay Optimization Design (MDO) Alenia JTI-GRA 3D HLD

- Generation of a database of shapes: selection of a sampling of 30 shapes
- Optimization process: multi objective genetic algorithm -> Pareto front
- Second step of optimization: enrichment of the Kriging models in the region of best designs, followed by optimization
- We also have to consider the improvement of lift coefficient at high angle of attack, not only at flight conditions (the use of a leading-edge device is to improve CL_{max} and α_{max})

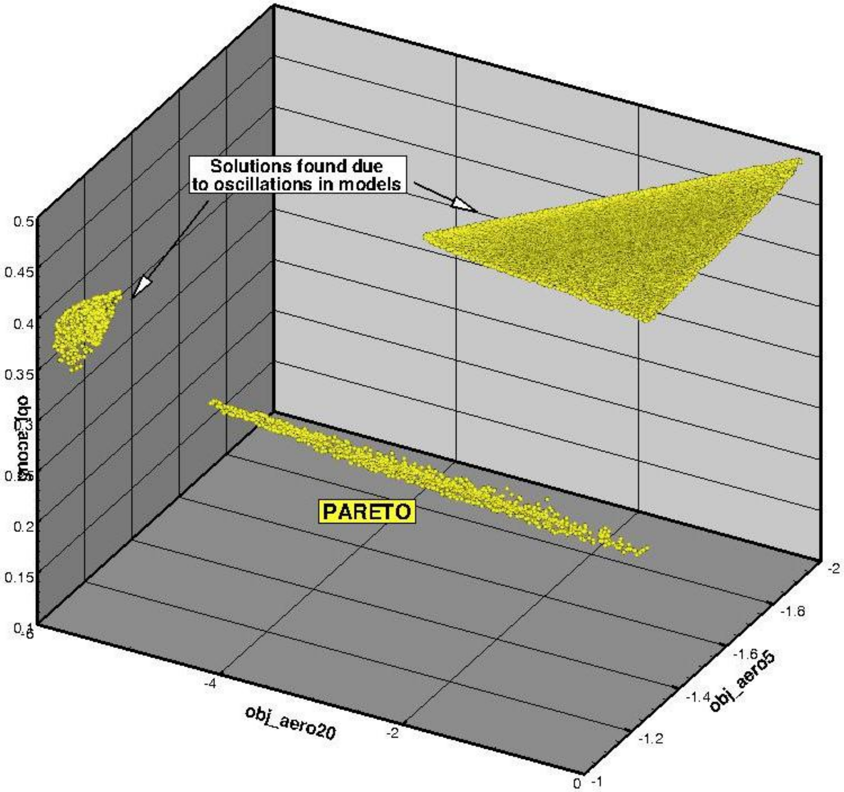


- Obj Aero 1: Increase lift at α_{max};
- Obj Aero 2: Increase lift at α_{nom}
- Obj Acou 3: Minimum noise at α_{nom}

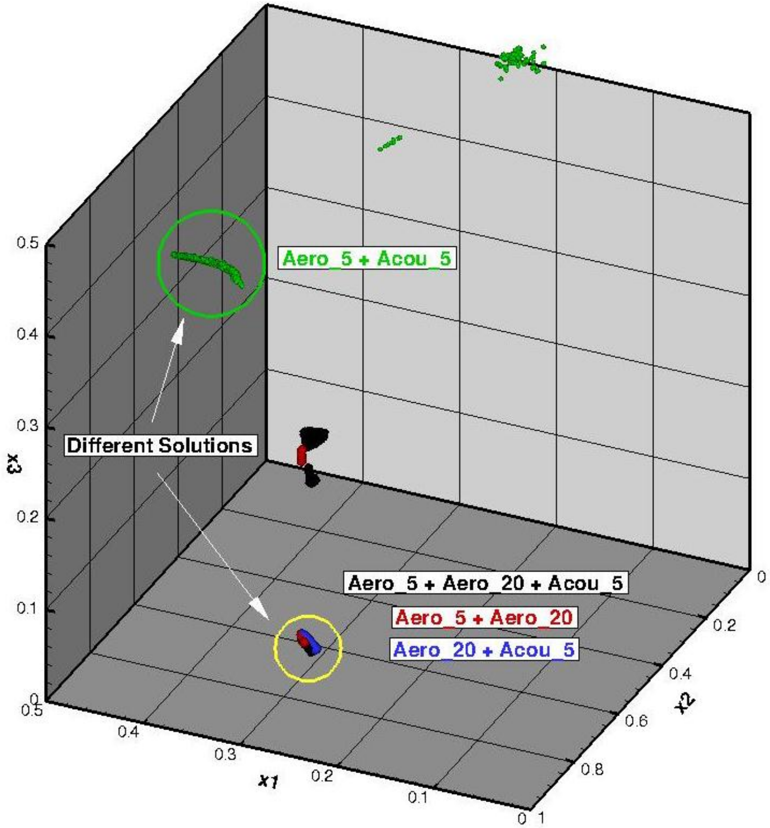
tri-objective optimization problem

Multidisciplinay Optimization Design (MDO)
Alenia JTI-GRA 3D HLD

The Pareto tri-objective optimum designs



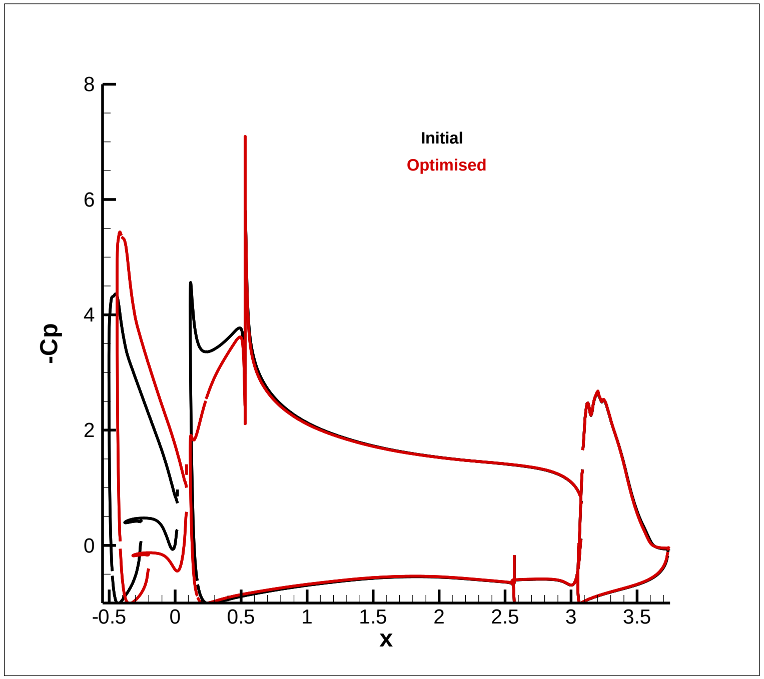
The Pareto tri-objective optimum designs in space of design

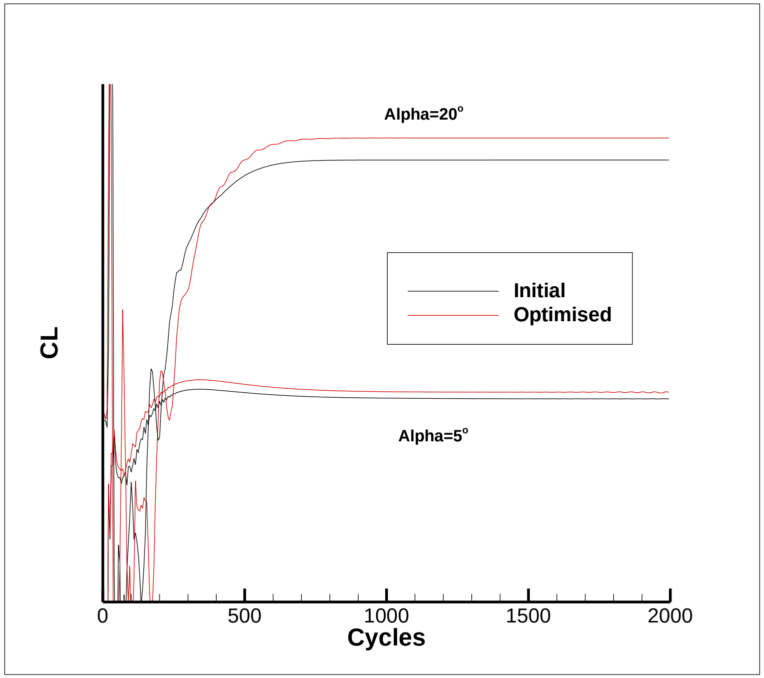


Multidisciplinay Optimization Design (MDO)
Alenia JTI-GRA 3D HLD

Comparison of best and baseline geometries (shape and Cp distribution)

	Obj_Aero5	Obj_Aero20	Obj_Acou5
INITIAL	0	0	1
OPTIMISED	1.259%	2.789%	-71%





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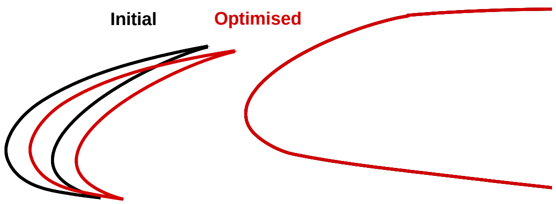
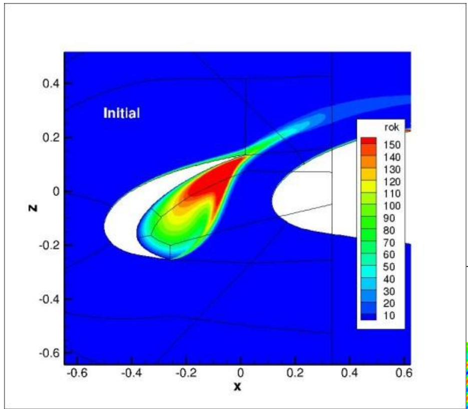
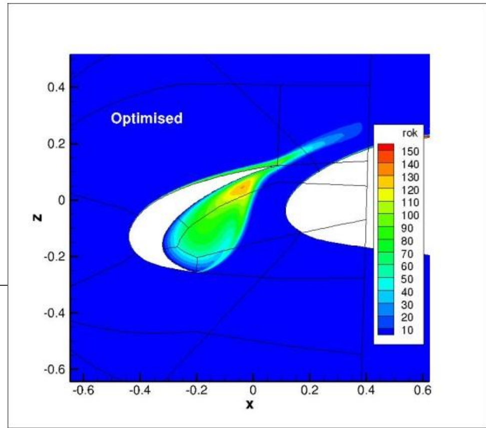
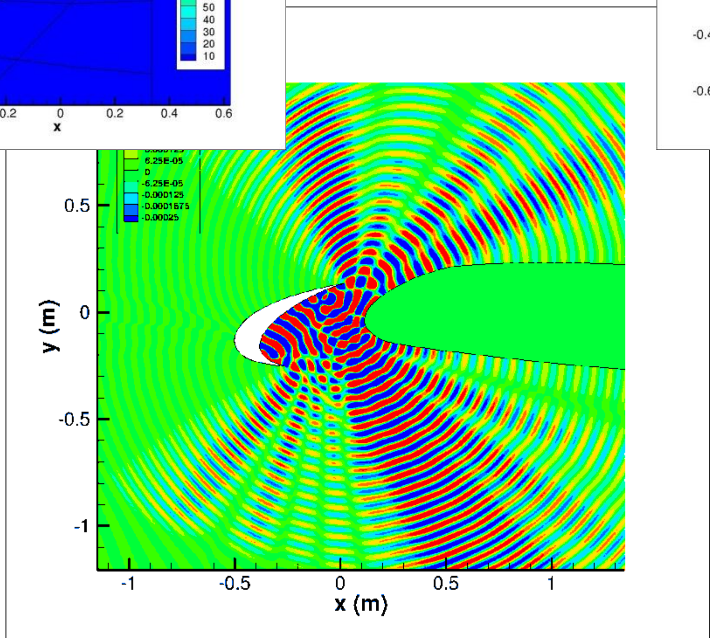
Multidisciplinay Optimization Design (MDO)
Alenia JTI-GRA 3D HLD

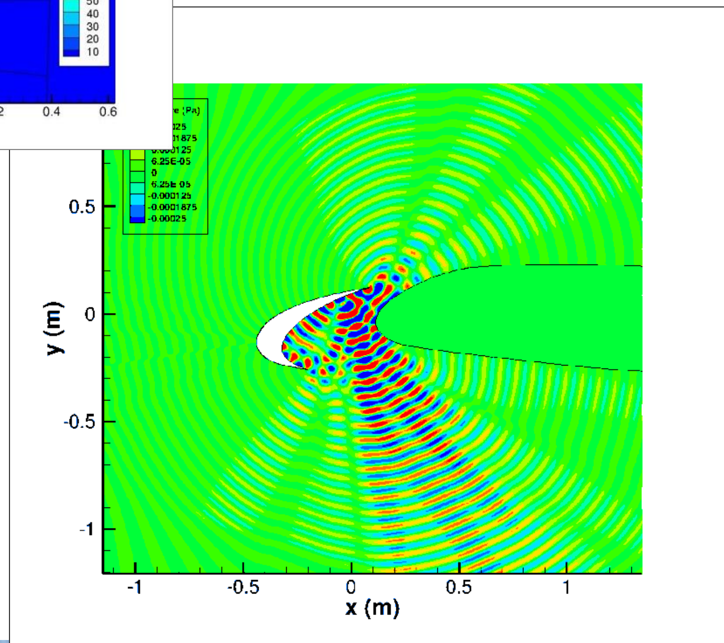


	Obj_Aero5	Obj_Aero20	Obj_Acou5
INITIAL	0	0	1
OPTIMISED	1.259%	2.789%	-71%









➢ Conclusions:

- Optimisation of the slat position of a 2D high lift airfoil has been performed considering aerodynamic and acoustic criteria
- A complete optimisation tool has been set-up for this work
- The objective is to minimize airframe noise (downward acoustic power) while maintaining aerodynamic low speed performance (lift)
- The optimisation is done with a multi-objective genetic algorithm and considers surrogate models, generated with a Kriging technique applied to database of results for different airfoil shapes

Conclusions

- **Conclusions:**

  - The optimisation was performed firstly on a baseline shape (RA16SC1) and showed the capabilities of this tool
  - The regions of maximum lift and minimum noise are located at the same position in the design space
  - This region is located at the border of the authorised design space (maximum overlap, minimum setting angle)

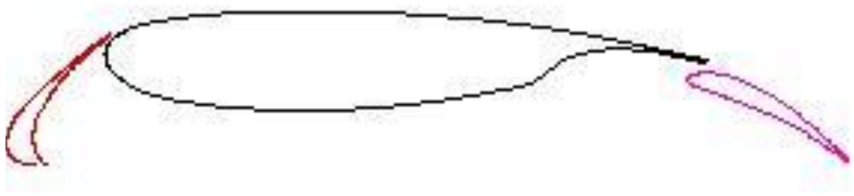
  - Following the previous up-and-downs the methodology was applied to the Alenia JTI-GRA regional HLD wing
  - A new optimization parameter was identified
  - A complete different slat position for the three parameters optimum
  - 1-2% CL improvement and up to 70% noise reduction

➢ **Different steps for liner influence assessment:**

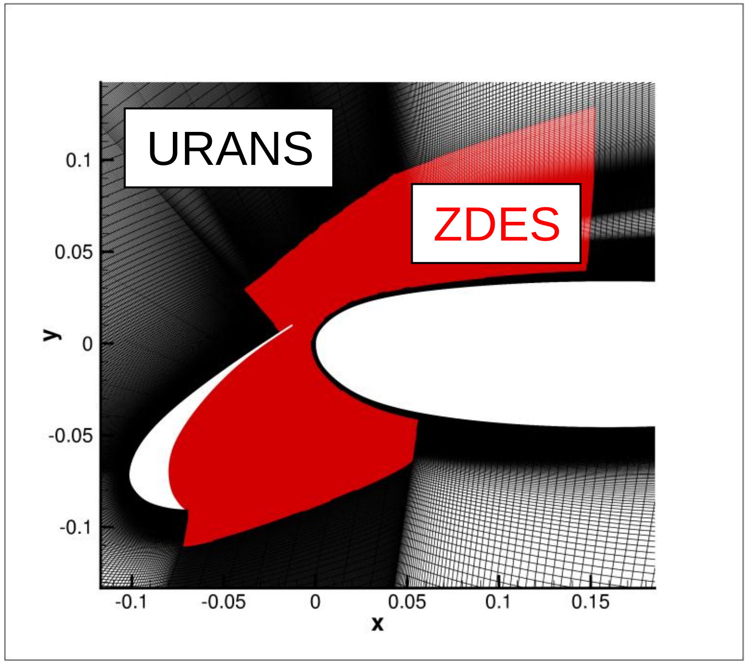
- ➢Generation of aerodynamic meshes for RANS and ZDES computations without liner
- ➢Aerodynamic RANS computation without liner, to initiate ZDES computation
- ➢Aerodynamic ZDES computation without liner
- ➢Acoustic propagation computation without liner, with Ffowcs-Williams Hawkings method, using the aerodynamic flow as inputs
- ➢Parametric study to determine the most efficient position of liner on the airfoil, with acoustic propagation computations performed with an Euler solver -> selection of an “optimum” liner position
- ➢Aerodynamic RANS computation, followed by ZDES computation with liner
- ➢Acoustic propagation computation with liner, with FW-Hawkings method
- ➢Comparison between numerical results without and with liner

ZDES computations
HLD geometry

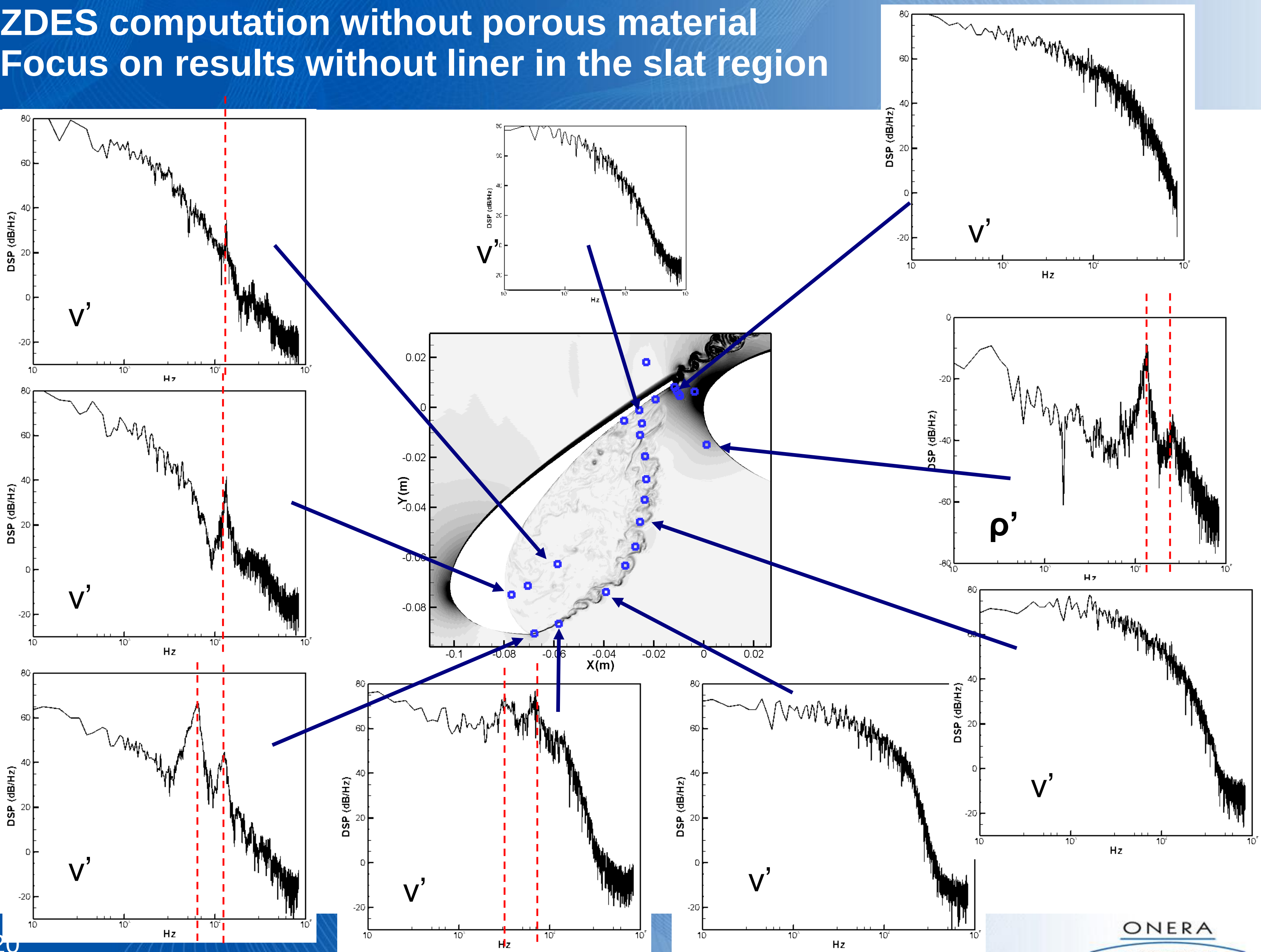
- Aerodynamic conditions considered:
  - Velocity 54 m/s
  - Angle of attack 9 degrees
  - Reynolds number 1.7 million (L_{ref} 0.5 m)
- Structured meshes (with ICEM-CFD):
  - 2D : 714 10^3 mesh points for RANS computation
  - 3D : ~72,19 10^6 mesh points (101 nodes in the spanwise direction) for ZDES computation
- $\Delta t=3.\ 10^{-7}$s
- Mesh generation (two configurations)
  - Controled stretching
  - Smooth transitions between the LES/URANS zones
- Unsteady CFD extractions
  - Solid walls
  - In fluid surfaces for FW-H integrals (MIA solver)
  - Longitudinal lines



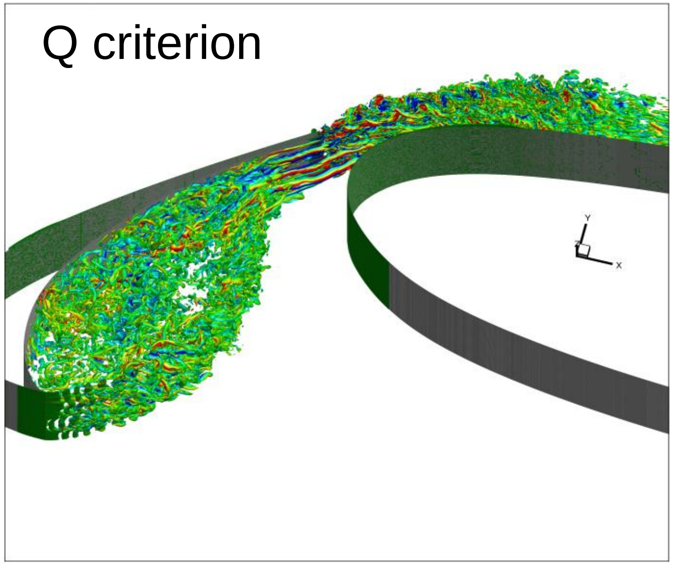
RA16SC1 generic high lift airfoil
(slat deflection 30 degrees, flap deflection 40 degrees)
EUROPIV configuration

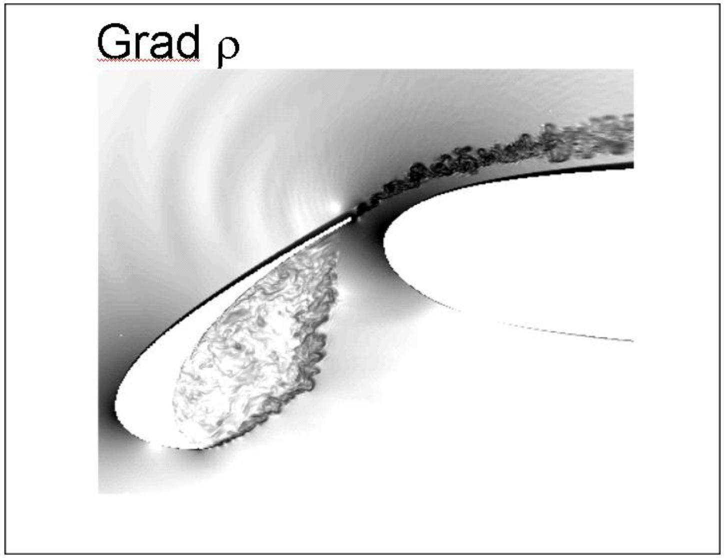


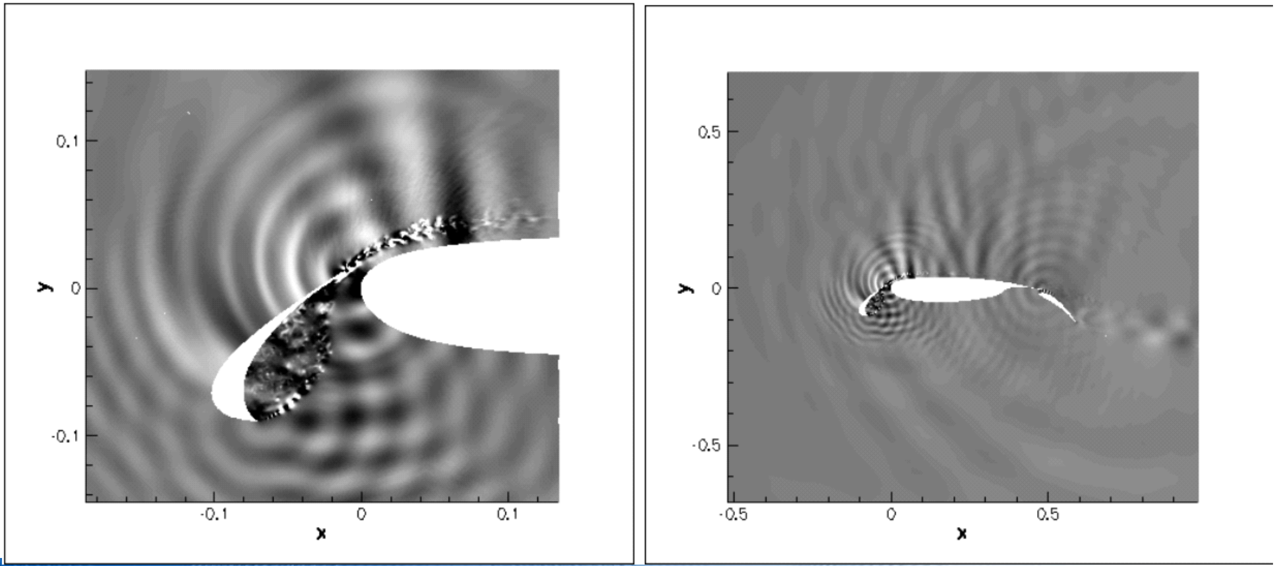
ZDES computation without porous material
Focus on results without liner in the slat region



ZDES computation without porous material
Some results without liner







Acoustic field p'

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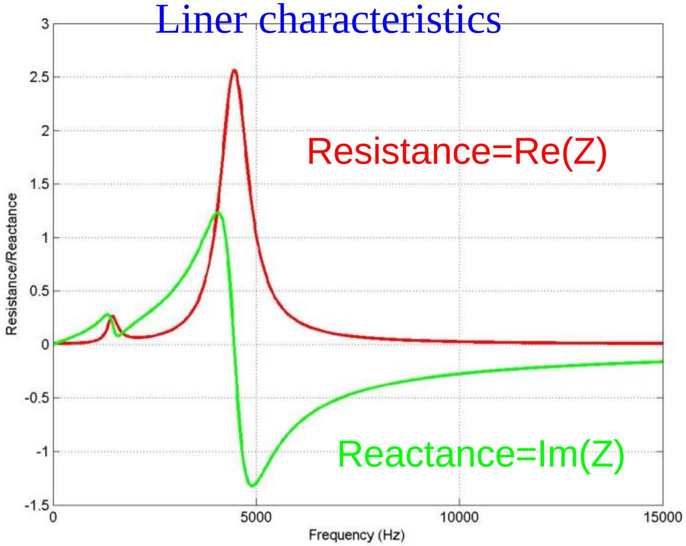
Liner position determination

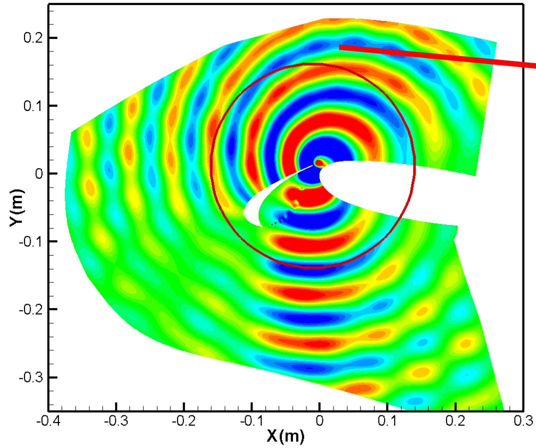
➢ CAA computations with sAbrinA_v0 solver

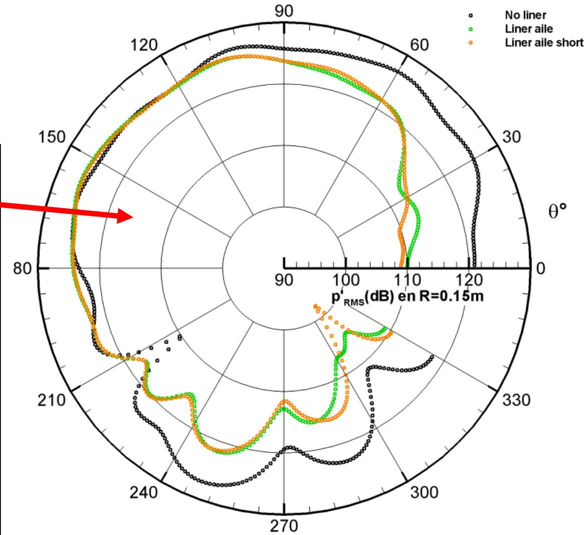
Comparison of acoustic directivities

Liner characteristics

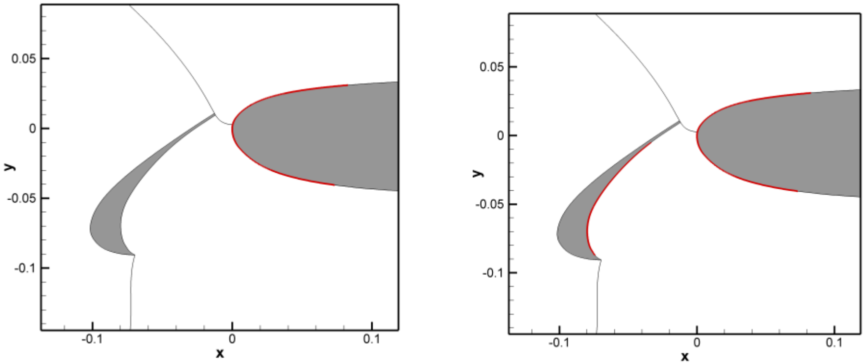


Instantaneous acoustic pressure field





Liner position and extent



Decision parameter : downward acoustic power

	P_{acou}/P_{acou}(no liner)
No liner	**1**
Liner on wing	**0.4**
Liner inside the slat	**1.14**
Liner on wing and slat	**0.54**

Best choice : liner on wing only

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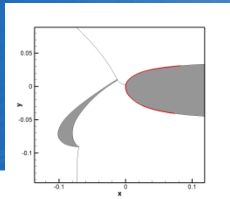
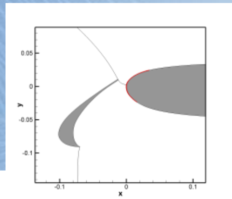
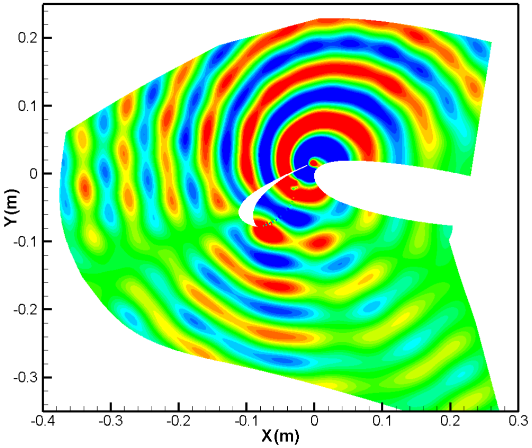
Liner position determination

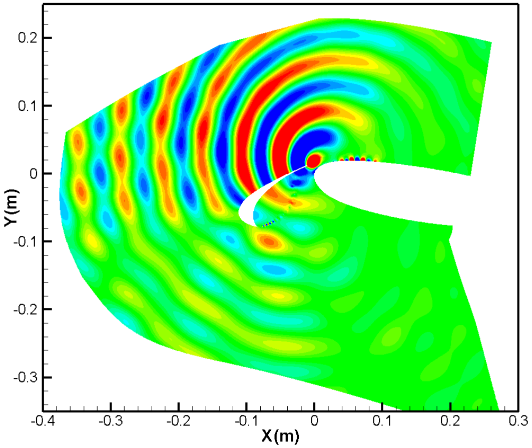


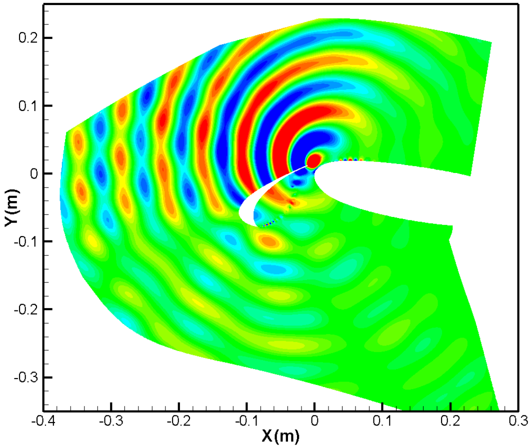


Without liner | Liner on wing | Reduced liner on wing

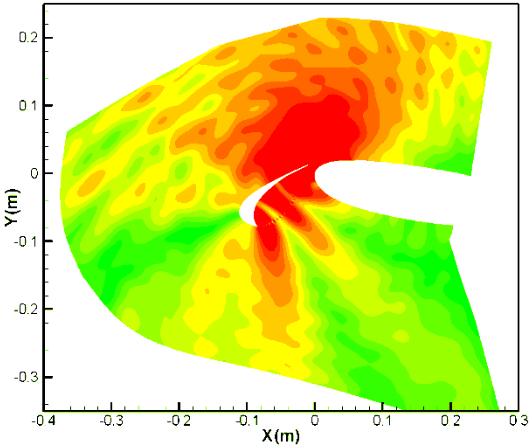
Instantaneous acoustical field

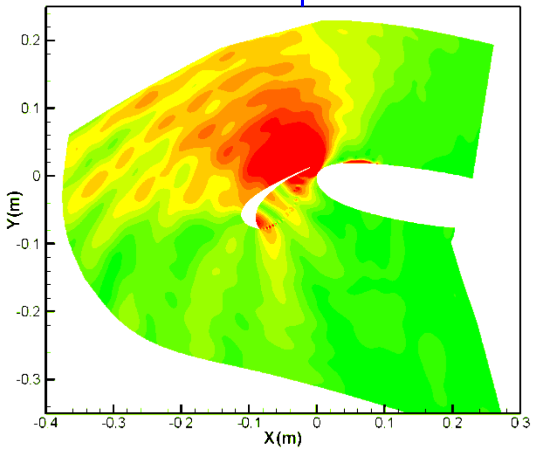


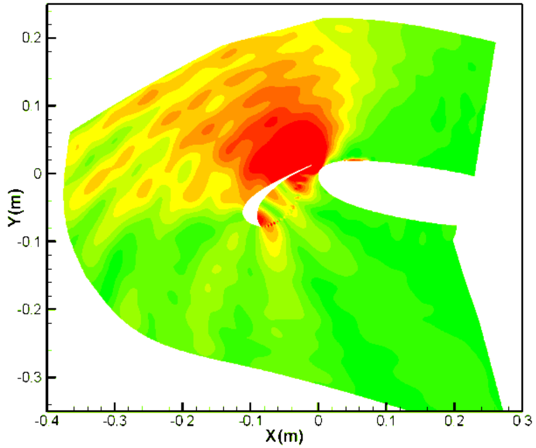




RMS pressure







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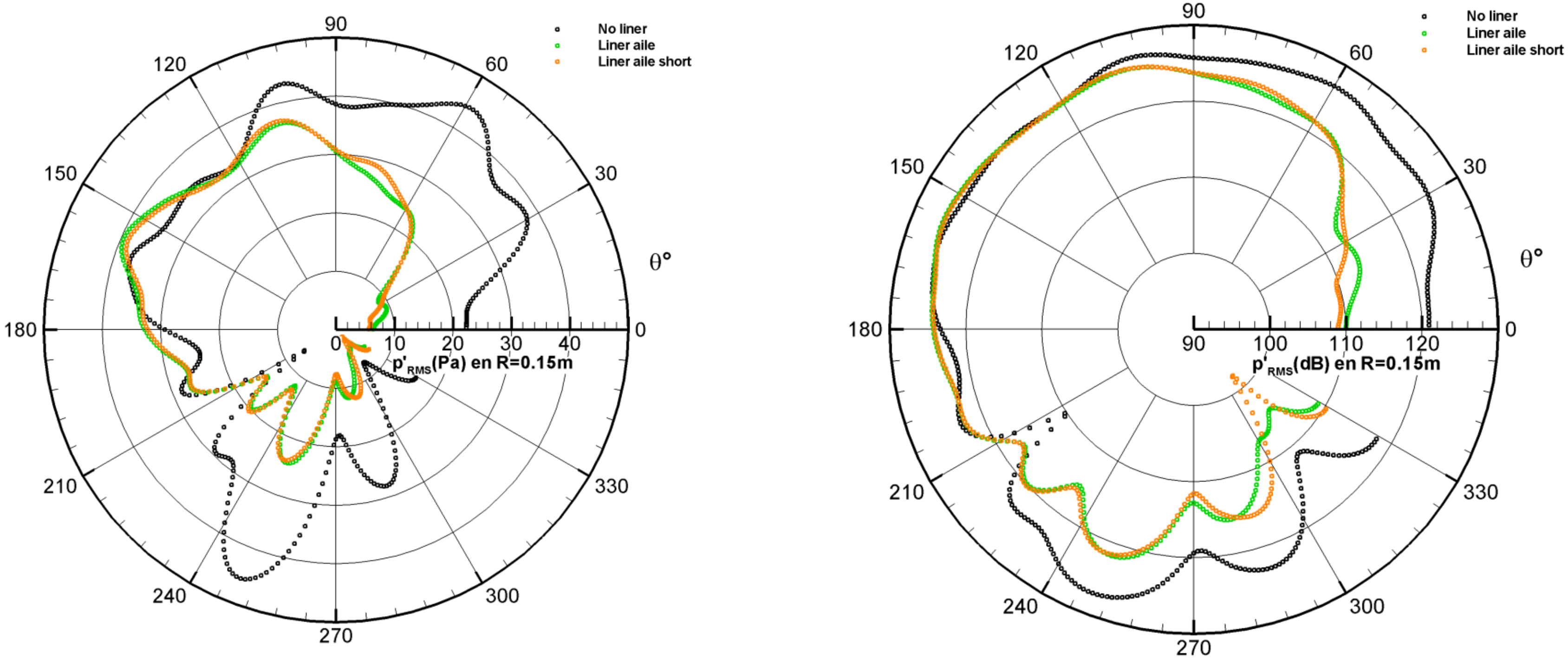
Liner size reduction

Acoustical directivity p'_{RMS} (R=0.15m) in Pa (left) and in dB (right)



	P_{acou}/P_{acou}(without liner)
Without liner	**1**
Liner on wing	**0.4**
Reduced Liner on wing	**0.39**

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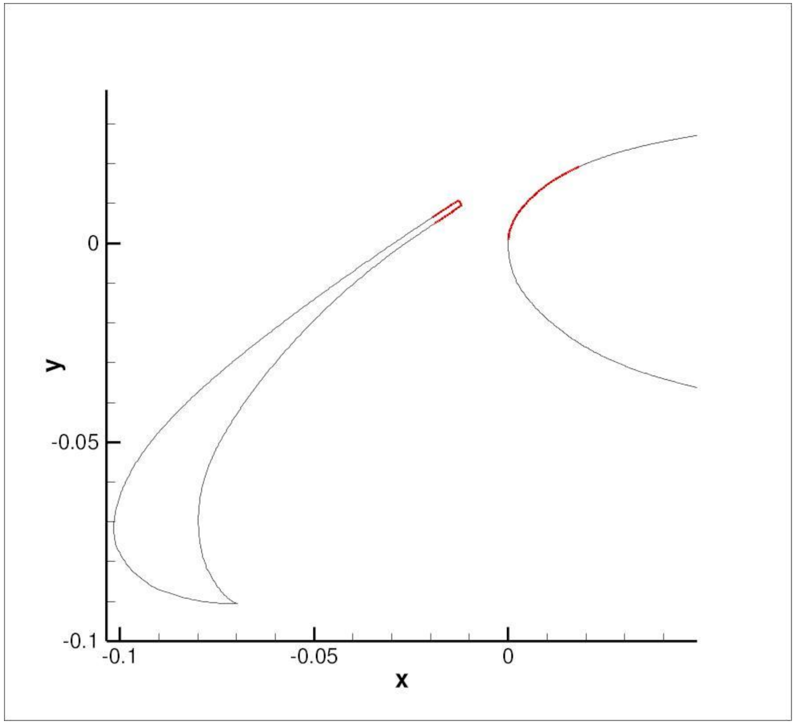
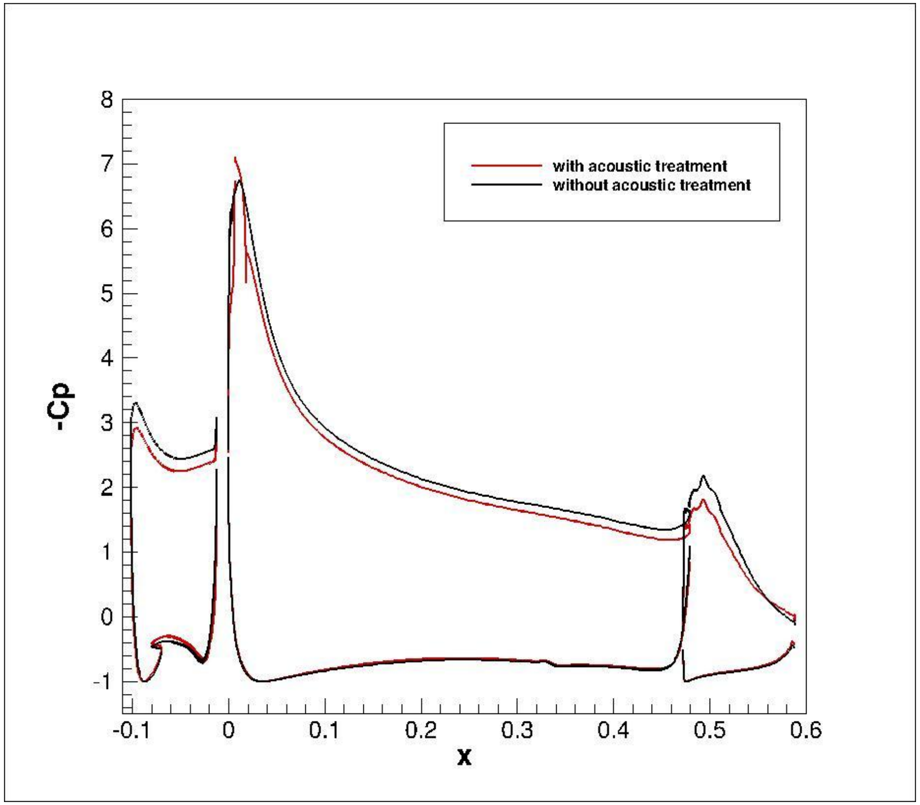
ZDES computation with porous material

Liner position and extent





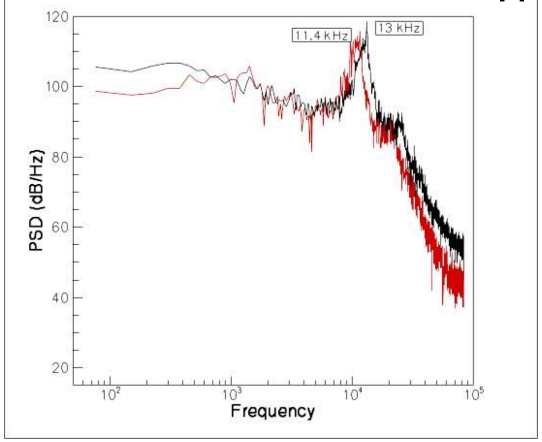
- Aerodynamic influence of the acoustic treatment on average pressure and lift coefficient

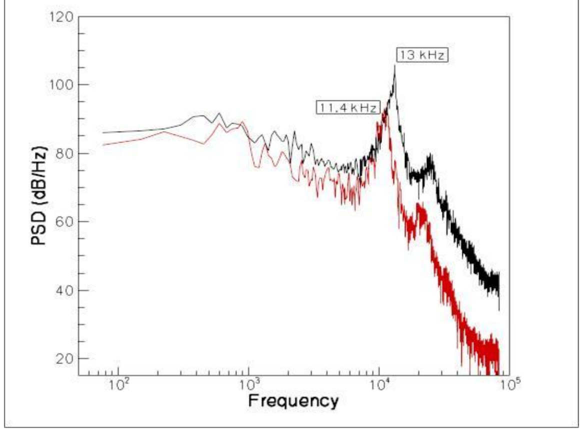
- CL = 4 without porous material
- CL = 3.73 with porous material

ZDES computation with or without porous material

- Comparison <u>without</u> and <u>with</u> liner: Pressure frequency spectral

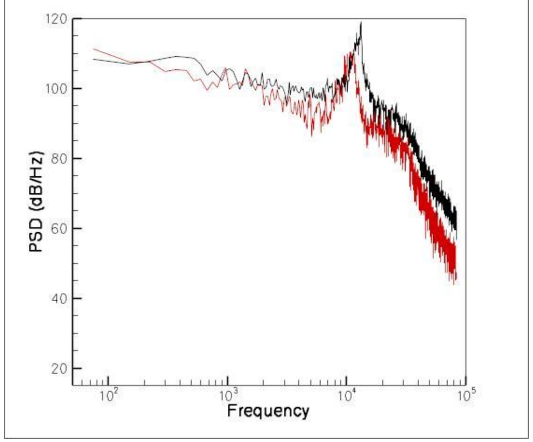
Slat upper surface

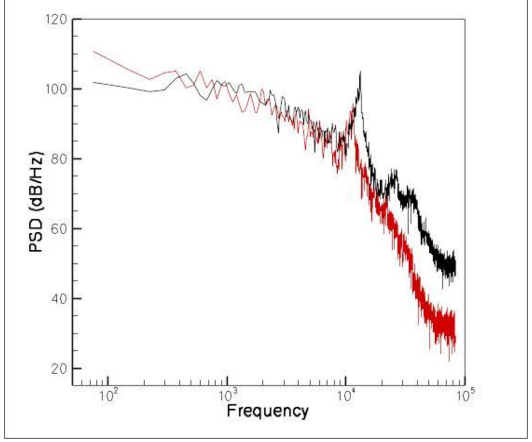


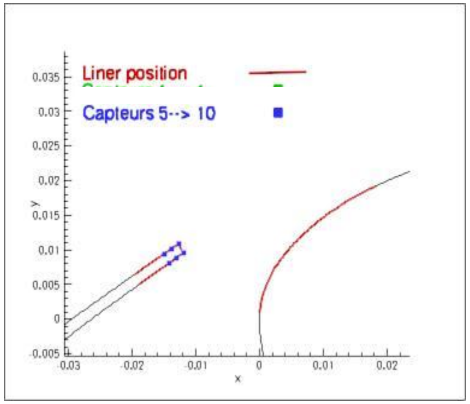


- A peak due to turbulent vortex shedding of the slat trailing edge:
  - At 13 kHz without porous material
  - At 11.4 kHz with porous material

Slat lower surface





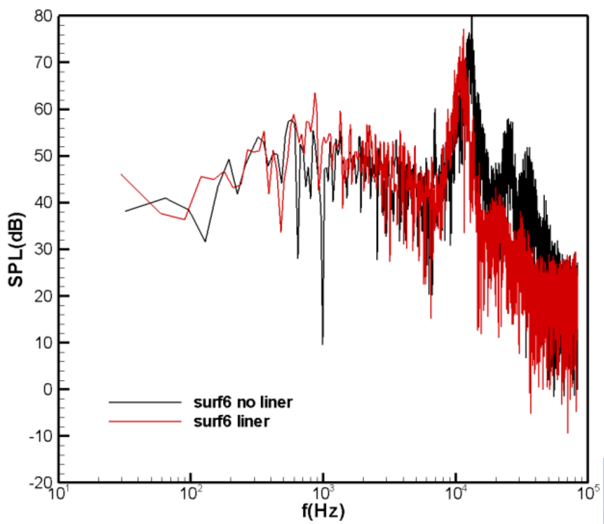


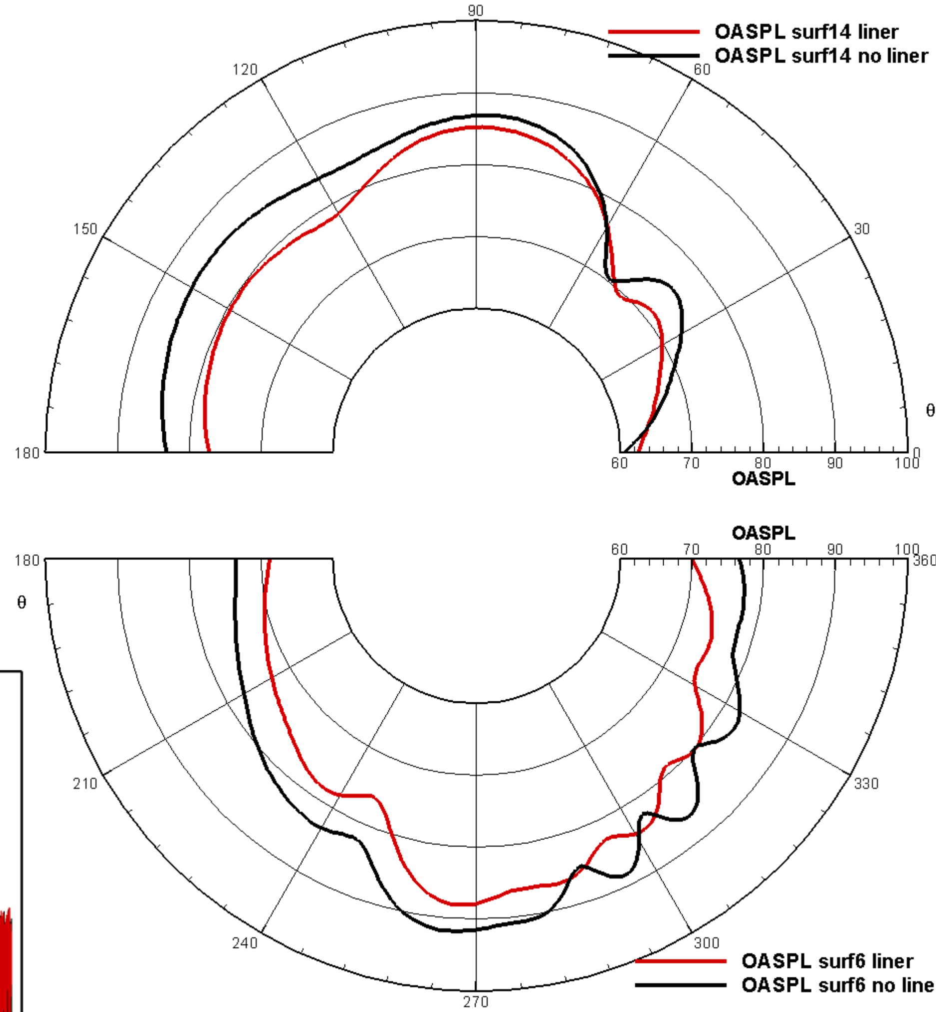
ZDES computation with or without porous material
Liner effect on acoustics

➢ **<u>Conclusions</u>:**

- ➢Influence of the porous material on average pressure distribution
- ➢ Influence of the porous material on the vortex shedding phenomenon (noise source intensity)
- ➢ Modification of the pressure spectra
  - ➢ Decrease of the peak frequency
  - ➢ Decrease of the spectra level (1-5 dB)

θ=90°





Directivity at R=1m

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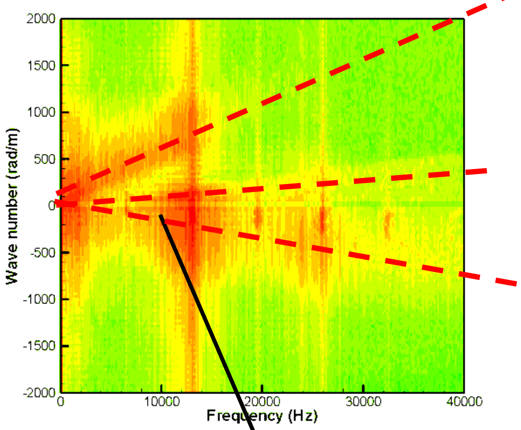
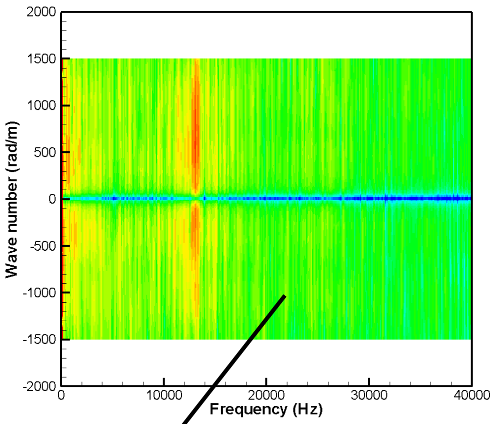
Thank you for your attention

Upper surfaces analysis
k-omega et k1k2-omega spectra

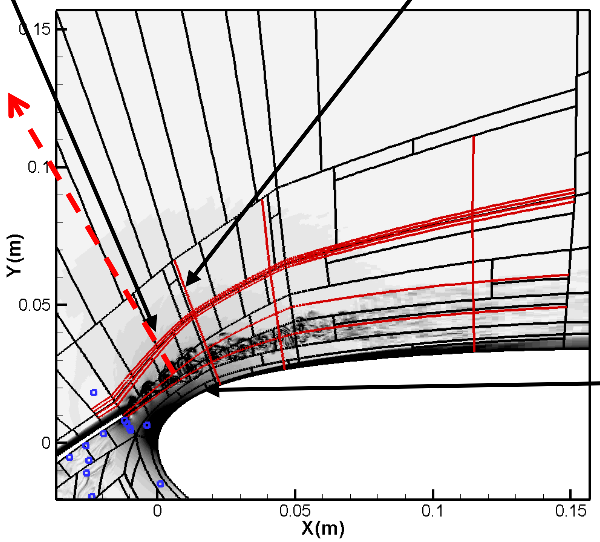
Surface 15

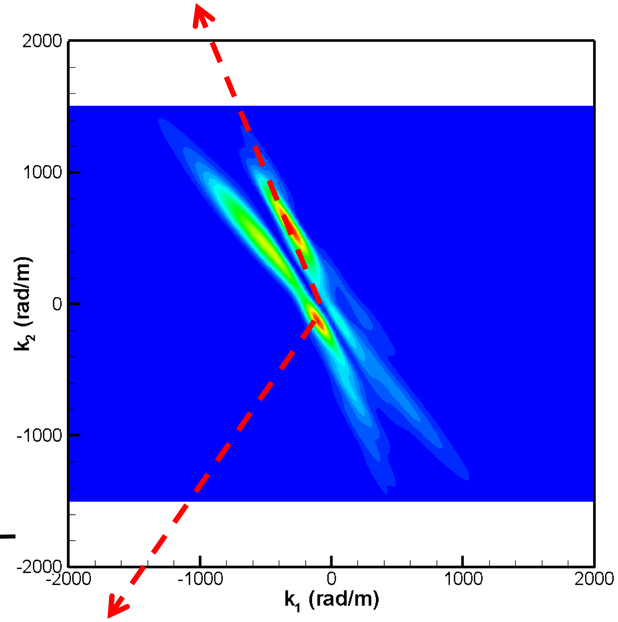


Surface 18



k_1k_2 - spectrum
15 and 18 crosses surfaces
Freq. = 13,335kHz





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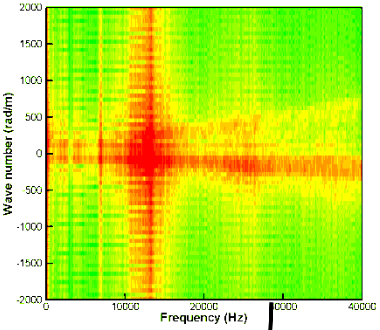
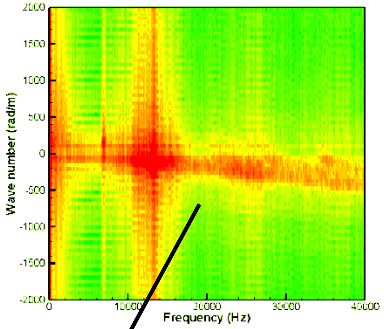
Lower surfaces analysis
k-omega et k1k2-omega spectra

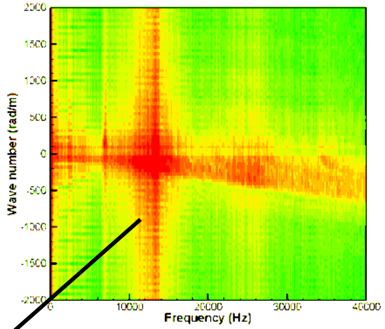
Surface 9



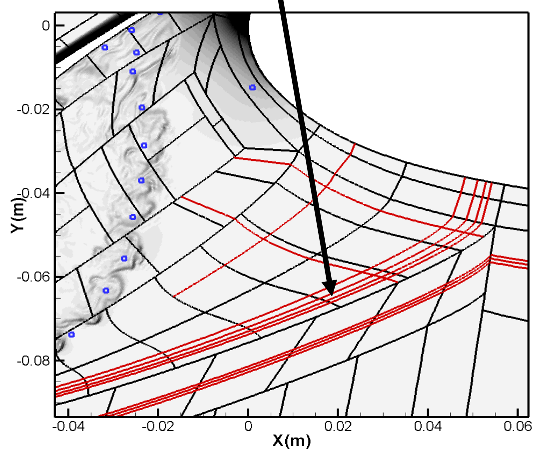
Surface 10

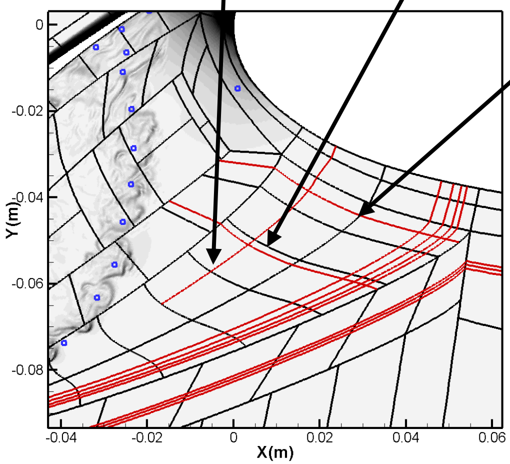


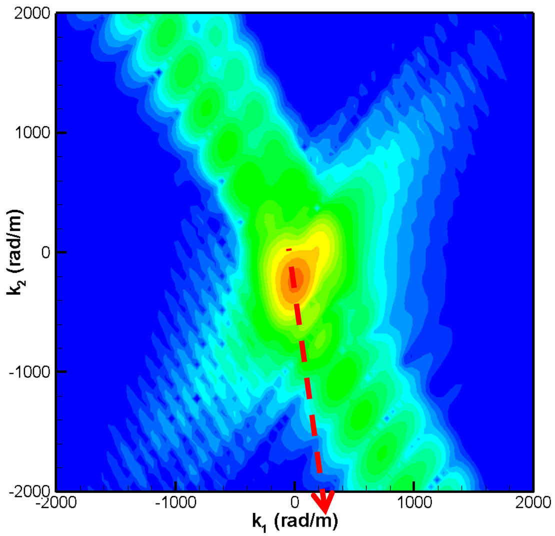
Surface 11

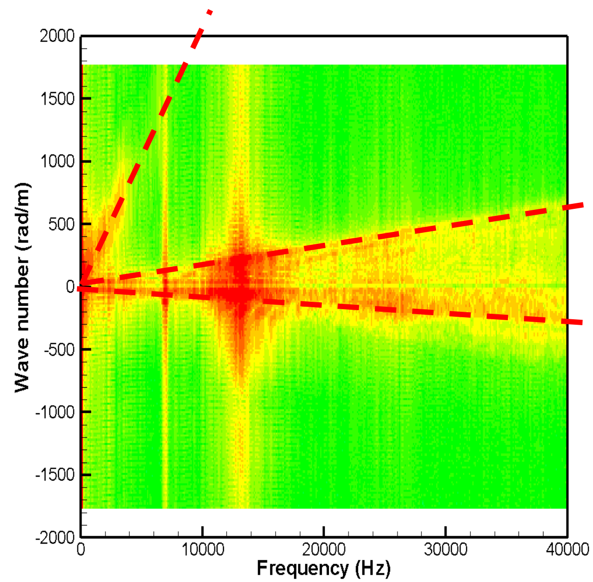


Surface 6







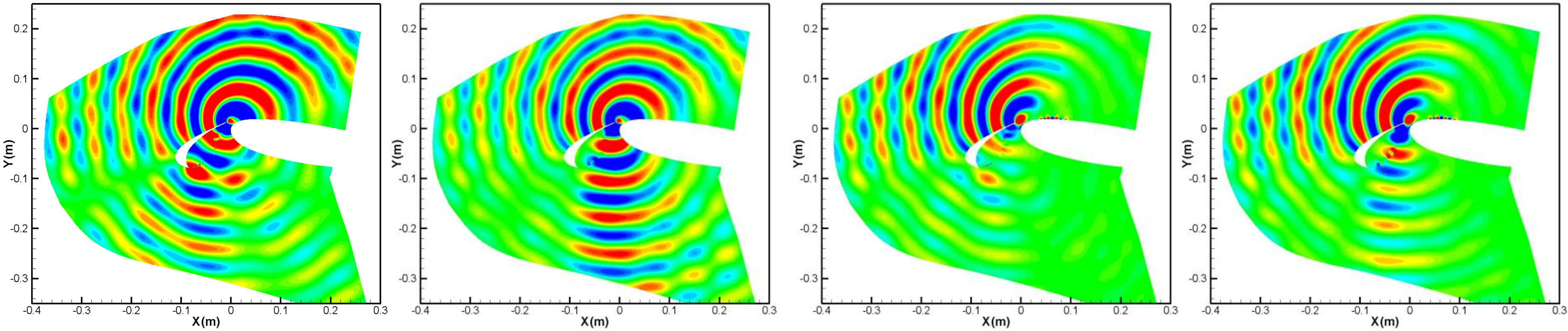


Crosses 9 et 10
Spectrum k_1k_2
f = 13,335 kHz

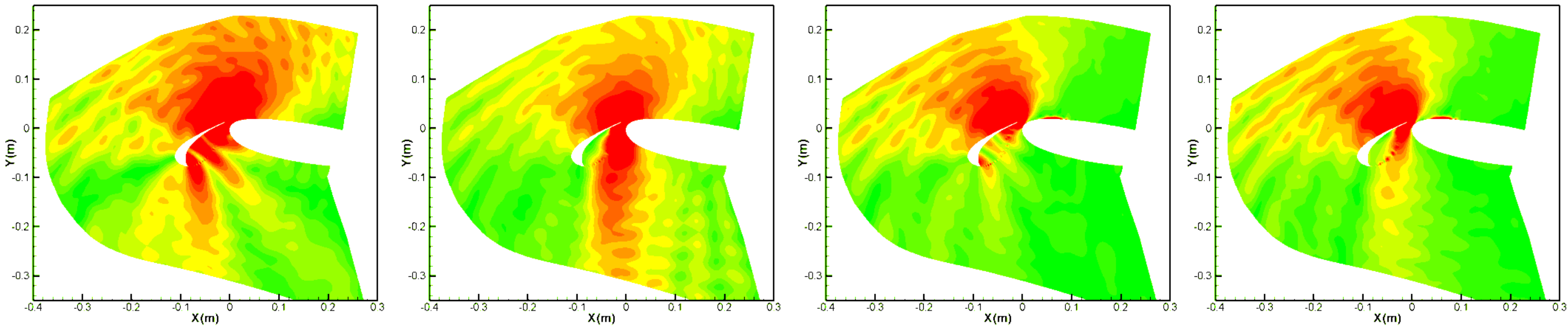
Liner position determination

Without liner	Liner inside the slat	Liner on wing	Liner on both

Instantaneous pressure field



RMS pressure



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