NSMB contribution to the 2nd High Lift Prediction Workshop

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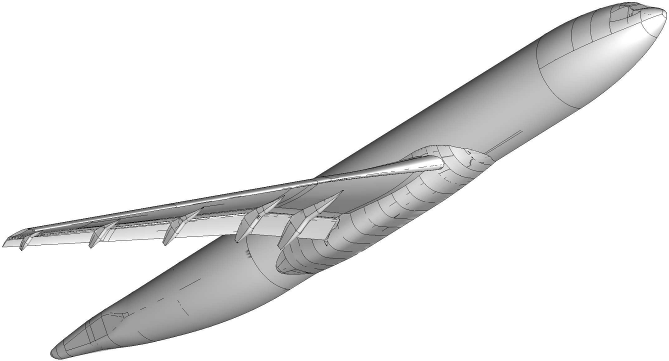
Contents

POLYTECHNIQUE MONTRÉAL

Configuration of the HiLiftPW-2 : DLR-F11 in landing configuration

full-span slat (26.5˚) and flap (32˚)



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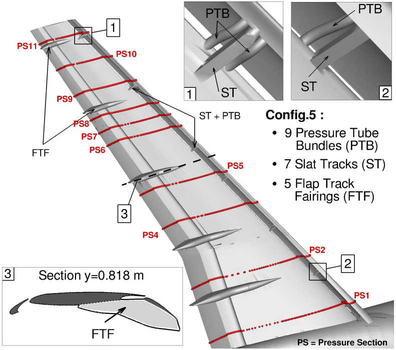
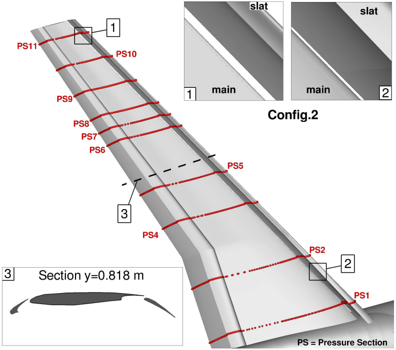
Accuracy of the CAD :



Config.5



Config.2

⇒ Simplified Config.2 choose for this numerical study

⇒ Config.5 closest to the experiment

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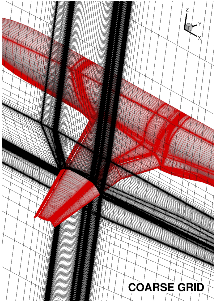
Grid :

Committee-supplied structured 1-to-1 grids :
A_str_1to1_Case1Config2
made by Boeing-Huntington Beach

3 grid sizes :

	cells	dy [mm]	dy / MAC
coarse	9,556,725	0.0006525	1.88e-6
medium	31,998,440	0.000435	1.29e-6
fine	100,561,536	0.00029	0.83e-6



Reference :

$$C_{ref} = MAC = 347.09\text{mm}$$
$$S_{ref} = 419{,}130\text{mm}^2$$
$$(x, y, z)_{ref} = (1428.90 , 0.0 , -41.61)\text{mm}$$

CFD solver : NSMB (Navier-Stokes Multi-Block)

History :

- In 1992, NSMB is developed in an international consortium with industrial partners (Airbus & SAAB Military Aircraft, CFS Engineering) and academic partners in France, Germany and Switzerland (EPFL, SERAM, IMFT, KTH, CERFACS)
- Today, it is developed by EPFL, ETH, Icube, IMFT, TUM, Polytechnique Montreal, CFS Engineering and RUAG and NSMB is being used by Airbus-France, EADS-ST and KTH

Descriptions :

- Finite volume Navier-Stokes solver with multi-blocks definition
- Wide code based on general features of modern CFD (grid flexibility, space discretization schemes, time integration, convergence acceleration, parallel computing, ...)

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Parameters of simulations :

All simulations were performed using the following parameters :

- Space discretization :
  4th order central scheme with Jameson artificial dissipation
- Time integration :
  implicit 2nd order backward, LU-SGS
  - steady : local time step, no multigrid
  - unsteady : dual time stepping, multigrid,
    $$\Delta t = \Delta t \cdot U_{ref}/c_{ref} = 0.06 \text{ [-]}$$
- Turbulence models : SA, SA Edwards, SA-salsa
- Initial Condition (IC) :
  - freestream (so-called from scratch),
  - pre-stall (from solution at $\alpha = 16°$),
  - ramping angle (from solution at $\alpha = \alpha - 1°$).

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Simulations performed

Turbulence model	Grid Size	Angle of attack [°]	Initial Condition	Time Resolution
HiLiftPW requirement : Grid Convergence Study (case 1 of HiLiftPW-2)				
SA	C, M, F	7, 16 and 22.4	freestream	steady
SA-Edwards	C, M, F	7, 16 and 22.4	freestream	steady
SA-salsa	C, M, F	7, 16 and 22.4	freestream	steady
Extended simulations, part 1 : Initial condition issues on stall prediction				
SA-Edwards	M	20 to 24 in steps of 1	freestream	steady
SA-Edwards	M	18.5 to 24 in steps of 0.5	from $\alpha = 16^{\circ}$	steady
SA-Edwards	M	17 to 26 in steps of 1	from $\alpha = \alpha - 1^{\circ}$	steady
Extended simulations, part 2 : Unsteady Simulations				
SA-Edwards	M	7,16 and 22.4	from steady state	unsteady

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Grid convergence study
Case 1 of the HiLiftPW-2

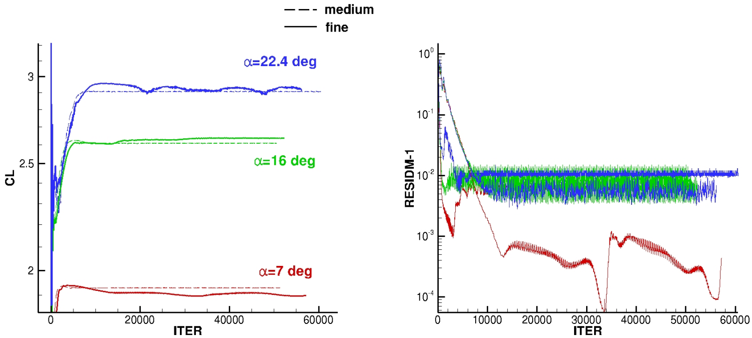
Purposes :

- Test of NSMB
- Test of the influence of the grid size
- Test of the influence of the turbulence models

Parameters :

- Steady solver, freestream IC
- 3 turbulence models : SA, SA-Edouards, SA-salsa
- 3 grid sizes : coarse, medium and fine

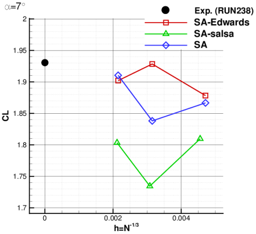
Histories of force and convergence



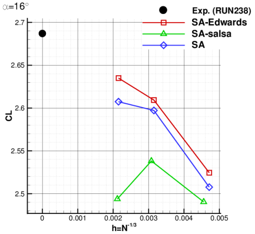
(SA-Edouards)

⇒ Oscillation of the forces, weak convergence
⇒ Less oscillation on fine grid than on coarse/medium grids

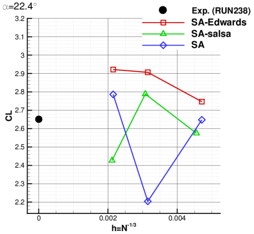
Grid convergence of the lift :



$\alpha = 7°$



$\alpha = 16°$



$\alpha = 22.4°$

$\Rightarrow$ No overall grid convergence for the three angles-of-attack

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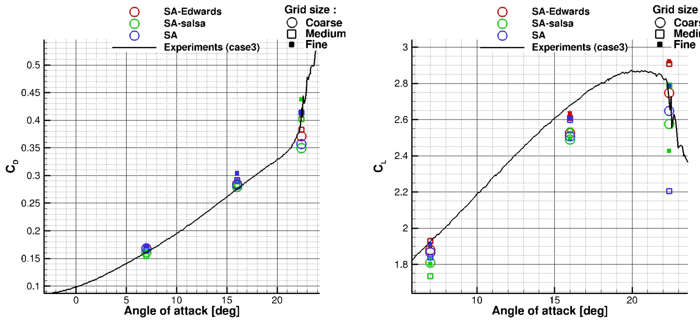
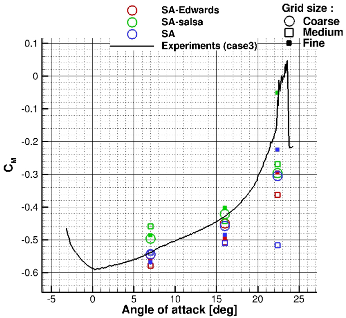
Forces :



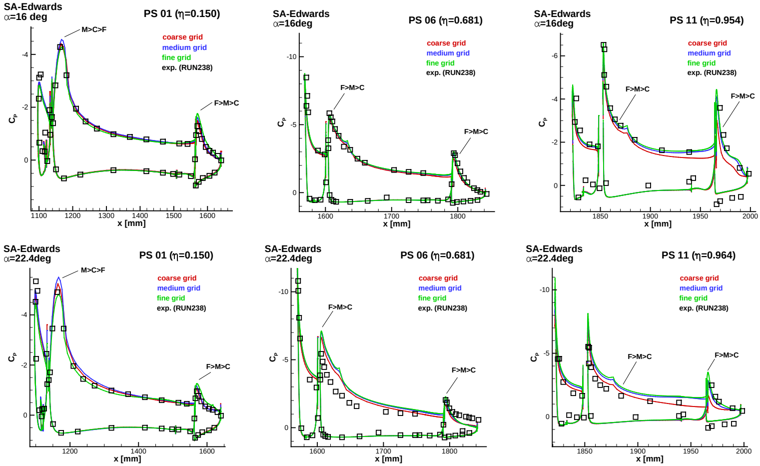
⇒ Large dispersion of the results at high angles-of-attack
⇒ Under-estimation of the lift

Pitching Moment :



⇒ Dispersion of the results at all angles-of-attack

Pressure Distribution : Effect of the grid size ($\alpha = 16°; 22.4°$)



⇒ Coarse grid results off the results of fine/medium grids

⇒ Good agreement with the experiment

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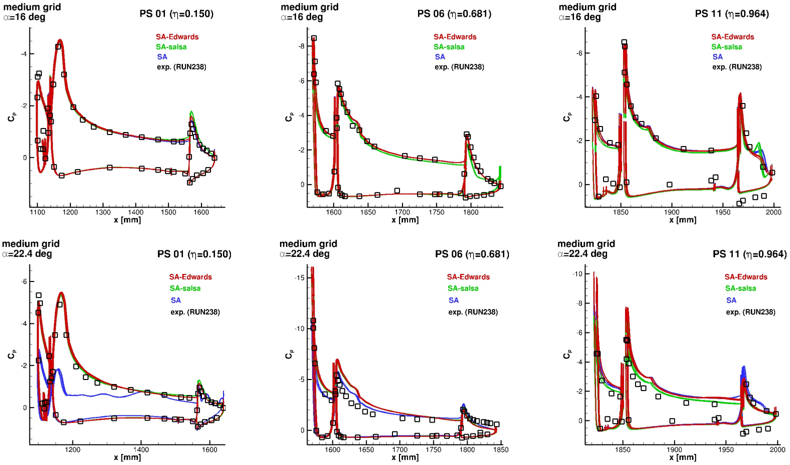
Pressure Distribution : Effect of the turbulence model



⇒ Low effect of the SA-models,
excepted for SA $\alpha = 22.4°$ (root flow separation predicted)

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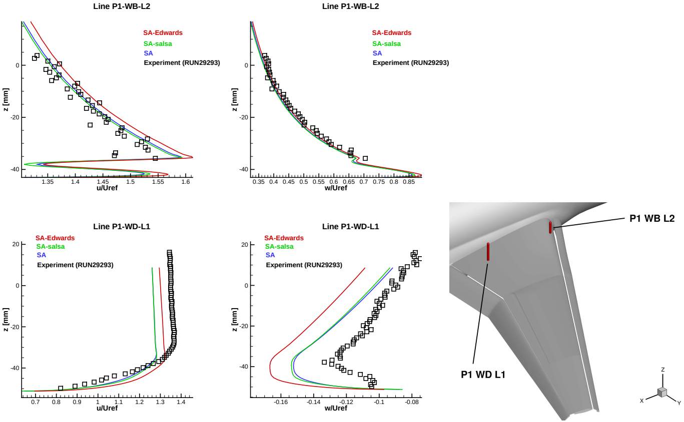
Velocity Profiles :



N.B. : the experimental results are at low Reynolds Number

Stall study

Purposes :

- Fine angle-of-attack definition at the stall range
- Description of the flow behavior until the stall
- Test of initial conditions

Parameters :

- Steady solver, SA-Edouards, medium grid
- 3 IC : freestream, pre-stall and ramping

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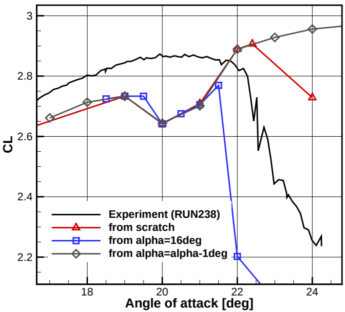
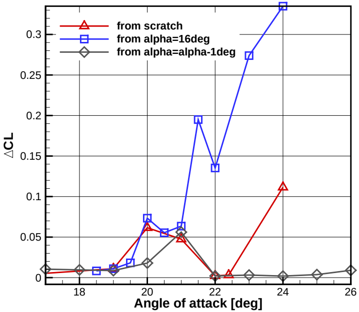
Lift : Influence of the initial condition





⇒ Small lift decrease at stall without influence of the IC
⇒ Strong influence of the IC at the post-stall with lift drop

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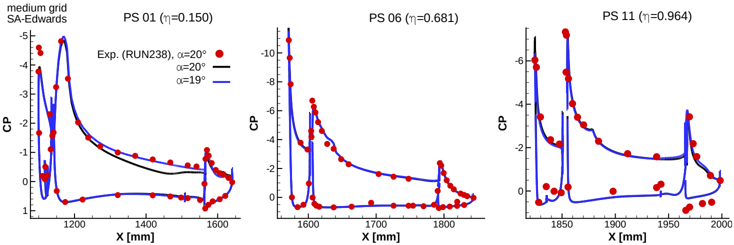
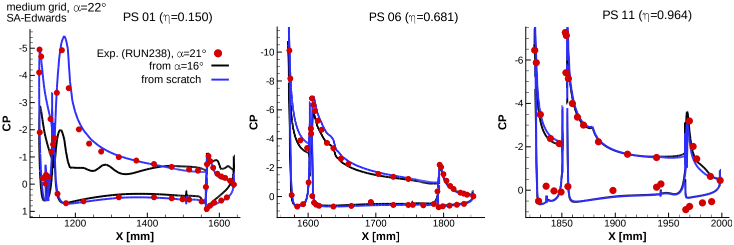
Pressure Distribution : Origin of the first lift decrease, Comparison between $\alpha = 19^{\circ}$ and 20°



(Pre-stall IC results)

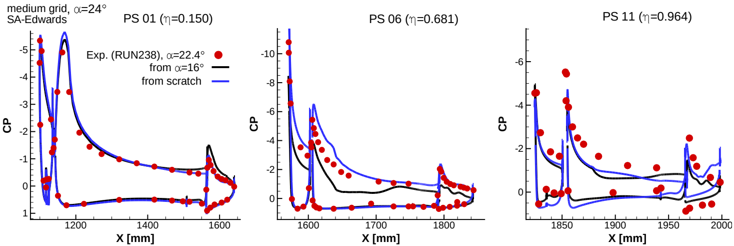
$\Rightarrow$ Lift decrease at $\alpha = 20^{\circ}$ is caused by low pressure at the root section

Pressure Distribution : Post-stall simulations, Influence of the initial condition at $\alpha = 22^{\circ}$



$\Rightarrow$ pressure drop at the root section (separated flow) for pre-stall IC

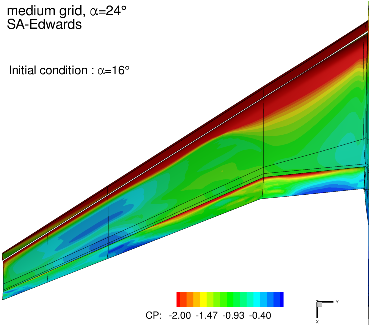
Pressure Distribution : Post-stall simulations, Influence of the initial condition at $\alpha = 24^{\circ}$

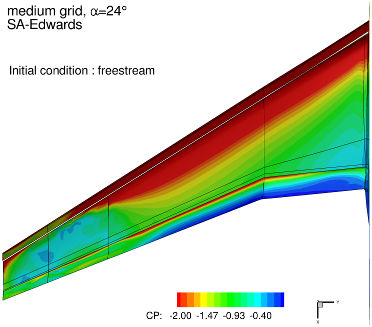


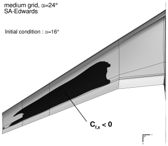
⇒ Pressure lost at the tip section (separated flow) for all IC
⇒ Separated flow larger with freestream IC than with pre-stall IC

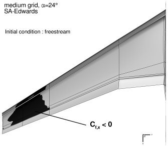
Separated flow at $\alpha = 24^\circ$:

Pressure distribution (rescaled, $C_P \in [-2:0]$)









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Time-resolution effect

Purposes :

- Determination of the accuracy add of time-resolution
- Unsteady flow description
- Localization of the unsteadiness

Parameters :

- Unsteady solver, SA-Edouards, medium grid
- Angle-of-attack : $\alpha = 7, 16$ and 22.4°
- IC : from steady solution at the same angle-of-attack

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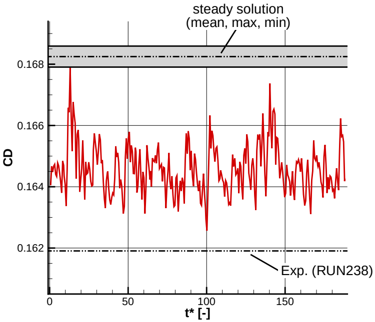
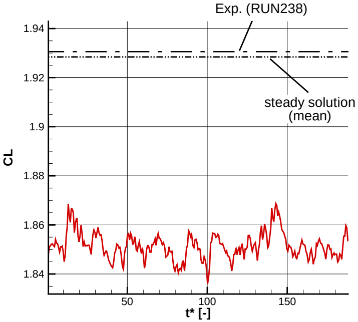
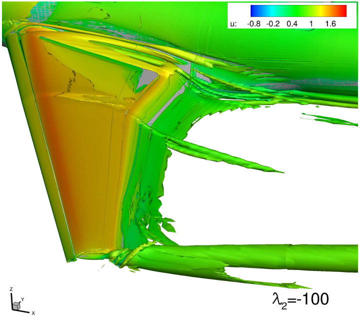
At $\alpha = 7^{\circ}$, force histories :



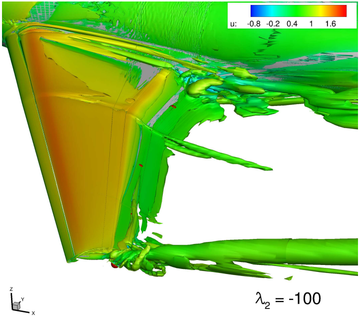


$\Rightarrow$ larger oscillations than steady simulation
$\Rightarrow$ decrease of drag and of lift compared to the steady solution

At $\alpha = 7^{\circ}$, flow visualization : steady vs. unsteady



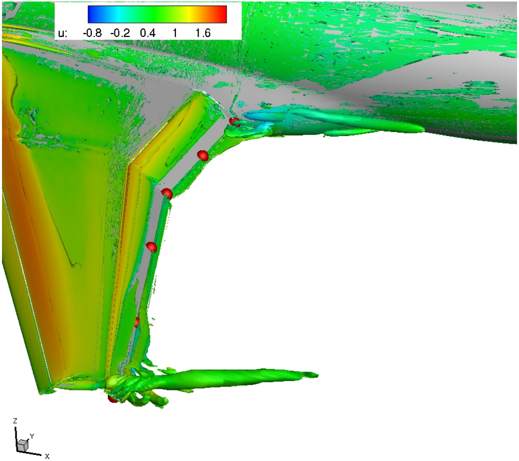
Steady solver



Unsteady solver

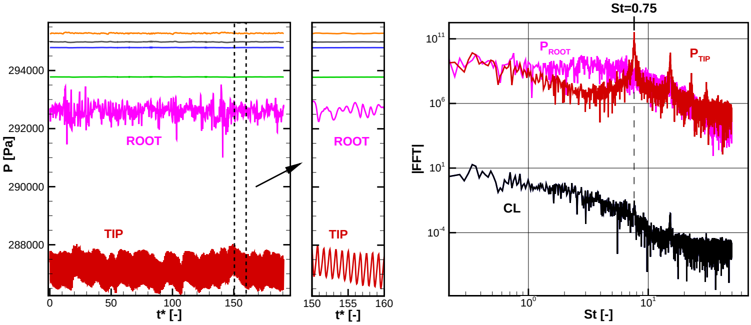
$\Rightarrow$ Analogous global flow
$\Rightarrow$ Small differences at the root vortex and at the wing wake close to the tip

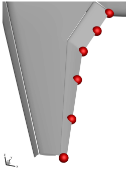
At $\alpha = 7^{\circ}$, flow visualization : time animation



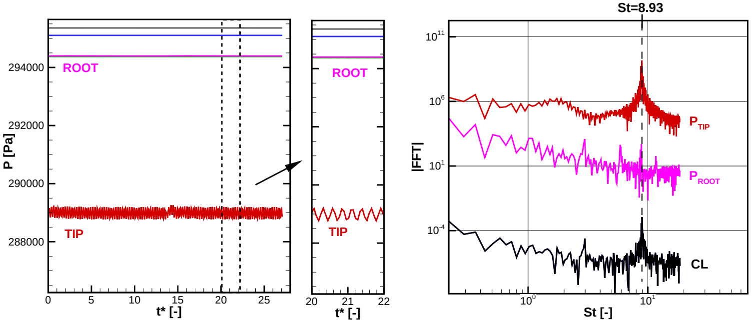
Isovalue of criteria λ_2=-2000, colored by U-velocity

At $\alpha = 7^{\circ}$, unsteadiness of the flow :





At $\alpha = 16^{\circ}$, unsteadiness of the flow :



monitor at	ΔP (% on P_{mean})	
	$\alpha = 7^{\circ}$	$\alpha = 16^{\circ}$
tip	0.62%	0.17%
root	0.86%	0.002%

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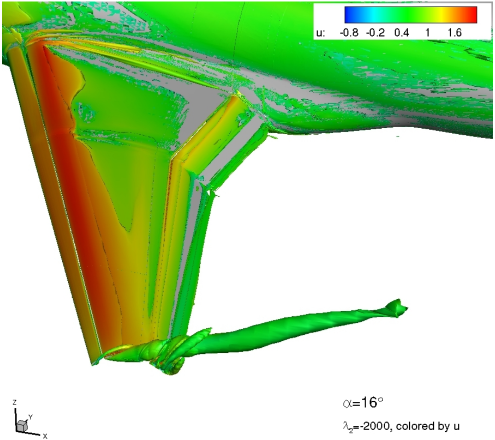
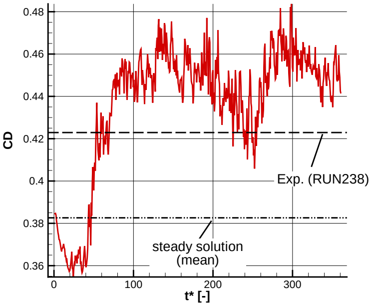
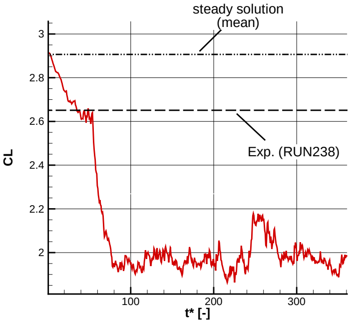
At $\alpha = 16^{\circ}$, flow visualization : time animation



$\Rightarrow$ Less unsteadiness than at $\alpha = 7^{\circ}$, but higher frequency

At $\alpha = 22.4^{\circ}$, force histories :





$\Rightarrow$ Drop of the lift (large flow separation)

$\Rightarrow$ Break in the lift history close the experimental value, before the drop

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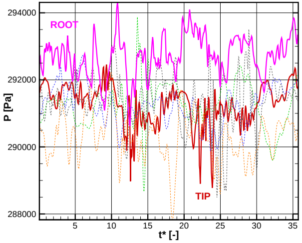
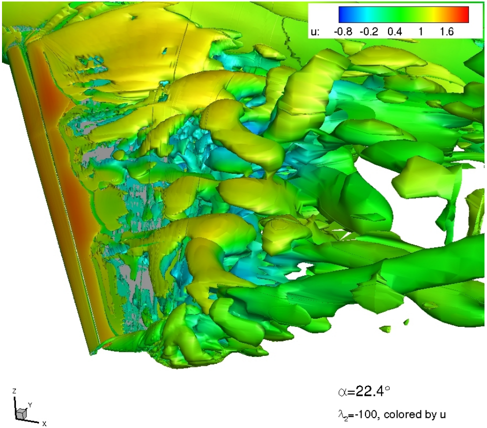
At $\alpha = 22.4^{\circ}$: separated flow visualization



Monitor point histories



Flow visualization

$\Rightarrow$ Large flow separation

Conclusion

- Low influence of the different SA models before stall
- High influence of the CI at post-stall
- Pre-stall CI not more stable than freestream CI against early detached flow prediction
- No grid convergence
- Loss of lift close to the maximum lift (turbulence model lack)
- Unsteady flow for all angles-of-attack
- Unsteadiness more pronounced for $\alpha = 7^{\circ}$ than 16°
- Complex flows with different time/space scales
- Importance of the root vortex

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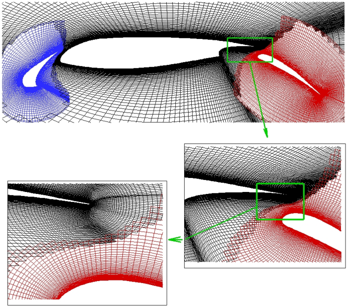
Outlook :

- Comparison for unsteady simulation with time-average values
- Simulation with lower timestep for high angle-of-attack
- Simulation of the configuration with brackets, case 3 (need structured mesh)
- Simulation of the case 1 with overset grid and flap motion



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Thank you for your attention

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