Automatic chimera method for moving bodies in NSMB

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Outline

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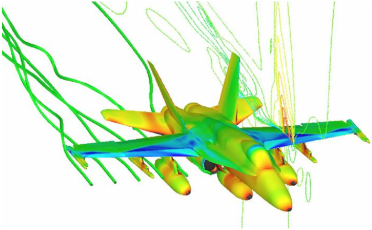
1. The NSMB Solver
   - The NSMB Solver
   - Discretisation and modeling in NSMB
2. The chimera method in NSMB
3. Chimera simulations with NSMB
4. Conclusion

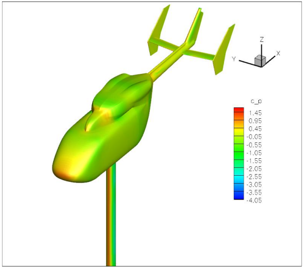
The history of NSMB

- First version in 1991
- From 1992 to the end of 2003, NSMB was further developed in the NSMB consortium, which included several universities (EPFL, Lausanne, Switzerland ; SERAM, Paris, France ; KTH, Stockholm, Sweden ; IMFT,Toulouse, France), one research establishment (CERFACS, Toulouse, France), and several industrial partners EADS-France (Airbus France and EADS Space Technologies), SAAB Military Aircraft and CFS Engineering.
- Since 2004, NSMB is further developed by EPF-Lausanne ; ETH-Zuerich, IMFS-Strasbourg ; IMF-Toulouse, Technical University of Muenchen ; University of the Army, Muenchen ; CFS Engineering and RUAG Aerospace. Besides these groups, NSMB is being used by Airbus-France, EADS-ST and KTH.

The Navier-Stokes Solver NSMB

- Both compressible and incompressible Navier-Stokes solver, multi-blocs and parallel
- Developed in the NSMB consortium which included several universities and industries
- Large area of applications : external aerodynamics, internal flows, SBLI, combustion, fluid/structure interaction, chemistry, ...
- Large choice of discretisation and numerical modeling

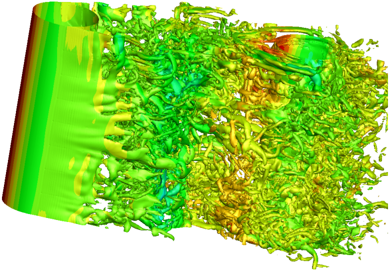




Discretisation and modeling in NSMB

- Spatial discretisation
- Temporal discretisation
- Incompressible scheme
- Turbulence
- Chemistry
- Grid Motion
- Moving Chimera
- Moving Immersed Boundary Method

- Central schemes (2nd and 4th order)
- Upwind schemes (1st up to 5th order)



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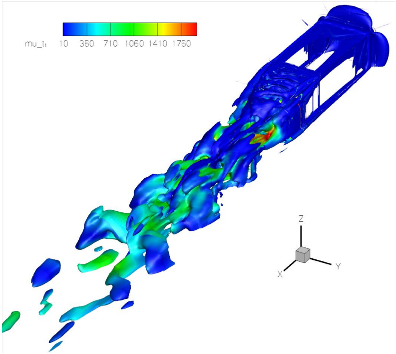
- *Steady flows* :
  explicit Runge Kutta or implicit LU-SGS
- *Unsteady flows* :
  explicit Runge Kutta, Dual-time stepping, LU-SGS



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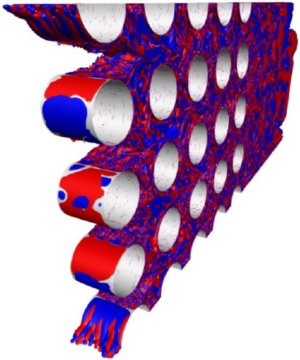
- *Preconditionners* : Turkel, Chorin ...
- *Pressure velocity coupling* : SIMPLE, SIMPLEC, PISO, Chorin-Temam
- *Rhie and Chow* stabilisation
- *Linear solver* : PSBLAS library



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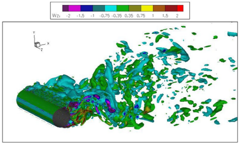
- Algebraic model
- Spalart-Allmaras and variants
- k-ϵ Chien, OES
- k-ω Menter, Wilcox, LLR, BPD
- EARSM Girimagi, GS, AJL
- NLEVM SZL, WJ
- DES, DDES, WMLES, IDDES, SAS
- Tensorial OES
- RSM SSG
- LES Smagorinsky, FS, FSF, WALE, ADM



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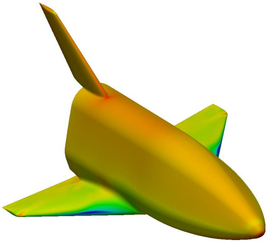
- Diffusion Flame model
- Air/N2-chemistry
- General Non-equilibrium Chemistry : CHEMKIN II coupling



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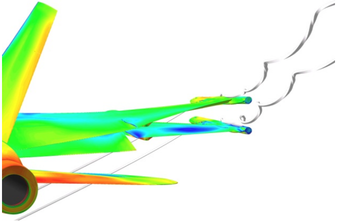
- ALE (Arbitrary Lagrangian Eulerian)
- Remeshing techniques (Volume Spline Interpolation or the Transfinite Interpolation) and elliptic smoother



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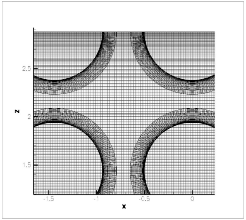

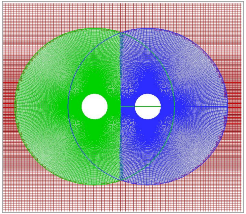

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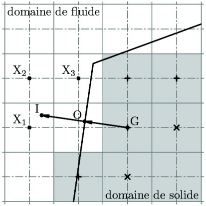
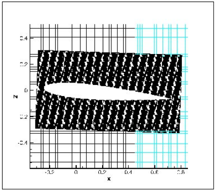
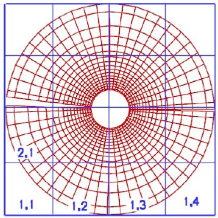




Outline

The chimera method in NSMB

- Detection of superposed cells : *The bucket method*
- Determination of the type of superposed cells : unused, computed, interpolated ou hole
- Buffer layer and hole cuting cells
- Interpolation scheme : tri-linear, inverse distance, tetraedra method and gradients method
- Fully automatic blanking for moving bodies



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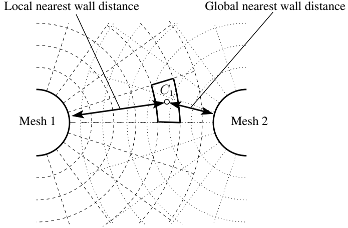

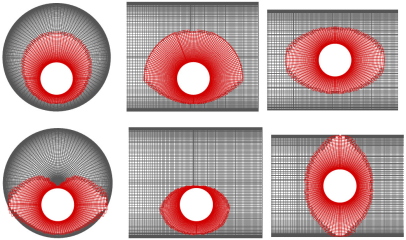

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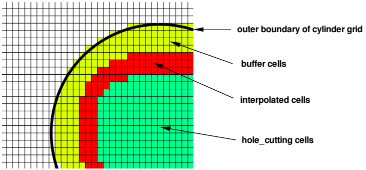

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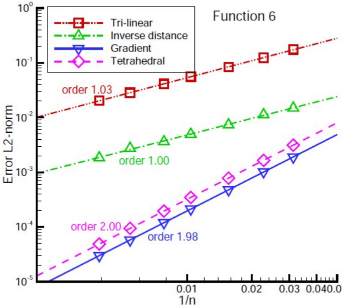

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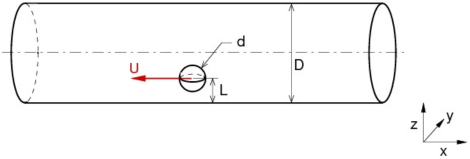
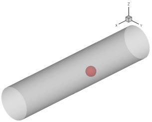
V_ma_1.jpg

Outline

Configuration





The equations of the movement :

$$m\ddot{x}_i = g_i\left(1 - \frac{\rho_0}{\rho}\right) + \frac{\rho_0}{\rho}\frac{F_H}{V} \qquad \text{with } i = x,y,z$$

$$\ddot{\alpha}_i = \frac{1}{J_G}M_{G,i} \qquad \text{with } i = x,y,z$$

The parameters of the problem

Parameters : $(Ga, D/d, \rho_r)$

- Galileo number : $Ga = \sqrt{\frac{gD^3\rho_f\left(\rho_b - \rho_f\right)}{\mu^2}}$

  $Ga = [50\ 100\ 150\ 155\ 160\ 165\ 170\ 180\ 190\ 200\ 250\ 275\ 300\ 350]$
- Diameters ratio : $D/d = 5$
- Densities ratio : $\rho_r = \rho_s/\rho_f = 2$

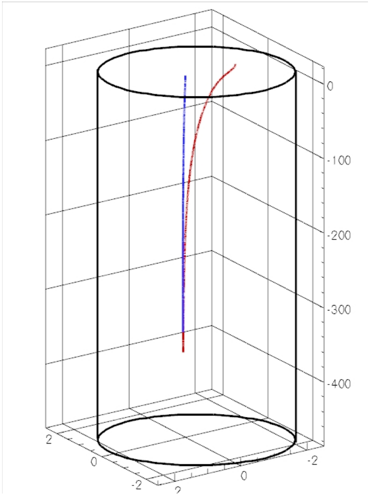
Initial condition

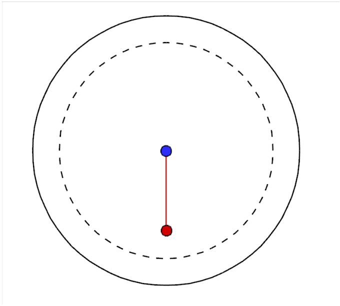
Position of the sphere center, defined by the distance $(L/d)_0$ here equal to D/2 and 1

Reynolds number

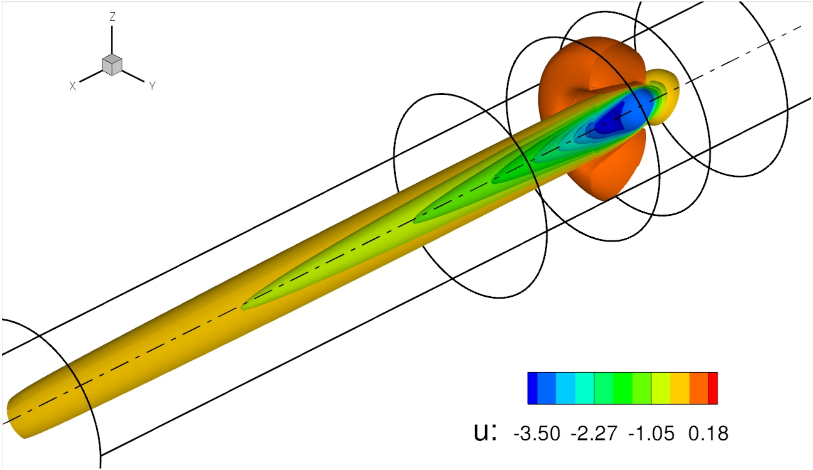
defined with the terminal velocity : $Re = \frac{U_t\ D}{\nu}$

Vertical trajectory : $Ga = 100$

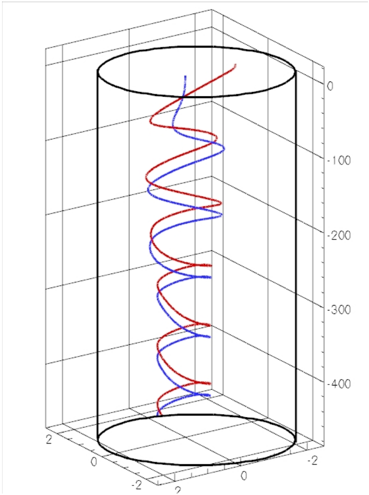


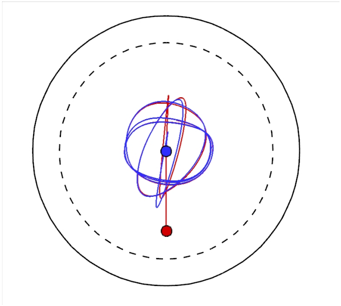


Axisymmetric flow



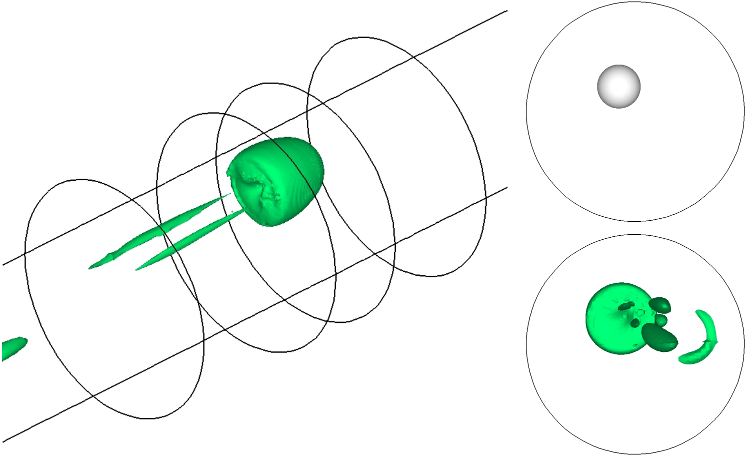
Non oscillatory helicoidal trajectory : $Ga = 170$



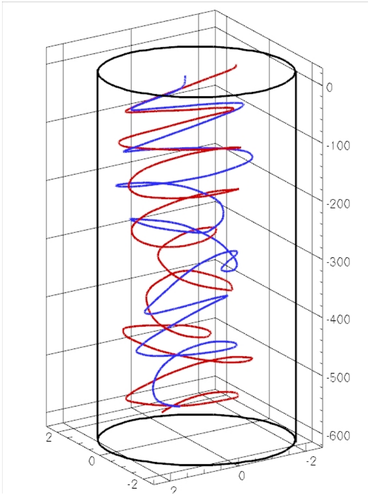


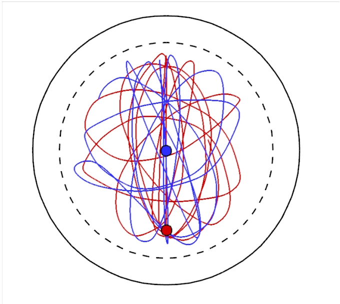
$T_{Ga=170} = 19.4, \; T_{Ga=200} = 17.8$

Non oscillatory helicoidal trajectory : $Ga = 170$

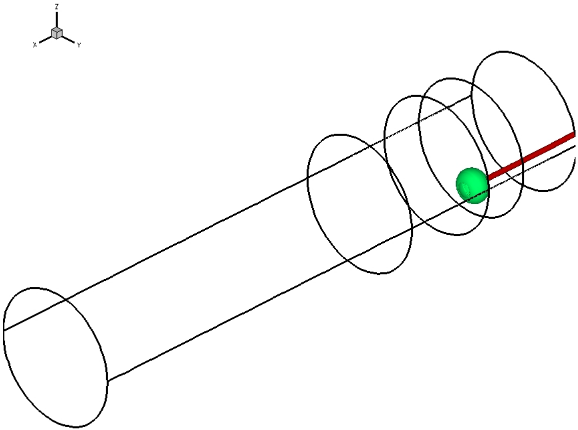


Oscillatory helicoidal trajectory : $Ga = 250$



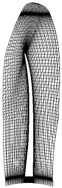


Flow and trajectory



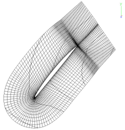
10 blades rotating propeller

- Each blade has his own mesh



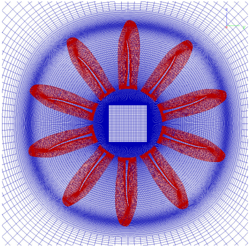
X-view

Y-view



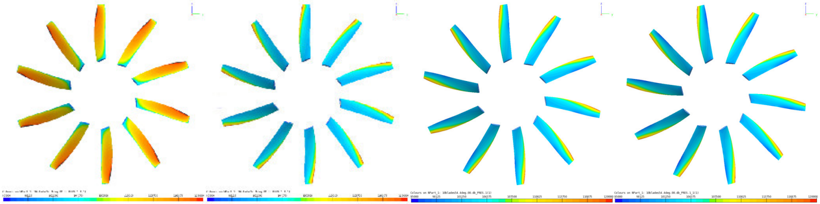
Z-view

- Placed in a background mesh



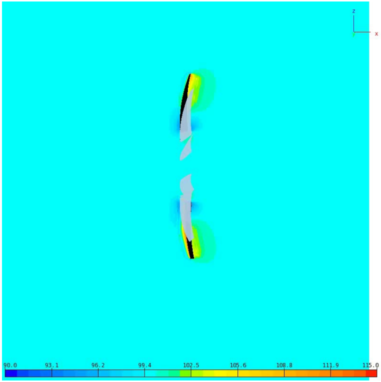
The operating conditions

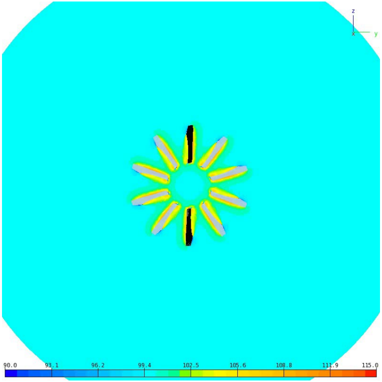
- Rotation velocity : 8500 rpm
- Incoming velocity : 100 m/s
- Unsteady simulation, 5° of rotation per time step
- Freestream initial condition
- Global mesh size : 13M cells



after 1 step | after 15 steps | after 30 steps | after 45 steps

The results


z
x
90.0
93.1
96.2
99.4
102.5
105.6
108.8
111.9
115.0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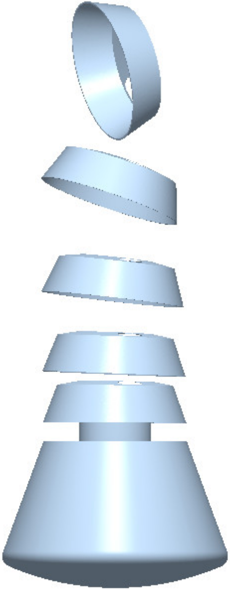
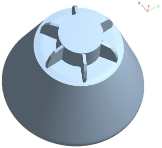
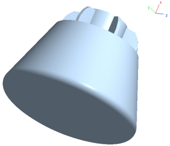
ARV-APEX cover separation process

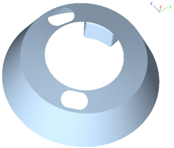


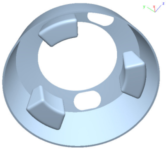
- ARV module





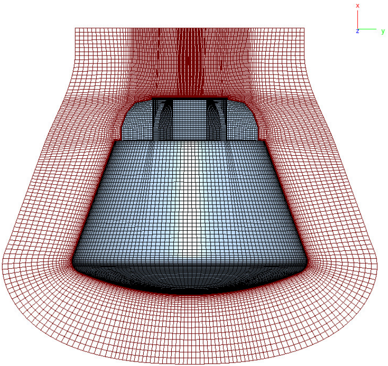
- APEX cover (with 3 parachute bags and 2 opened drogue hatches)





The grids

- ARV module mesh (2M cells)
- APEX cover mesh (1.6M cells)
- Background mesh (4.6M cells)



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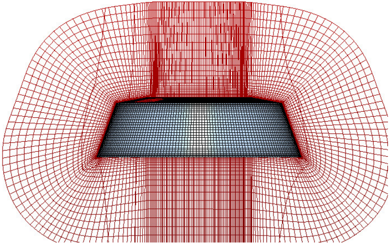

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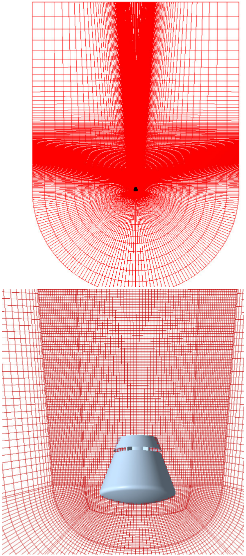
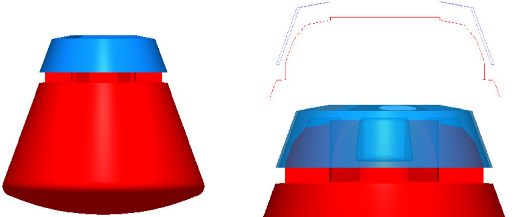
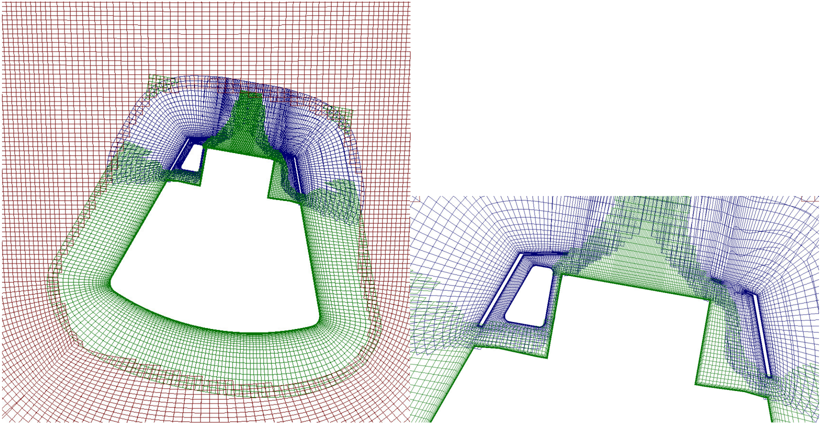


Initial configuration : 20cm separation between ARV and APEX



Fully automatic blanking at the initial configuration



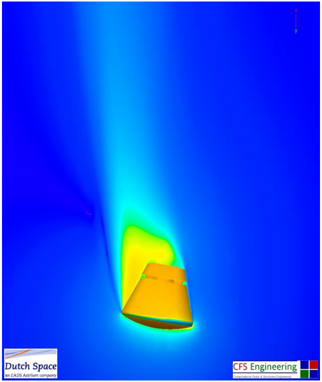
The operating conditions

- ARV has a prescribed velocity(60m/s) and acceleration
- APEX cover movement determined by a 6DOF solver
- Extraction (coming from drogue parachutes) force applied on the APEX cover (distributed at the drogue brackets location according to their altitudes)
- Time of a simulation : until the distance between ARV and APEX reaches 60m : 2 sec
- Monitoring of all the forces and moments applied on the APEX cover and all the Euler angles and their time derivatives describing the APEX cover rotation

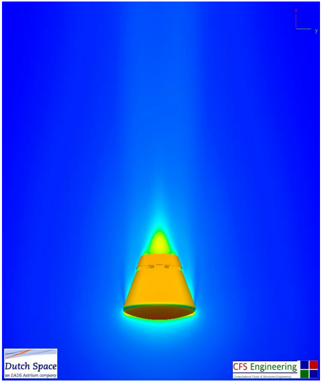
The results

Extraction force distributed at 3 drogue brackets location + 10˚ initial angle

Y-view

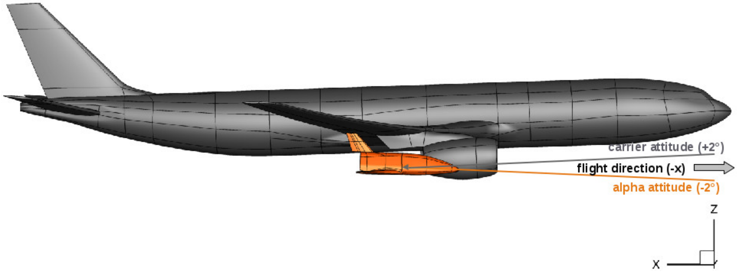


Z-view



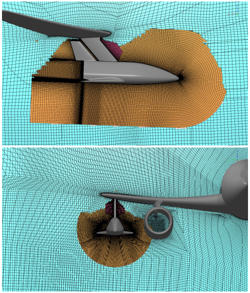
The ALPHA separation process

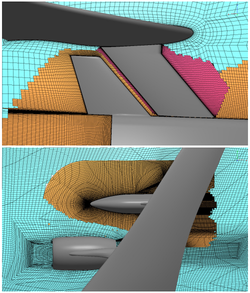
Future high-Altitude high-Speed Transport 20XX
Unsteady simulations of the ALPHA separation process for under-wing scenario with different flow conditions



Structured grids provided by ONERA

- 1 structured background grid for A330 carrier 11.4 million cells
- 1 structured chimera grid for ALPHA vehicle (without nozzle) 6.8 million cells
- 1 structured chimera grid for pylon supporting ALPHA vehicle 2.4 million cells
- Near-wall refinement for Navier-Stokes computations

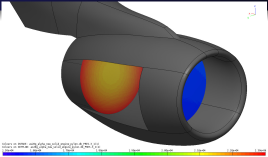




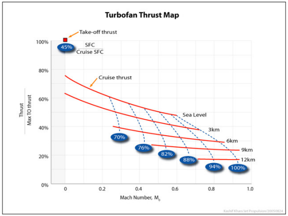
Separation parameters

- Separation altitude : 14.4 Km
- Separation speed : M=0.8
- AoA (with respect to flight attitude) : 0˚
- Pressure : 13308 Pa
- Temperature : 216.65 ˚K
- Density : 0.214 Kg/m^3
- Reynolds : $Re = 3.5524E + 6$
- Gravity acceleration : $g = 9.7624$
- Vehicle Mass : 3615.1 Kg
- Moment of inertia Ixx : 1480 $Kg.m^2$
- Moment of inertia Iyy : 10027 $Kg.m^2$
- Moment of inertia Izz : 10264 $Kg.m^2$

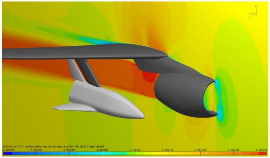
Engine conditions



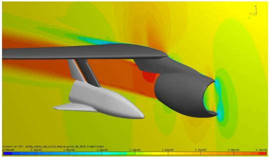
- Based on GE-Aviation engine CF6-80E1A2
- Engine Max Thrust 300 kN
- At separation conditions 20% of max thrust
- Intake Pressure 16000 Pa
- Outflow Total Pressure 28400 Pa
- Outflow Total Temperature 400 ˚K
- Velocity of the jet at nozzle exit 400 m/s



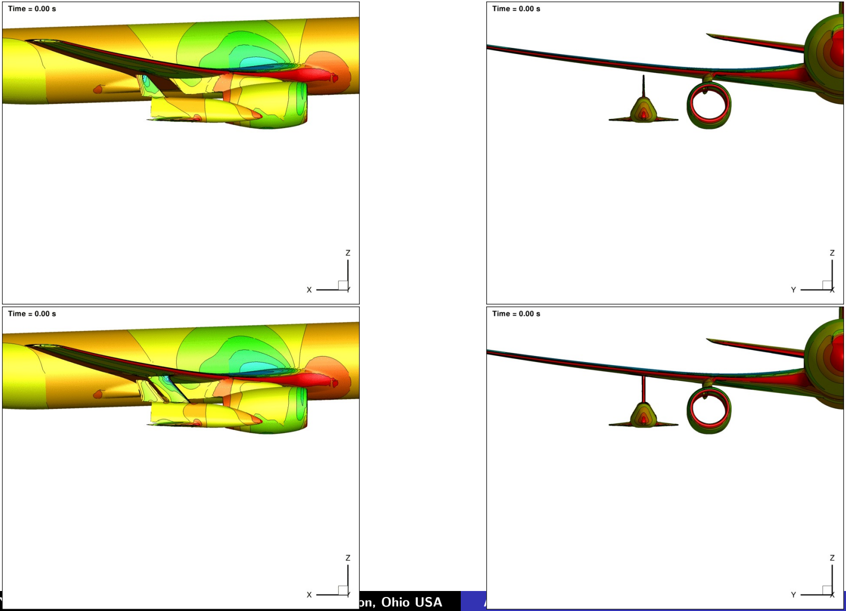
Relative velocity – cutting plane Y = 9.4



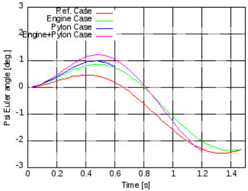
Relative velocity – cutting plane Z = -3



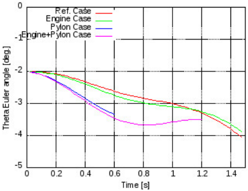
Results



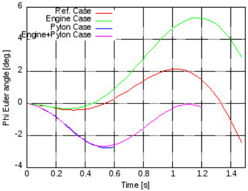
Euler angles comparison



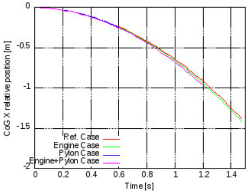
ψ



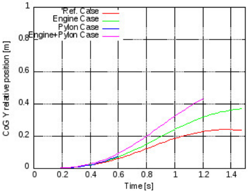
θ



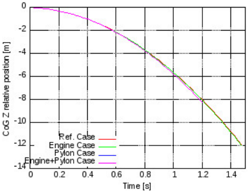
ϕ



X



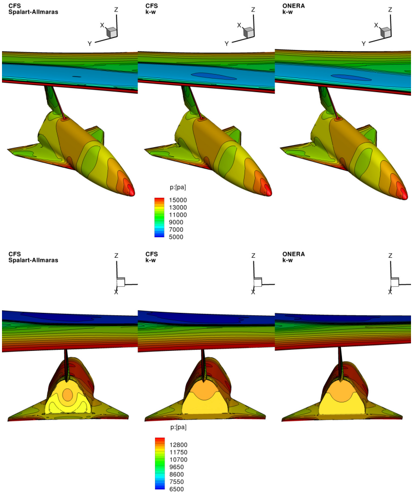
Y



Z

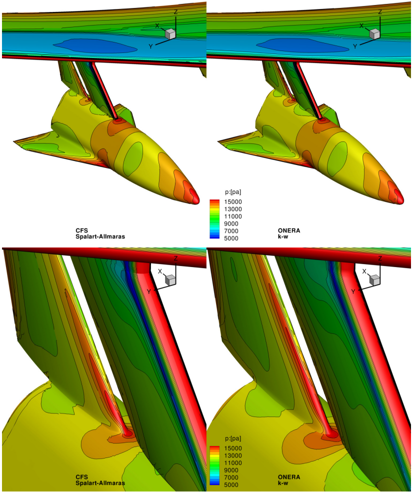
Cross-check with ONERA's solver (ELSA)

Turbulence modeling effect



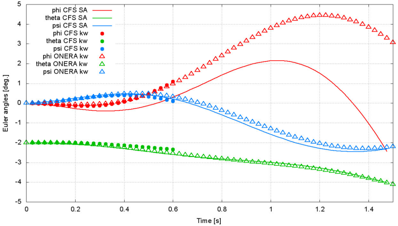
Cross-check with ONERA's solver (ELSA)

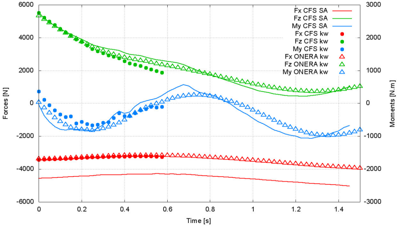
Pylon effect



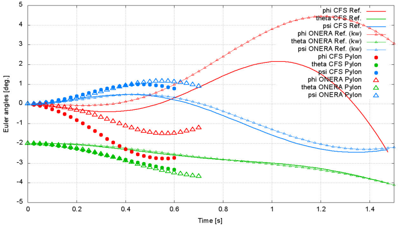
Cross-check with ONERA's solver (ELSA)

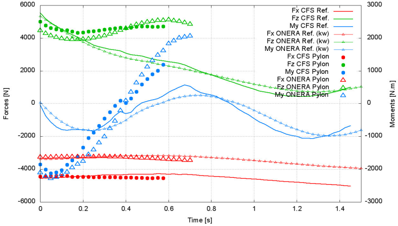
Turbulence modeling effect





Pylon effect





Outline

Conclusion and perspectives

▷ Parallel chimera methodology implemented and validated in NSMB

- Fully automatic blanking for moving bodies
- Application to 6 DOF falling bodies
- Multiple moving bodies capabilities

▷ Automatic mesh refinement with chimera

- Cavitation with chimera and Level-Set
- Compressor (TFAST project)
- Active Gurney Flap on rotorblades
- Icing simulations with chimera and Level-Set
- Moving flap

Thank you for your attention

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