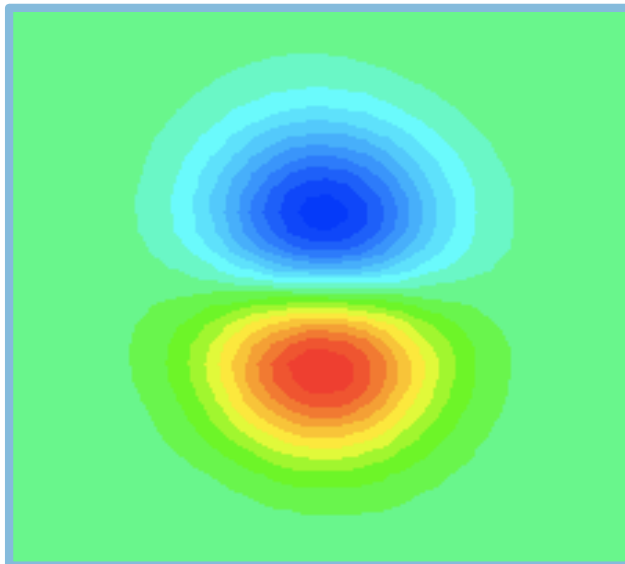
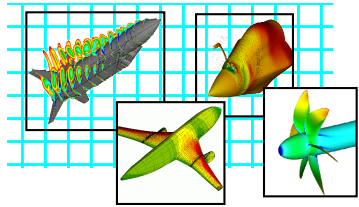


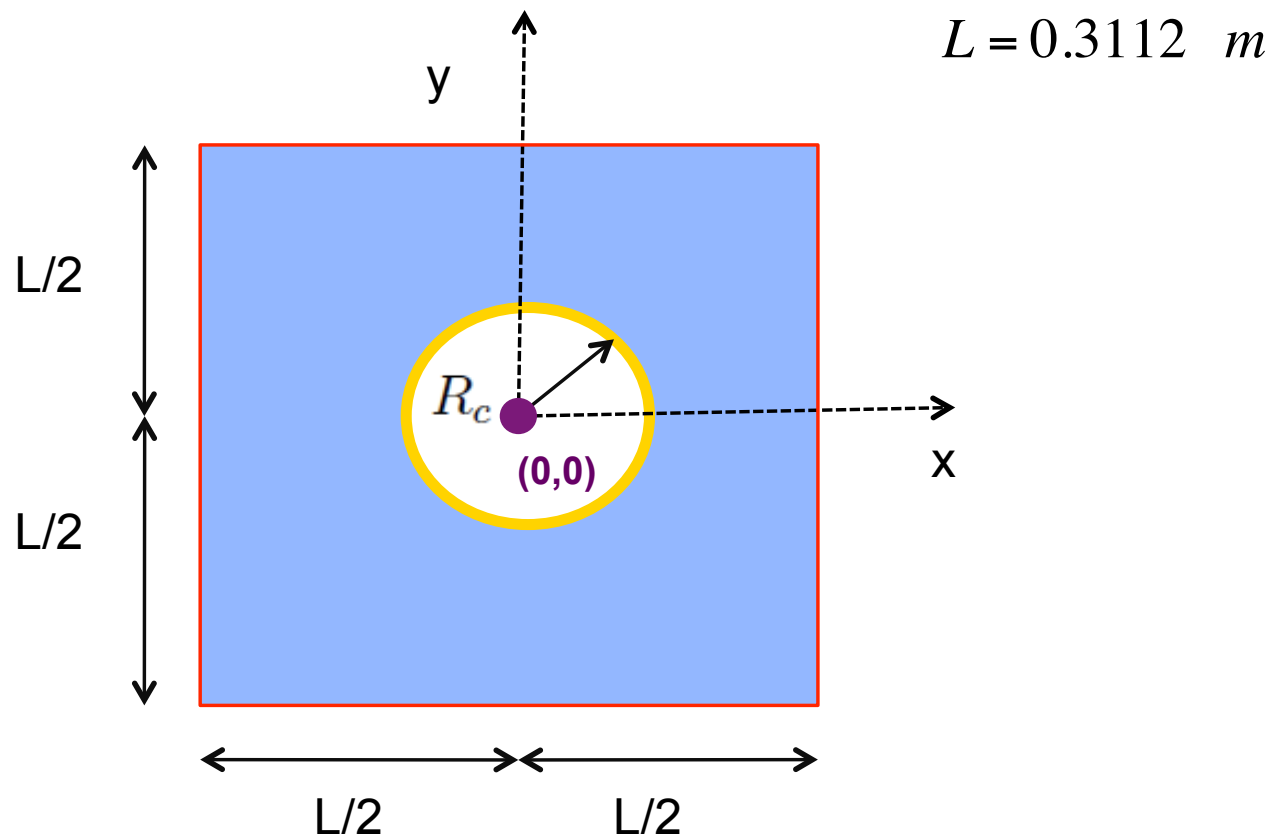
BENCHMARK “CONVECTION D’UN TOURBILLON”

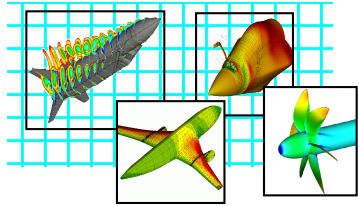


J.-C. JOUHAUD
S. HERMETH (AVBP)
H. KREDIET (OpenFOAM)
B. ENAUX (elsA)
M. KRAUSHAAR (YALES)
Y. Cheny (NTMIX)

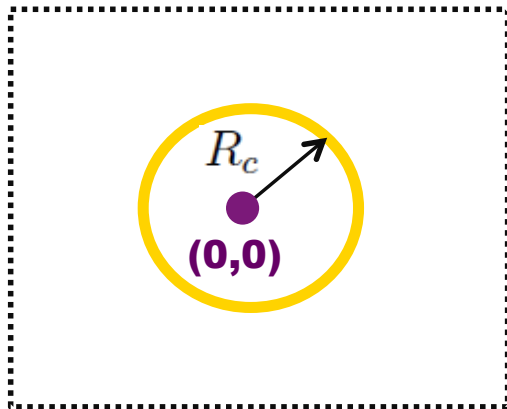


- **Données géométriques**





• Données Initiales



$$u = U_0 + \frac{\partial \Psi}{\partial y} \quad v = -\frac{\partial \Psi}{\partial x}$$

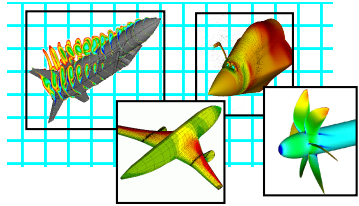
$$p - p_0 = -\frac{\rho \Gamma^2}{2R_c^2} e^{-\frac{(x-x_c)^2 + (y-y_c)^2}{R_c^2}}$$

$$\rho_0$$

$$\Psi(x, y) = \Gamma e^{-\frac{(x-x_c)^2 + (y-y_c)^2}{2R_c^2}}$$



Dés qu'un point se trouve en dehors du cercle $4 R_c$ la fonction exponentielle est tronquée pour éviter des problèmes de CL !



- **Données Aérodynamiques**

$$\rho_0 = 1.17170407 \text{ kg.m}^{-3}$$

$$T_0 = 300 \text{ K}$$

$$P_0 = 101300 \text{ Pa}$$

$$U_0 = 35 \text{ m.s}^{-1}$$



$$Mach = 0.1$$

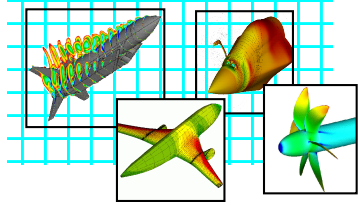
- **Caractéristiques du Tourbillon**

$$U_{\max} = 4\% U_0 = 1.4 \text{ m.s}^{-1}$$

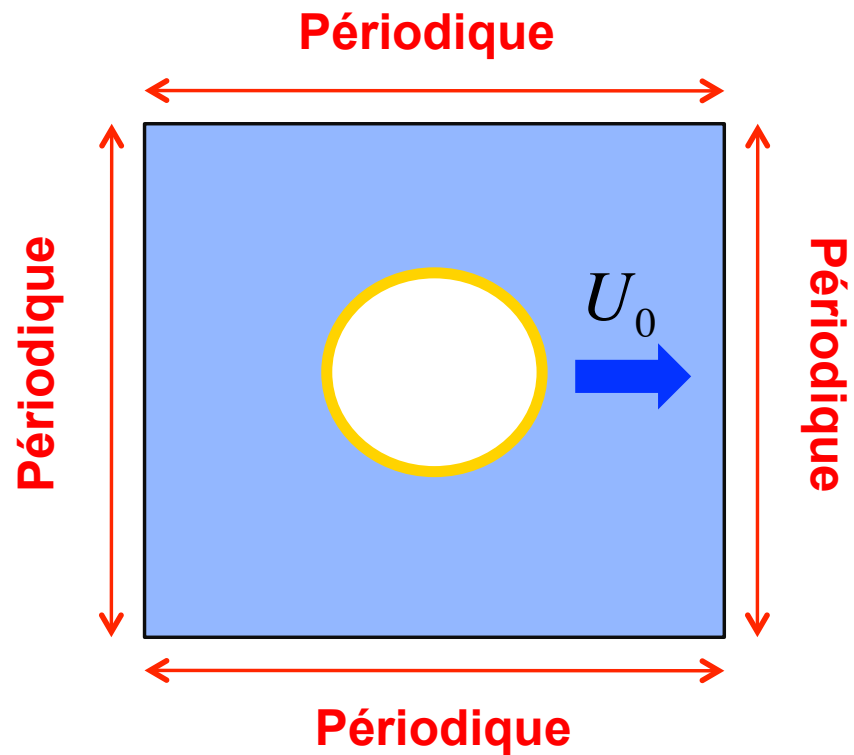
$$\Gamma = U_{\max} R_c \sqrt{e} = 3.59157 \cdot 10^{-2}$$

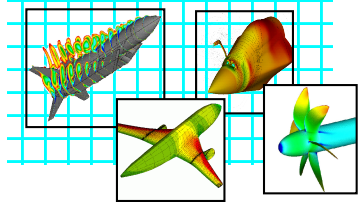
$$R_c = L/20 = 0.01556 \text{ m}$$





- **Conditions aux limites**





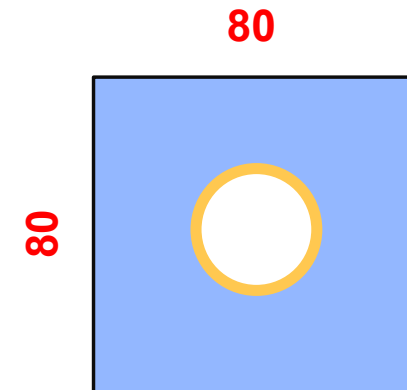
- Deux maillages cartésiens / plusieurs calculs

→ 2D, 1 calcul

Mono proc: 6400 cellules

Mach = 0.1

Analyse
de la précision

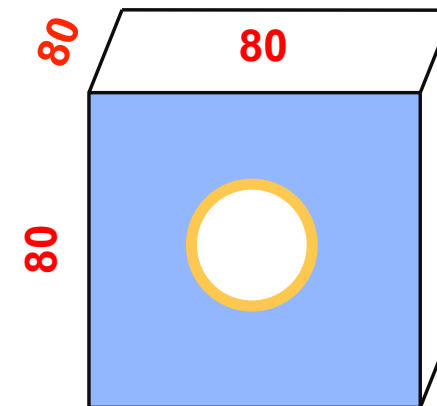


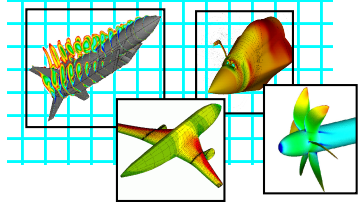
→ 3D en extrudant
4 calculs

En parallèle: 512000 cellules

Mach = 0.01, 0.1, 0.2, 0.3

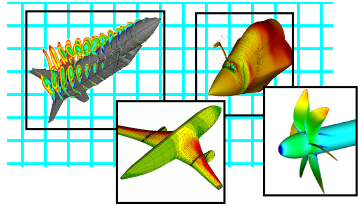
Analyse
des performances





• Règles du jeu

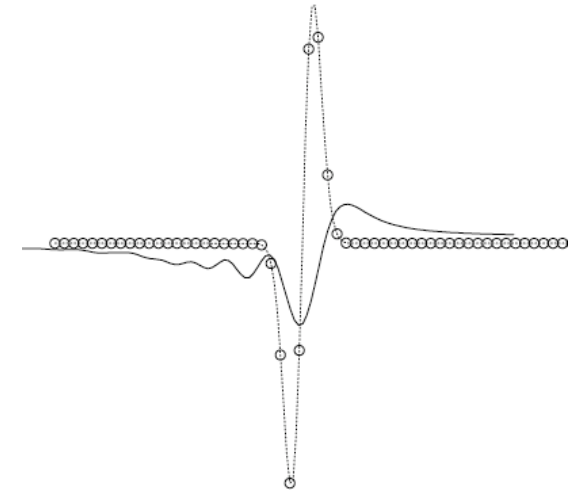
- ➡ Utiliser les schémas (temps & espace) ayant l'ordre le plus élevé.
- ➡ Rester en explicite avec un CFL = 0.7 (**sauf** si le solveur est incompressible).
- ➡ Faire les calculs en dimensionnel et sortir les données brutes
- ➡ Format de données des résultats : Tecplot ASCII



• Éléments de comparaison

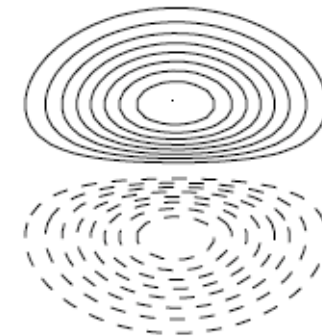
➔ Profils de la composante v en $y=0$:

$$t_1 = 10 \frac{L}{U_0} \quad t_2 = 20 \frac{L}{U_0} \quad t_3 = 30 \frac{L}{U_0} \quad t_4 = 40 \frac{L}{U_0}$$

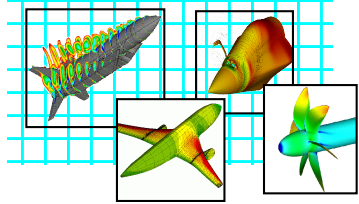


➔ Iso-contours de $u - U_0$:

$$t_1 = 10 \frac{L}{U_0} \quad t_2 = 20 \frac{L}{U_0} \quad t_3 = 30 \frac{L}{U_0} \quad t_4 = 40 \frac{L}{U_0}$$



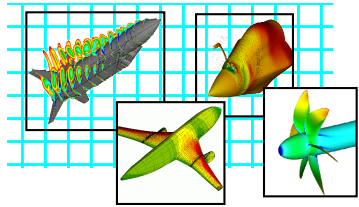
➔ Performances : speedup et efficacité réduite



- **Résumé des calculs à réaliser**

RUN	Name	Mach	Size	Output	Quantities	Format
1	vortex2D_0.1_80	0.1	80 x 80	t_1, t_2, t_3, t_4	v $u - U_0$	Tecplot ASCII
2	vortex3D_0.01_80	0.01	80 x 80 x 80	X	X	X
3	vortex3D_0.1_80	0.1	80 x 80 x 80	X	X	X
4	vortex3D_0.2_80	0.2	80 x 80 x 80	X	X	X
5	vortex3D_0.3_80	0.3	80 x 80 x 80	X	X	X





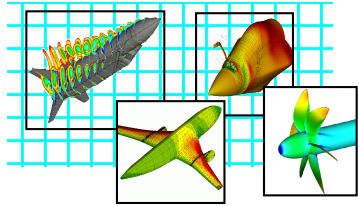
- **elsA Solver**

- ➔ **Temporal scheme** : explicit six-stage Runge-Kutta algorithm, **second order**
- ➔ **Spatial scheme** : **sixth order** compact finite-volume scheme
- ➔ **Filter operator**: schemes are coupled with a the compact filter operator ($\alpha_f=0.49$, applied every 100 iterations)
- ➔ **Numerical parameters**:
 - ➔ acoustic CFL number : 0.7
 - ➔ no artificial viscosity

A. Fosso, H. Deniau, F. Sicot, P. Sagaut. Curvilinear finite-volume schemes using high-order compact interpolation. *Journal of Computational Physics* (2010), vol. 229, pp. 5090-5122.

D.V. Gaitonde and M.R. Visbal. Further development of a Navier-Stokes solution procedure based on high-order formulas. *AIAA, Aerospace Sciences Meeting and Exhibit, 37 th, Reno* (1999).





- AVBP Solver

➡ **Scheme TTGC** (Taylor–Galerkin finite-element scheme), **third order** in space and time

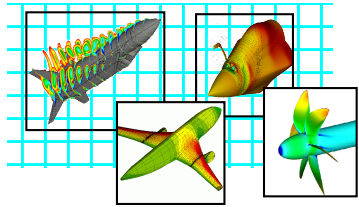
➡ **Numerical parameters:**

➡ acoustic CFL number : 0.7

➡ no artificial viscosity

Olivier Colin, Michael Rudgyard. Development of High-Order Taylor–Galerkin Schemes for LES. *Journal of Computational Physics* 162, 338–371 (2000).



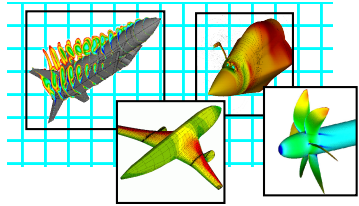


- OpenFoam Solver

- ➔ **Temporal scheme** : Euler backward, implicit **second order** backward-differencing
- ➔ **Spatial scheme** : cubic corrected, centered **fourth order** scheme
- ➔ **Numerical parameters:**
 - ➔ acoustic CFL number : 0.7
 - ➔ artificial viscosity : 1.25e-3
 - ➔ number of Piso-loops : 3

H. Jasak, Z. Tukovic and A. Jemcov. OpenFOAM: A C++ Library for Complex Physics Simulations. Coupled Methods in Numerical Dynamics, 2007.

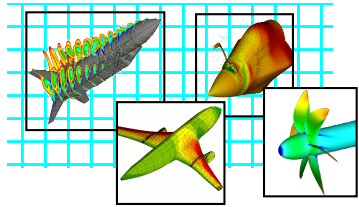




- **YALES Solver**

- ➔ **Temporal scheme** : TFV4A, **fourth order** time integration
- ➔ **Spatial scheme** : central finite-volume schemes of the **fourth order**
- ➔ **Linear Poisson solver** : Deflated PCG ($1.e-8$)
- ➔ **Numerical parameters:**
 - ➔ convective CFL number : 0.3
 - ➔ artificial viscosity : 0.2 (Cook & Cabot)

V. Moureau, P. Domingo, and L. Vervisch. Design of a massively parallel CFD code for complex Geometries. Comptes Rendus de l'Académie des Sciences (2010).



- NTMIX Solver

➡ **Temporal scheme** : explicit six-stage Runge-Kutta algorithm, **third order**

➡ **Spatial scheme** : **sixth order** Lele Derivative

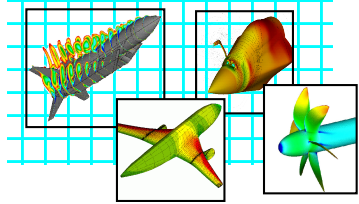
➡ **Numerical parameters:**

➡ acoustic CFL number : 0.7

➡ artificial viscosity : no

S. Lele. Compact finite difference schemes with spectral like resolution. J. Comput. Phys., 103:16-42, 1992.

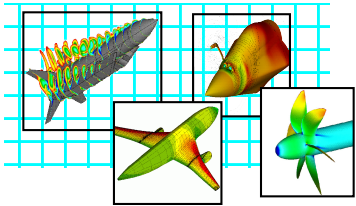




Analyse de la précision

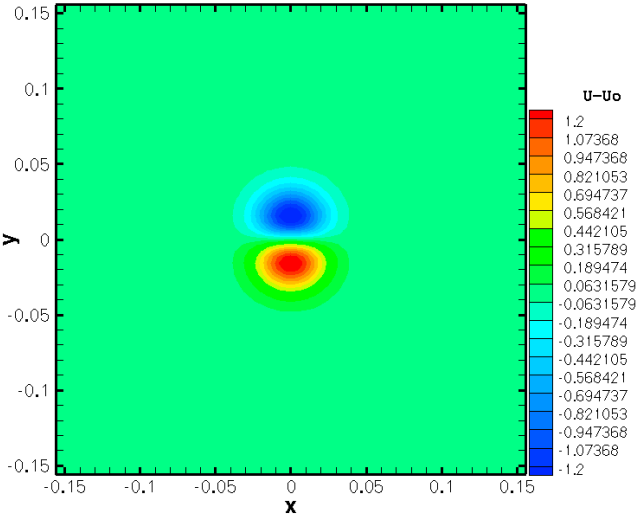
Solveurs	Schéma spatial	Schéma temporel	CFL convectif	CFL acoustique	Δt (s) nb_{it}	T_{CPU} (s)	$T_{CPU} / it / pt$ (s)
elsA	6 ^{ème} ordre	2 ^{ème} ordre	X	0.7	$5.0 \cdot 10^{-6}$ 71401	1318	$2.88 \cdot 10^{-6}$
AVBP	3 ^{ème} ordre	3 ^{ème} ordre	X	0.7	$5.17 \cdot 10^{-6}$ 68750	1620	$3.68 \cdot 10^{-6}$
OpenFoam	4 ^{ème} ordre	2 ^{ème} ordre	X	0.7	$7.5 \cdot 10^{-6}$ 23710	1330	$8.76 \cdot 10^{-6}$
YALES	4 ^{ème} ordre	4 ^{ème} ordre	0.3	X	$3.21 \cdot 10^{-5}$ 11080	1202	$1.7 \cdot 10^{-5}$
NTMIX	6 ^{ème} ordre	3 ^{ème} ordre	X	0.7	$5.13 \cdot 10^{-6}$ 69400	1355	$2.3 \cdot 10^{-6}$



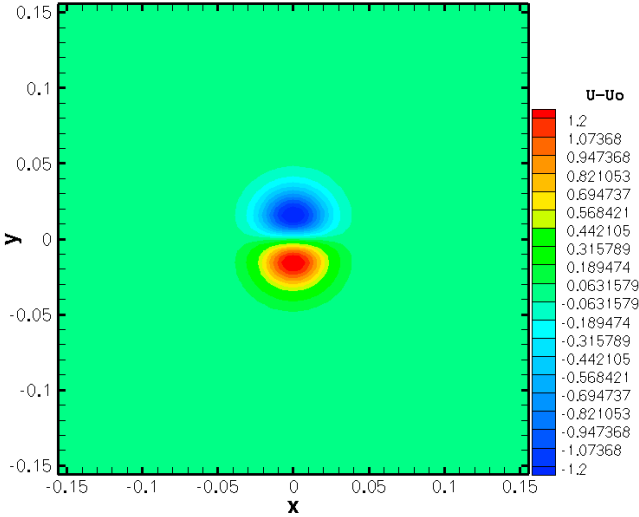


• Iso-contours de $u-U_0$: elsA

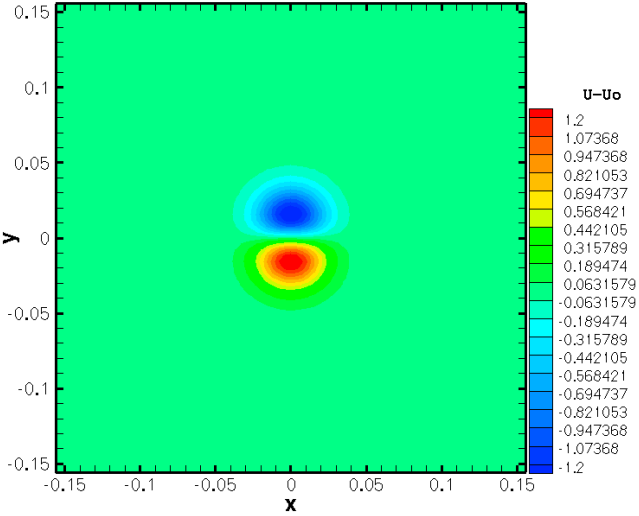
$T=10 \cdot L/U_0$



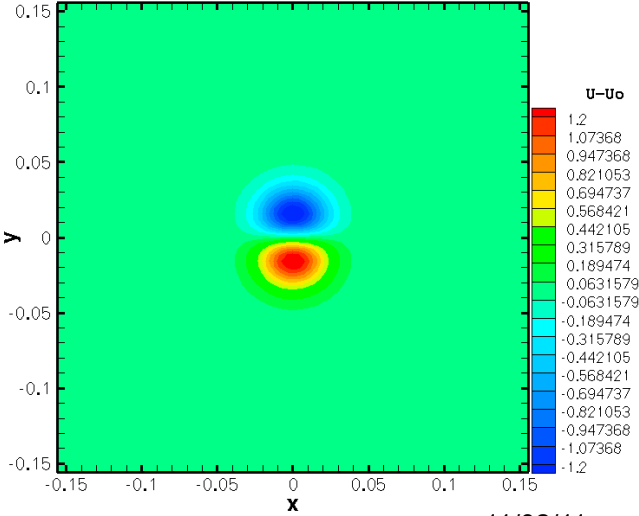
$T=20 \cdot L/U_0$

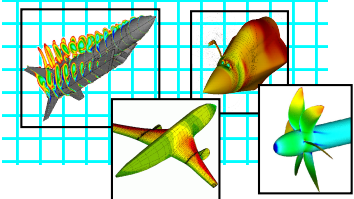


$T=30 \cdot L/U_0$



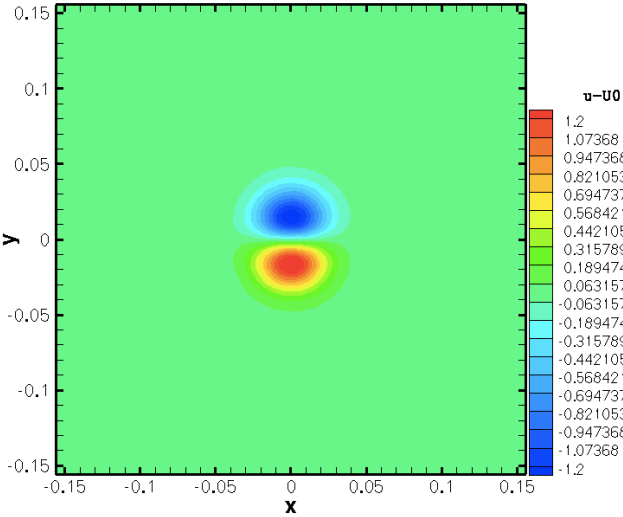
$T=40 \cdot L/U_0$



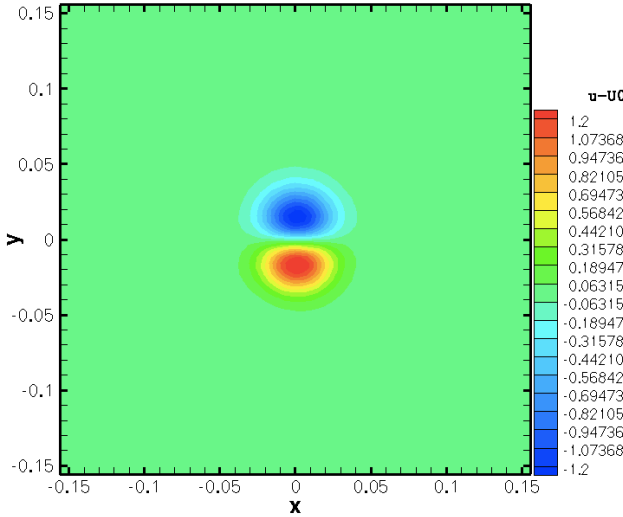


• Iso-contours de $u-U_0$: AVBP

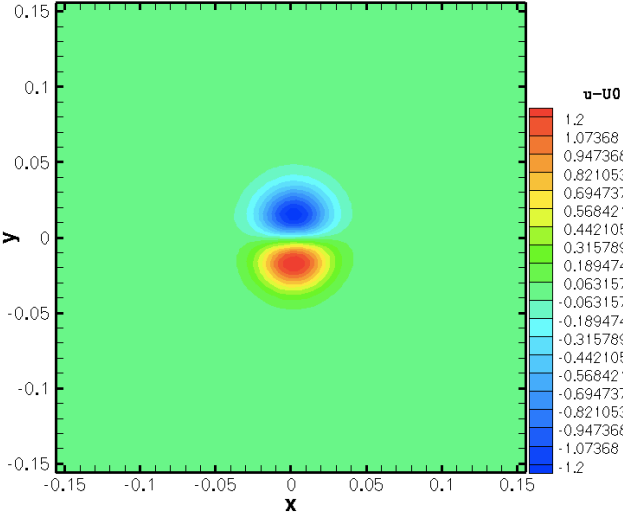
$T=10 \cdot L/U_0$



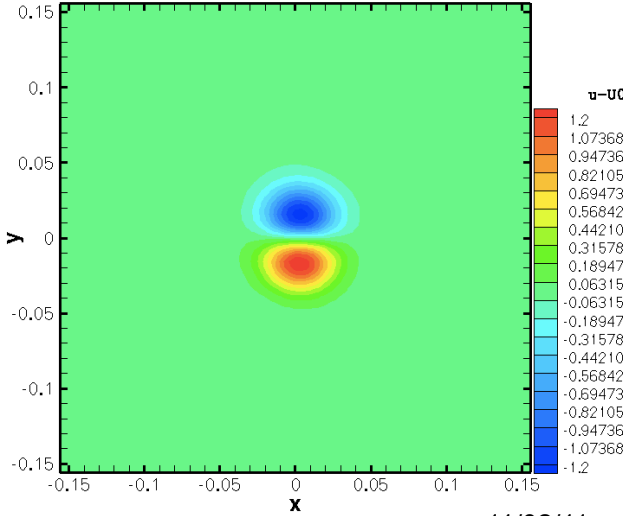
$T=20 \cdot L/U_0$

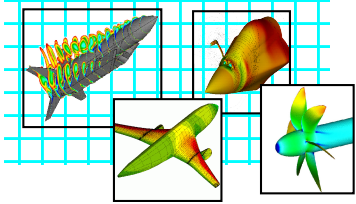


$T=30 \cdot L/U_0$



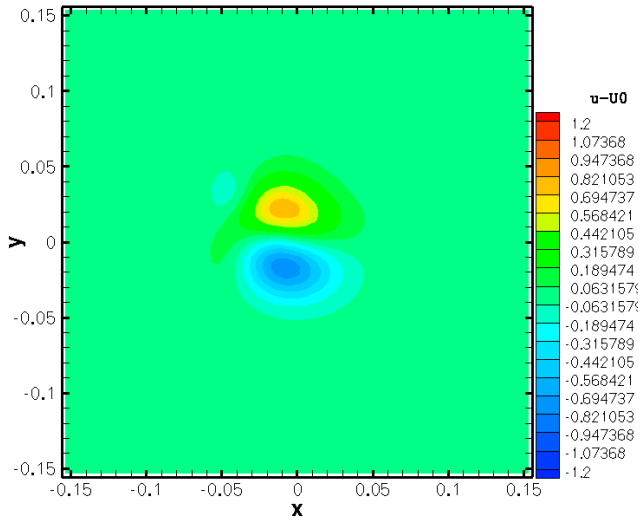
$T=40 \cdot L/U_0$



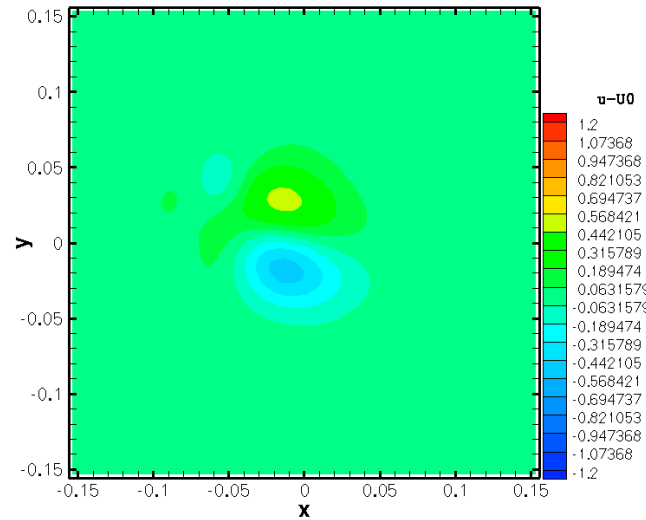


• Iso-contours de $u-U_0$: OpenFoam

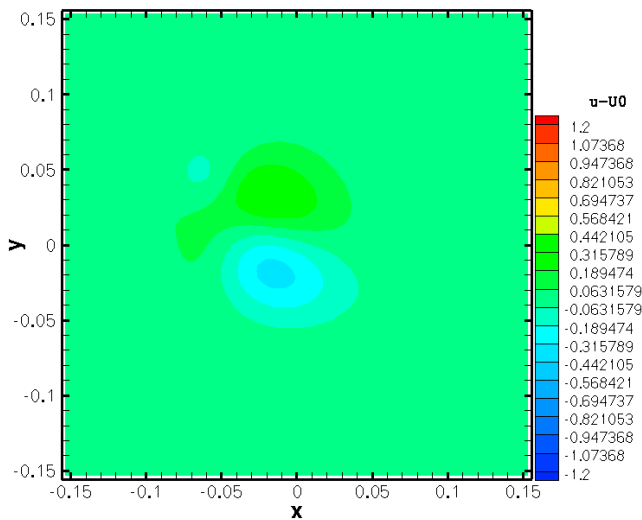
$T=10 \cdot L/U_0$



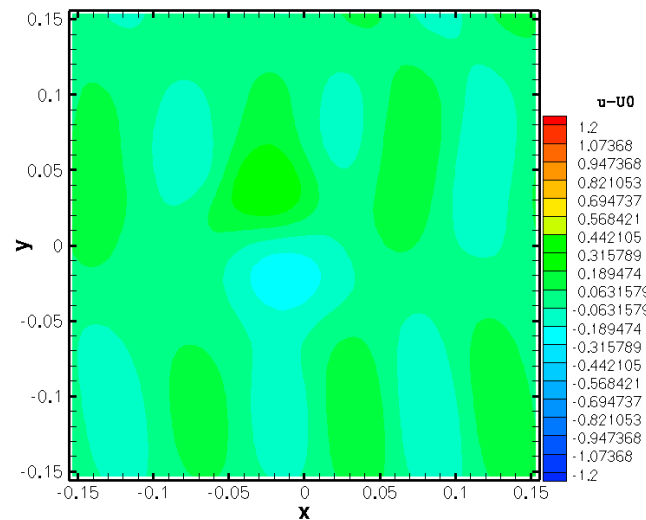
$T=20 \cdot L/U_0$

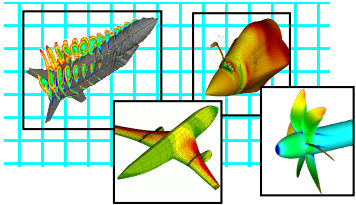


$T=30 \cdot L/U_0$



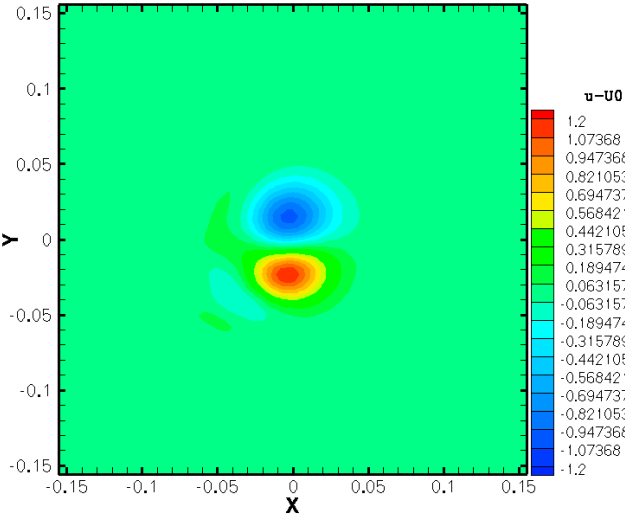
$T=40 \cdot L/U_0$



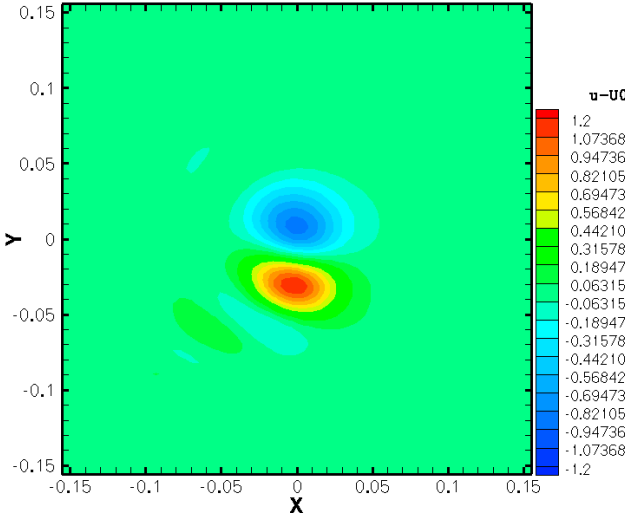


• Iso-contours de $u-U_0$: **YALES**

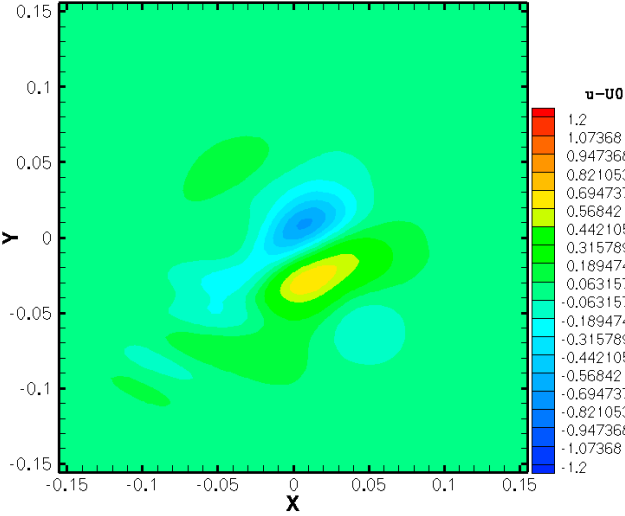
$T=10 \cdot L/U_0$



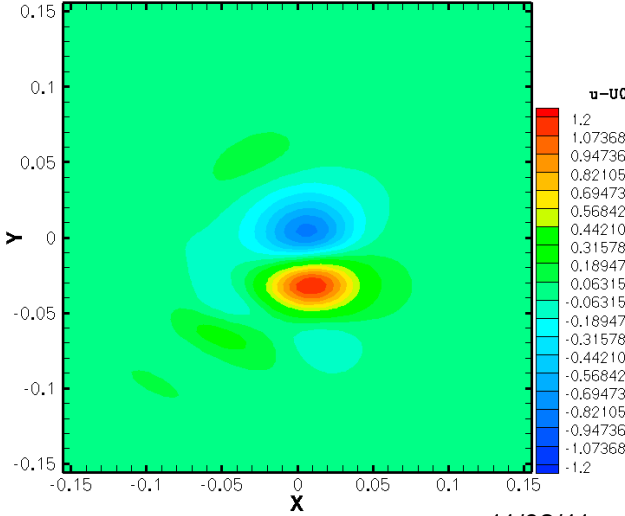
$T=20 \cdot L/U_0$

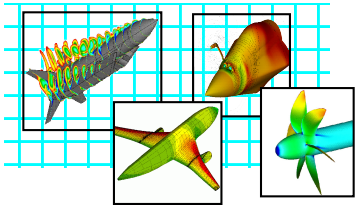


$T=30 \cdot L/U_0$



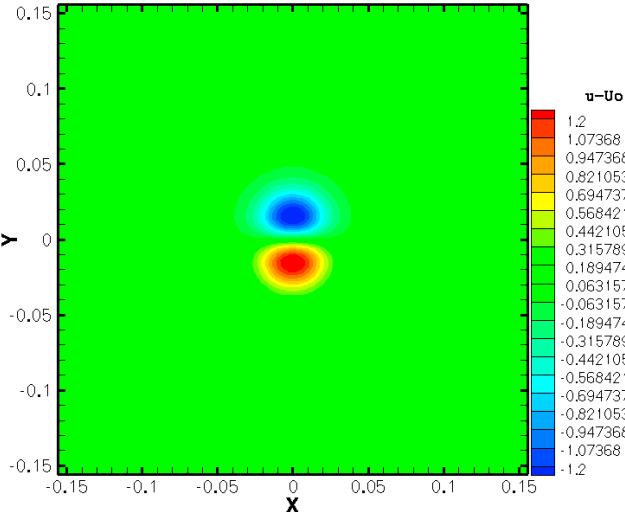
$T=40 \cdot L/U_0$



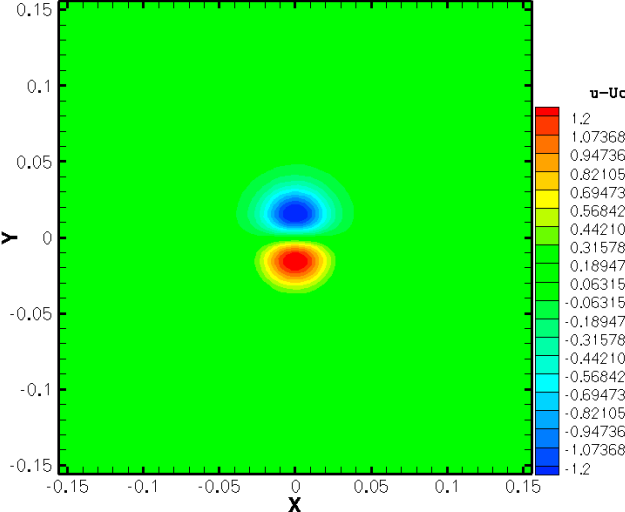


• Iso-contours de $u-U_0$: **NTMIX**

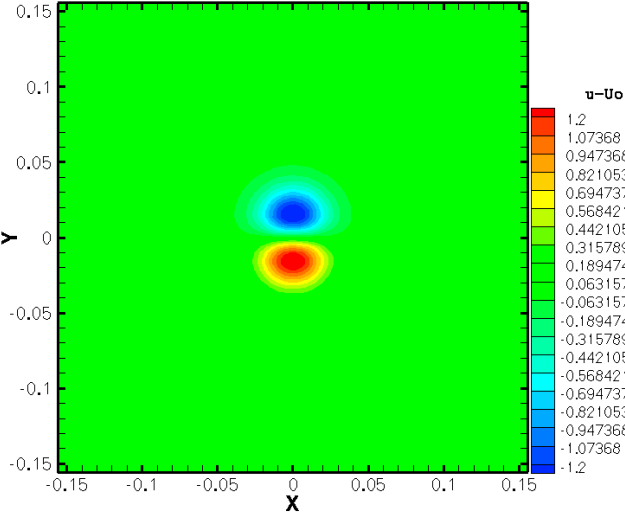
$T=10 \cdot L/U_0$



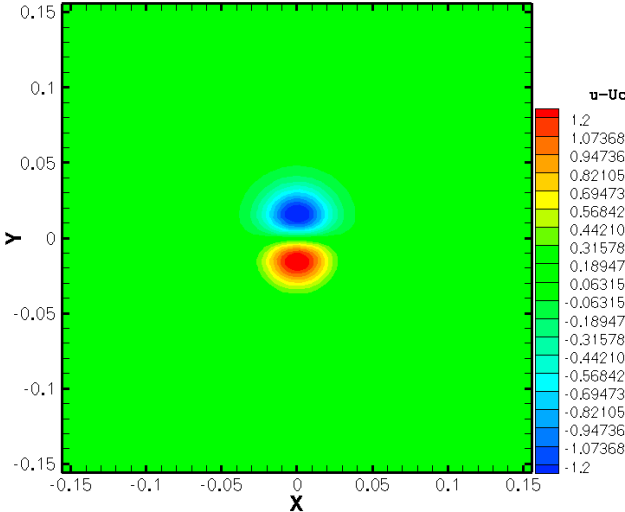
$T=20 \cdot L/U_0$

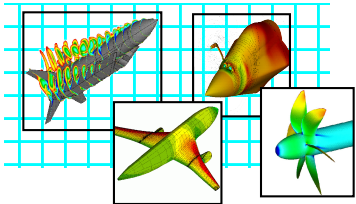


$T=30 \cdot L/U_0$

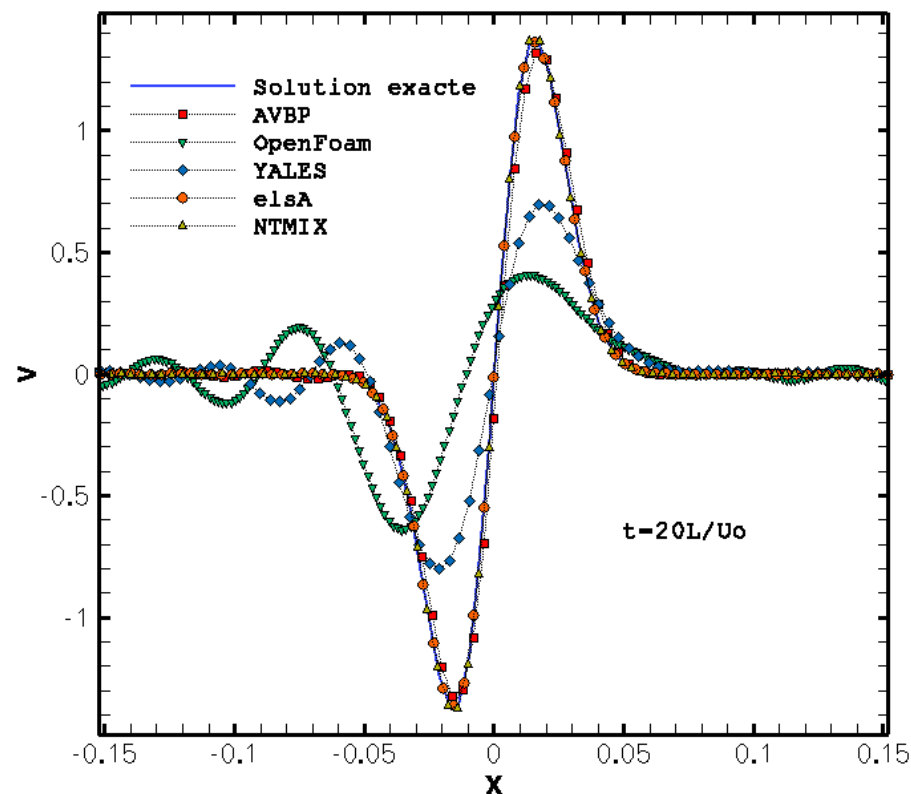
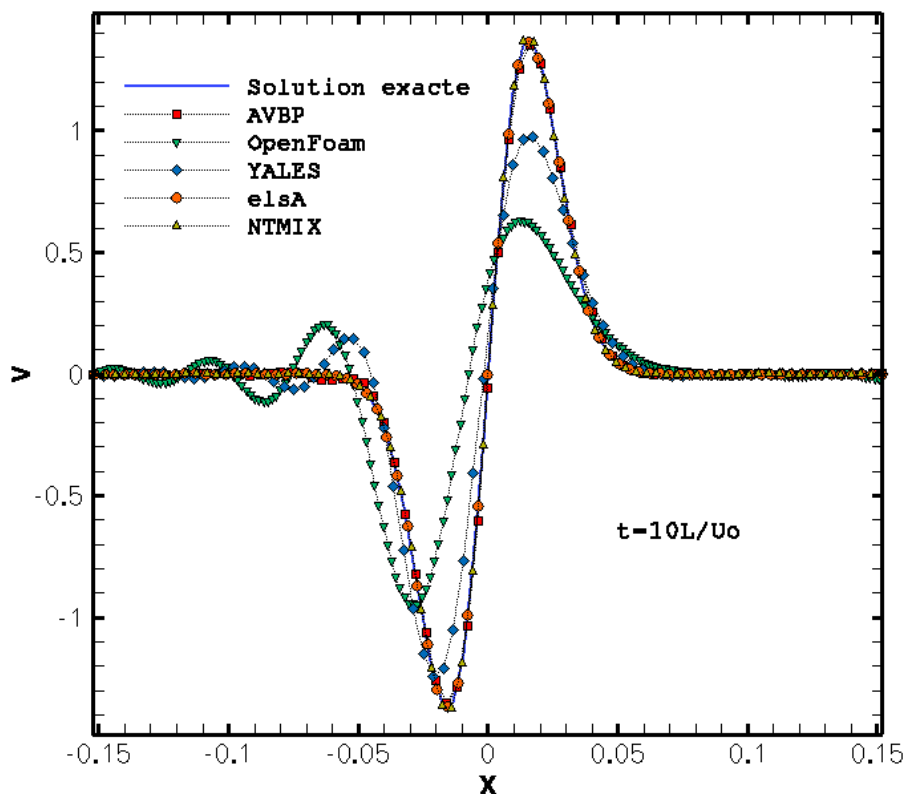


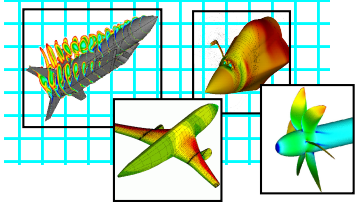
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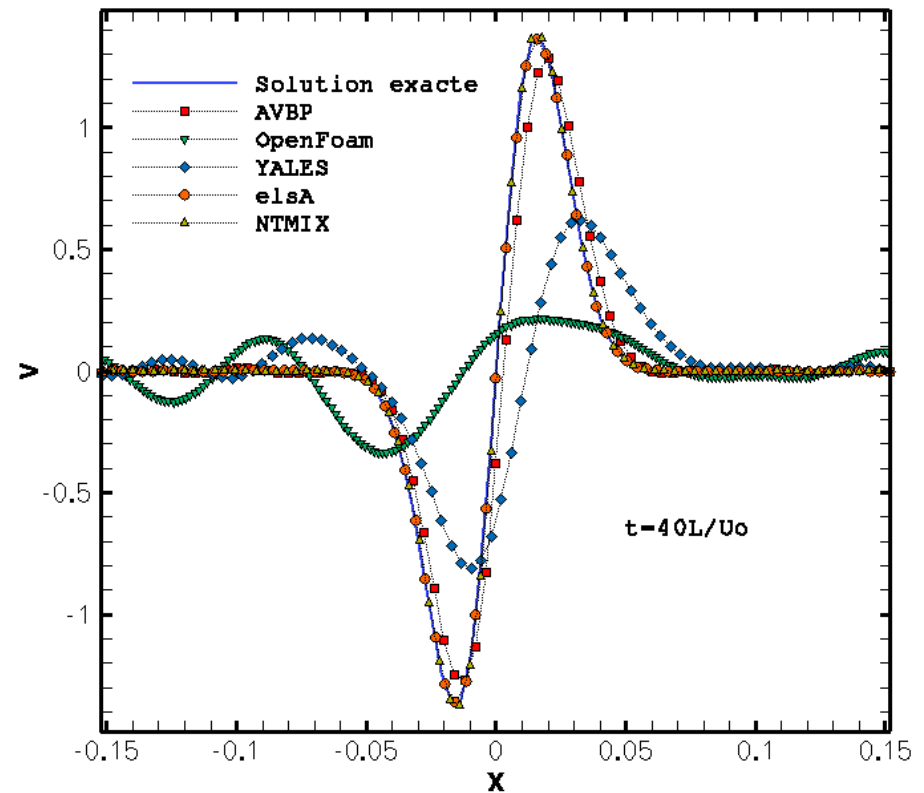
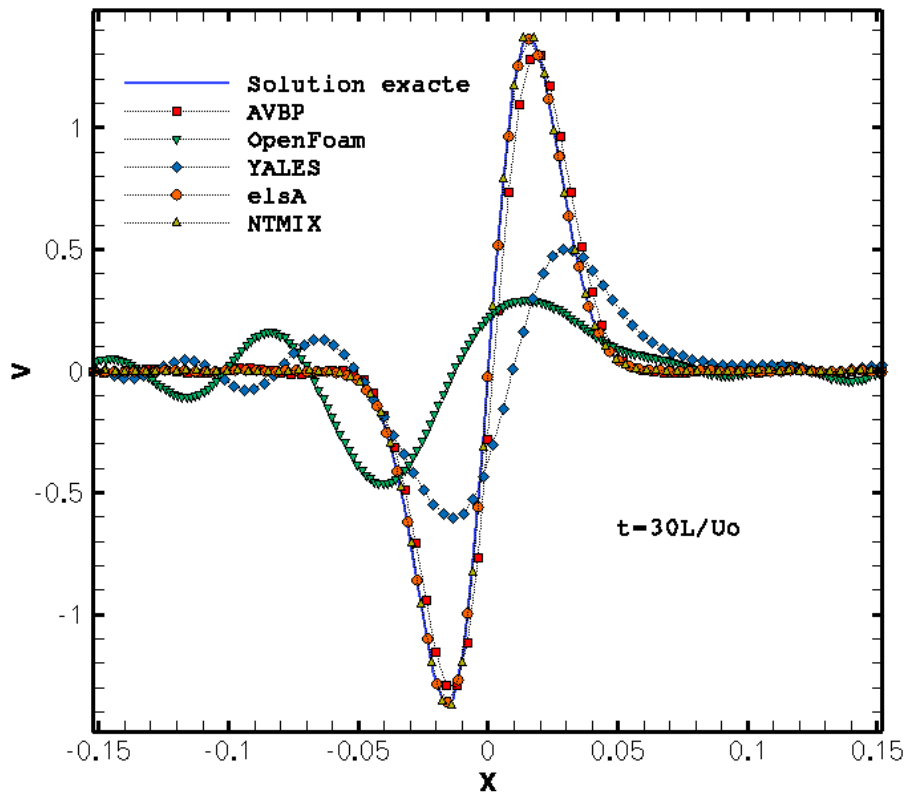


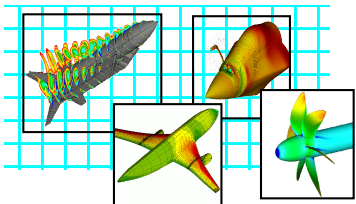
- Profils de vitesse v : $t=10*L/U_0$ et $t=20*L/U_0$



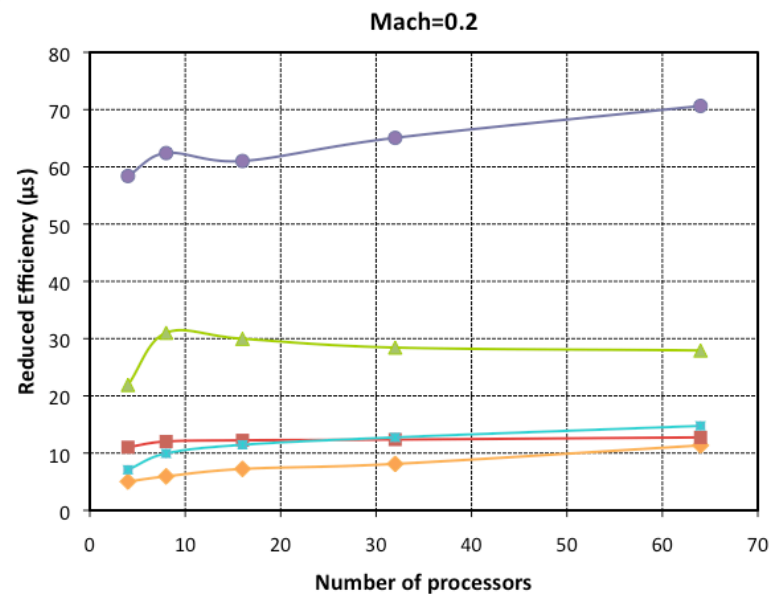
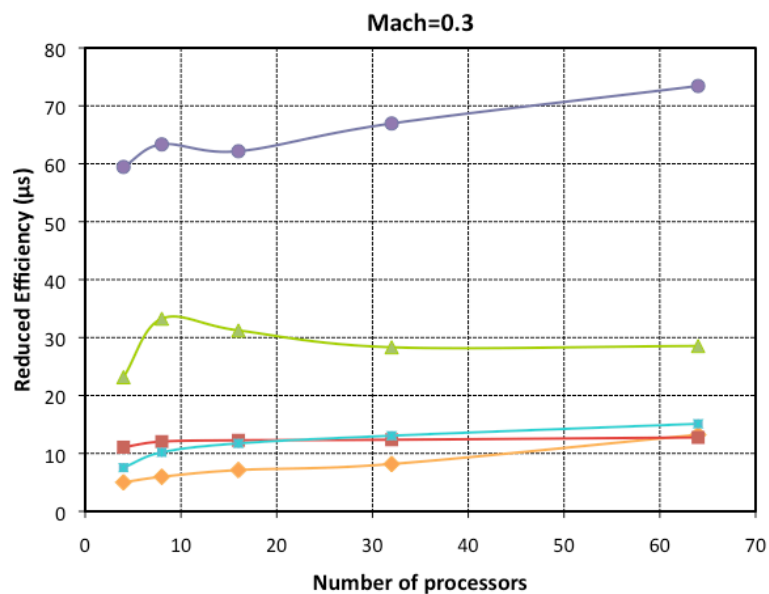
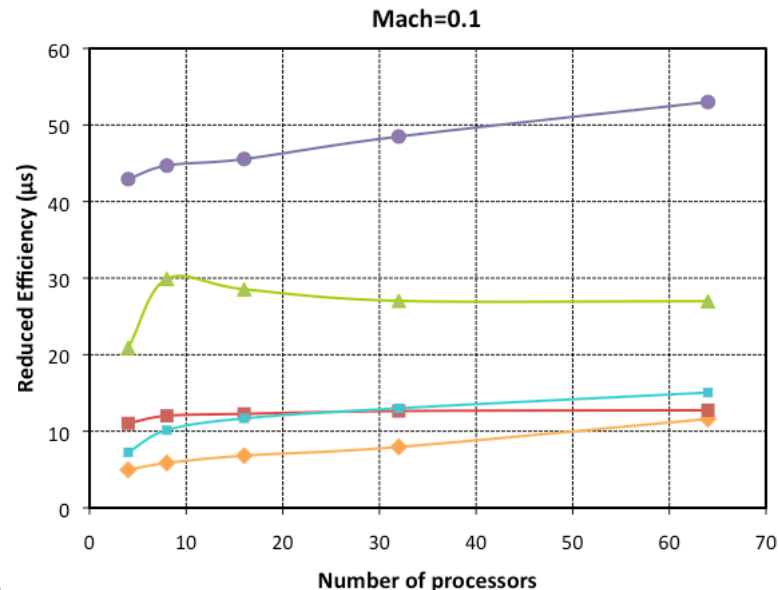
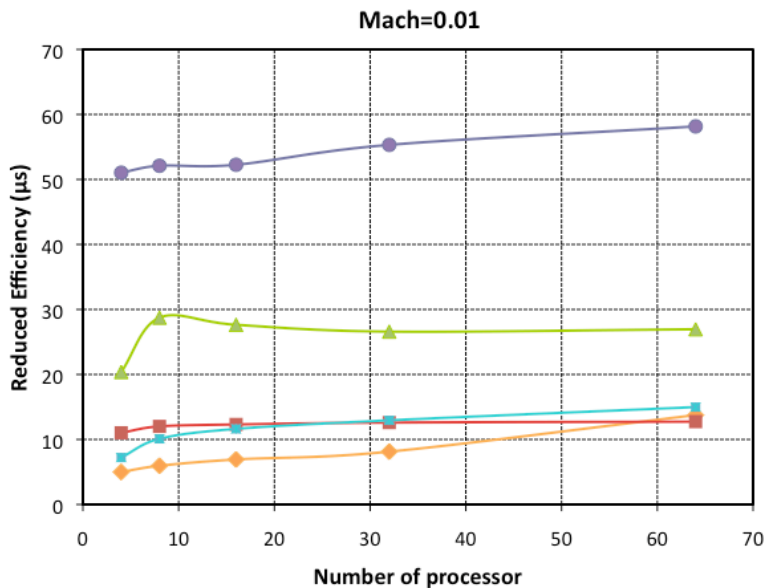


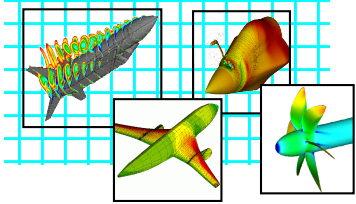
- Profils de vitesse v : $t=30*L/U_0$ et $t=40*L/U_0$





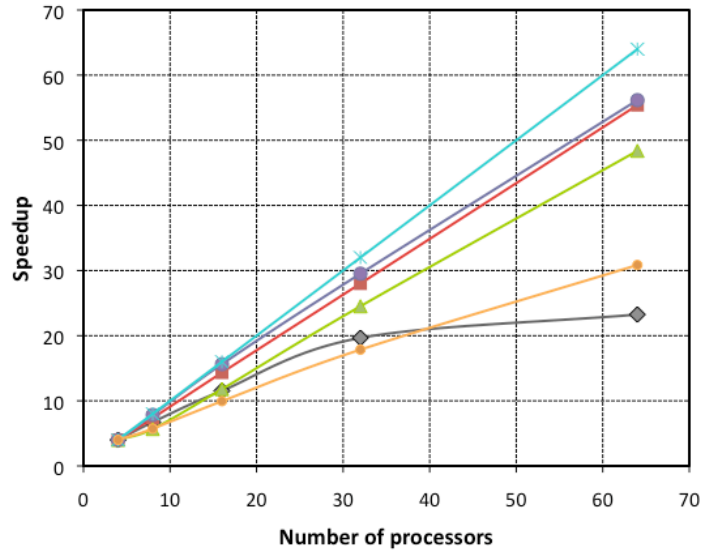
Analyse des performances: Efficacité Réduite



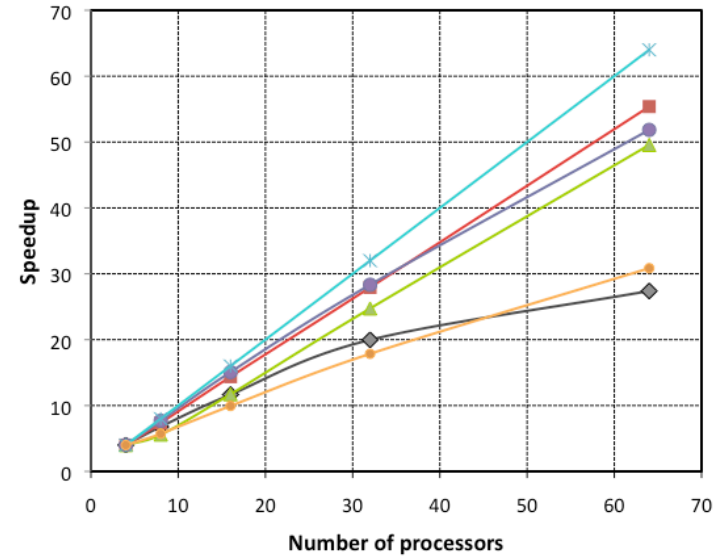


Analyse des performances: Speedup

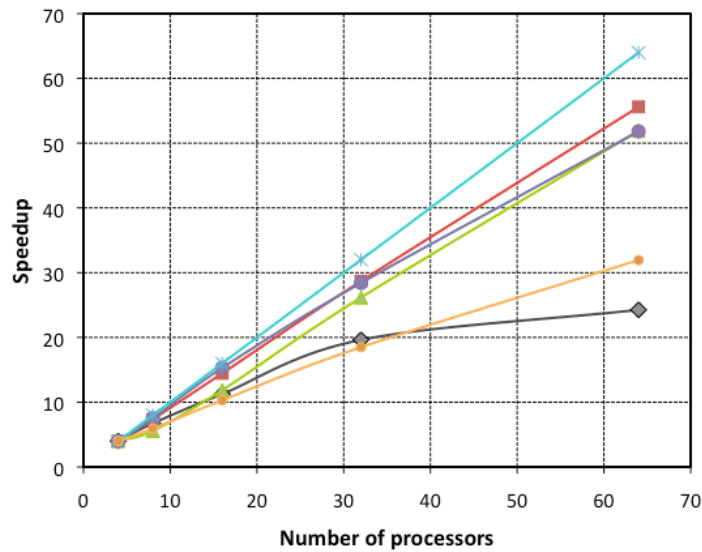
Mach=0.01



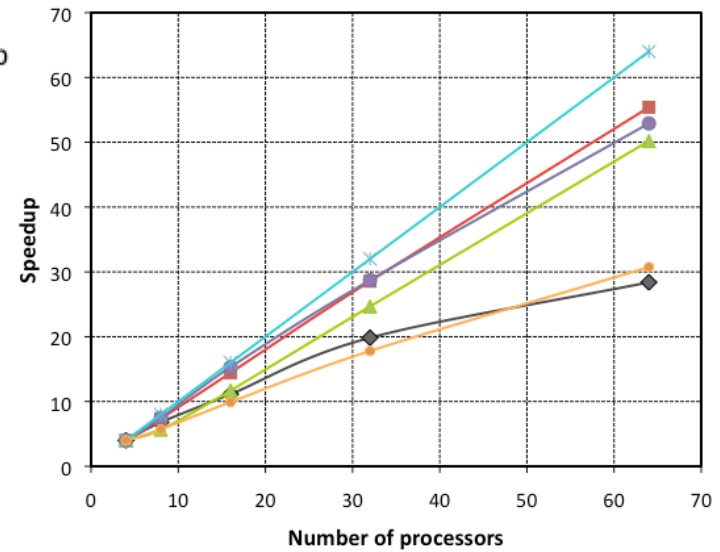
Mach=0.1



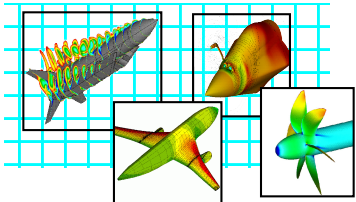
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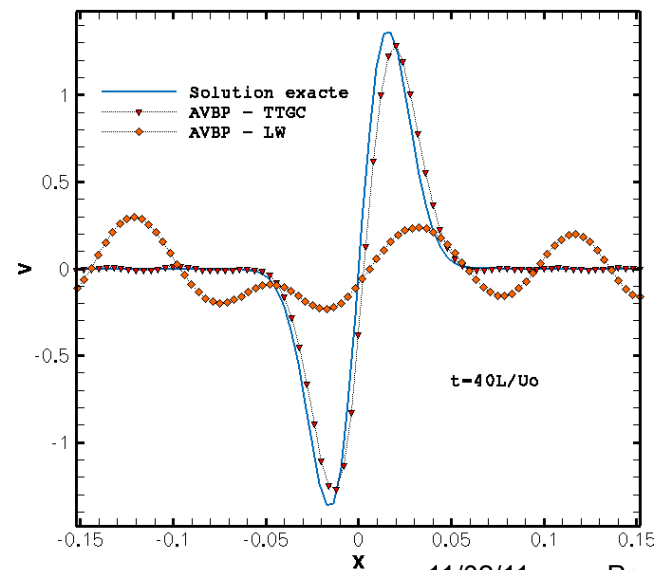
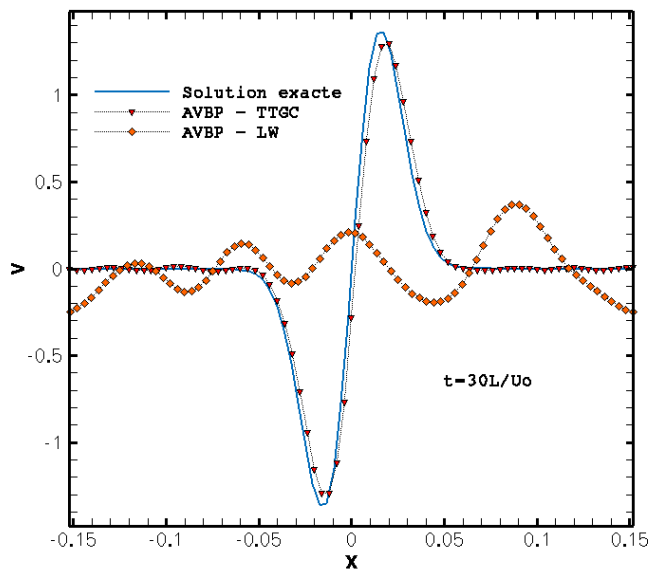
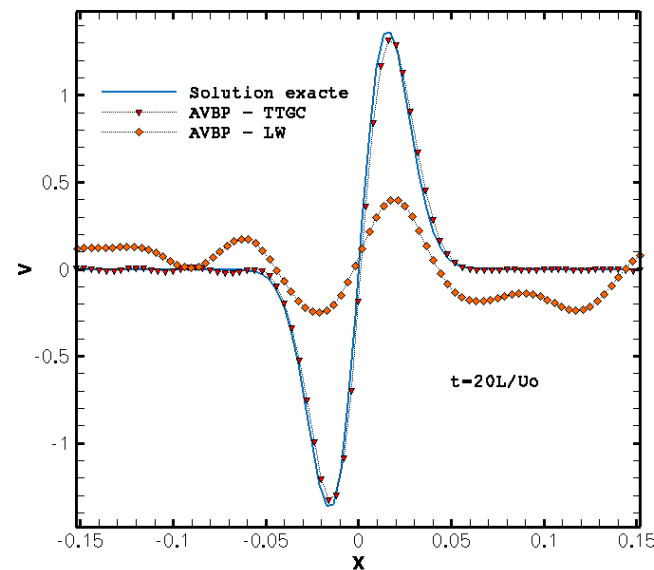
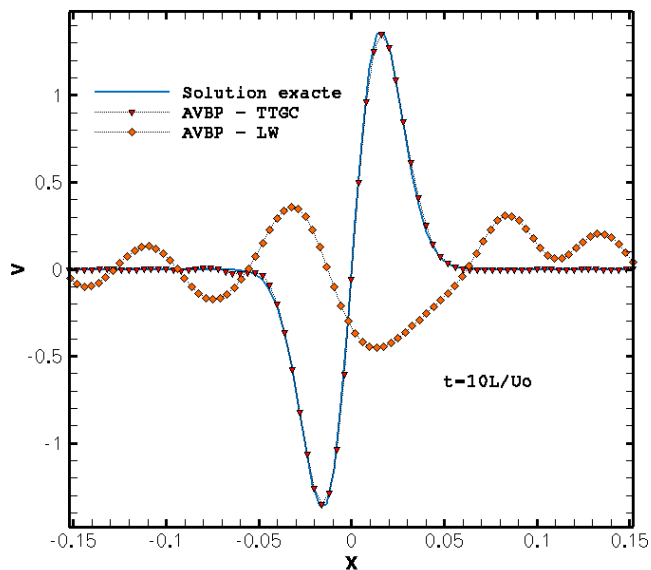
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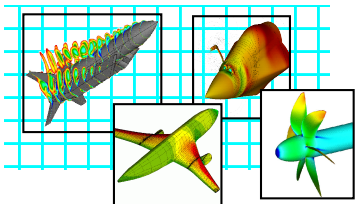


- ◆ Elsa
- AVBP
- ▲ OpenFOAM
- YALES2
- * LINEAR Speedup
- NTMIX

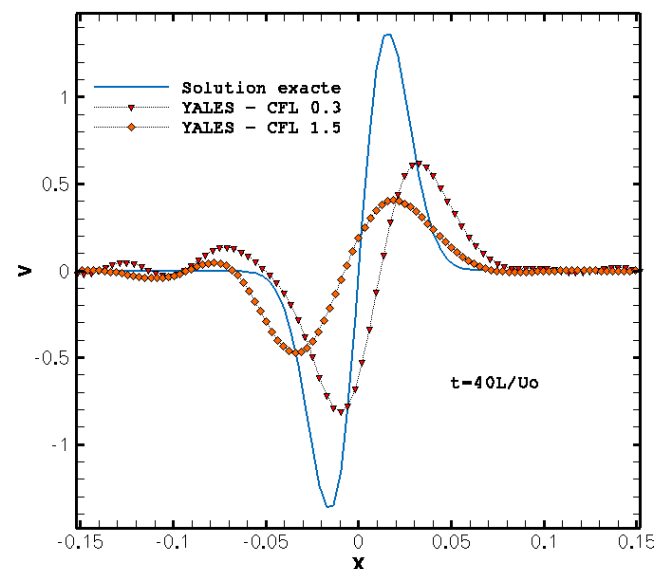
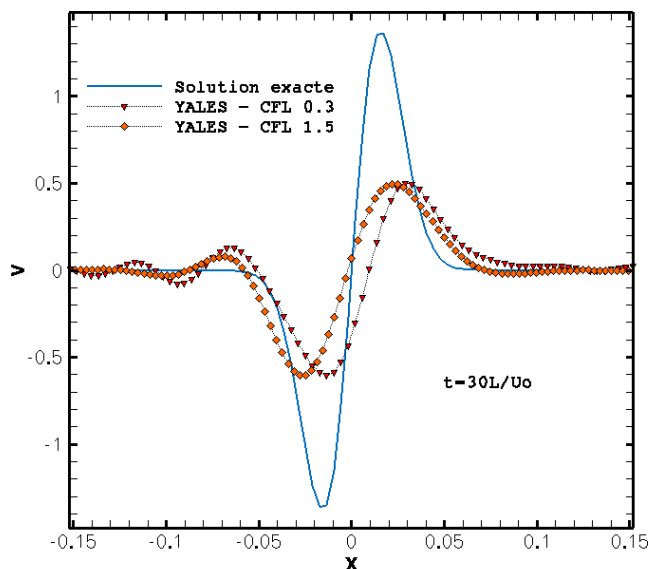
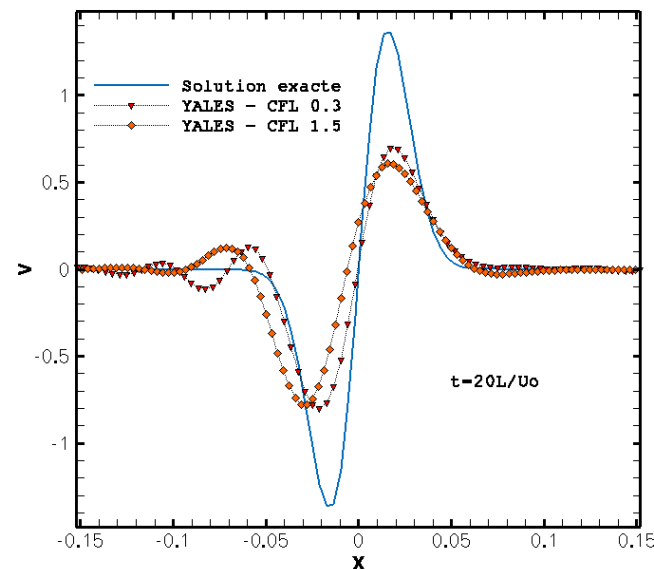
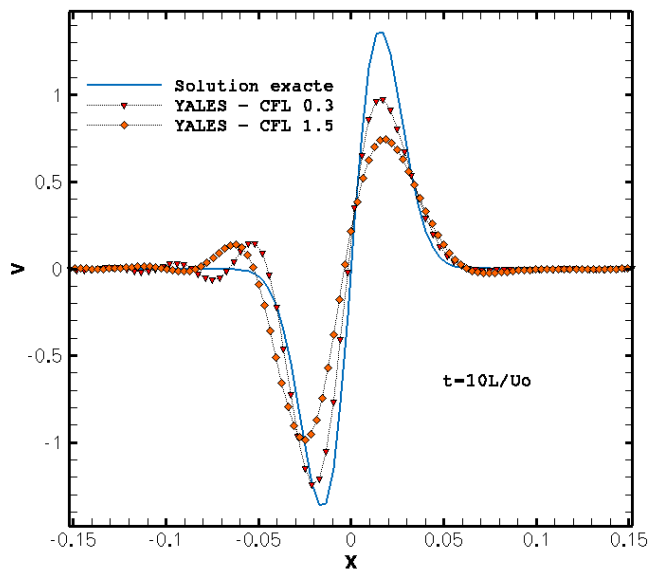


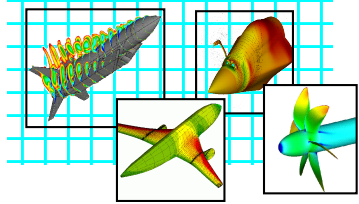
Comparaisons intra-code: AVBP





Comparaisons intra-code: YALES





A suivre ...