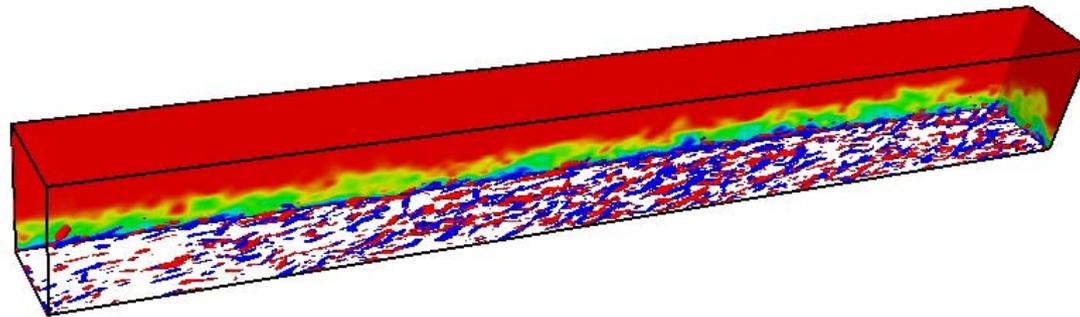




# LES fines et méthodes hybrides RANS/LES

*N. Jarrin, J. Uribe, A. Revell, R. Prosser, D. Laurence*



# Introduction

## ❑ Principe de la LES:

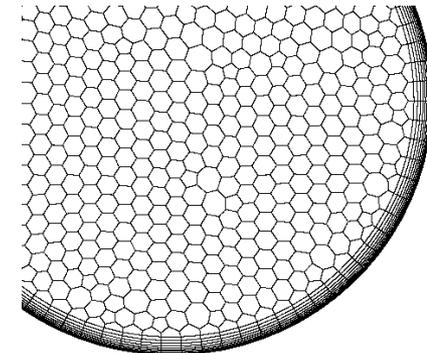
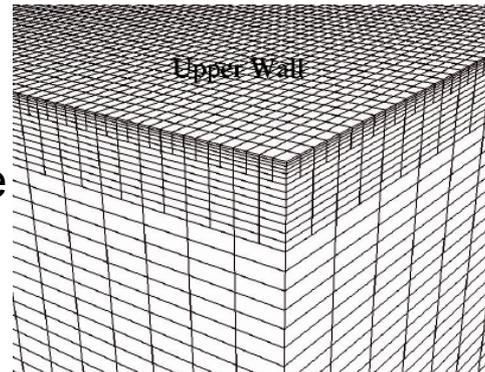
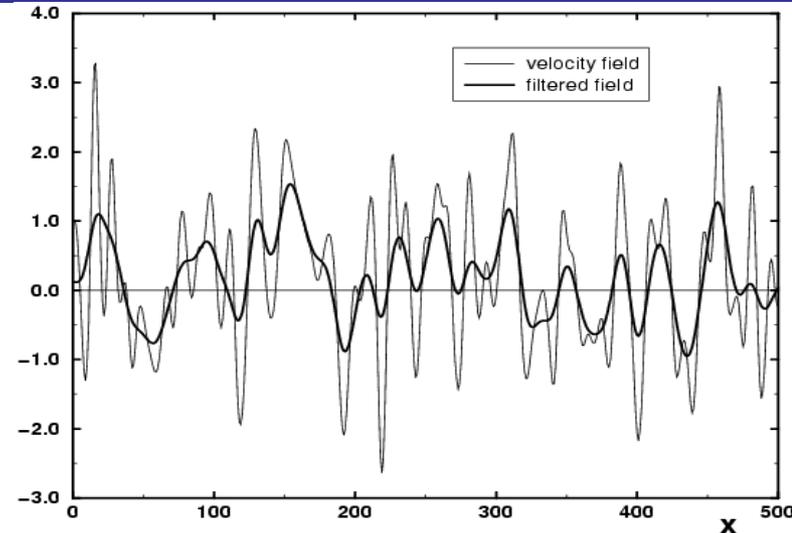
- ❑ Filtrage en espace de la turbulence
- ❑ Modélisation des petites échelles

## ❑ Modélisation de sous-maille:

- ❑ Modèle de Smagorinsky standard a 40 ans...
- ❑ Progrès limités en modélisation LES surtout en proche paroi

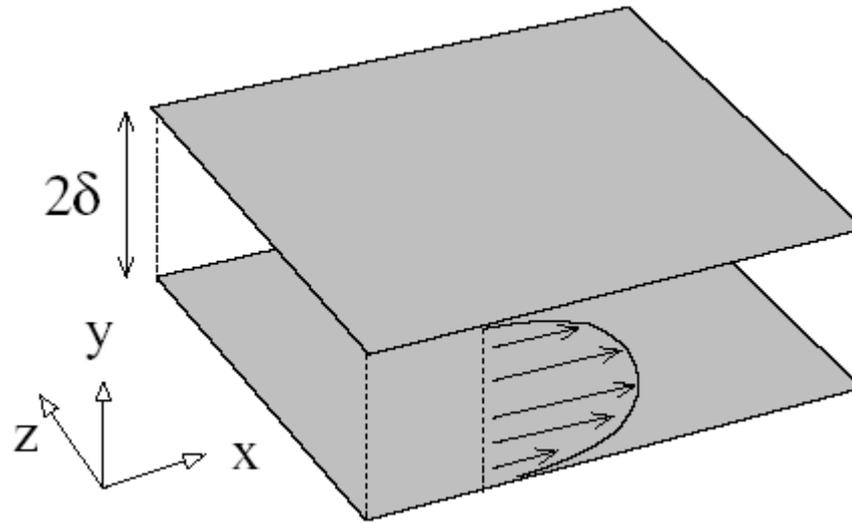
## ❑ Problématiques:

- ❑ Numérique, Qualité de maillage
- ❑ Couplage avec RANS
- ❑ Conditions d'entrée



# Ecoulement en canal $Re^* = 395$

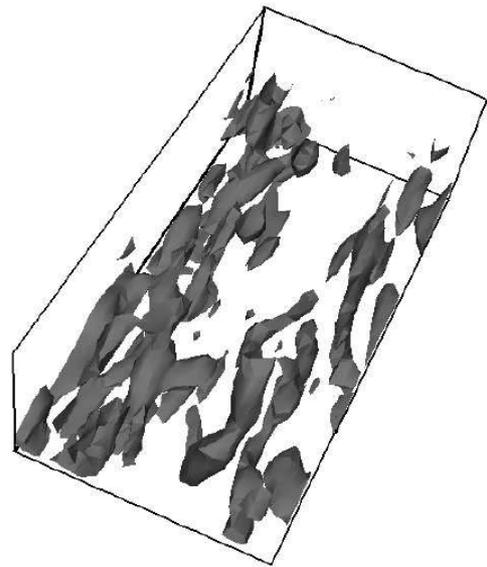
## Test de convergence de maillage (1/3)



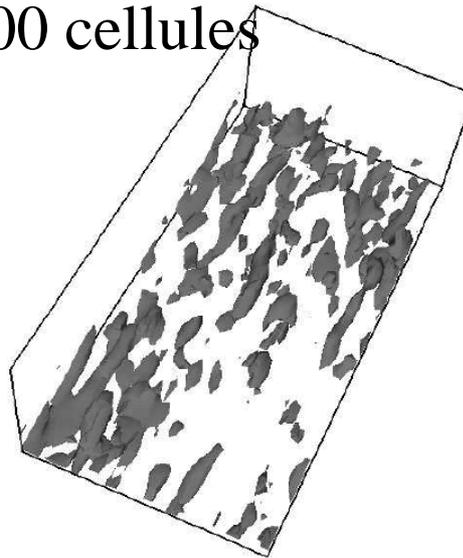
Run	$Re_\tau$	$N_x \times N_y \times N_z$	$\Delta x^+$	$\Delta z^+$	$\Delta y_{\min}^+$	$\Delta y_{\max}^+$
A	395	$32 \times 32 \times 24$	77	51	2.0	62
B	395	$48 \times 48 \times 32$	52	39	1.7	39
C	395	$64 \times 64 \times 64$	39	19	1.6	27
D	395	$96 \times 96 \times 96$	26	13	0.9	19
E	395	$128 \times 128 \times 128$	20	10	0.7	14

# Écoulement en canal $Re^* = 395$

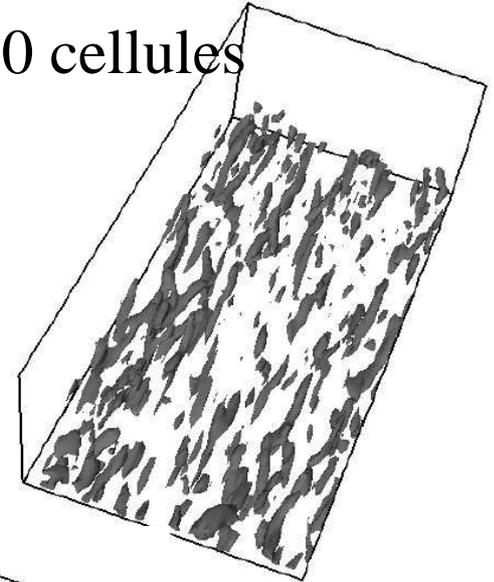
## Test de convergence de maillage (2/3)



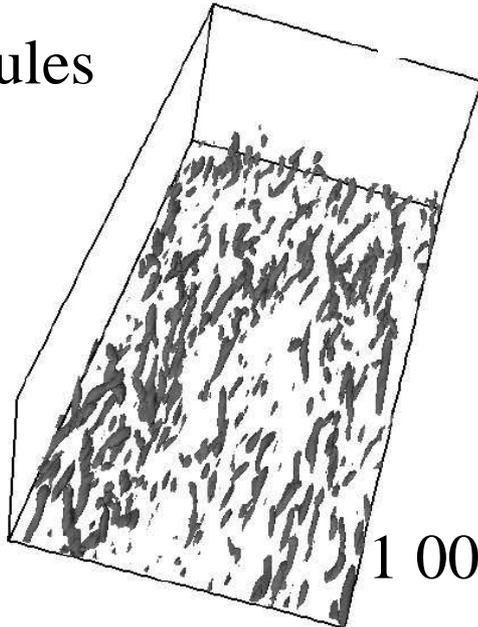
75 000 cellules



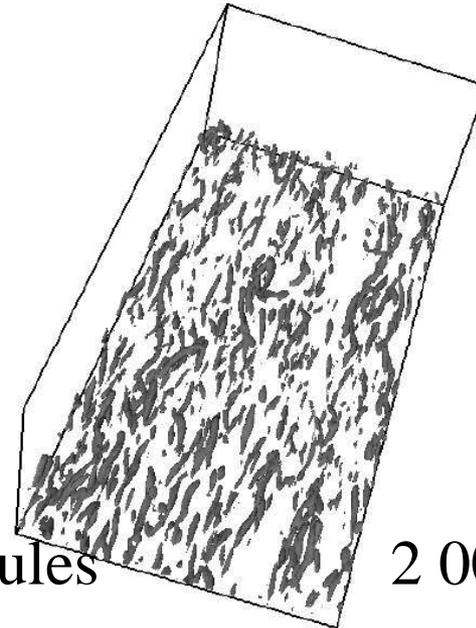
260 000 cellules



20 000 cellules



1 000 000 cellules

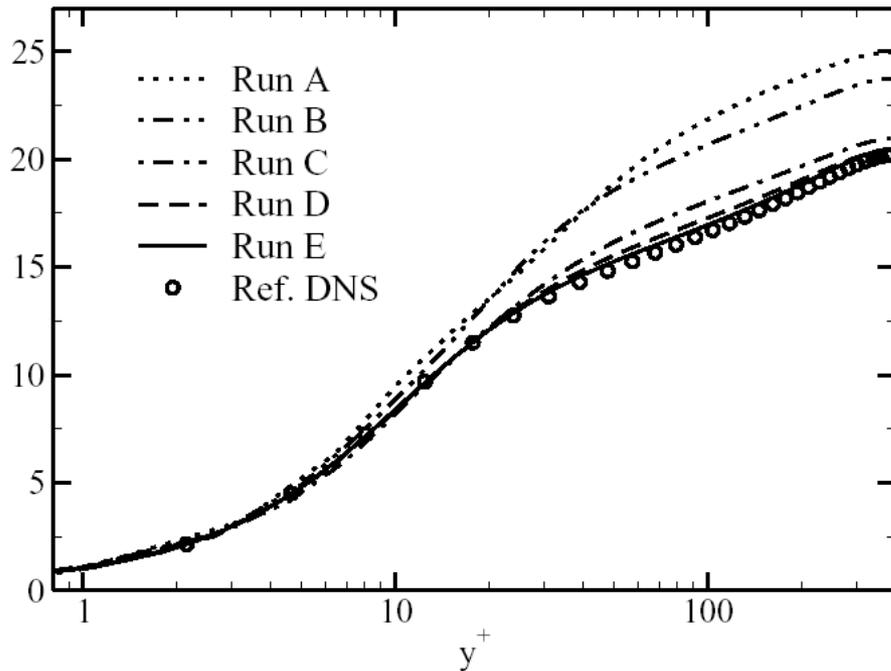


2 000 000 cellules

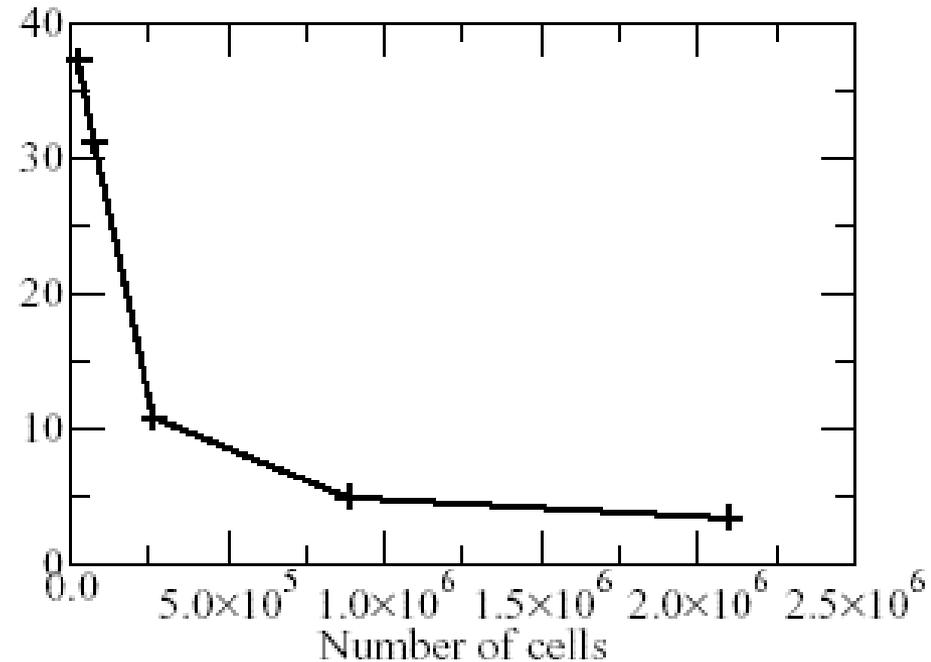
# Ecoulement en canal $Re^* = 395$

## Test de convergence de maillage (3/3)

□ Profile moyen de vitesse:

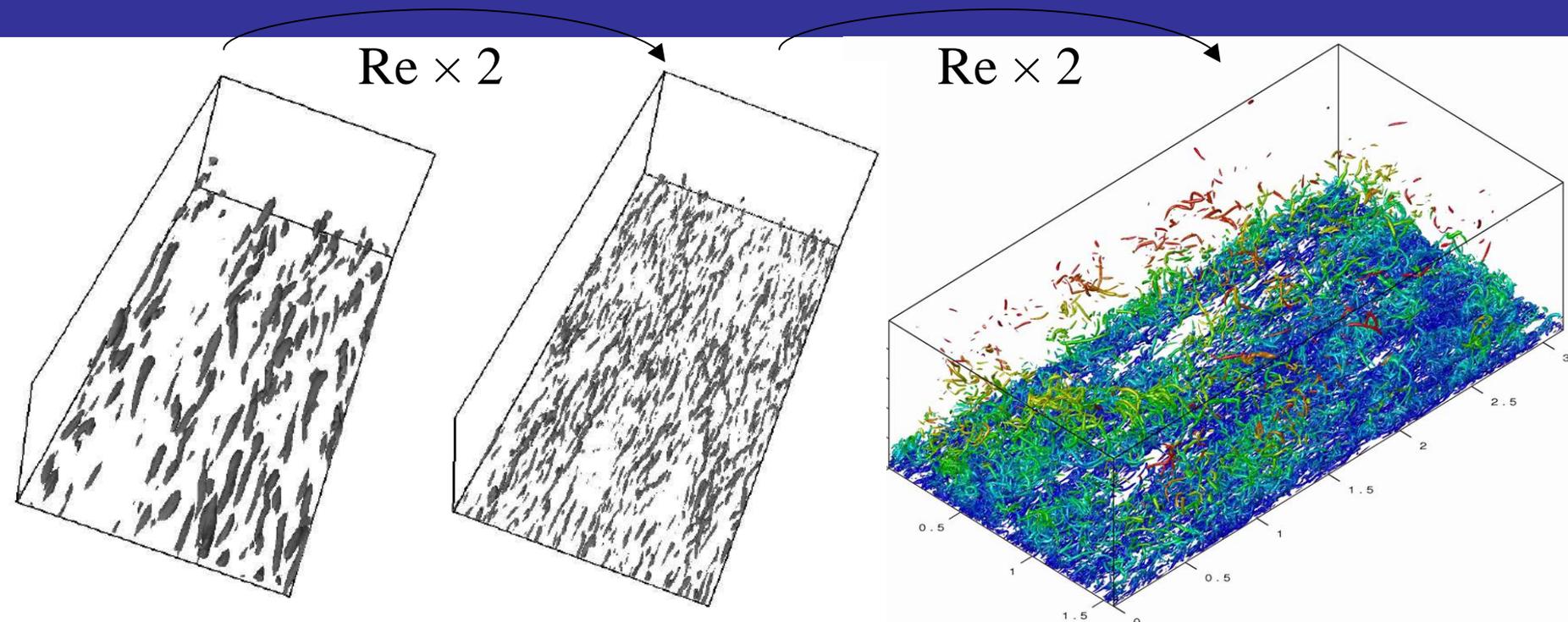


□ Erreur dans le coefficient de frottement: (en %)



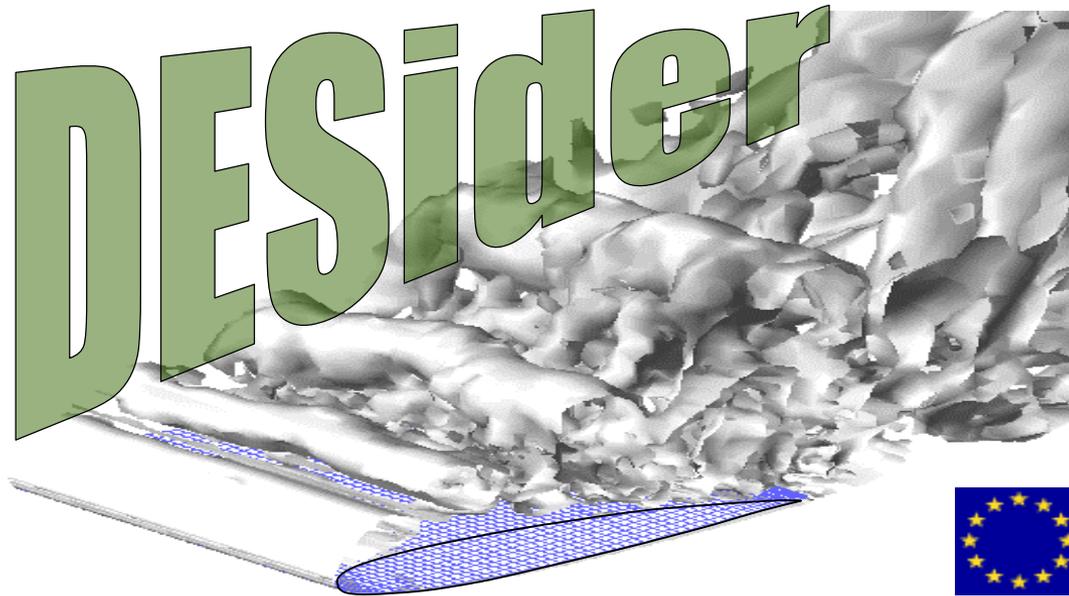
LES grossière beaucoup plus dangereux que RANS grossier !

# Prédictions de faisabilité LES fine en paroi

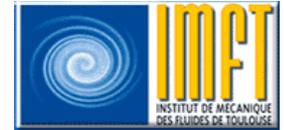


Method	Aim <sup>*)</sup>	Grid: Re-no. Dependence	Empiricism	Grid-Size	Number of time steps	Readiness
3D-URANS	Numerical	Weak	Strong	$10^7$	$10^{3.5}$	1995
LES	Hybrid	Weak	Weak	$10^{11.5}$	$10^{6.7}$	2045
DNS	Numerical	Strong	None	$10^{16}$	$10^{7.7}$	2080
<b>DES</b>	<b>Hybrid</b>	<b>Weak</b>	<b>Strong</b>	<b><math>10^8</math></b>	<b><math>10^4</math></b>	<b>2000</b>

# Projet européen Desider



Detached Eddy Simulation for Industrial Aerodynamics



# Principe de la DES

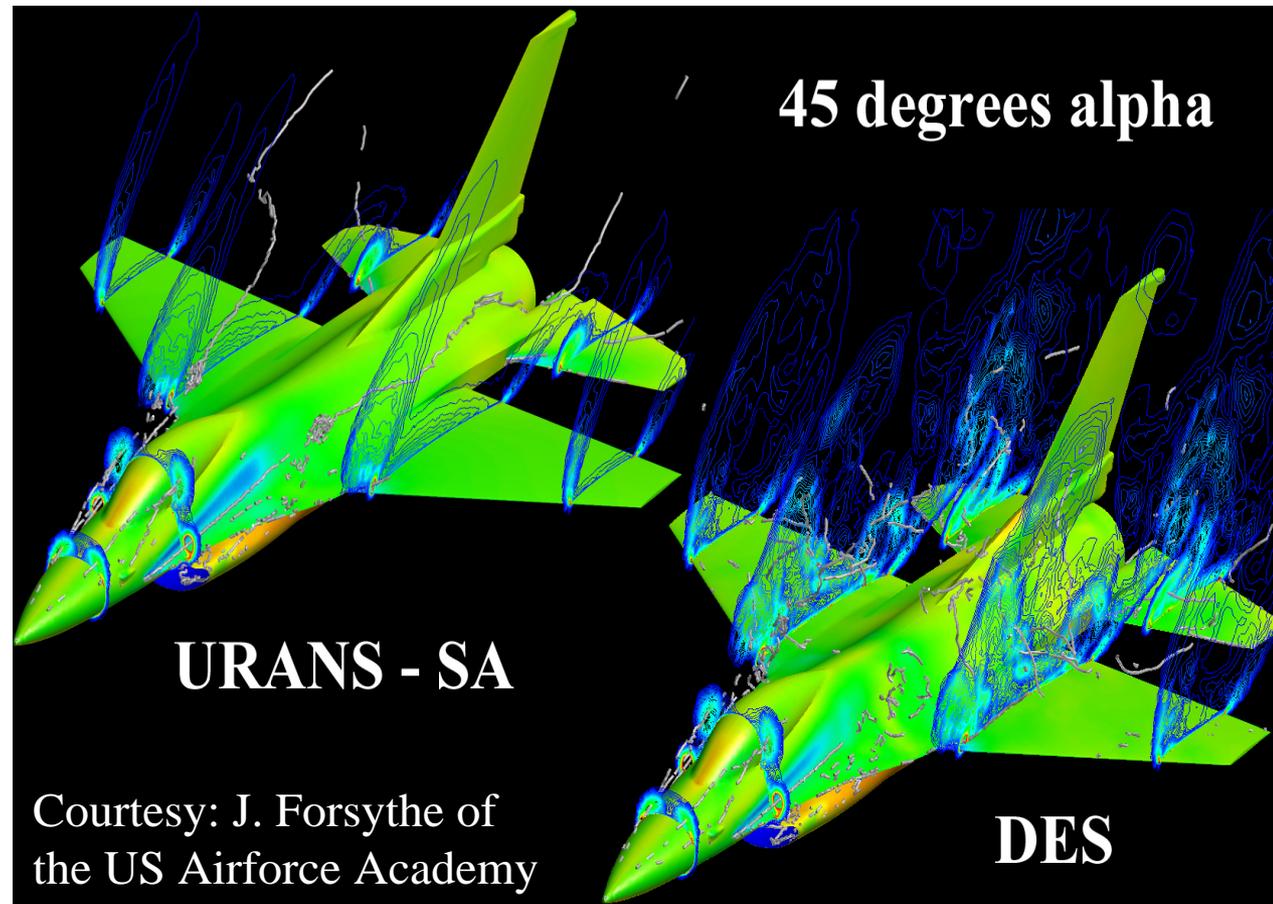
□ Modèle RANS classique avec :  $l_{DES} = \min(l_{RANS}, C_{DES}\Delta)$

□ A la paroi:

$$l_{DES} = l_{RANS}$$

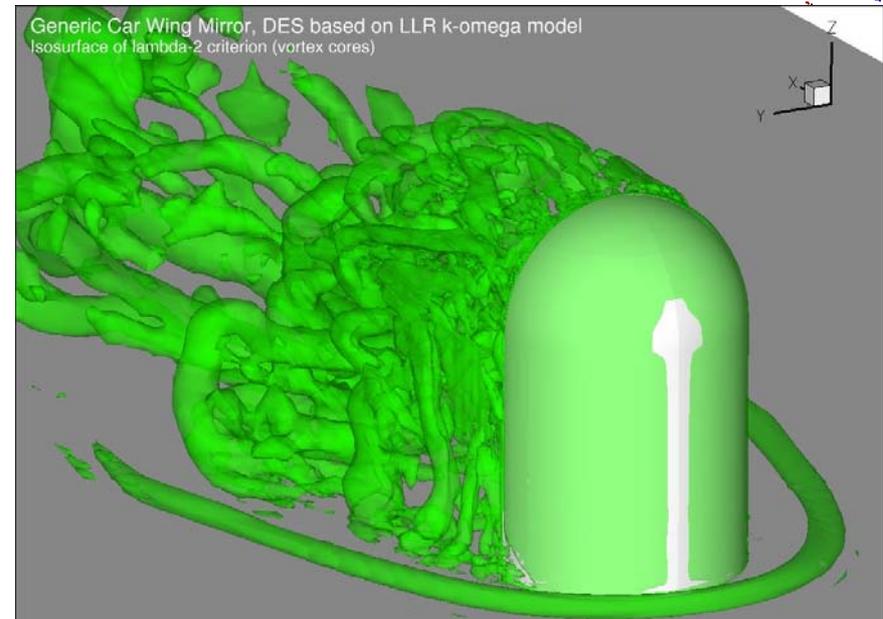
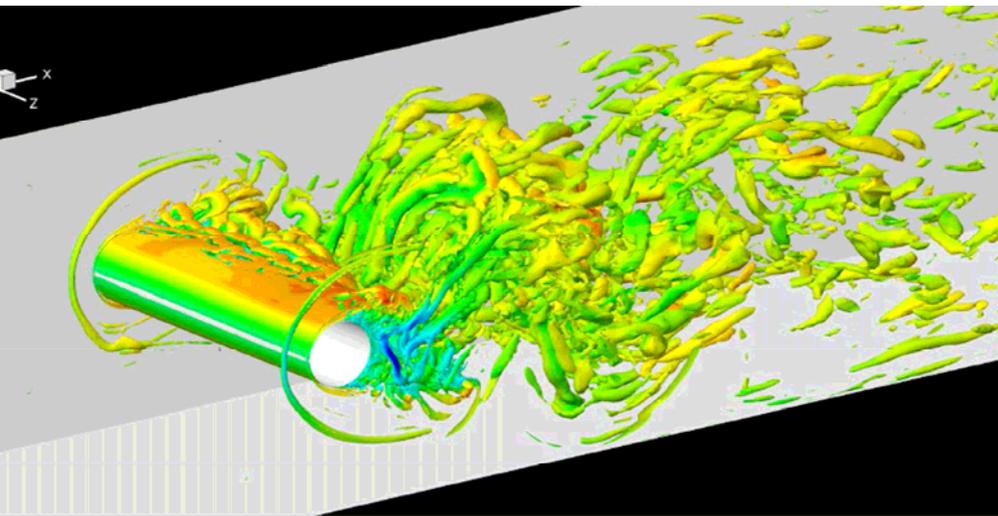
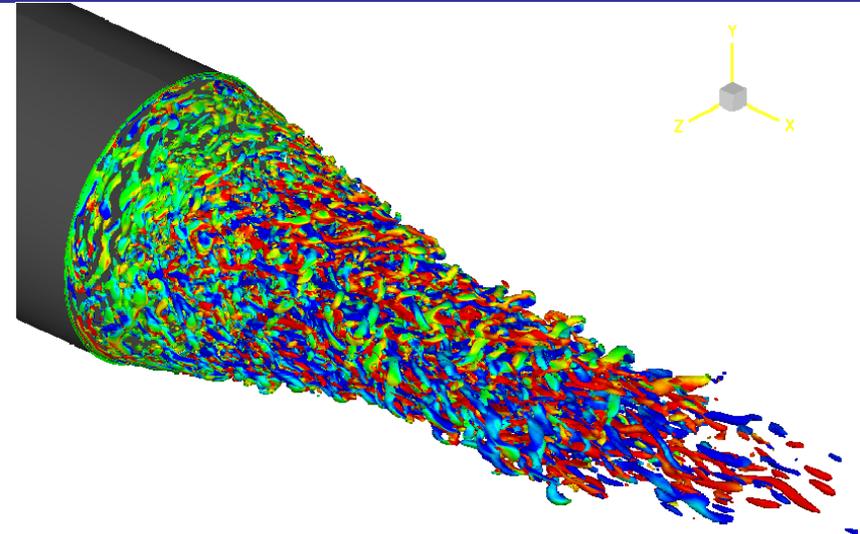
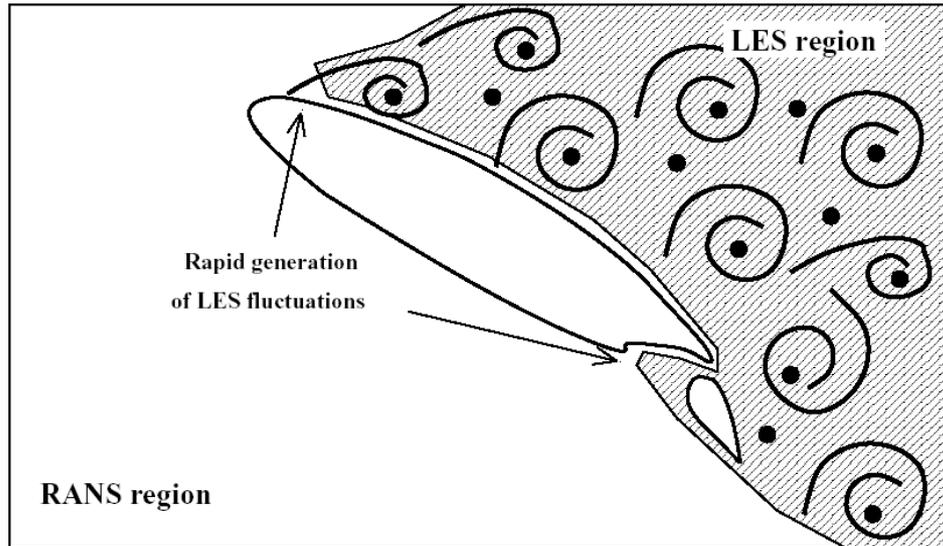
□ Loin de la paroi:

$$l_{DES} = C_{DES}\Delta$$



# Champ d'application de la DES

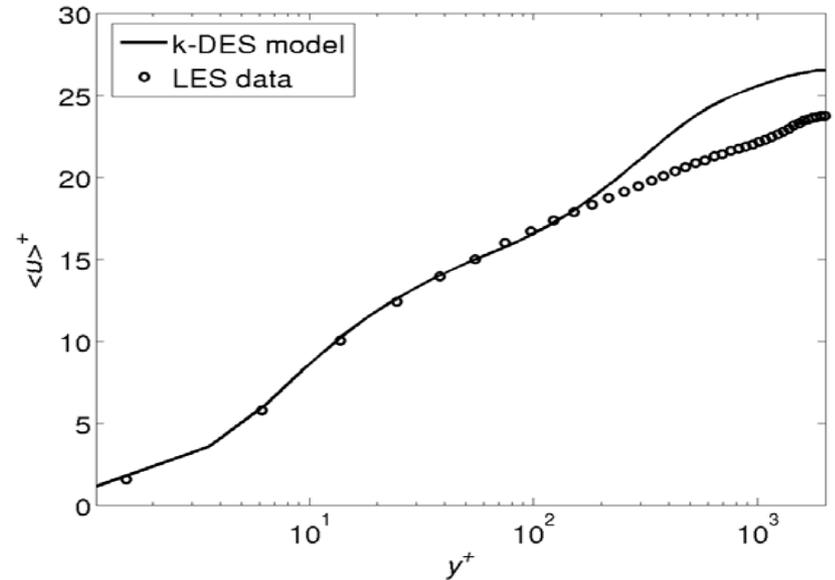
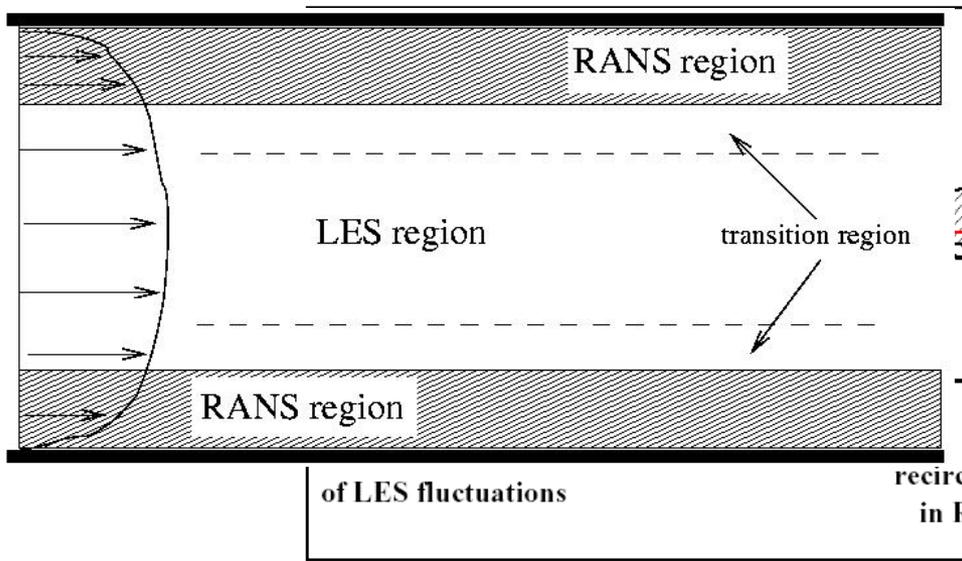
## Ecoulements fortement décollés



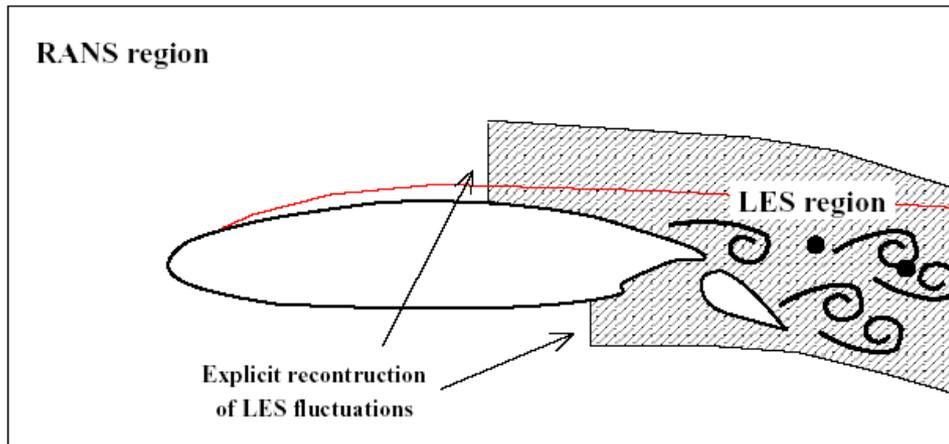
# Limites actuelles de la DES

## Ecoulements faiblement décollés

### ❑ Couplage tangentiel RANS/LES



### ❑ Transition RANS/LES amont/aval



- ❑ Interface stationnaire/turbulent
- ❑ Conditions d'interface
- ❑ Turbulence synthétique

# Synthetic Eddy Method (1/2)

- Création d'une boîte contenant les tourbillons

$$B = \{(x_i) \in \mathbb{R}^3, \quad x_{i,\min} < x_i < x_{i,\max}\}$$

$$x_{i,\min} = \min_{x \in P} (x_i - L)$$

$$x_{i,\max} = \max_{x \in P} (x_i + L)$$

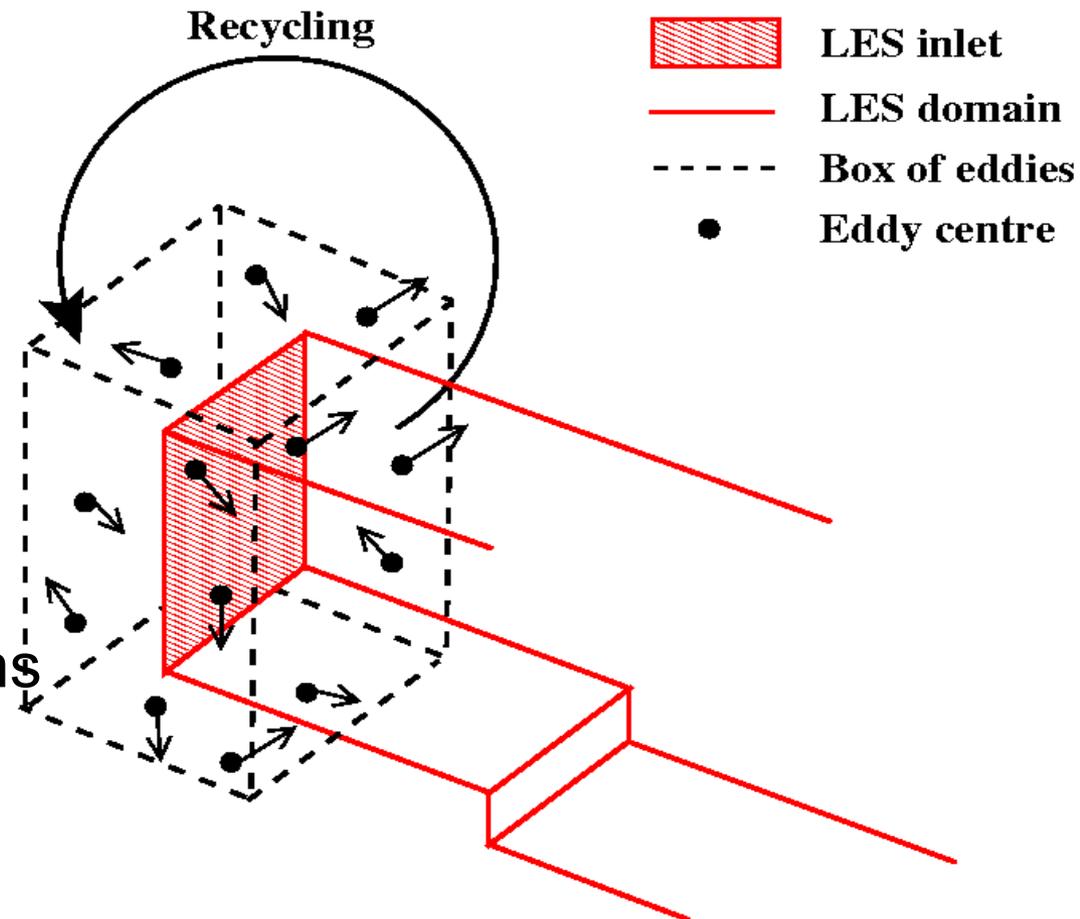
- Création des tourbillons

$$x_i \sim U([x_{i,\min}, x_{i,\max}])$$

$$\varepsilon_i \sim N(0,1)$$

- Convection des tourbillons

$$x_1^k(t + dt) = x_1^k(t) + U_b dt.$$



# Synthetic Eddy Method (2/2)

## □ Calcul du signal d'entrée LES

### □ Somme de la contribution de chacun des N tourbillons

$$u_i(x_j, t) = \sqrt{\frac{V_b}{N}} \sum_{k=1}^N \varepsilon_i^k f_L(x_1 - x_1^k) f_L(x_2 - x_2^k) f_L(x_3 - x_3^k)$$

$$f_L(r) = \begin{cases} \sqrt{\frac{3}{2L}} (1 - |r/L|) & \text{if } |r| \leq L \\ 0 & \text{otherwise} \end{cases}$$

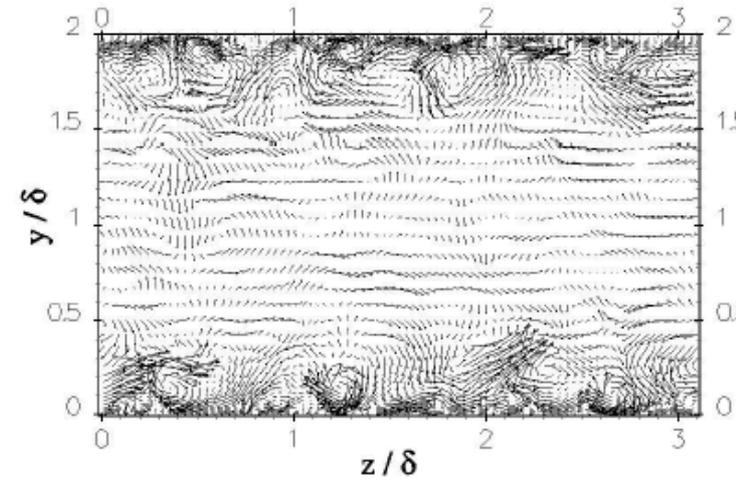
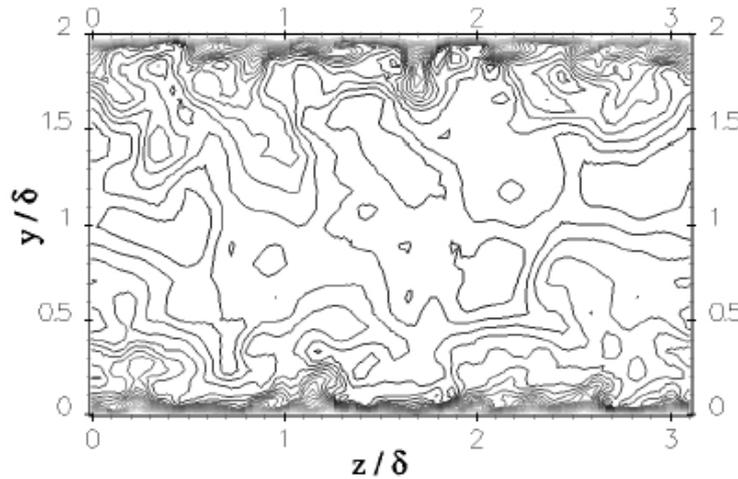
### □ Reconstruction des corrélations entre composantes de la vitesse

$$u_i = \langle U_i \rangle + a_{ij} \mathcal{U}_j \quad \left( \begin{array}{ccc} \sqrt{R_{11}} & 0 & 0 \\ R_{21}/a_{11} & \sqrt{R_{22} - a_{21}^2} & 0 \\ R_{31}/a_{11} & (R_{32} - a_{21}a_{31})/a_{22} & \sqrt{R_{33} - a_{31}^2 - a_{32}^2} \end{array} \right)$$

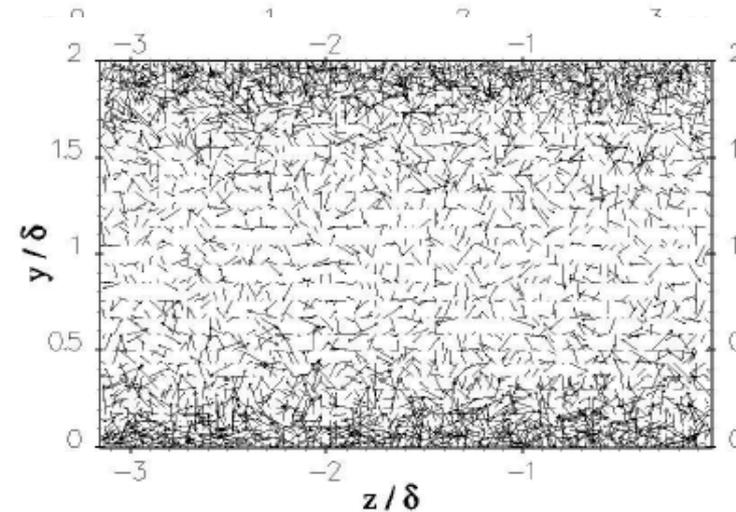
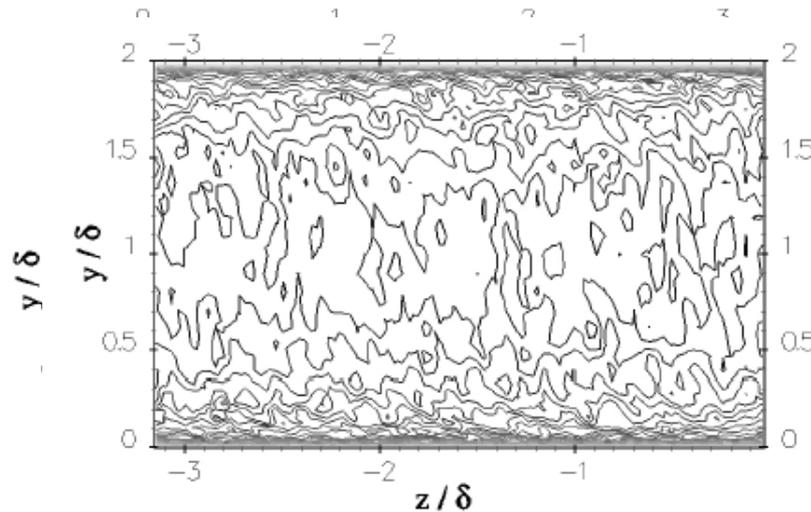
# Conditions d'entrée synthétiques

## Canal plan $Re^* = 395$

LES périodique



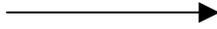
Méthode  
Spectrale  
aléatoires  
SEM



# Développement de la turbulence à la paroi

## Canal plan $Re^* = 395$

X



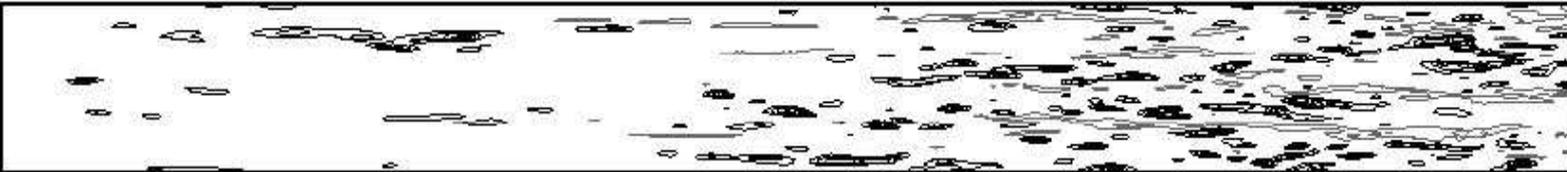
LES  
périodique



SEM



Méthode  
spectrale

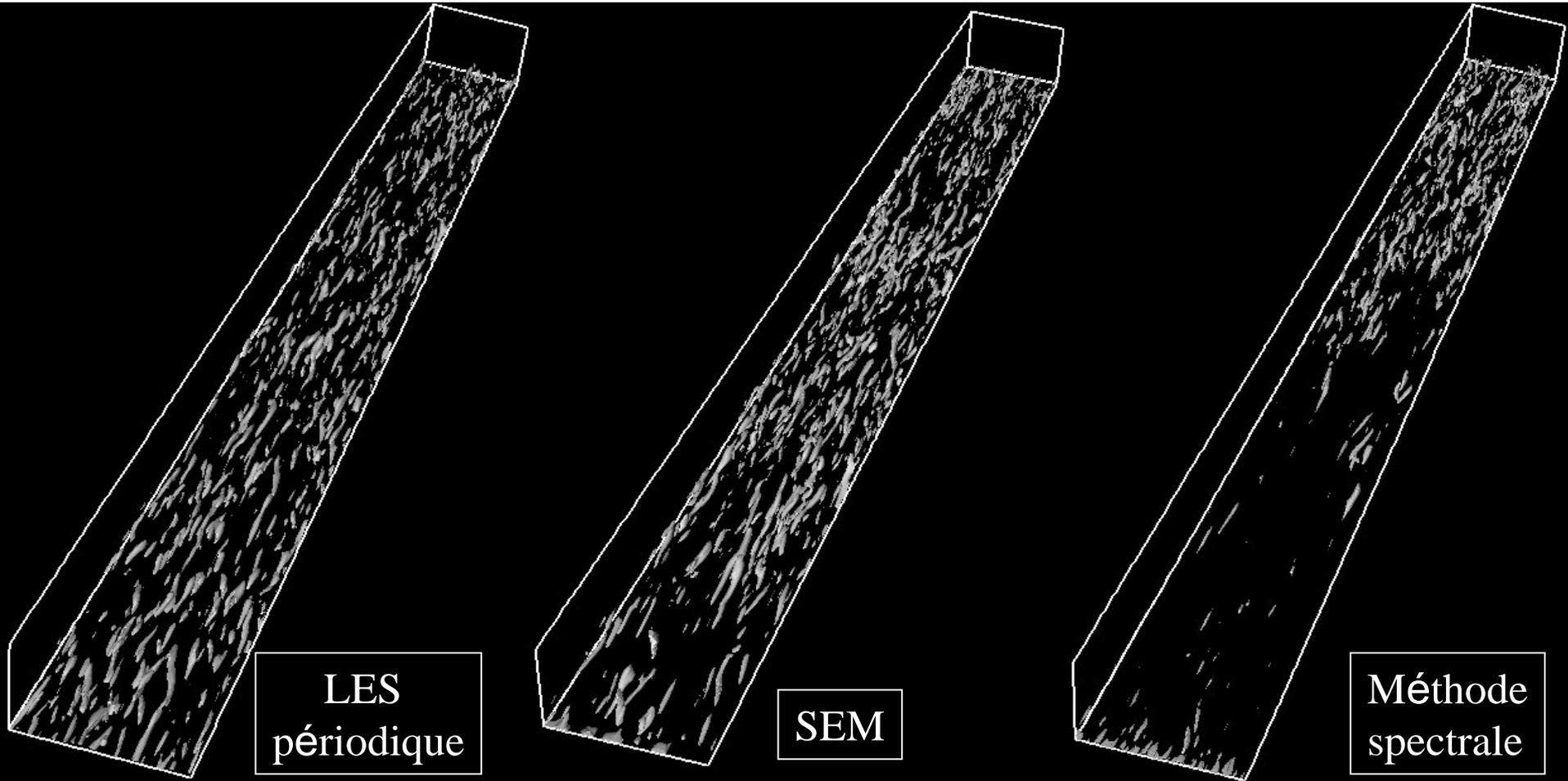


Nombres  
aléatoires



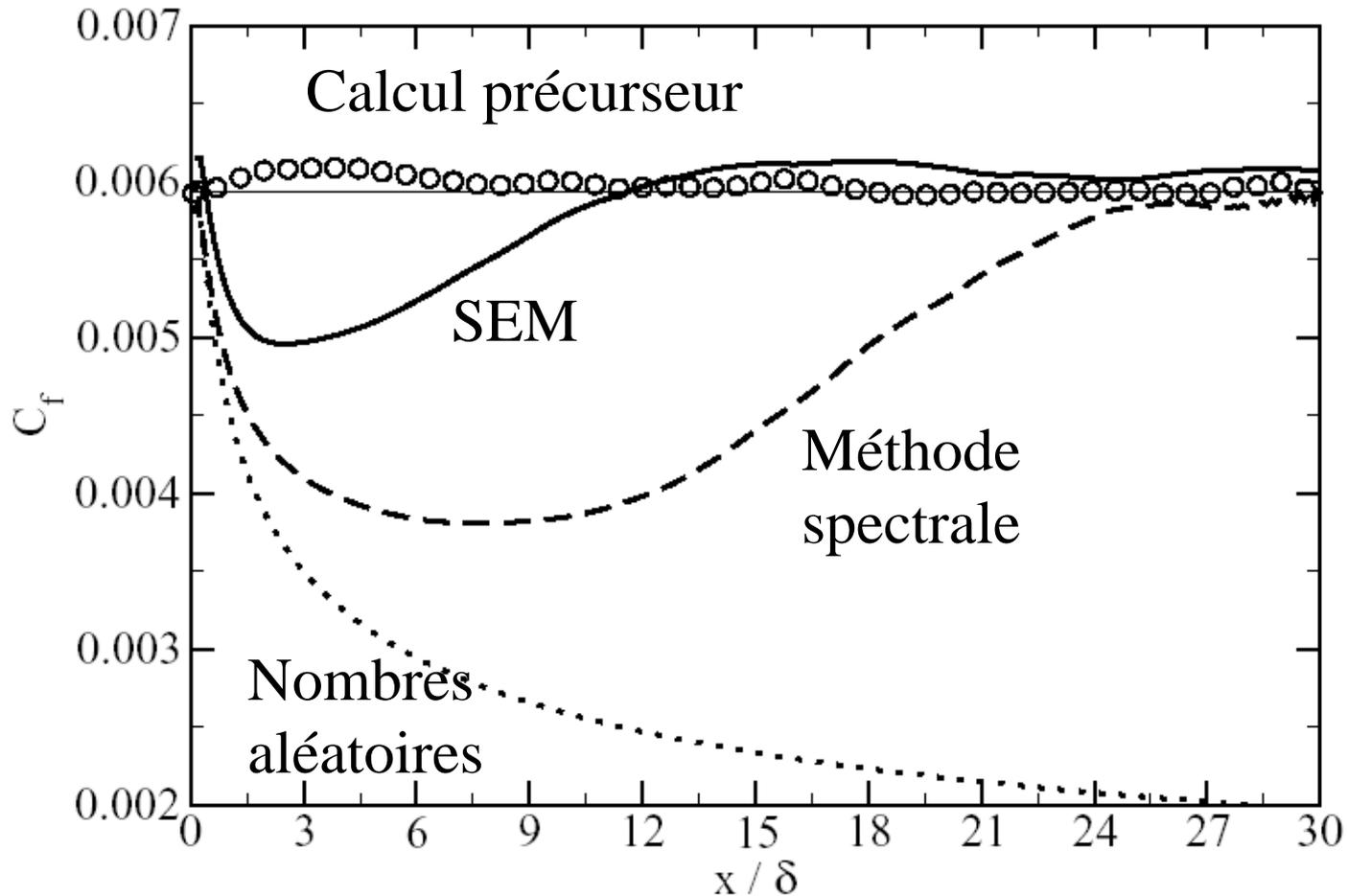
# Développement de la turbulence

## Canal plan $Re^* = 395$



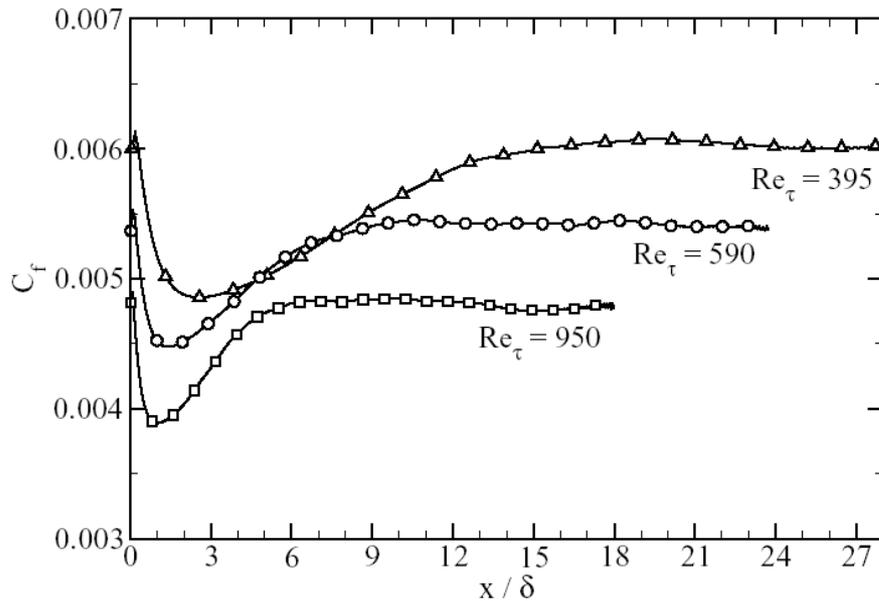
# Coefficient de frottement

## Canal plan $Re^* = 395$

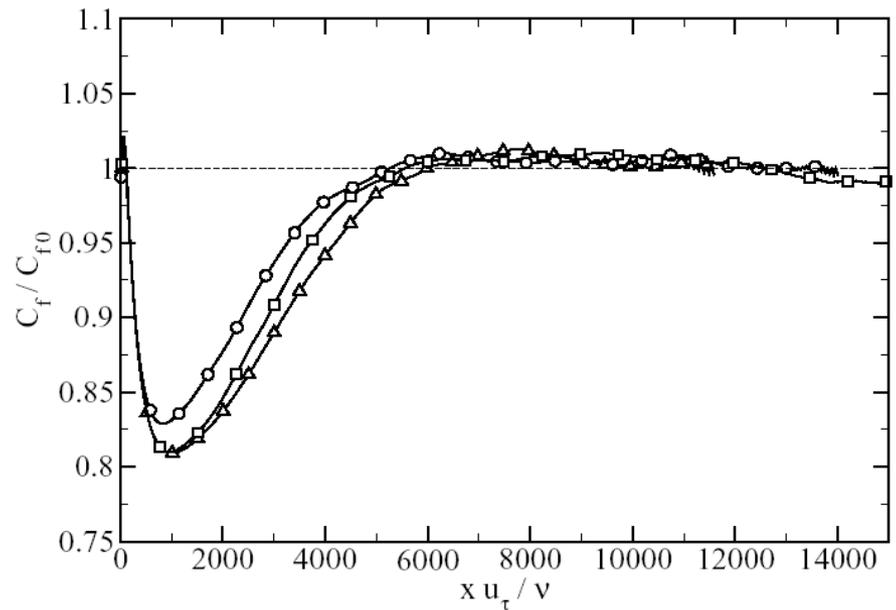


# Résultats SEM

## Influence du nombre de Reynolds



Rescaled by channel  
half width

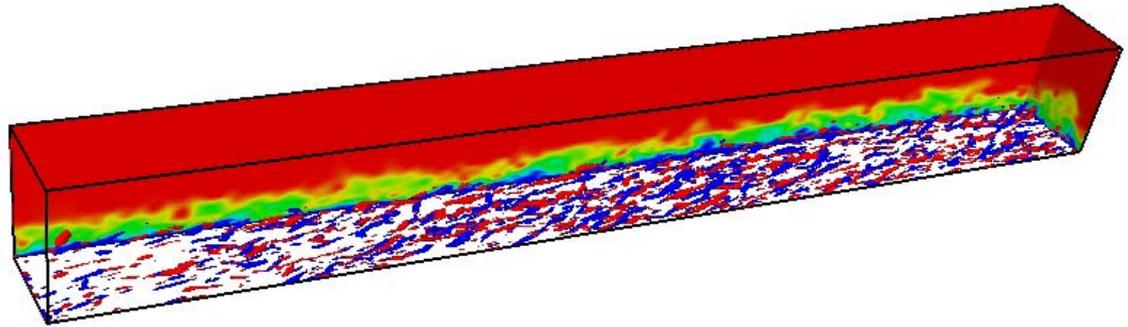


Rescaled by  
 $u/u^*$

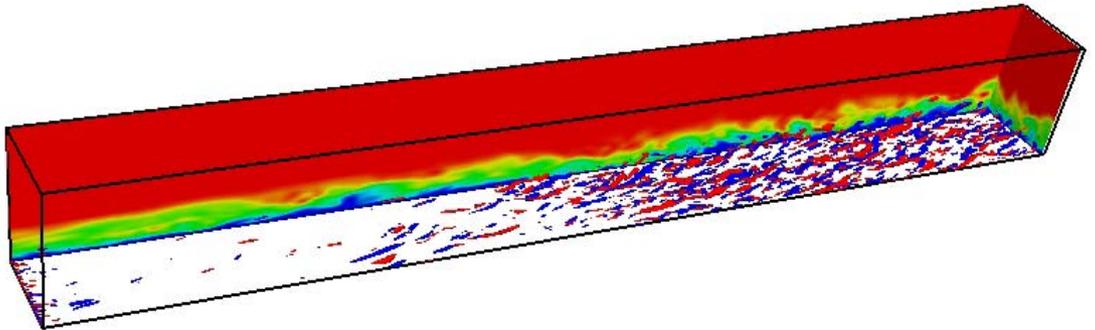
# Couche limite sur plaque plane $Re_\theta=700-1300$

## Isosurfaces de Q

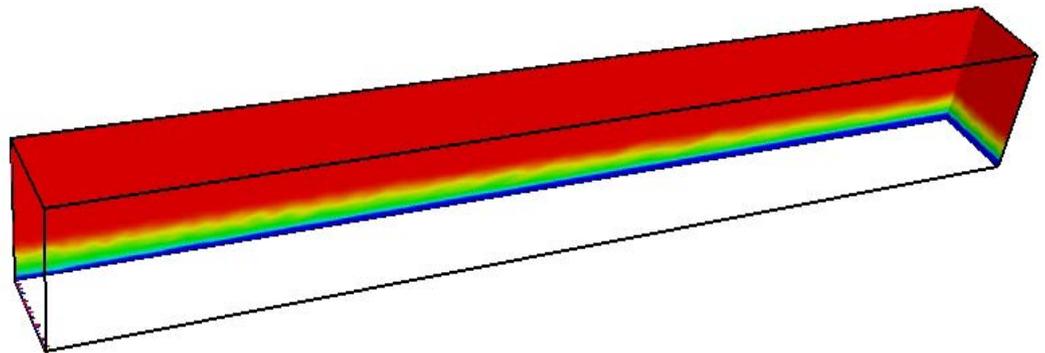
Synthetic Eddy Method



Méthode spectrale



Nombres aléatoires



# Couche limite sur plaque plane $Re_\theta=700-1300$

## Fluctuations de vitesse $w$

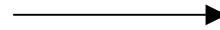
Synthetic Eddy Method

X



Méthode spectrale

X



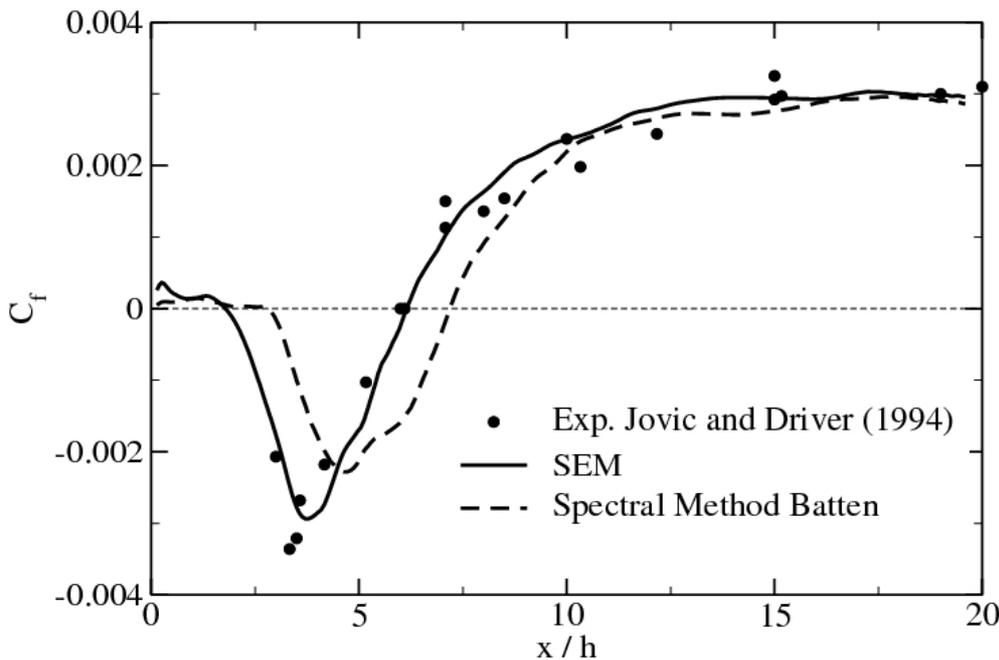
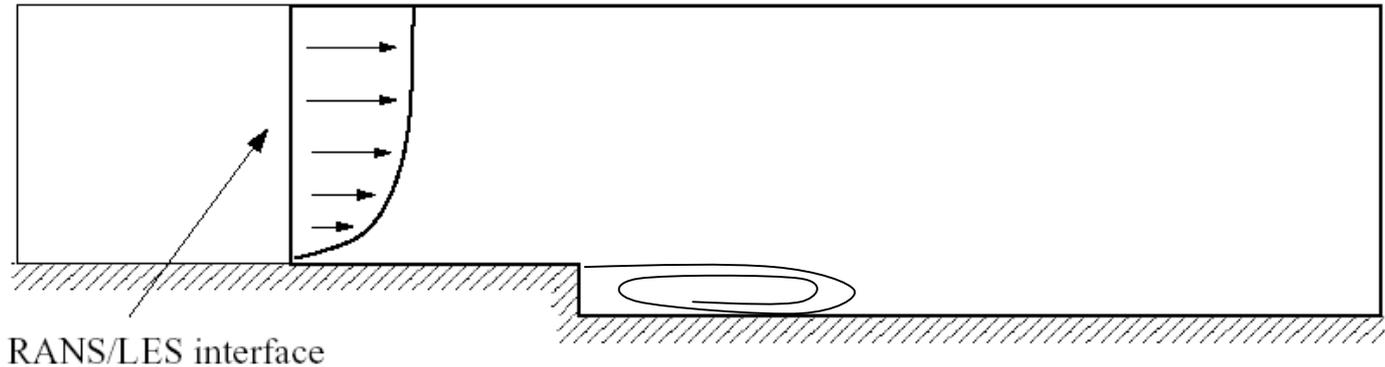
Nombres aléatoires

X



# Marche descendante $Re_h = 5100$

## Présentation du cas



- ❑ Longueur de recirculation depend de la turbulence en amont
- ❑ Inlet = Couche limite  $Re_\theta = 670$
- ❑ SEM donne bonne estimation de la longueur de recirculation moyenne
- ❑ Surestimation de la longueur de recirculation moyenne avec autres méthodes

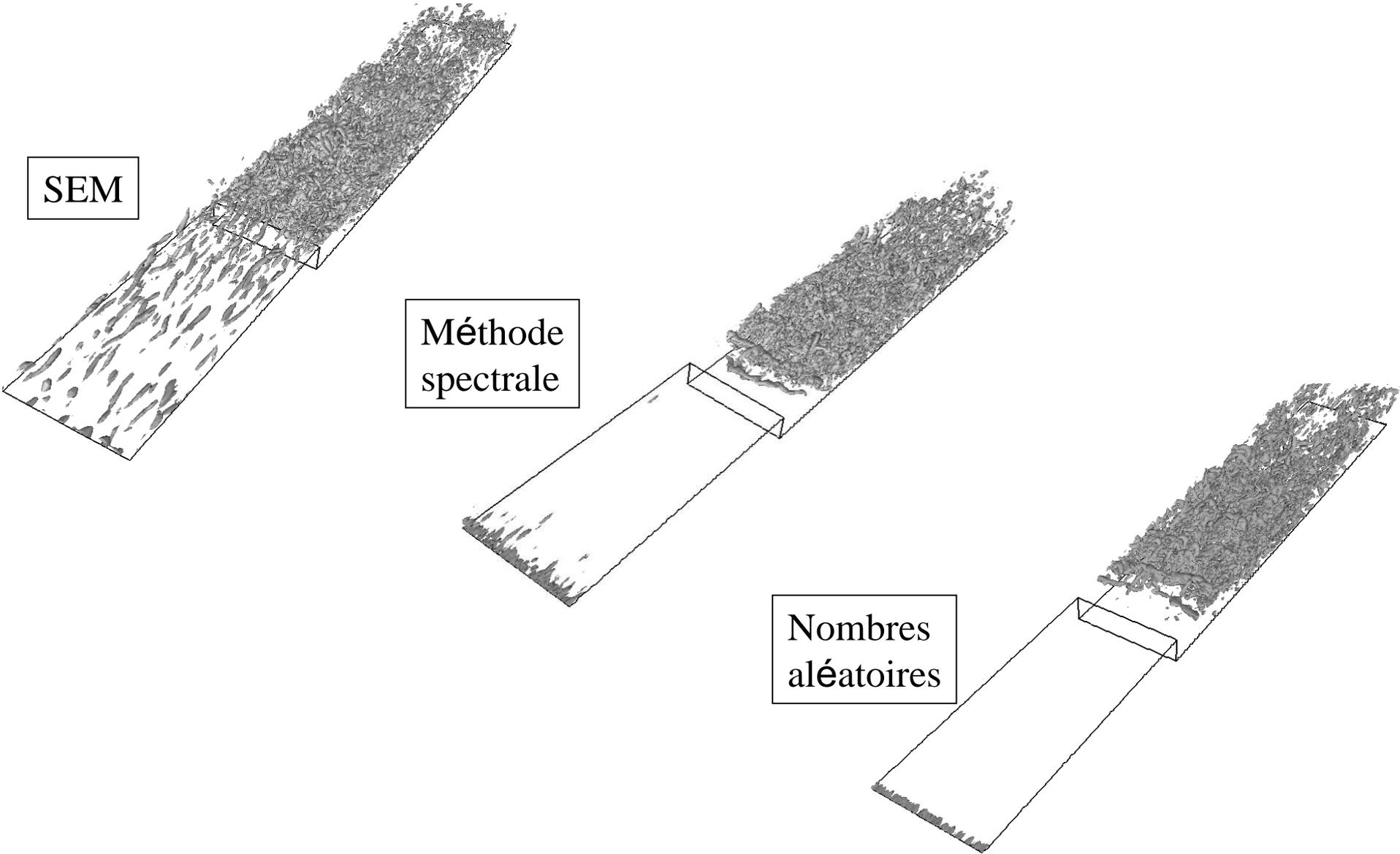
# Marche descendante $Re_h = 5100$

## Isosurfaces de $Q$ – vue globale

SEM

Méthode  
spectrale

Nombres  
aléatoires

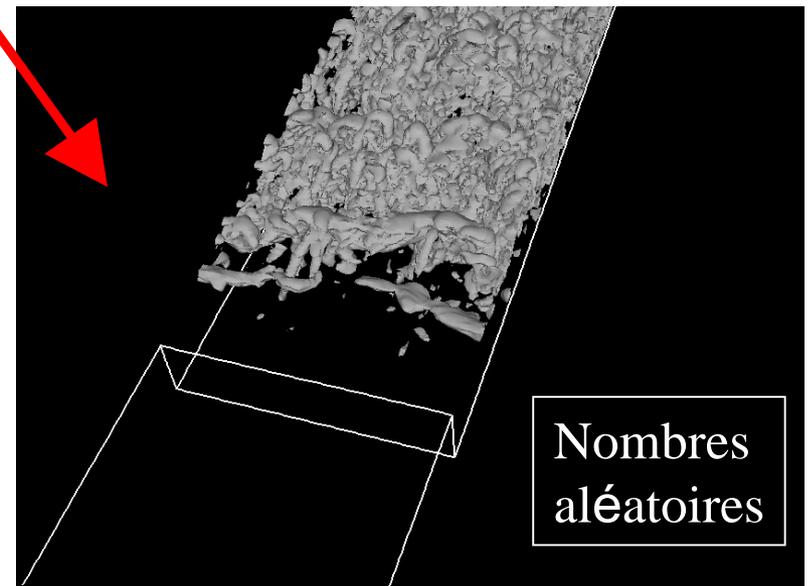
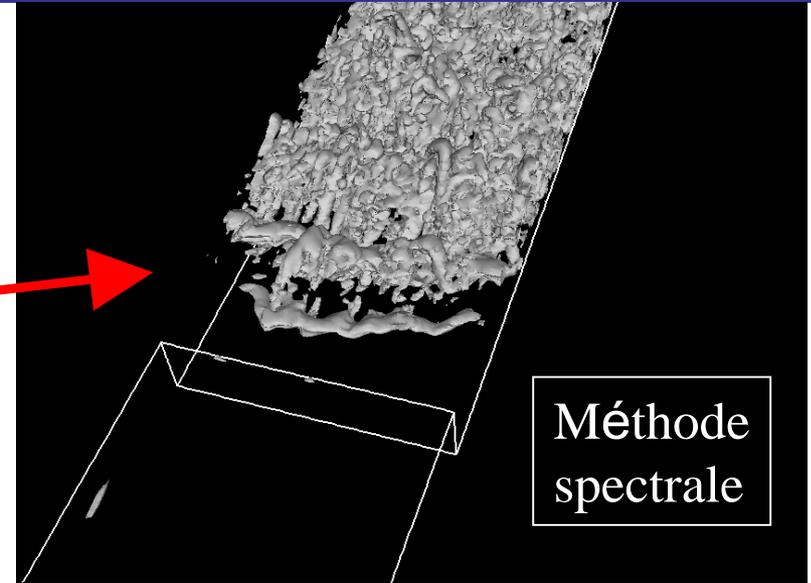
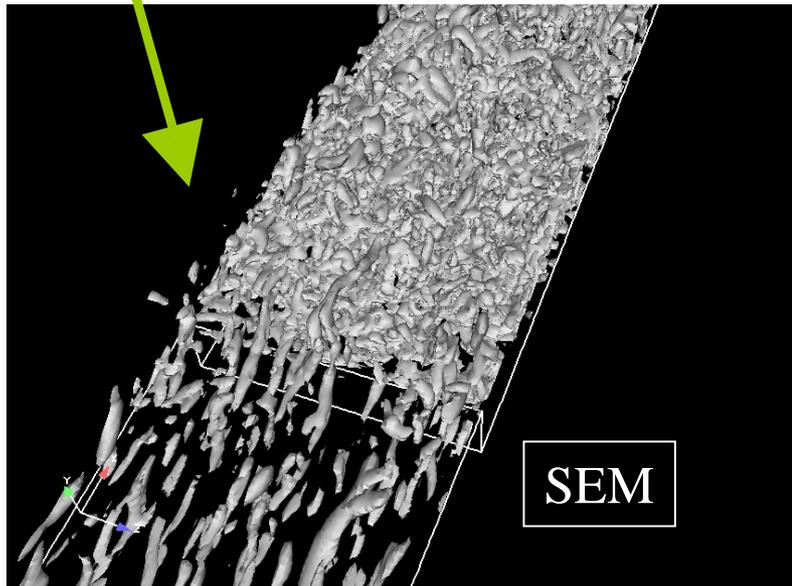


# Marche descendante $Re_h = 5100$

## Isosurfaces de $Q$ au niveau de la marche

Couche limite puis  
couche de mélange  
turbulente

Transition  
laminaire/turbulent



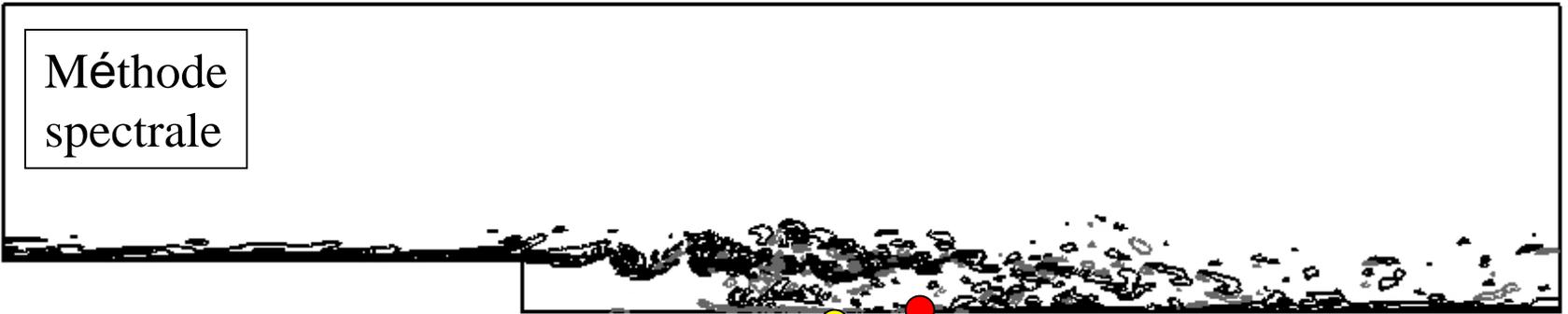
# Marche descendante $Re_h = 5100$

## Champ de vorticit 

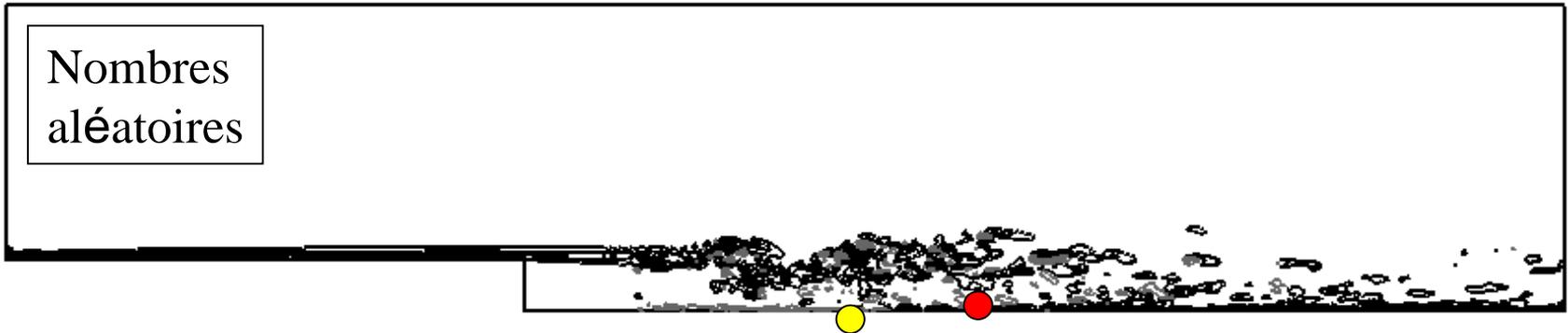
SEM



M thode  
spectrale



Nombres  
al atoires



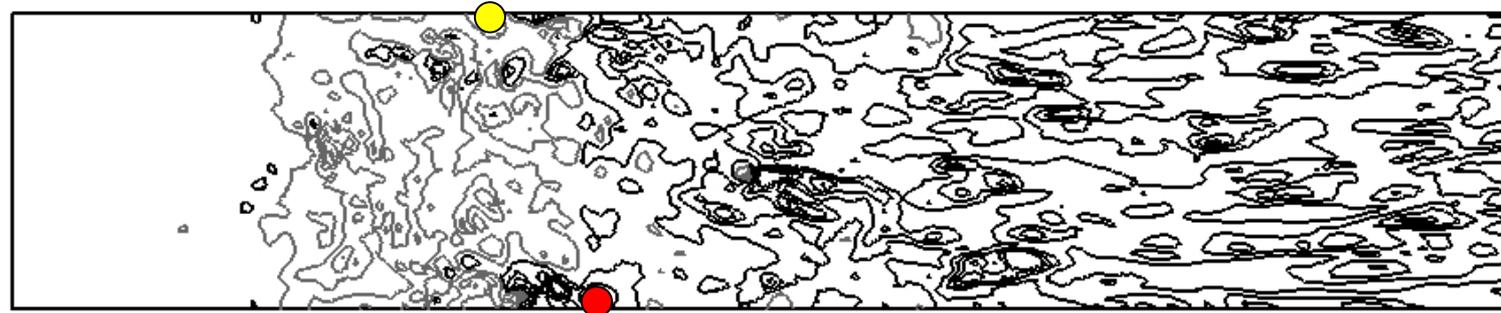
# Marche descendante $Re_h = 5100$

## Fluctuations de vitesse en proche paroi

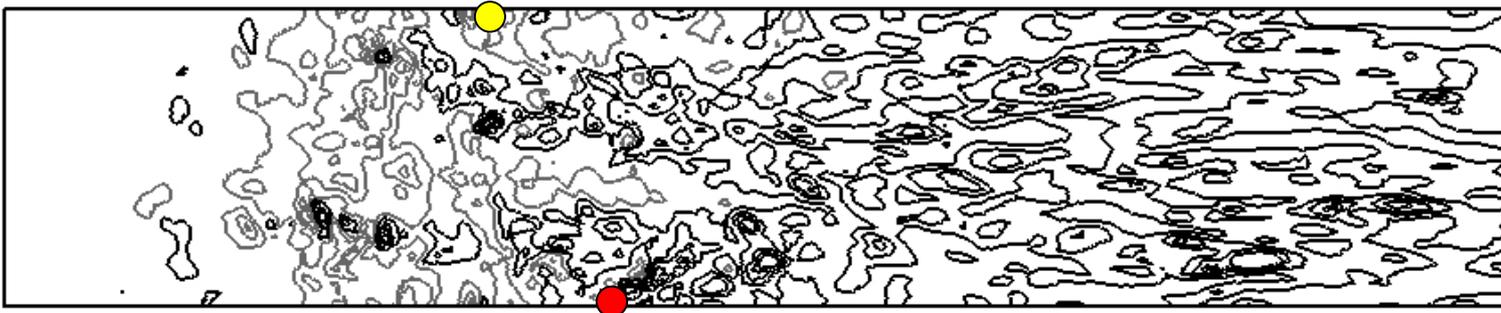
SEM



Méthode spectrale

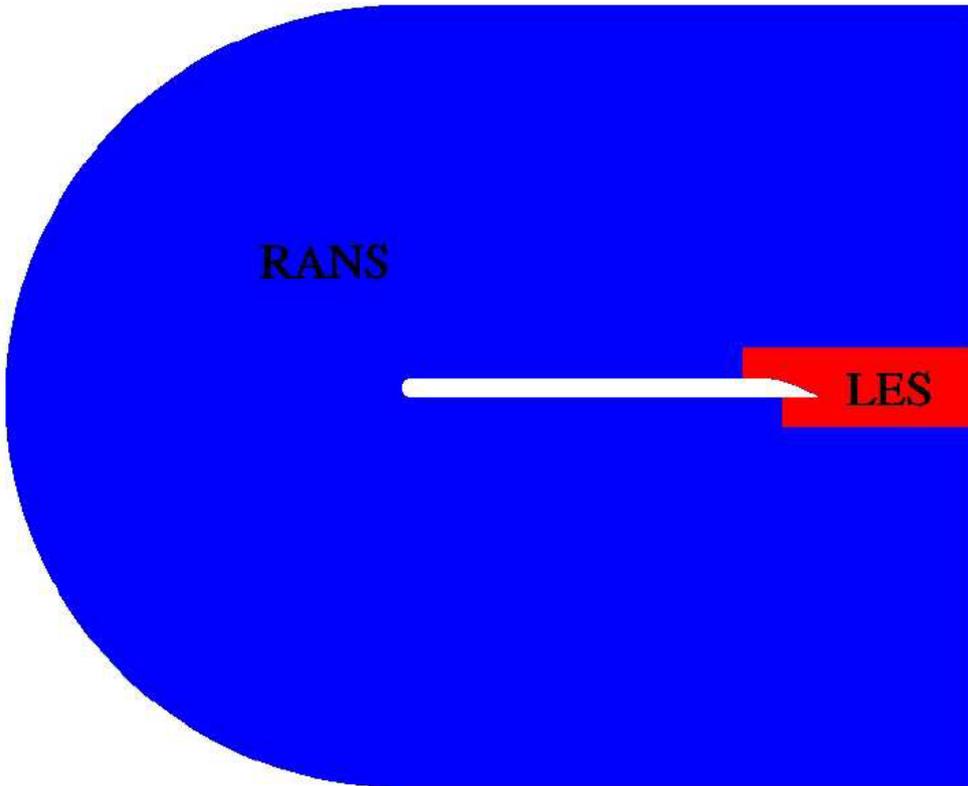


Nombres aléatoires



# Ecoulement autour d'un profile d'aile

$$Re_c = 2.15 \times 10^6$$



- ❑ Calcul 2D RANS SST sur un maillage de 100 000 cellules
- ❑ Calcul embedded LES sur un maillage 3D de 3.5M cellules
- ❑ Inlet = Couche limite  $Re_\theta = 3300$
- ❑ Simulation de toute l'aile nécessite un maillage de environ 25M cellules



Simulation à la limite des capacités LES R&D actuelles !

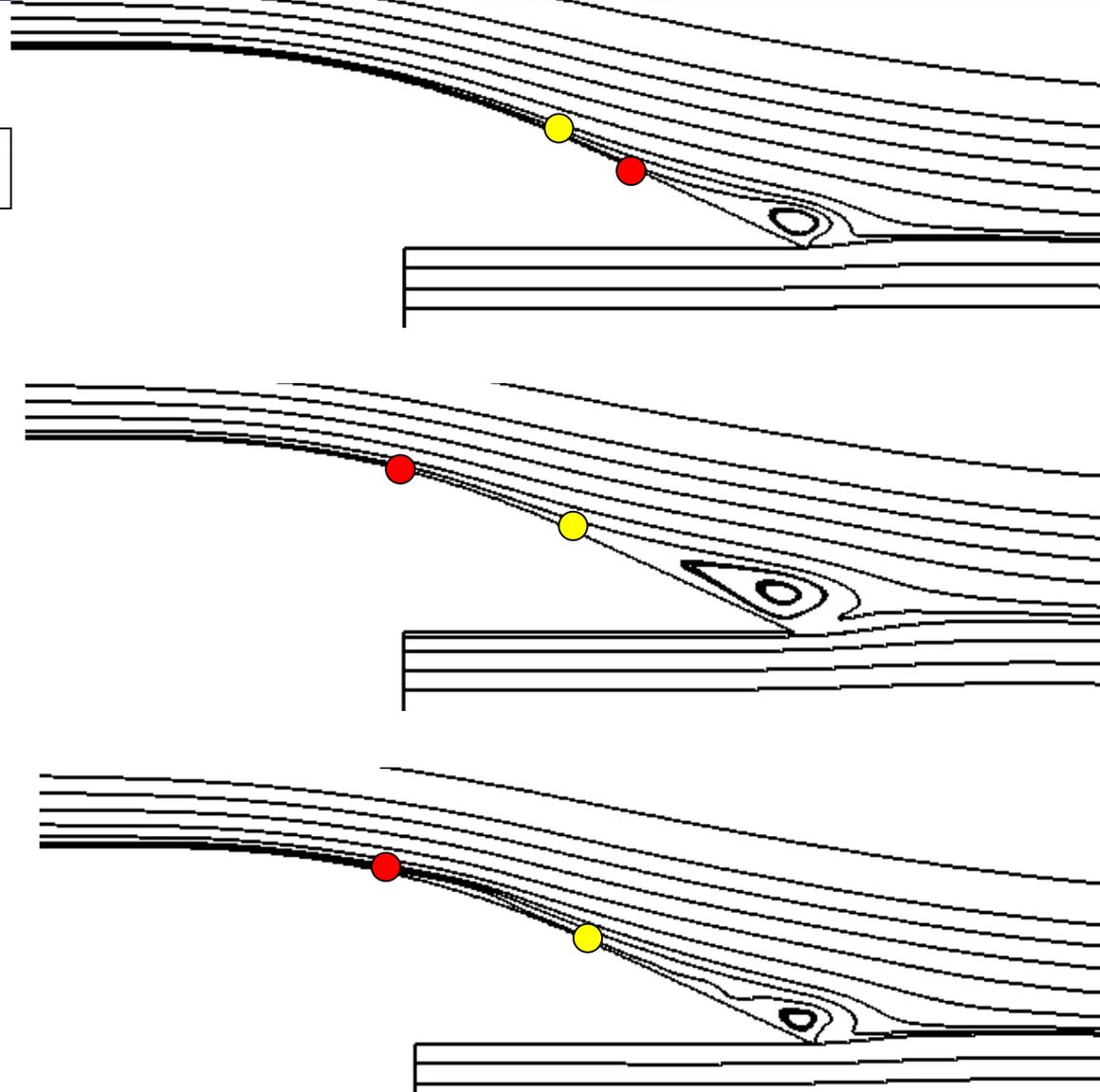
# Écoulement autour d'un profil d'aile

## Recirculation moyenne

Synthetic Eddy Method

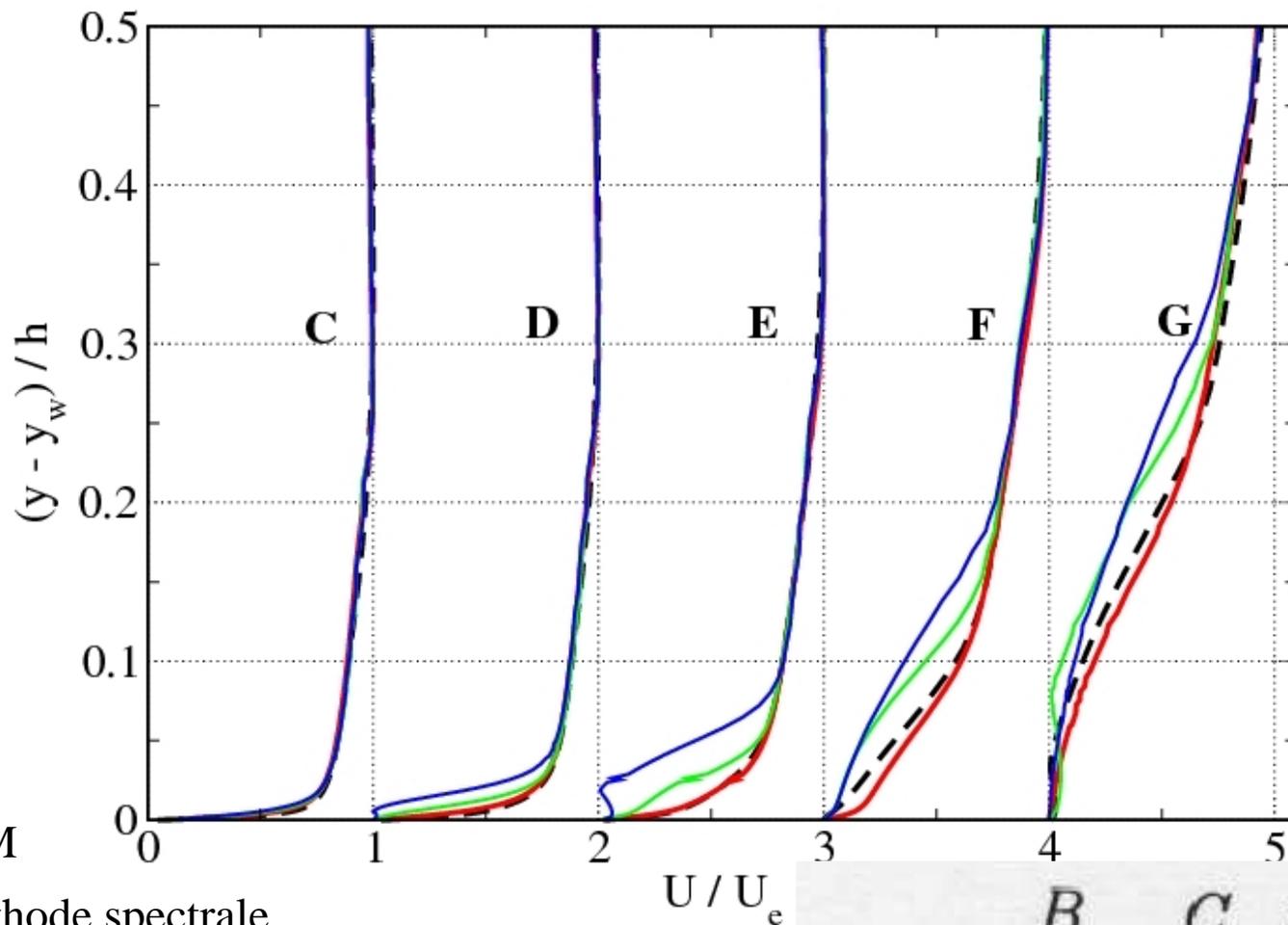
Méthode spectrale

Nombres aléatoires

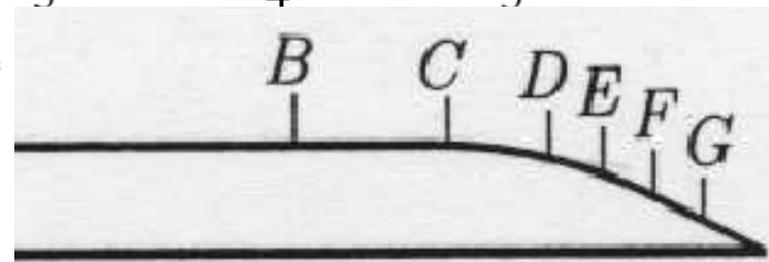


# Ecoulement autour d'un profil d'aile

## Profils moyens



- SEM
- Méthode spectrale
- Nombre aléatoires
- LES full domain Wang and Moin (2000)



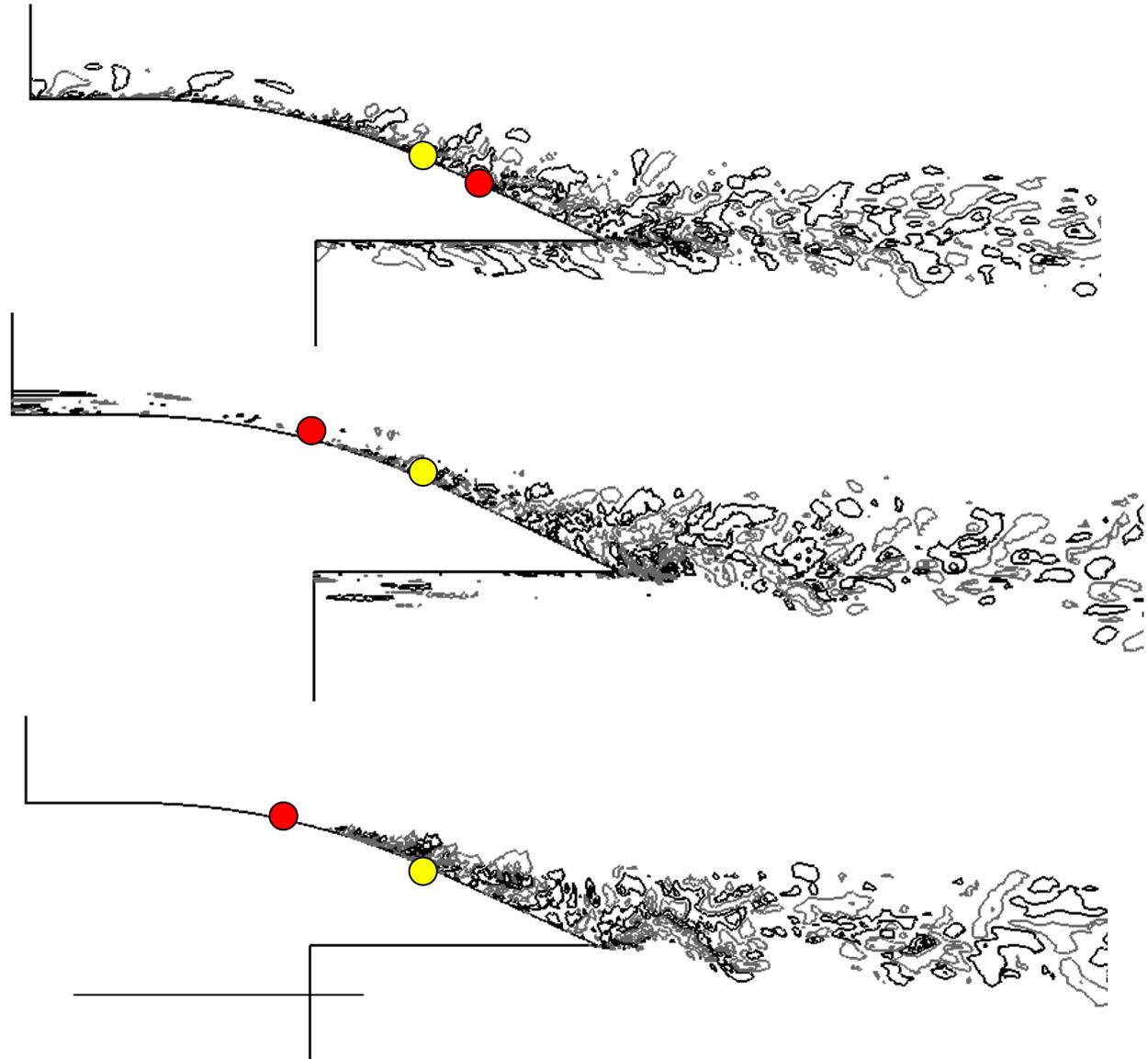
# Ecoulement autour d'un profil d'aile

## Champs instantanés

SEM

Méthode spectrale

Nombres aléatoires



# Conclusions et Perspectives

## ❑ Conclusions:

- ❑ LES fines à haut Reynolds nécessite maillages très fins
- ❑ DES approche populaire dans l'industrie aéronautique qui apporte des solutions aux limitations des modèles RANS et LES
- ❑ SEM supérieure a toutes les méthodes de génération de conditions d'entrée testées
- ❑ Evaluation qualitative et quantitative des erreurs dues à la SEM

## ❑ Future Works

- ❑ Améliorer la physique des structures SEM (hairpin vortices...)
- ❑ Générer des structures à divergence nulle (oscillations de pression)