

UNIBG contribution to AR2

A. Colombo

HiOCFD4

4th International Workshop on High-Order CFD Method
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**UNIVERSITÀ DEGLI STUDI
DI BERGAMO**



...with the contribution of

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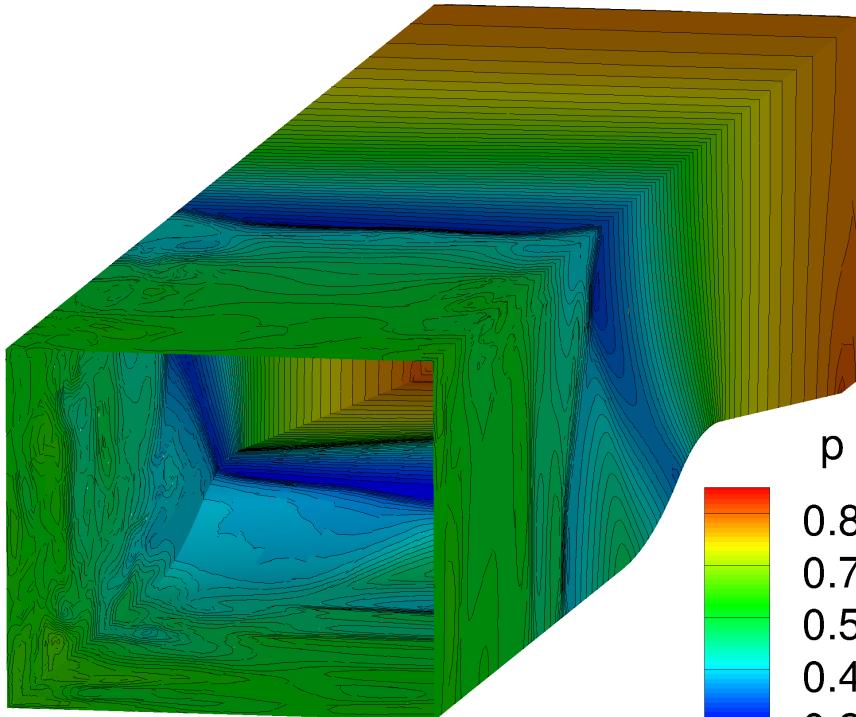
⁶ *SKF, Sweden*



Towards Industrial LES/DNS in Aeronautics
Paving the Way for Future Accurate CFD
grant agreement No.635962

Shock BL interaction on a swept bump (AR2)

P^2 converged computations with **RANS+k- ω** (also in its low-Re version) and **EARSM1** have been performed and used as **initialization** for **X-LES**



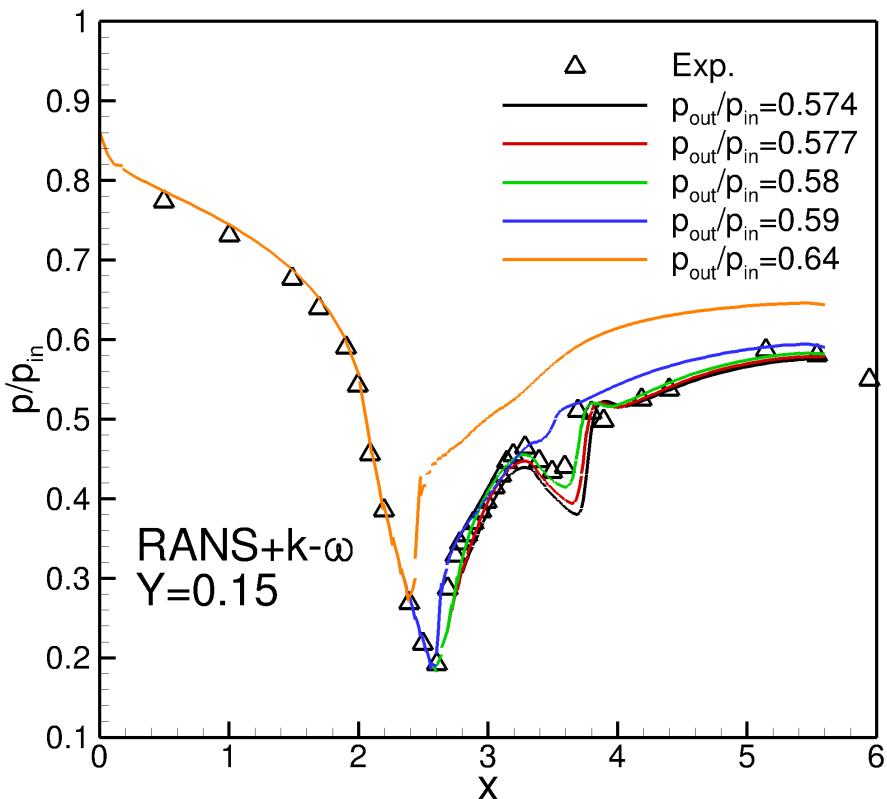
72960 hexahedral elements

- Inlet boundary conditions
 - $p_{0i} = 92000\text{Pa}$
 - $T_{0i} = 300\text{K}$
 - $\text{Re}_H = 1.69 \times 10^6$
- Outlet static pressure used to impose the shock position (*model dependent!*)
- LBE(RO1-1) to quickly find the “right” pressure ratio
- RO3-3 for the time-accurate solution
- Filter width $\Delta = 5\text{e-}2$ (*strong influence!*)
- 96 cores of our in-house Intel cluster :-)

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eXtra-Large Eddy Simulation (X-LES) in a nutshell (I/II)

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Pros

- hybrid RANS\LES formulation **independent** from the **wall distance**
- use in LES mode of a clearly defined SGS based on the k-equation
- use of a k- ω turbulence model integrated to the wall

Cons

the *filter width* parameter is often related to the local element size

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_j}(\rho u_j k) = \frac{\partial}{\partial x_j} \left[(\mu + \sigma^* \bar{\mu}_t) \frac{\partial k}{\partial x_j} \right] + P_k - D_k$$

$$\begin{aligned} \frac{\partial}{\partial t}(\rho \tilde{\omega}) + \frac{\partial}{\partial x_j}(\rho u_j \tilde{\omega}) &= \frac{\partial}{\partial x_j} \left[(\mu + \sigma \bar{\mu}_t) \frac{\partial \tilde{\omega}}{\partial x_j} \right] + (\mu + \sigma \bar{\mu}_t) \frac{\partial \tilde{\omega}}{\partial x_k} \frac{\partial \tilde{\omega}}{\partial x_k} \\ &+ P_\omega - D_\omega + C_D \end{aligned}$$

...an “original” interpretation for the X-LES implementation...

Bassi et al. “Time Integration in the Discontinuous Galerkin Code MIGALE - Unsteady Problems”

In IDIHOM: Industrialization of High-Order Methods - A Top-Down Approach, Vol. 128 of
Notes on Numerical Fluid Mechanics and Multidisciplinary Design Springer International Publishing



eXtra-Large Eddy Simulation (X-LES)

in a nutshell (II/II)

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$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_j}(\rho u_j k) = \frac{\partial}{\partial x_j} \left[(\mu + \sigma^* \bar{\mu}_t) \frac{\partial k}{\partial x_j} \right] + P_k - D_k$$

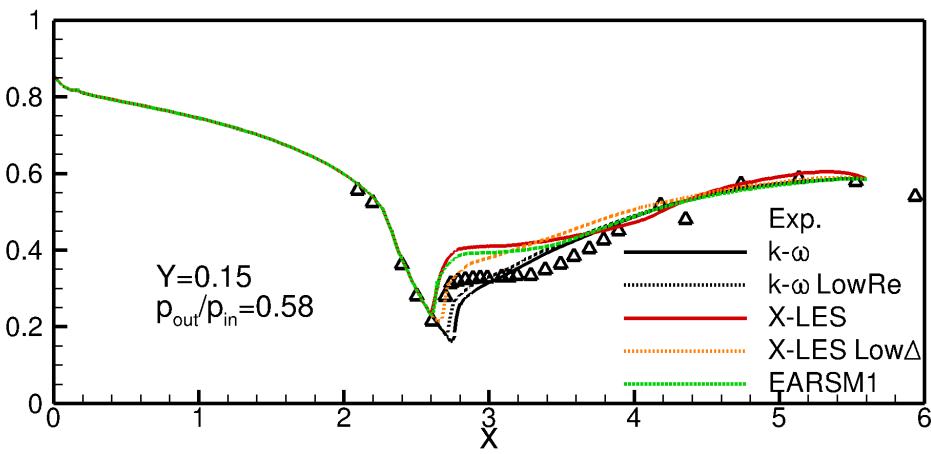
$$\bar{\mu}_t = \alpha^* \frac{\rho \bar{k}}{\hat{\omega}} \quad D_k = \beta^* \rho \bar{k} \hat{\omega} \quad \bar{k} = \max(0, k)$$

$$\hat{\omega} = \max \left(e^{\tilde{\omega}_r}, \frac{\sqrt{\bar{k}}}{C_1 \Delta} \right)$$

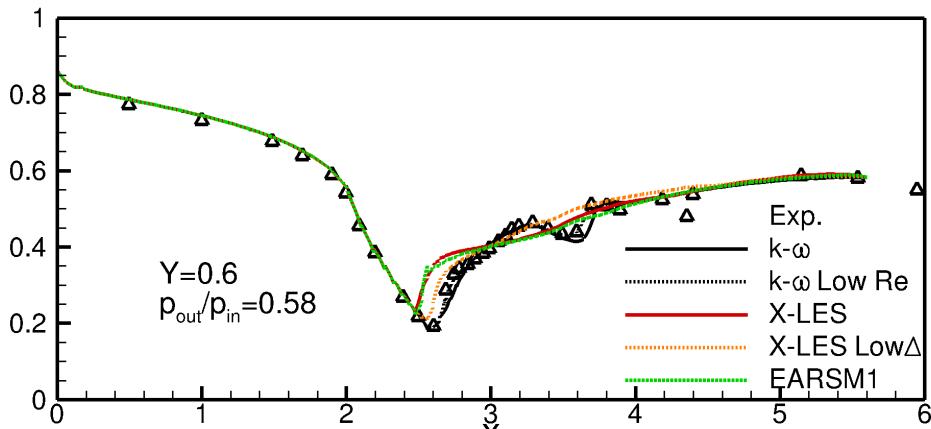
	RANS	LES	ILES
$\bar{\mu}_t$	$\alpha^* \frac{\rho \bar{k}}{e^{\tilde{\omega}_r}}$	$\alpha^* \rho \sqrt{\bar{k}} C_1 \Delta$	0
D_k	$\beta^* \rho \bar{k} e^{\tilde{\omega}_r}$	$\beta^* \rho \frac{\bar{k}^{\frac{3}{2}}}{C_1 \Delta}$	0

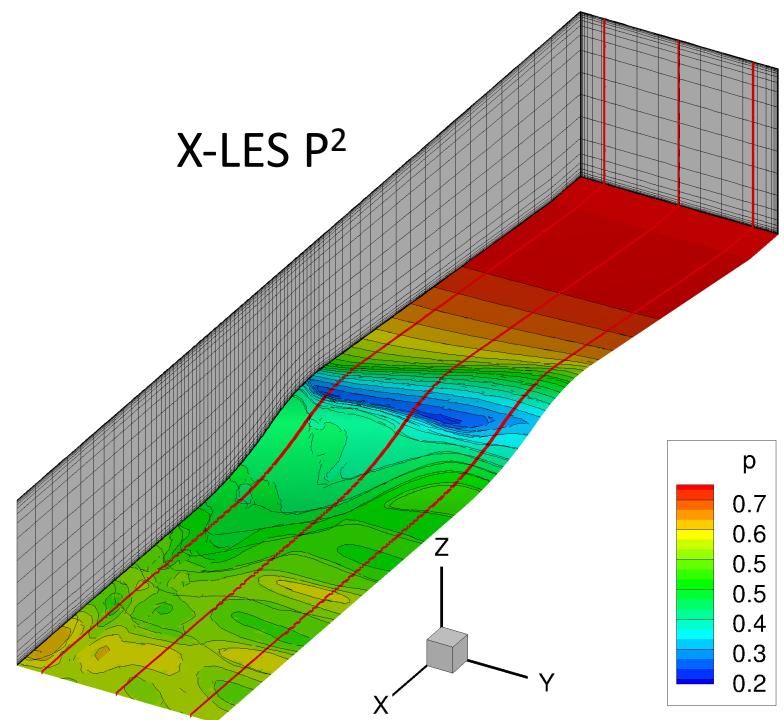
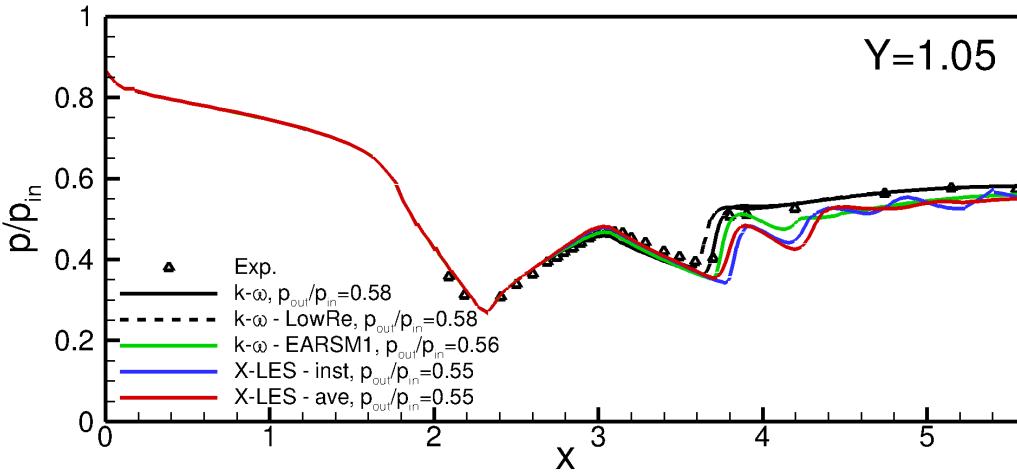
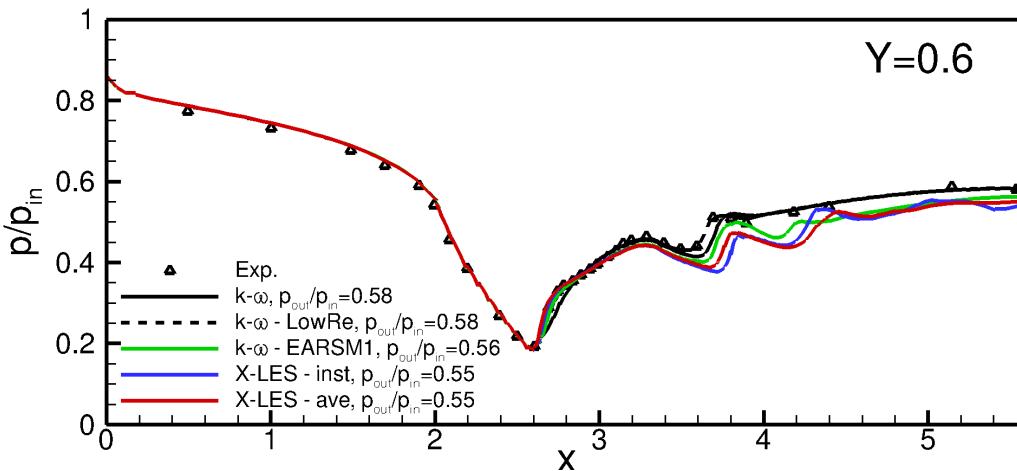
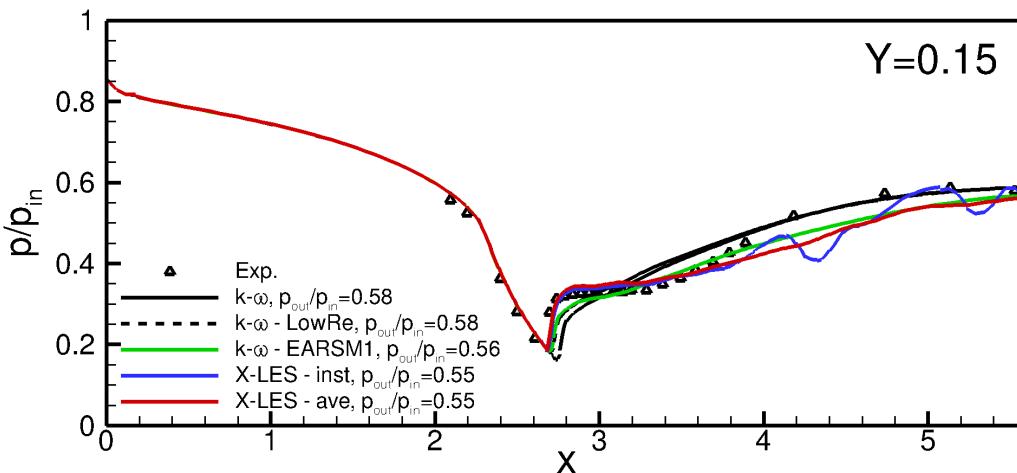
X-LES of a shock BL interaction on a swept bump (AR2)

P^2 converged computations with **RANS+k- ω** (also in its low-Re version) and **EARSM1** have been performed and used as **initialization** for **X-LES**

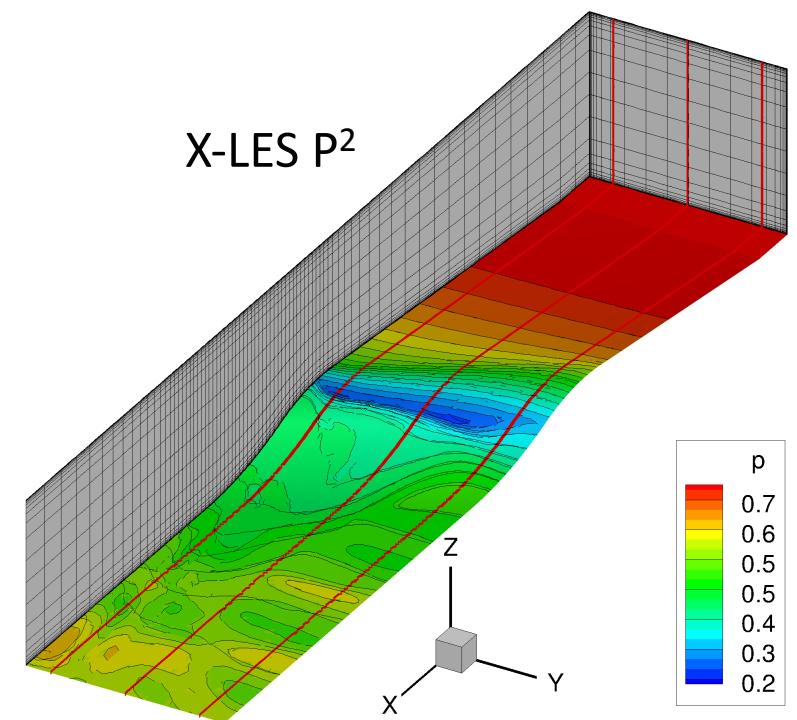
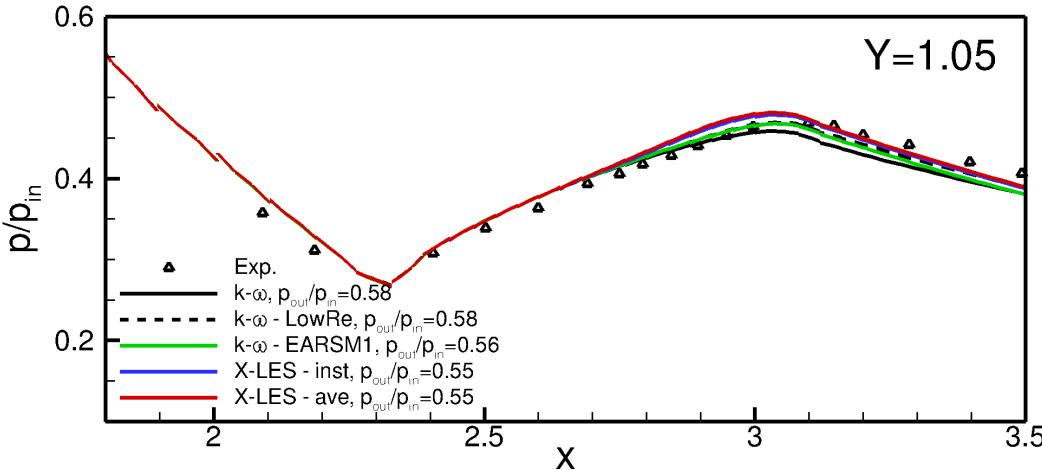
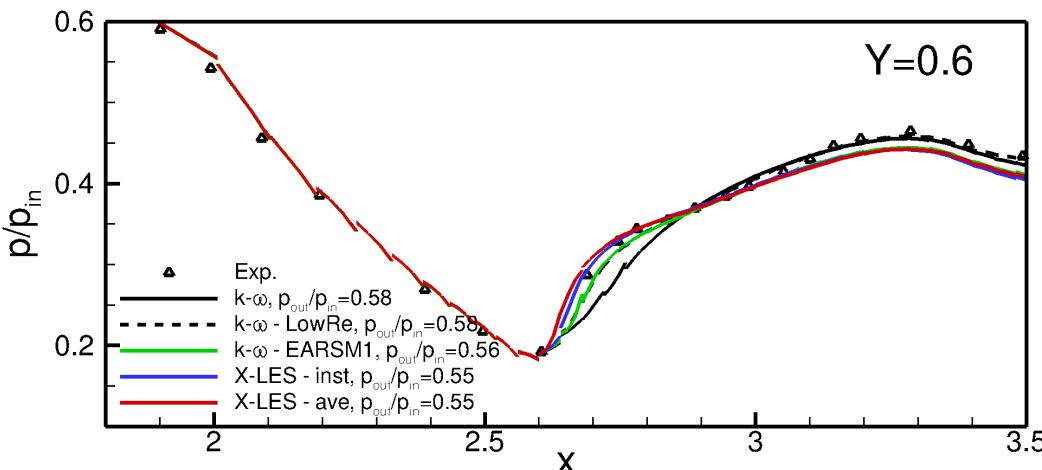
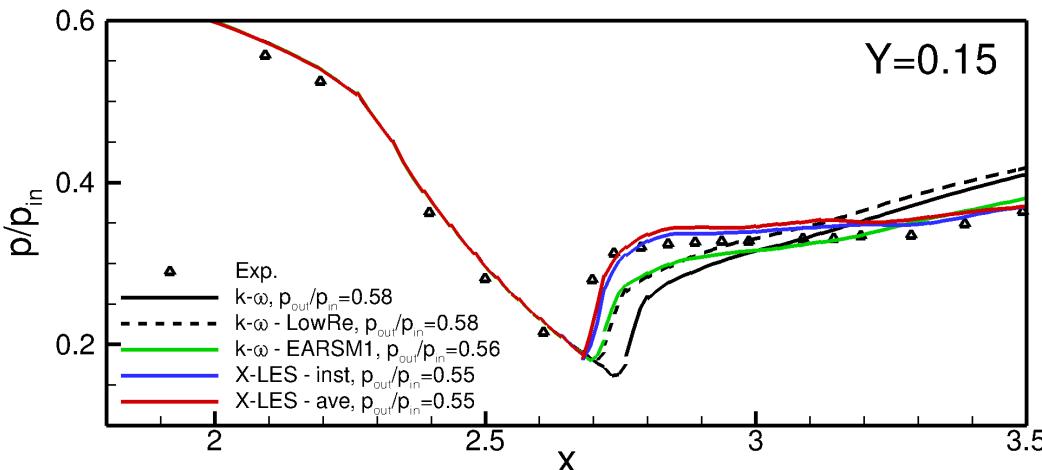


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The profiles are in reasonable agreement with the experiments and the numerical results of Cahen et al.



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$y=0.1$

M: 0.1 0.5 0.9 1.3 1.7

 $k-\omega$ $k-\omega$ LowRe $y=0.3$ $y=0.6$ $y=0.9$

10

$y=0.1$

M: 0.1 0.5 0.9 1.3 1.7

 $y=0.3$ $y=0.6$ $y=0.9$ $k-\omega$

EARSM1

$y=0.1$

M: 0.1 0.5 0.9 1.3 1.7

 $y=0.3$ $y=0.6$ $y=0.9$ $k-\omega$

X - LES ave., RO1-1

$y=0.1$

M: 0.1 0.5 0.9 1.3 1.7

 $y=0.3$ $y=0.6$ $y=0.9$ $k-\omega$

X – LES ave., RO3–3

$y=0.1$

M: 0.1 0.5 0.9 1.3 1.7

 $y=0.3$ $y=0.6$ $y=0.9$ $k-\omega$

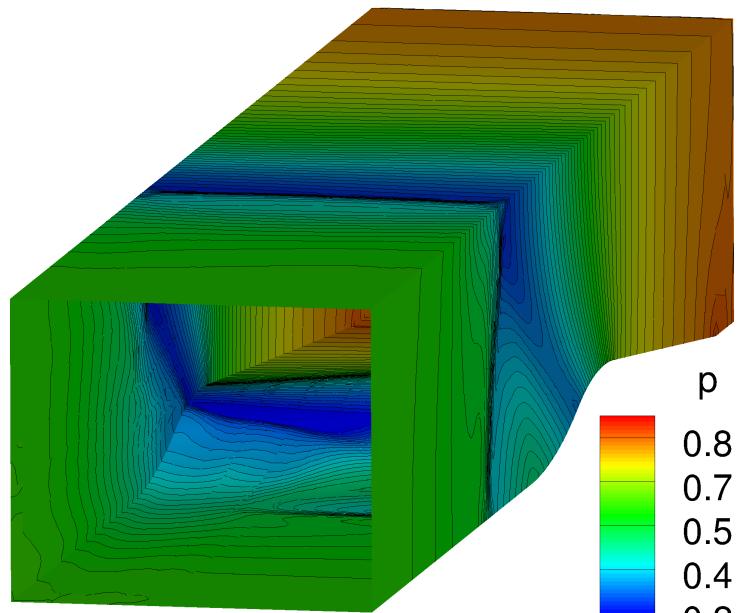
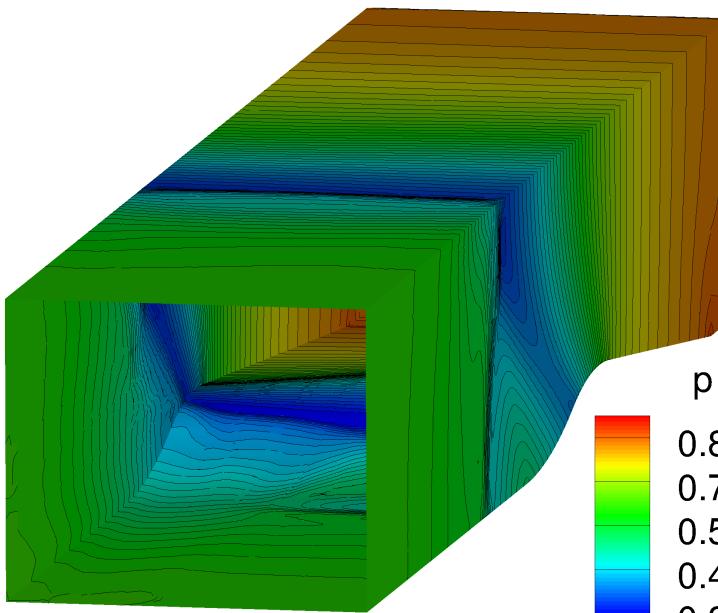
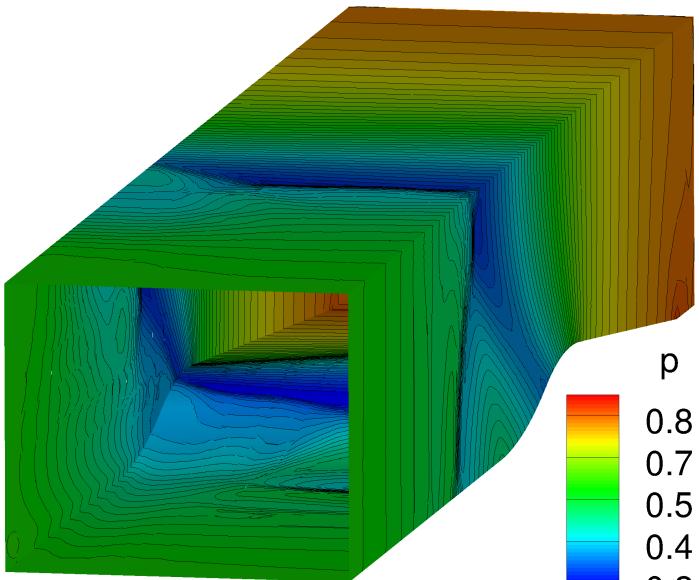
X – LES inst., RO1–1

$y=0.1$

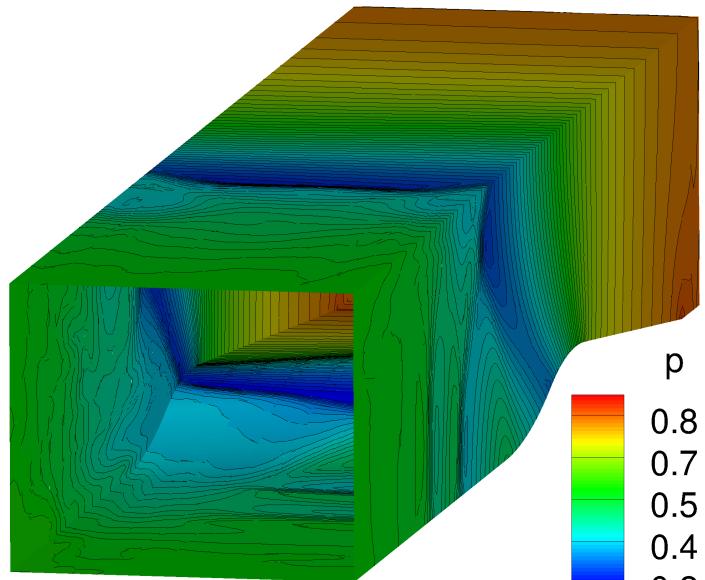
M: 0.1 0.5 0.9 1.3 1.7

 $y=0.3$ $y=0.6$ $y=0.9$ $k-\omega$

X – LES inst., RO3–3

 $k-\omega$  $k-\omega$ LowRe

EARSM1



X – LES ave., RO3-3