



Journée thématique SFT
« Echangeurs thermiques et multi-fonctionnels »
16 MARS 2011



**Intensification par voie passive des échanges
dans les échangeurs à tubes ailetés :
outils et méthodes d'analyses.**

**Daniel BOUGEARD, Serge RUSSEIL,
Jean-Luc HARION, Vincent KUBICKI, Jules Voguelin SIMO-TALA**

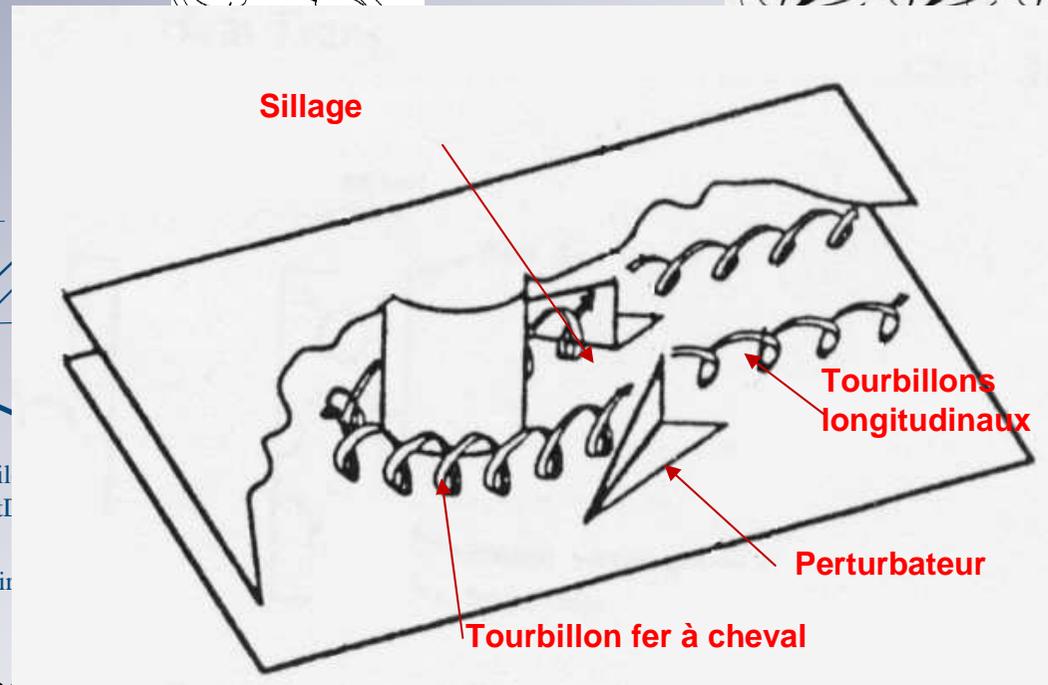
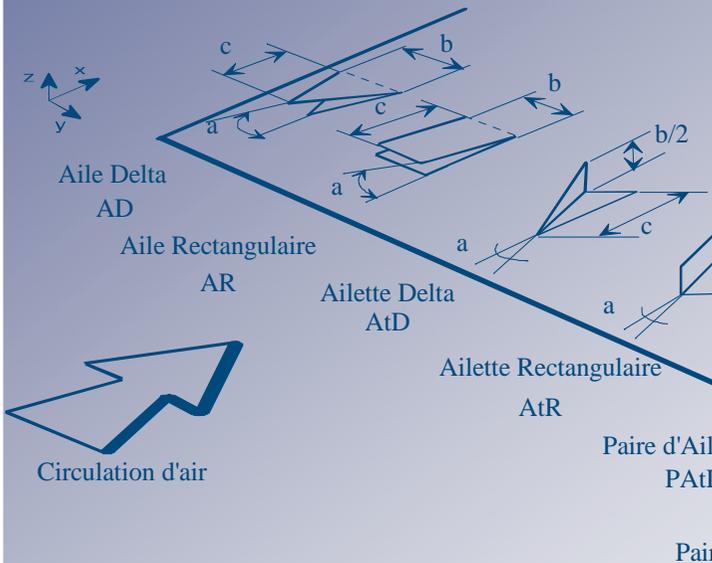
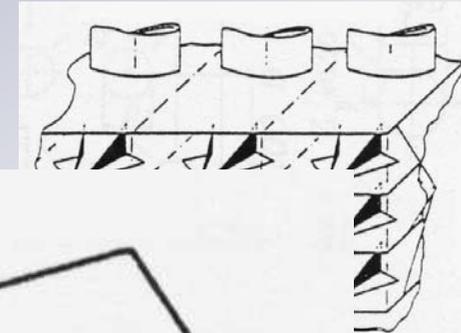
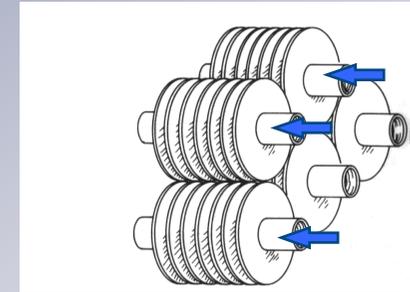
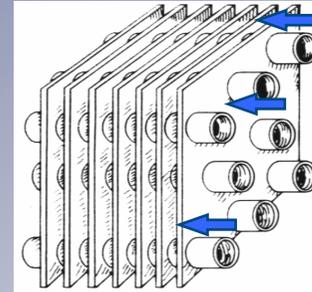
EMDouai, EI, F-59500 Douai, France

Contexte et enjeux

- **Intensification des échanges convectifs**
 - Accroître les performances thermo-aérauliques des échangeurs
 - Qualité de mélange dans les échangeurs multifonctionnels
 - Diminution de quantité de matière nécessaire à la fabrication du composant (coût matière)
 - UE : FP7 Energy
 - ANR : EESI, SEED..., PIE CNRS
 - ADEME : APEPI, TTD
 - Monde industriel
- **Techniques expérimentales**
 - IR, PIV 2D2C, LDV, Veines hydrodynamique & aéraulique
- **Simulations numériques**
 - RANS, U-RANS, DNS

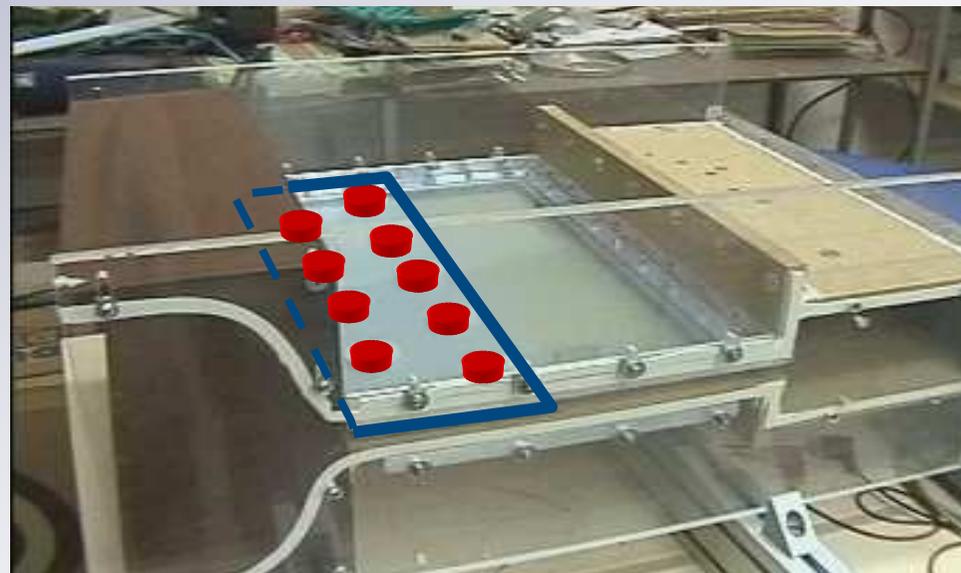
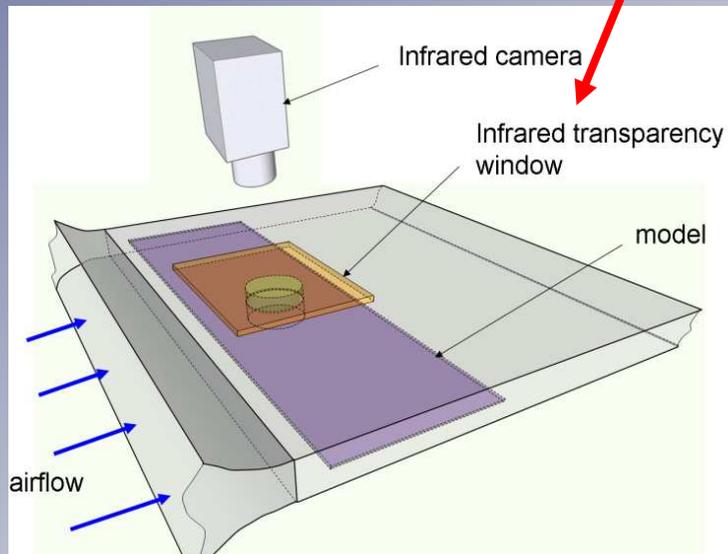
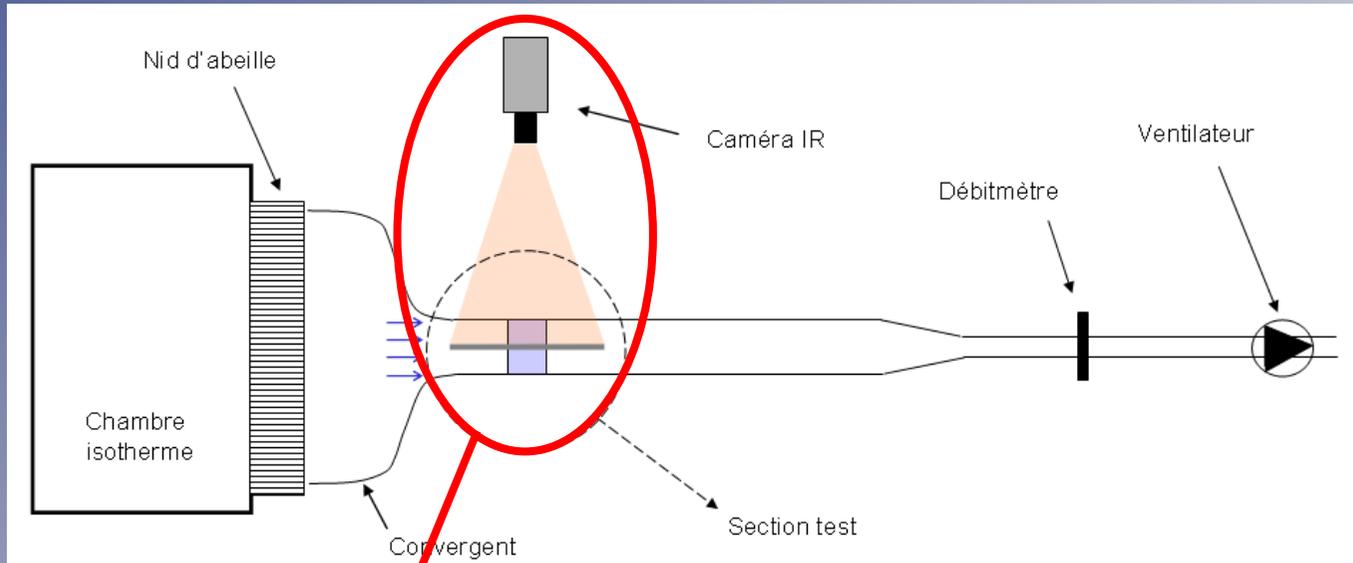
Promoteurs de tourbillons

- Configurations à tubes et ailettes (continues ou discontinues)
- Très nombreux travaux existants

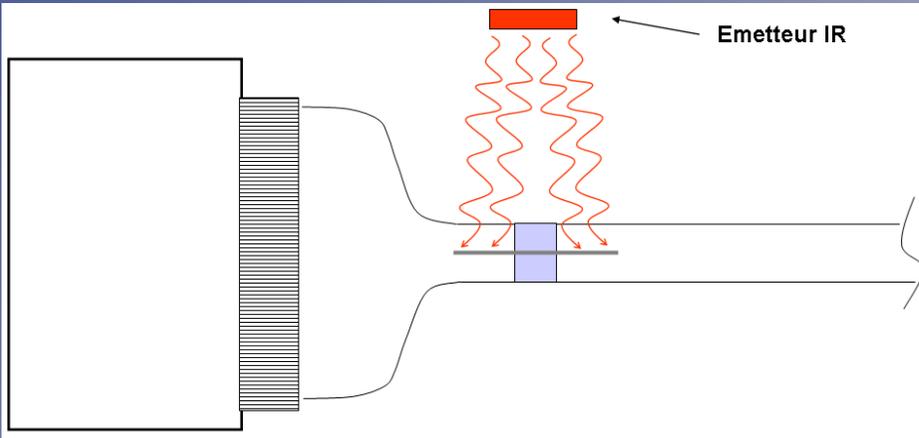


Analyse expérimentale : thermique

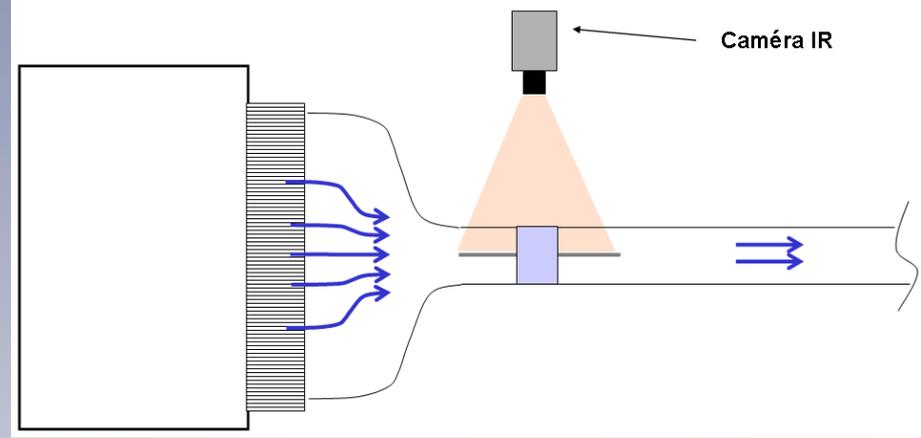
Caractérisation thermique par IR (1/4)



Caractérisation thermique par IR (2/4)

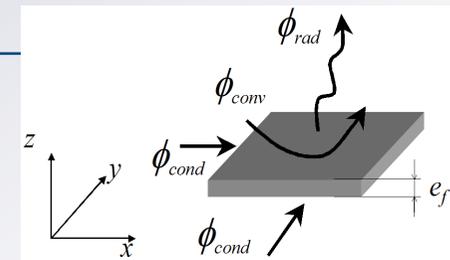


1^{ère} phase : Chauffage uniforme

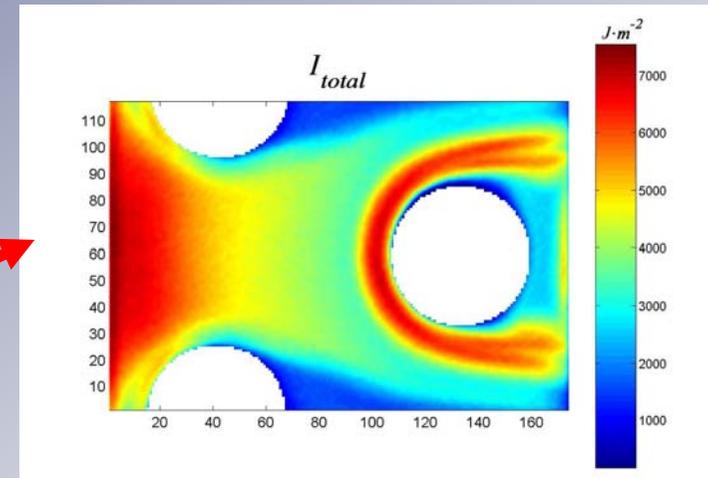
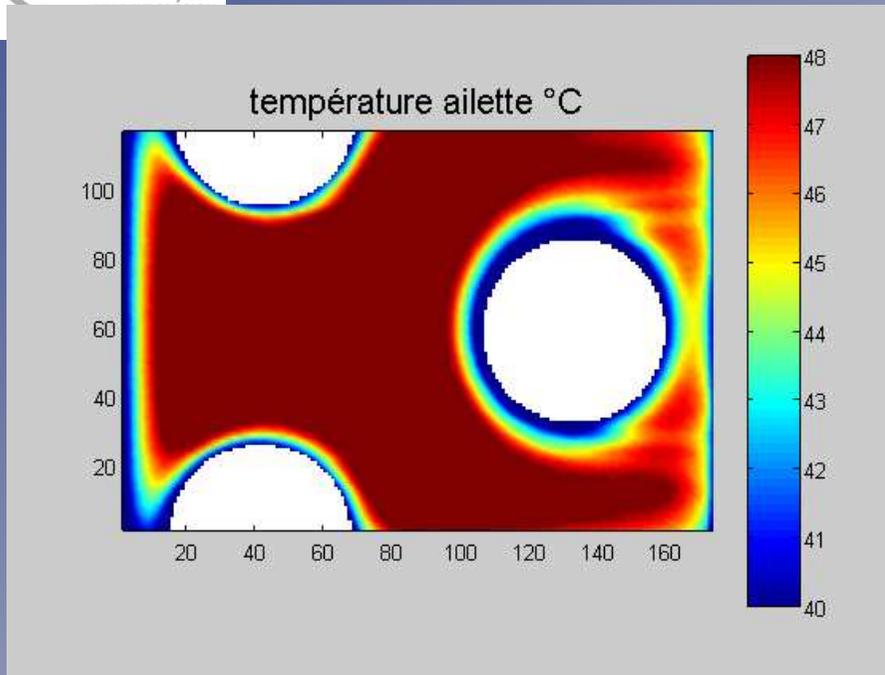


2^{nde} phase : Enregistrement de la décroissance temporelle de T(x,y)

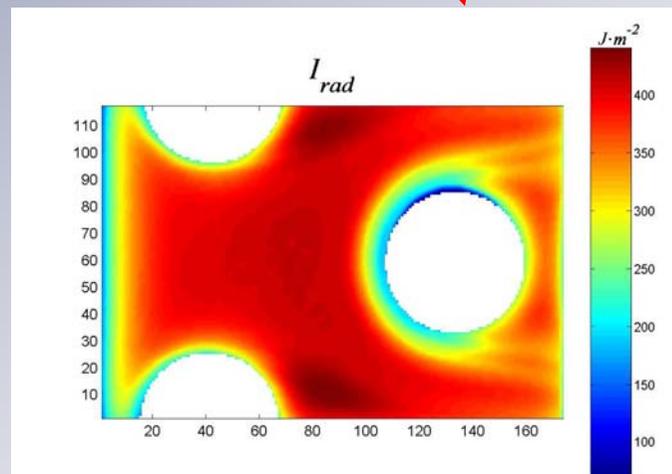
$$\underbrace{\rho C_p e \int_{t_{init}}^{t_{final}(x,y)} \frac{dT(x,y,t)}{dt} dt}_{I_{total}(x,y)} = \underbrace{h(x,y) \int_{t_{init}}^{t_{final}(x,y)} (T(x,y,t) - T_{ref,conv}) dt}_{I_{temp}(x,y)} + \underbrace{\lambda e \int_{t_{init}}^{t_{final}(x,y)} \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} \right) dt}_{I_{cond}(x,y)} + \underbrace{\varepsilon \sigma \int_{t_{init}}^{t_{final}(x,y)} (T^4(x,y,t) - T_{ref,ray}^4) dt}_{I_{ray}(x,y)}$$



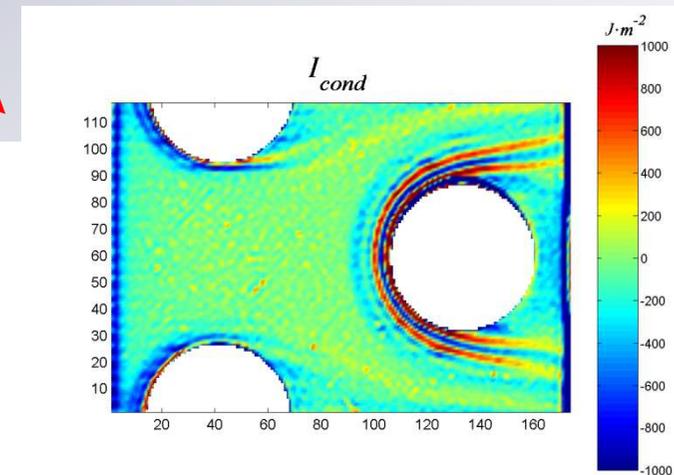
Caractérisation thermique par IR (3/4)



(a) total energy exchange



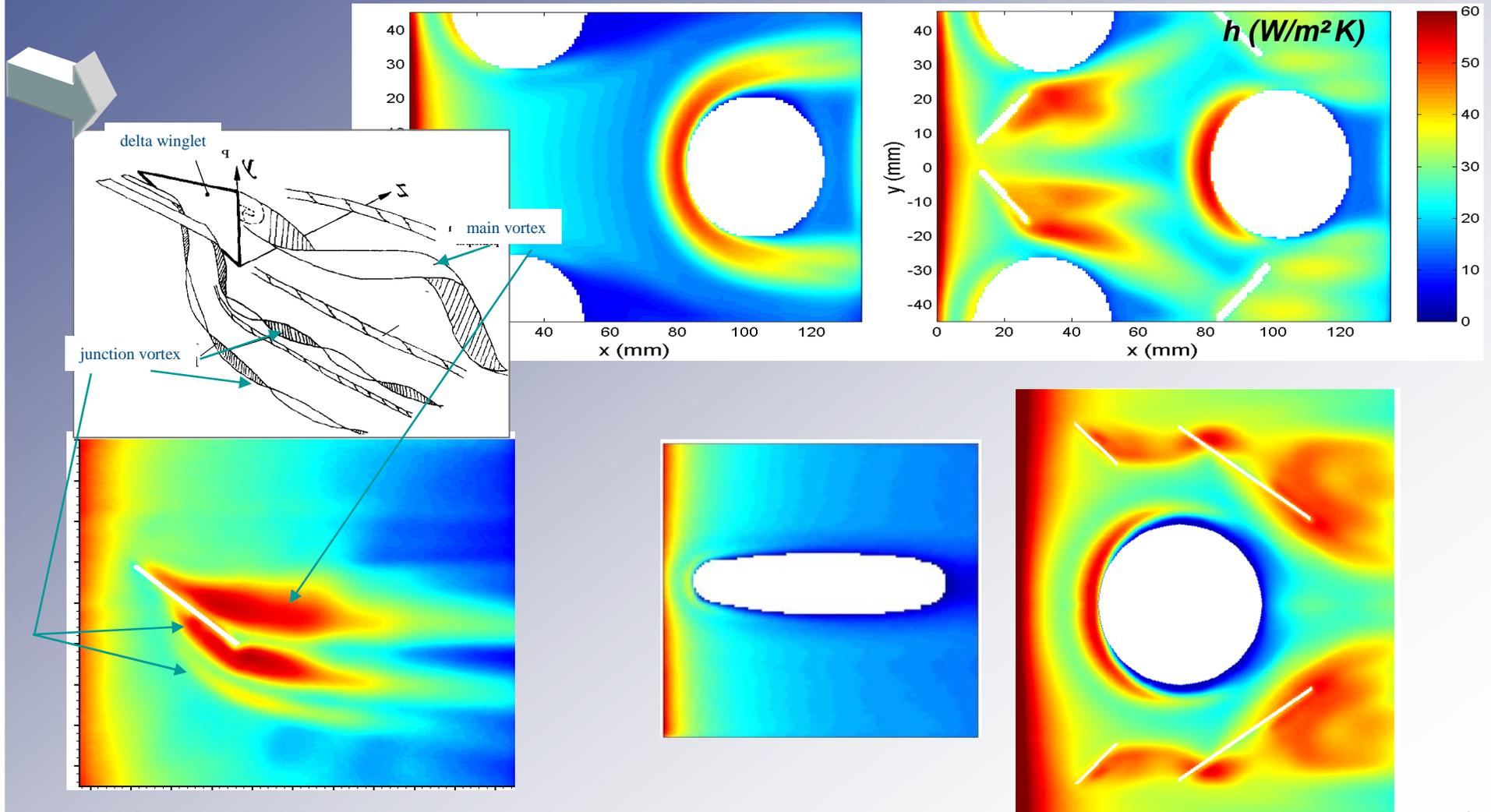
(c) energy exchanged by radiation



(b) energy exchange by conduction

Caractérisation thermique par IR (4/4)

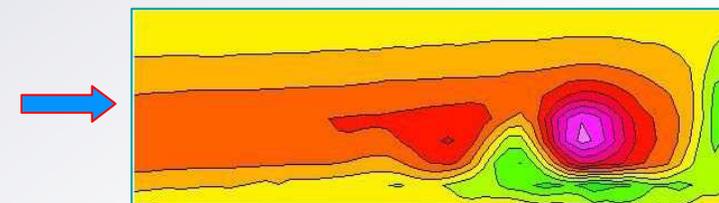
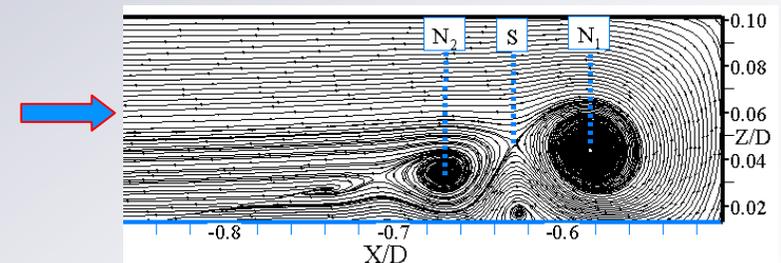
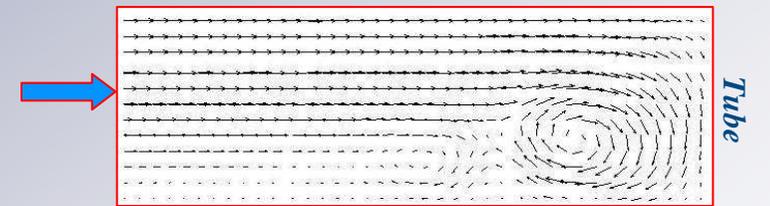
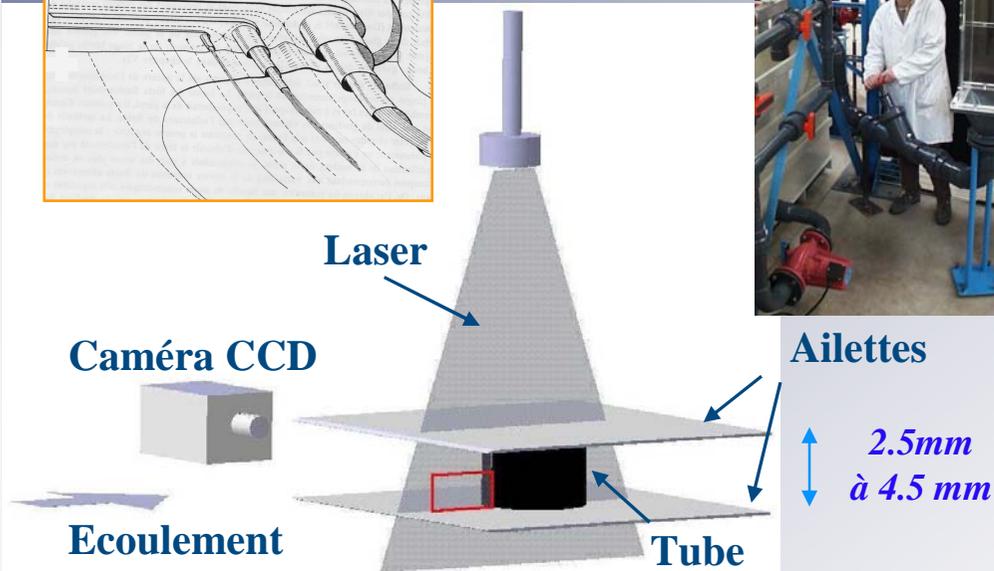
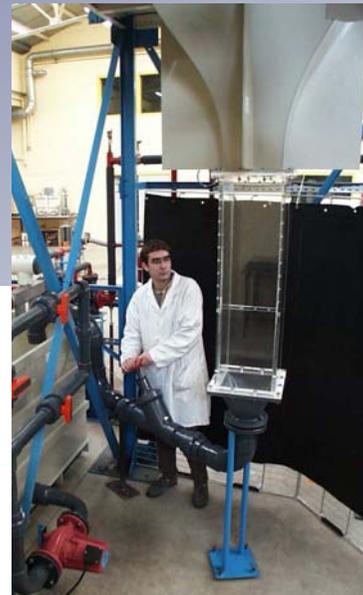
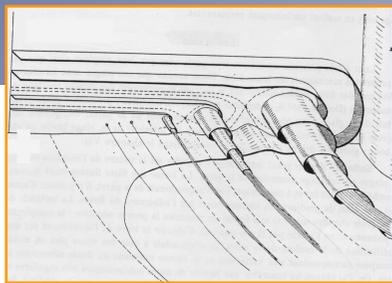
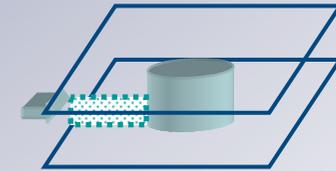
- Exemples de distribution de coefficient d'échange convectif



Analyse expérimentale : dynamique

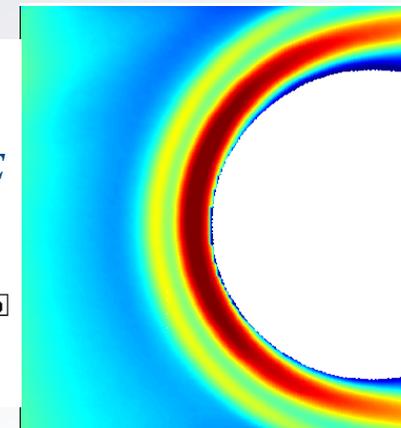
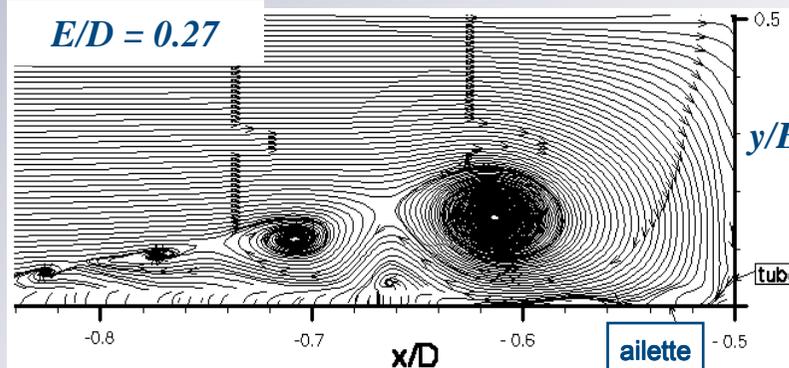
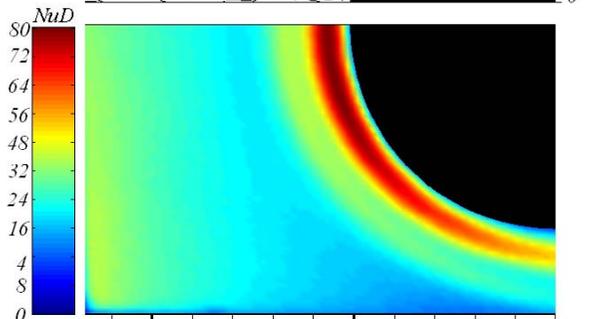
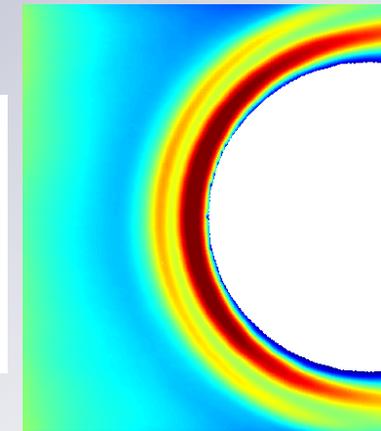
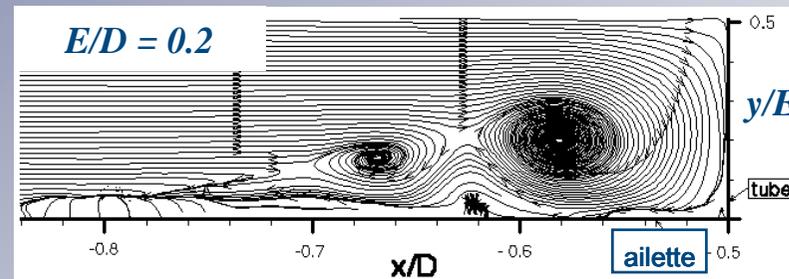
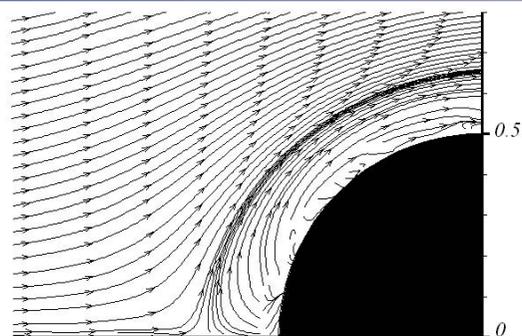
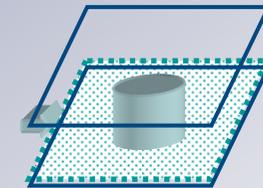
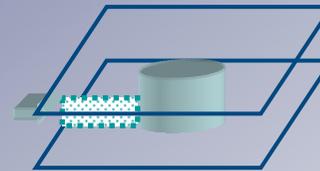
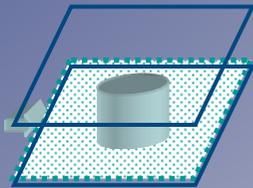
Caractérisation dynamique (1/4)

- **Géométrie élémentaire d'écoulement de jonction : PIV**
 - Caractérisation des tourbillons de pied de tube
 - Zone de sillage à l'aval du tube
 - Paramètres :
 - Pas inter-ailettes
 - Reynolds



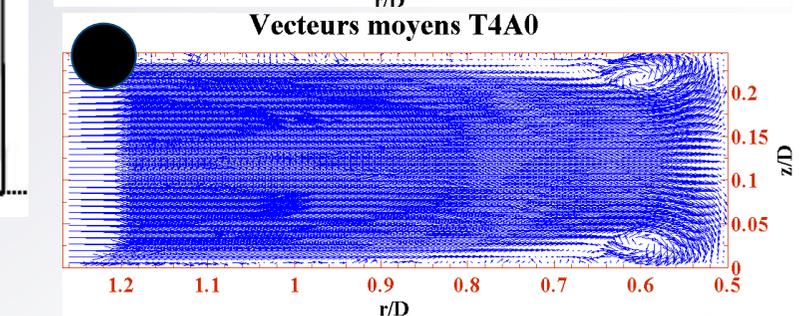
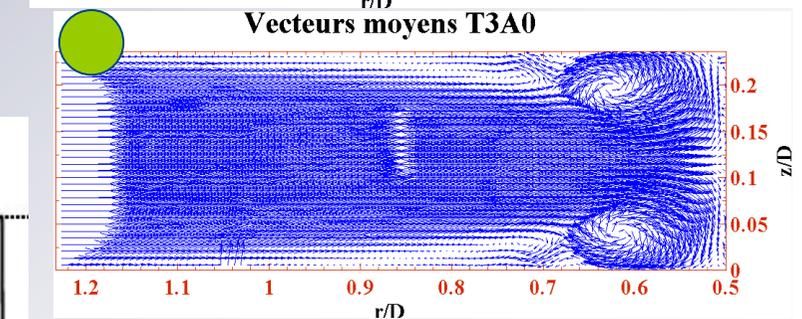
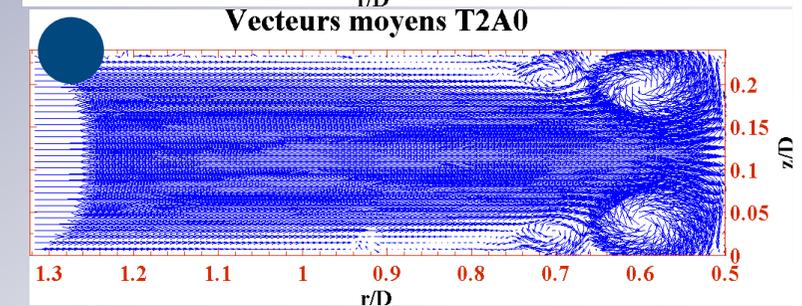
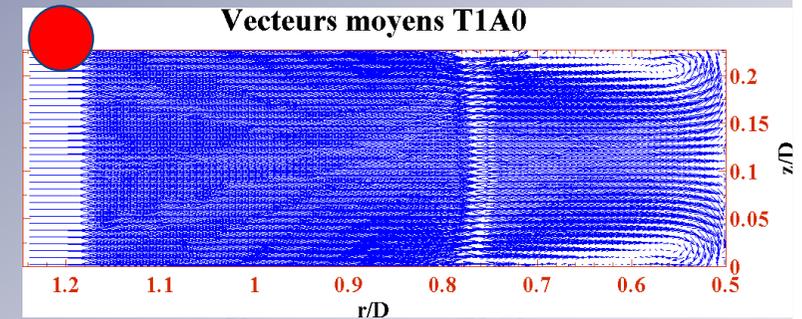
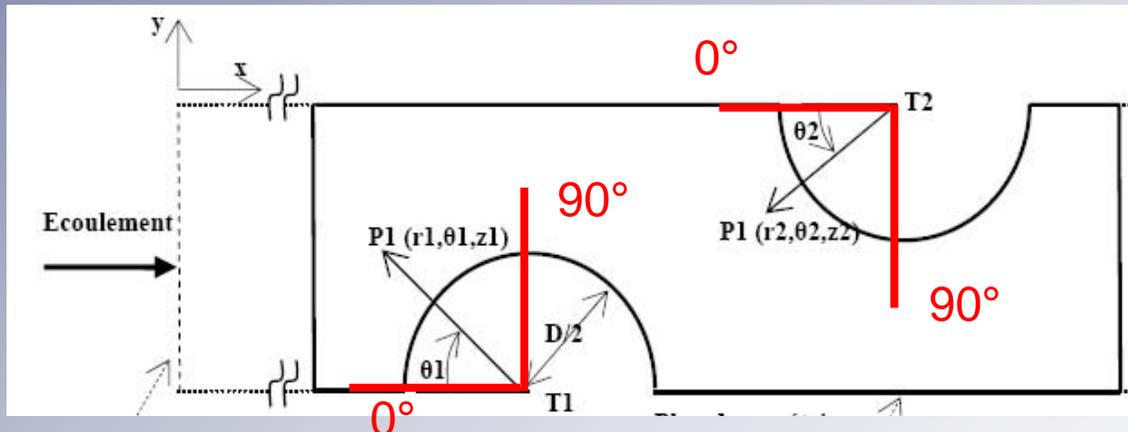
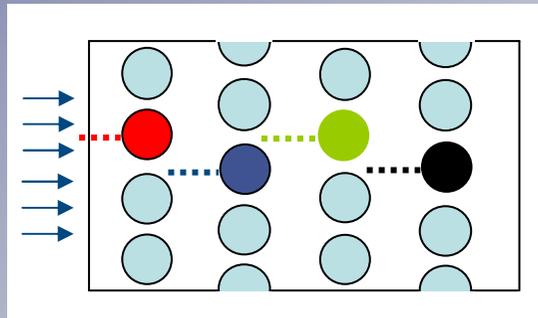
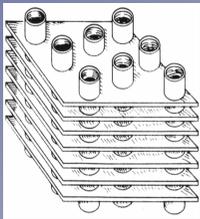
Caractérisation dynamique (2/4)

- Géométrie élémentaire d'écoulement de jonction :
PIV vs IR



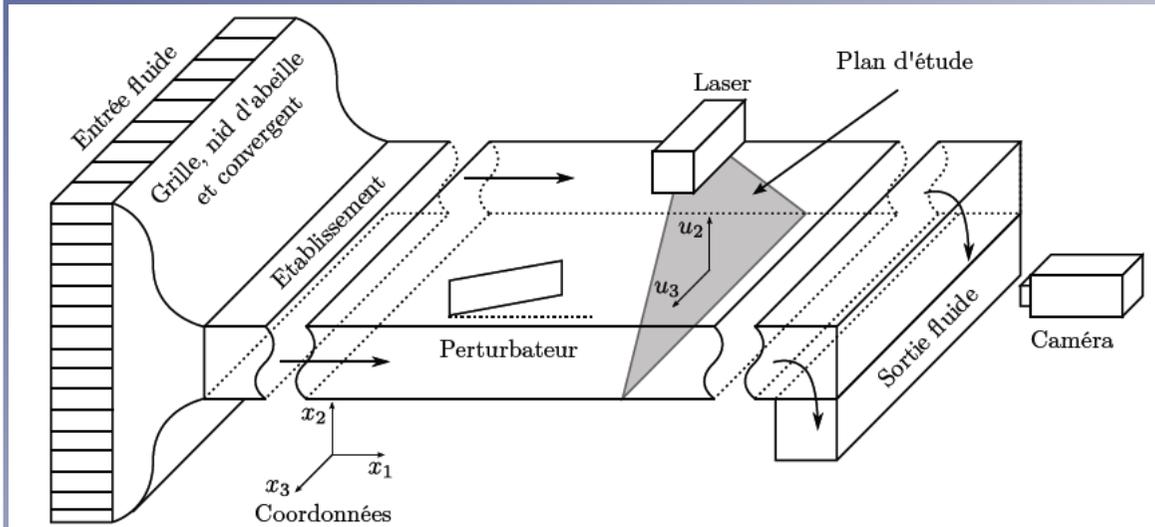
Caractérisation dynamique (3/4)

- Configuration multi-rangs de tubes
 - Analyse rang par rang
 - Evolution angulaire (topologie, vorticité...)

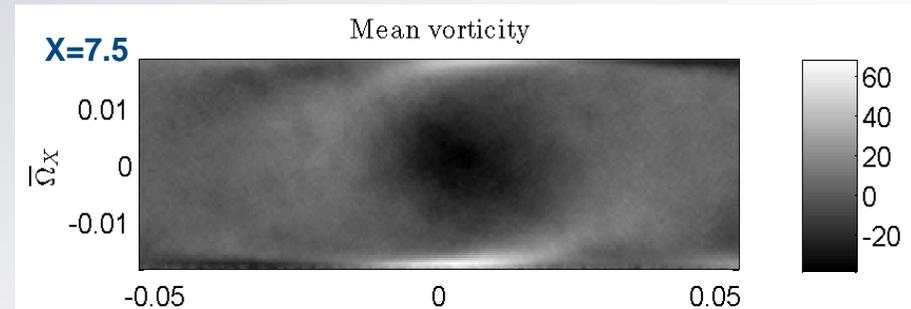
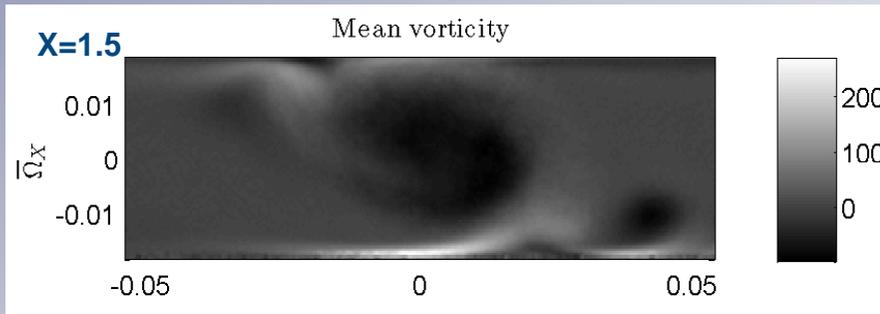
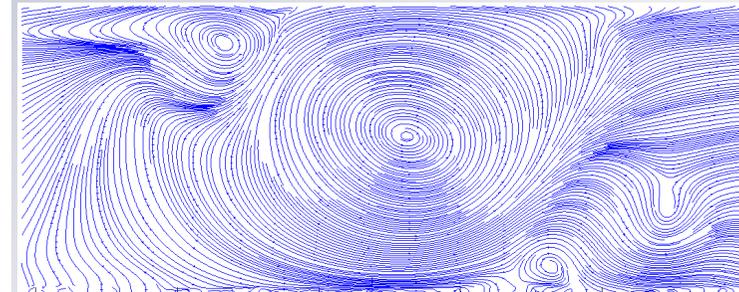


Caractérisation dynamique (4/4)

- **Tourbillon longitudinal issu d'un promoteur en incidence à 30°**
 - Promoteur dans un écoulement de canal turbulent développé
 - Analyse de la dissipation dans des plans transverses à l'aval



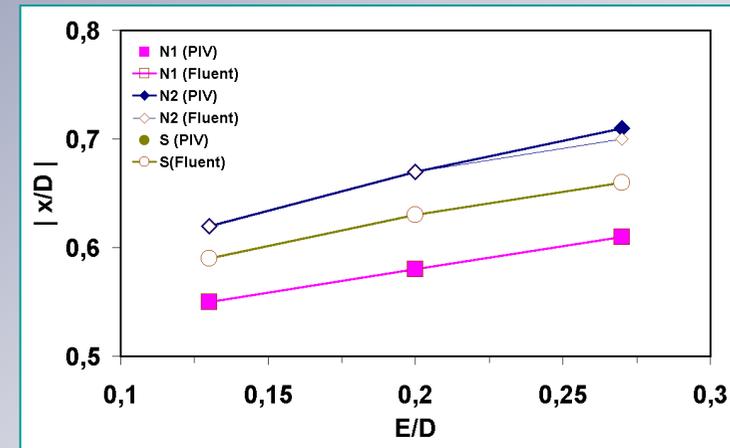
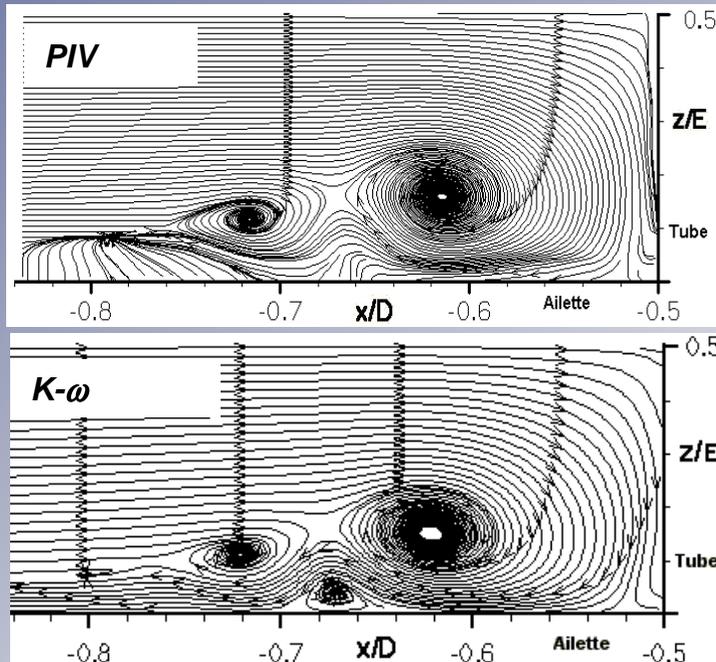
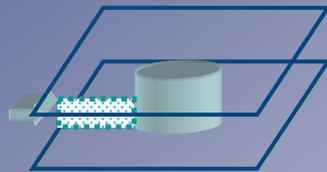
*Etablissement : 4 m, analyse : 1,3 m
Re = 11300 (turbulent bas Reynolds)*



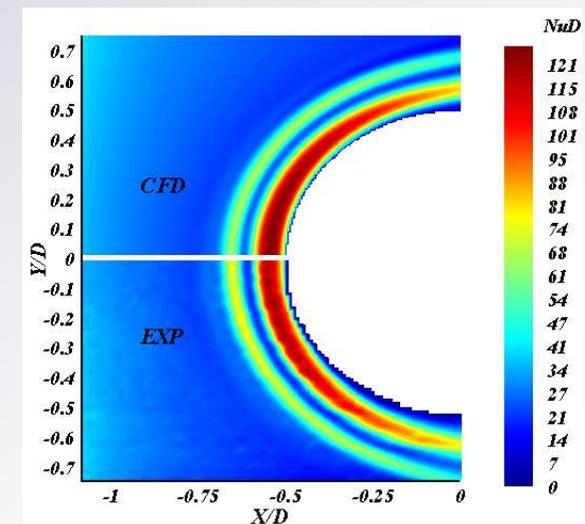
Analyse par simulations numériques

Approche numérique par CFD (1/5)

- Simulations RANS ($k-\omega$) vs data expérimentales : amont du tube
 - Validation des modèles

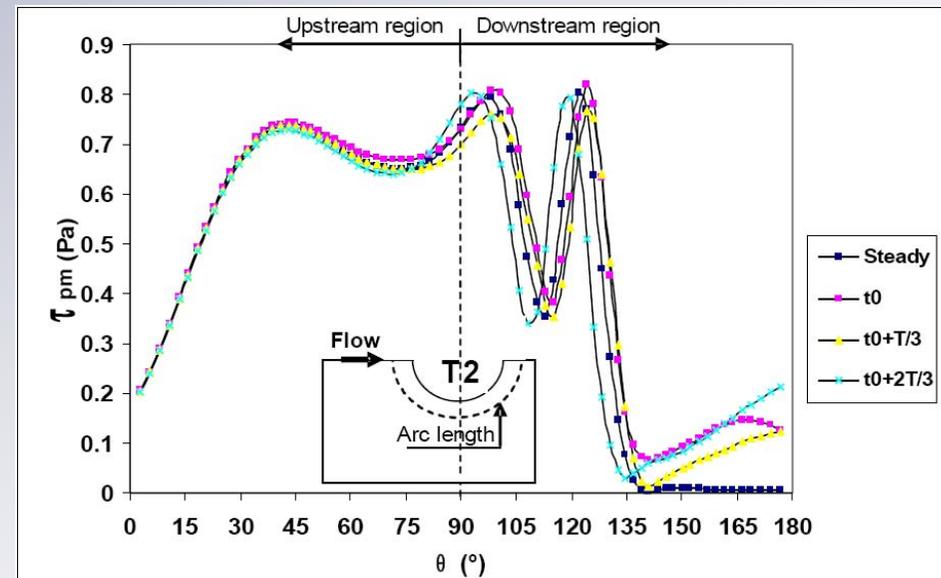
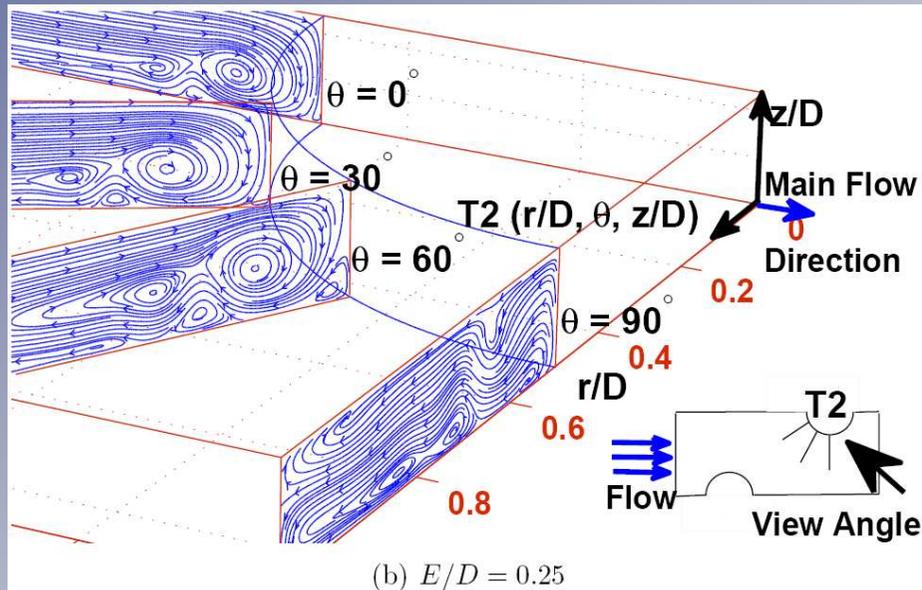
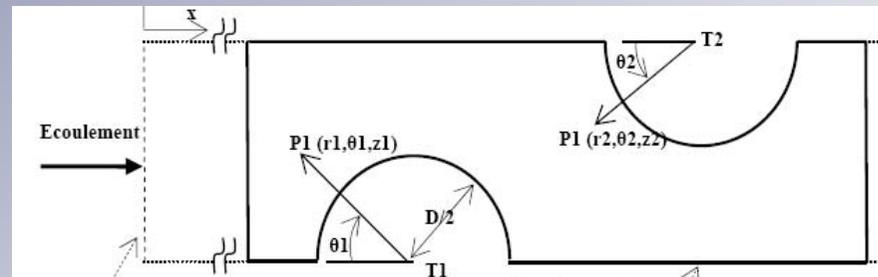


x-position de N1, N2 et S1



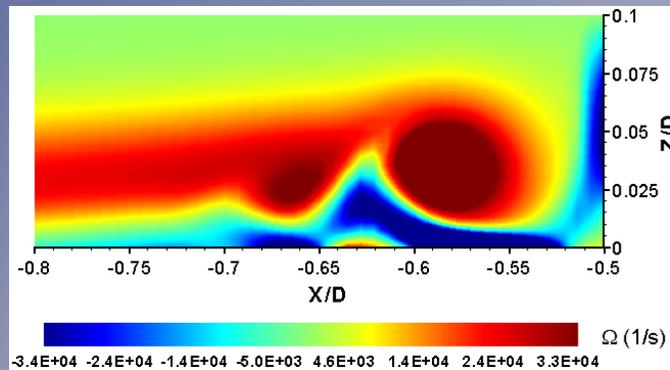
Approche numérique par CFD (2/5)

- Simulations U-RANS ($k-\omega$) vs data expérimentales : autour du tube
 - Topologie et dissipation angulaire
 - Instationnarité

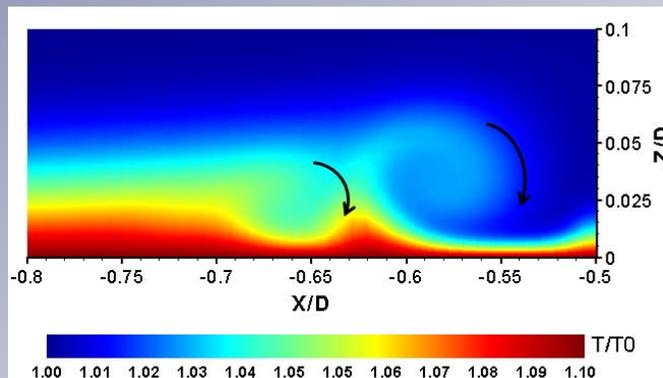


Approche numérique par CFD (3/5)

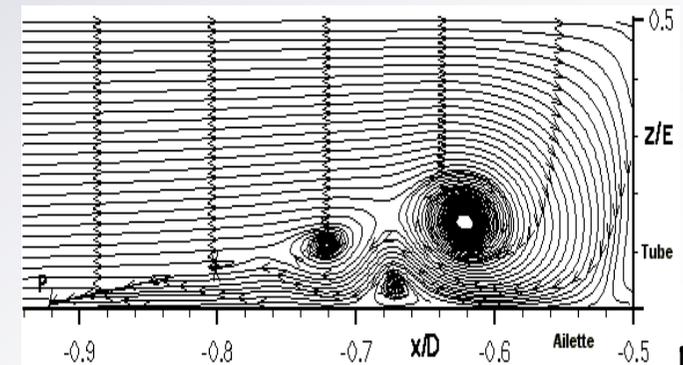
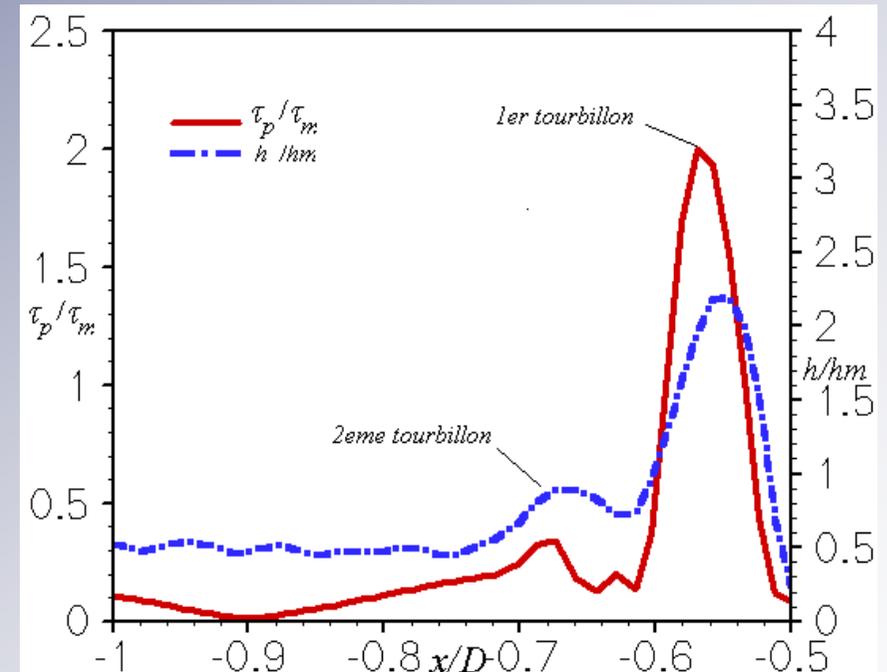
- Outil d'analyse des mécanismes physiques



Contour de vorticité

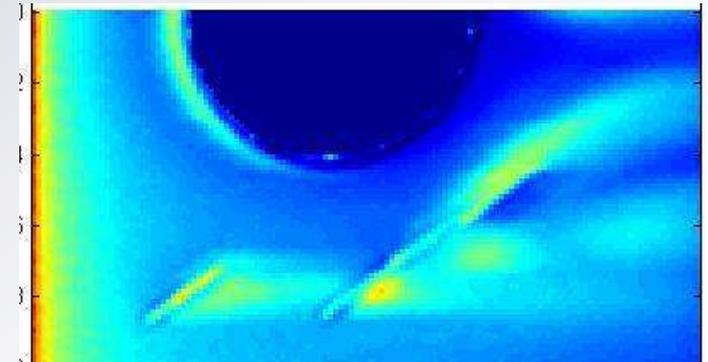
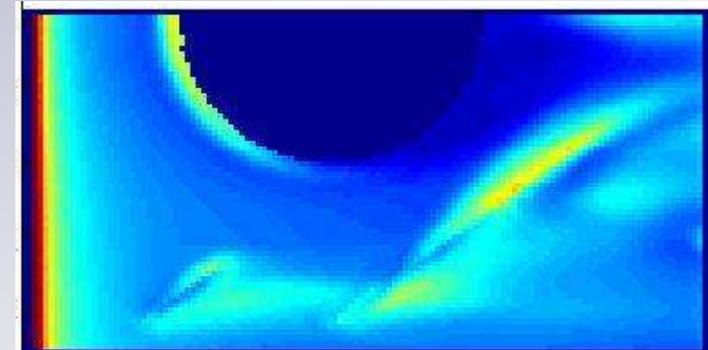
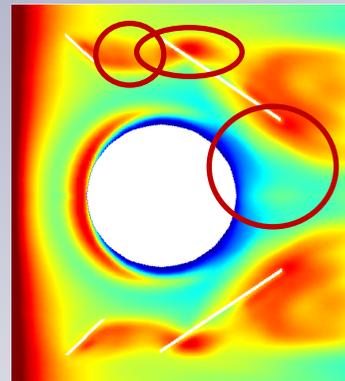
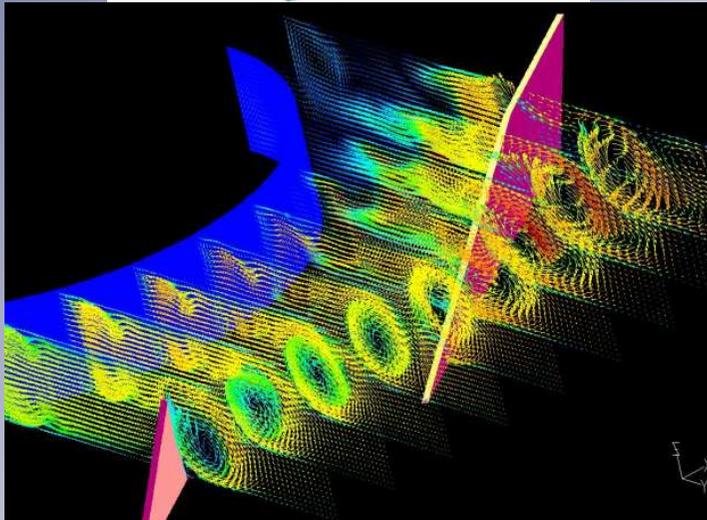
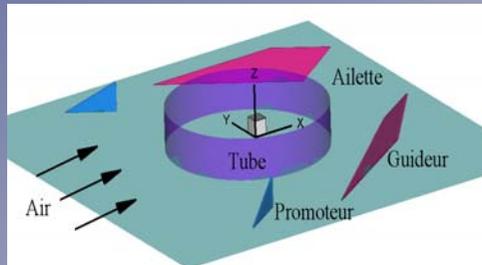


Contour de température adimensionnée



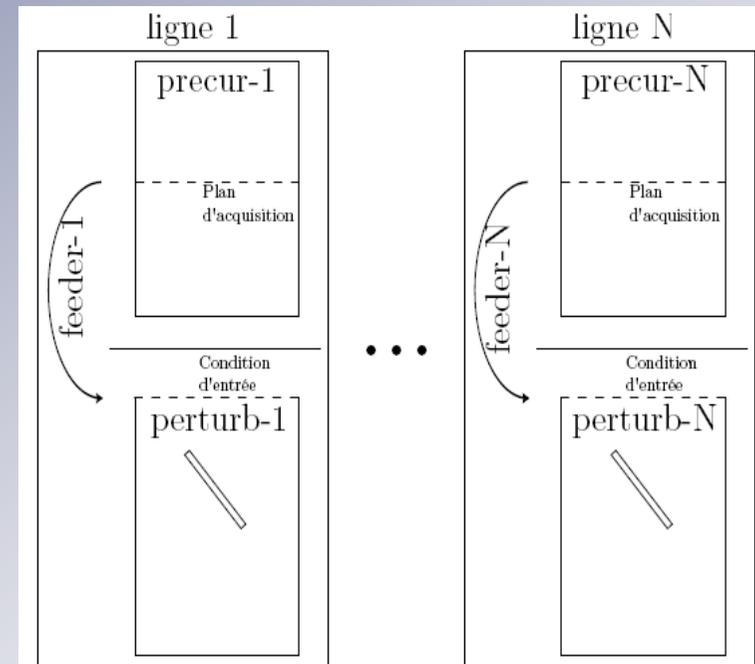
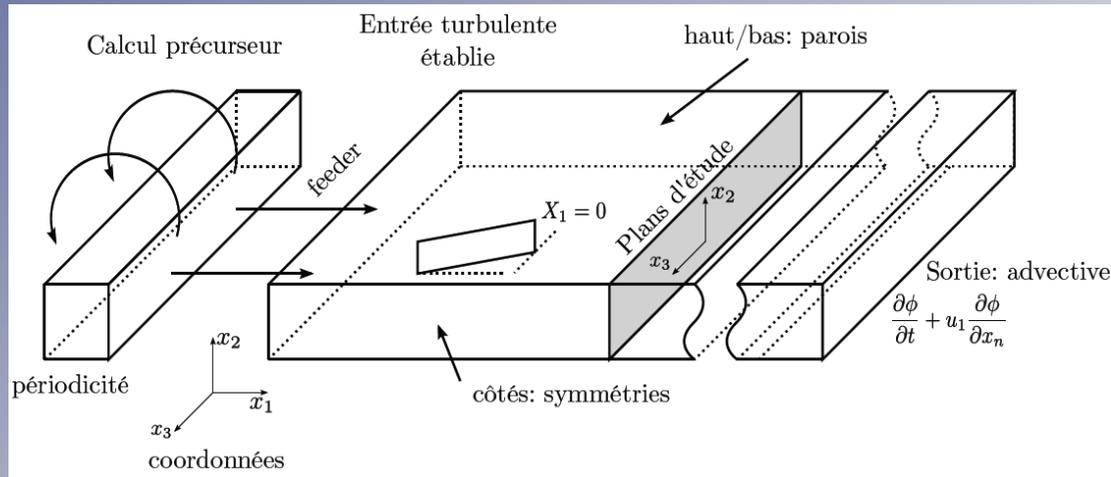
Approche numérique par CFD (4/5)

- **Outil de design : nouvelle géométrie (brevet VALEO 2007)**
 - Pour une configuration standard (tubes ronds) à $P_{\text{thermique}} = C^{\text{ste}}$:
 - Diminution matière et diminution de la puissance aéraulique



Approche numérique par CFD (5/5)

- **Outil d'analyse fine des transferts turbulents : la DNS**
 - Fonction de dissipation, vorticit  moyenne et turbulente...
 - Anisotropie de la turbulence



- **Syst me automatis  robuste**
- **Lignes statistiquement ind pendantes**
- **724 000 r alisations statistiques**
- **24 lignes sur cluster = 48 n uds quadricore**
- **(14 + 7) Millions de mailles par ligne soit un total de 504 Millions de mailles**
- **1 mois de calcul**
- **1000 calculs/semaine en autonomie**



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Merci pour votre attention

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