

# INSTABILITES EN INTERACTION FLUIDE-STRUCTURE

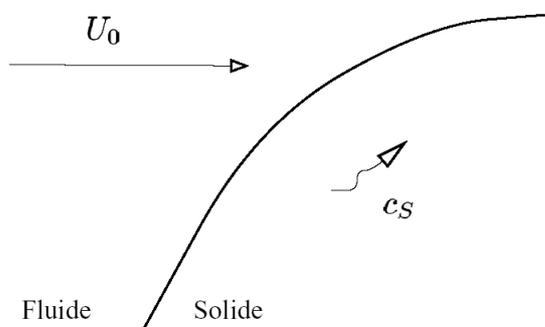
*E. de Langre*  
*LadHyX, Ecole polytechnique*

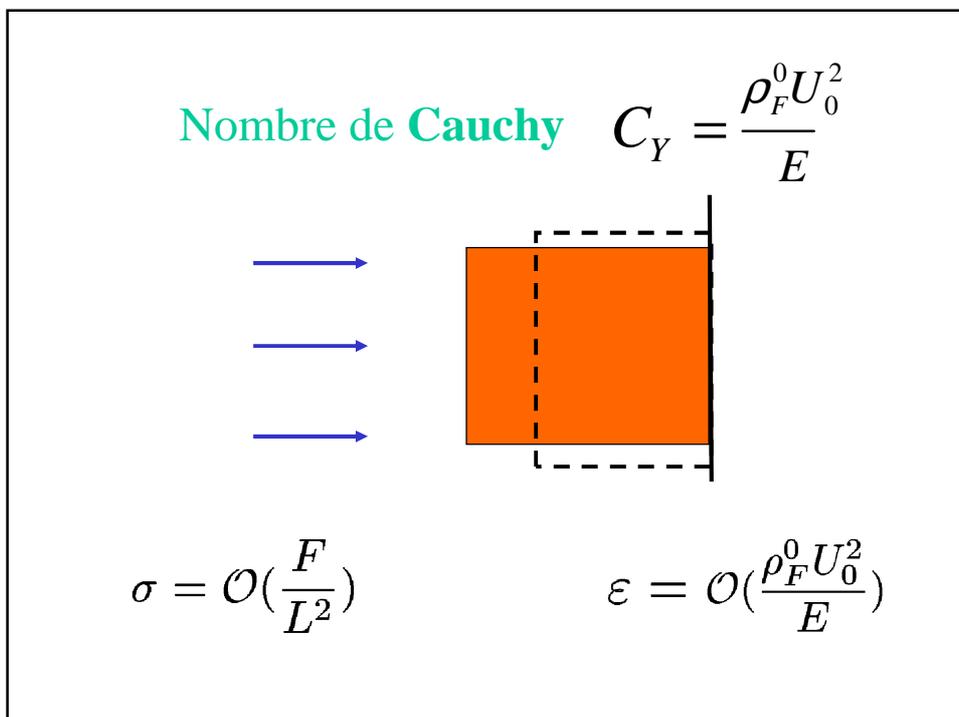
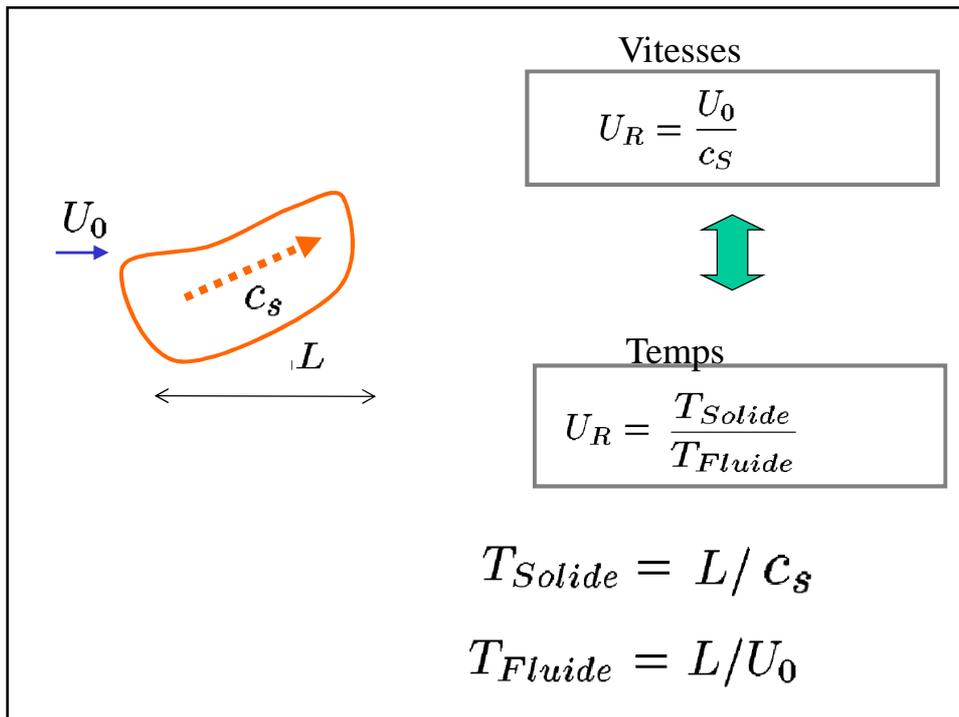
- Cadre général pour se comprendre
- Quelques problèmes actuels

## NOMBRES ADIMENSIONNELS

Vitesse réduite

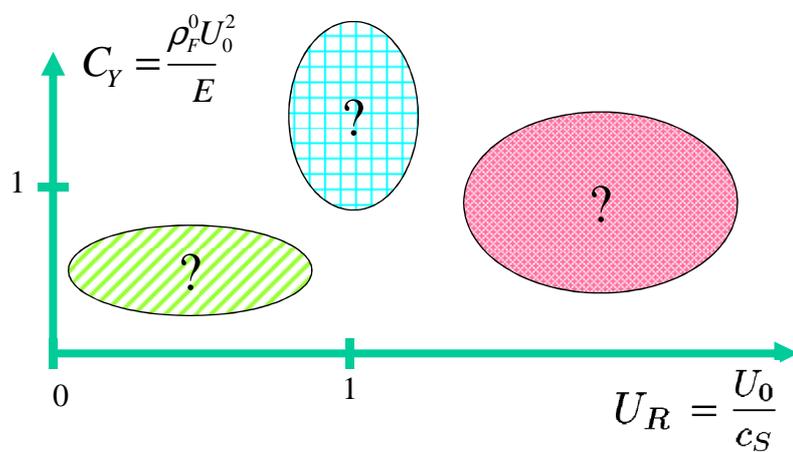
$$U_R = \frac{U_0}{c_S}$$





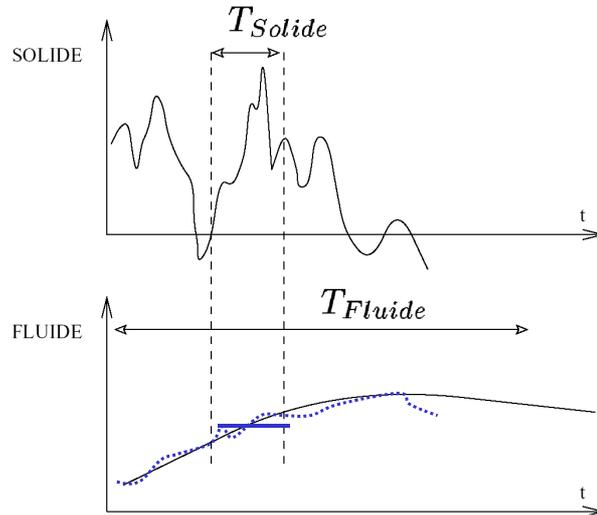
Nombre de Masse  $M = \frac{\rho_F^0}{\rho_S^0}$

$$C_Y = M (U_R)^2$$



**FLUIDE AU REPOS**

$$U_R \ll 1$$



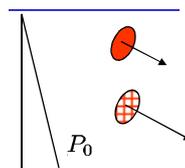
**LE FLUIDE SEMBLE IMMOBILE**

**MASSE AJOUTEE, ...**

**RAIDEURS AJOUTEES**

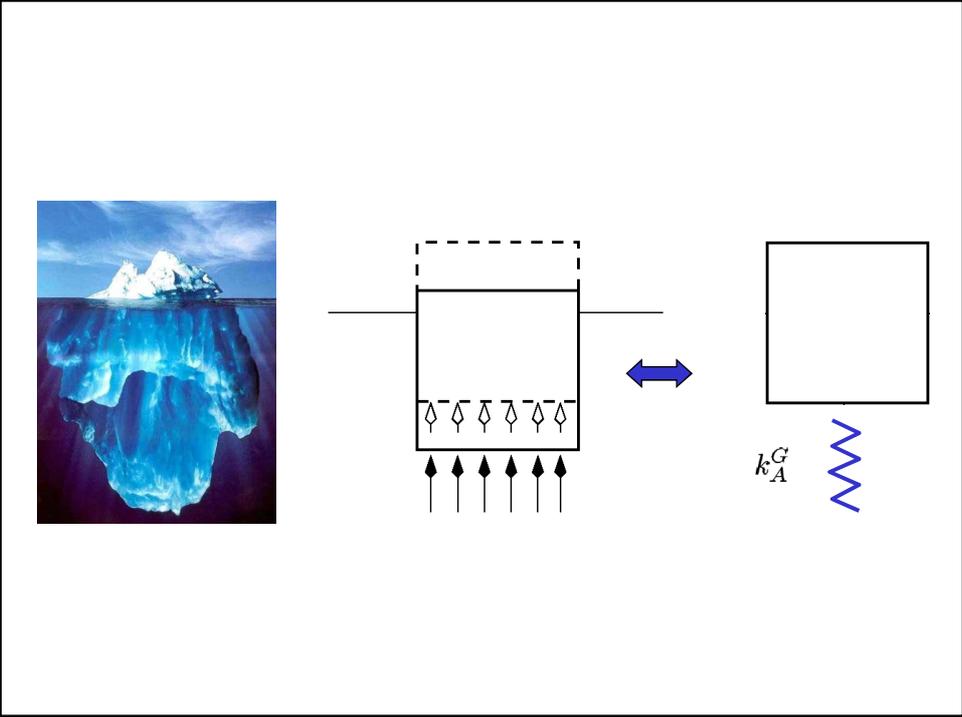
Déplacement dans un champ de pression non-uniforme

$$f_{FS} = -q(t) k_A^G$$

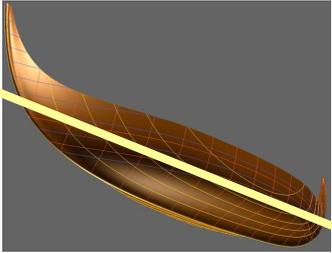


$$k_A^G = \mathcal{M} \int_{\partial\Omega_{FS}} (\varphi \cdot \underline{n}) (\nabla P_0 \cdot \underline{\varphi}) dA$$

Géométrie  
Mouvement



**RAIDEURS AJOUTEES : INSTABILITES STATIQUES**



Mouvement de roulis

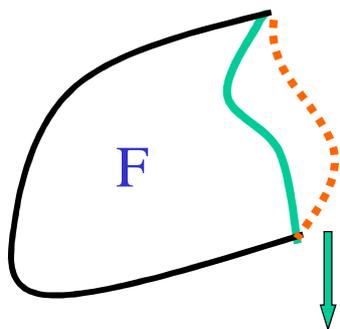
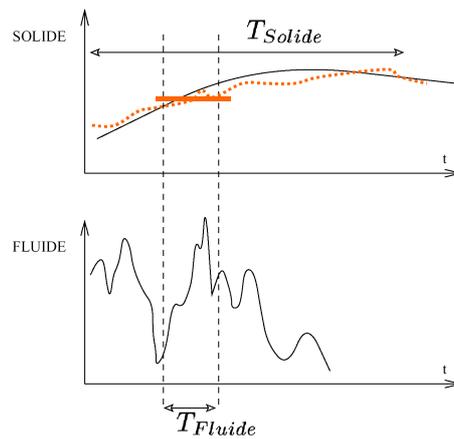


$$k_A^G > 0 \quad \text{ou} \quad < 0$$

## AEROELASTICITE QUASI-STATIQUE

$$U_R \gg 1$$

LE SOLIDE SEMBLE IMMOBILE



On ne néglige pas  
le changement de  
de position de l'interface

On néglige la vitesse  
propre du solide

Problème fluide stationnaire

$$\operatorname{div} \tilde{\underline{U}} = 0$$

$$\frac{d \tilde{\underline{U}}}{d \tilde{t}} = -\frac{1}{F_R^2} \underline{e}_z - \operatorname{grad} \tilde{p} + \frac{1}{R_E} \Delta \tilde{\underline{U}}$$

$\tilde{\underline{U}} = \mathcal{O}(1)$

$\tilde{\underline{U}} = 0$

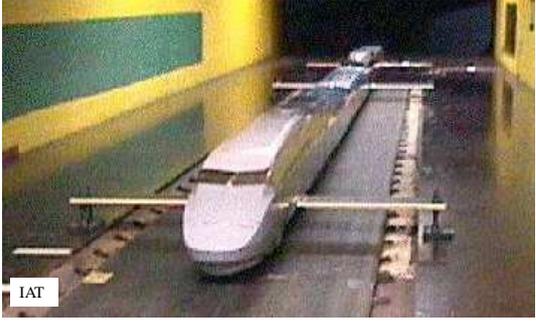
Position



Effort



Problème fluide stationnaire



Condition  
écoulement

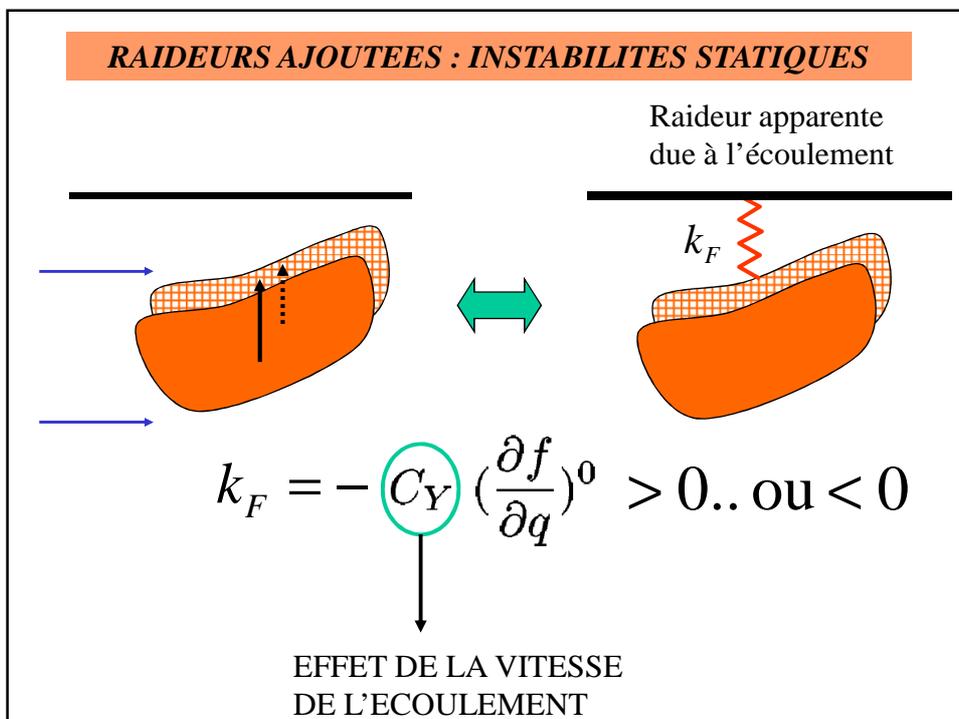
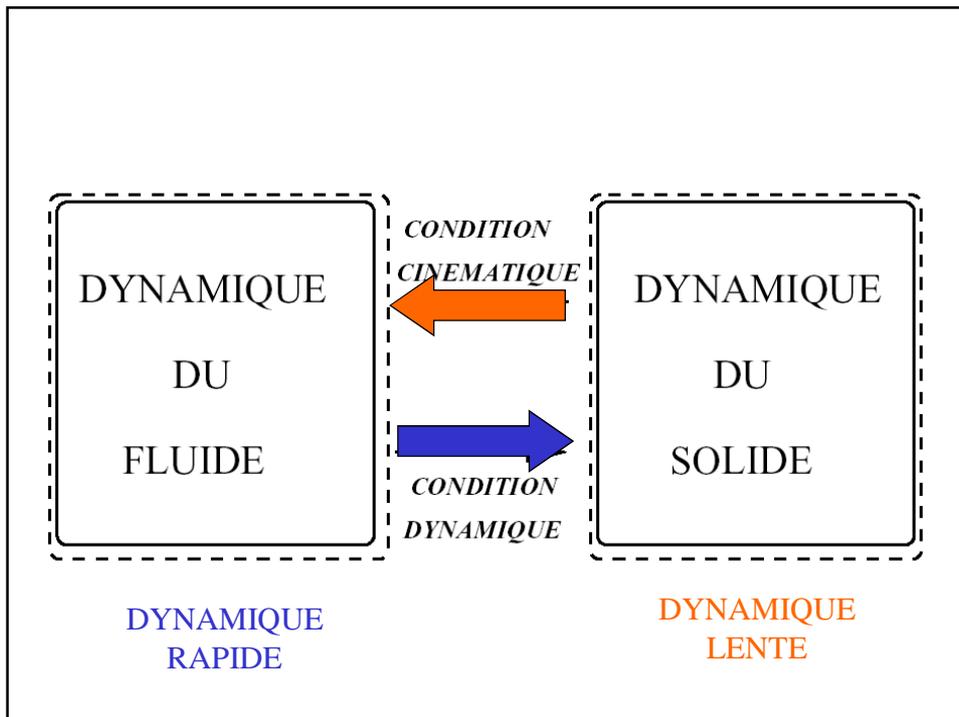
Maquette  
immobile

Position

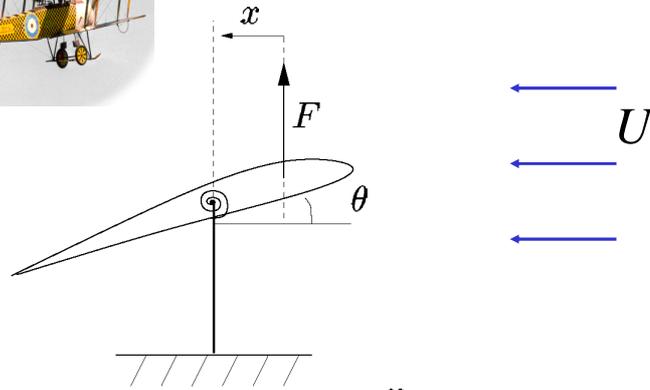


Effort

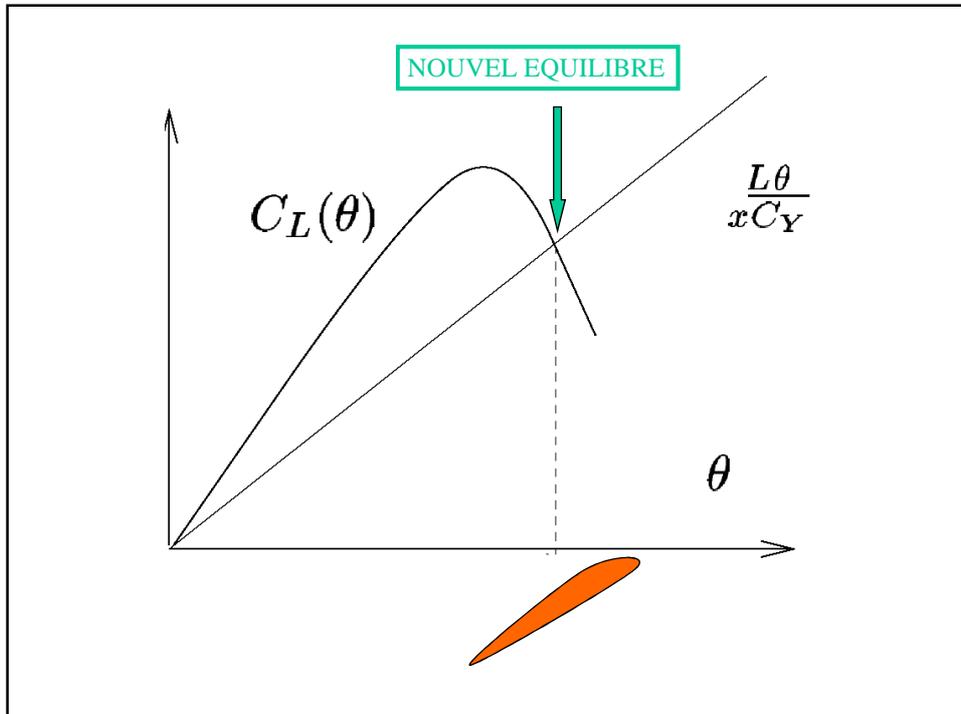




# INSTABILITE DE TORSION DES AILES



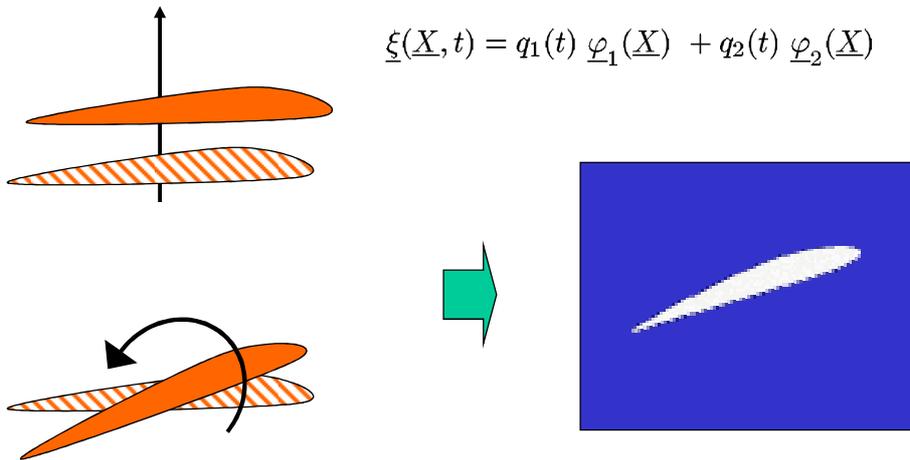
$$\ddot{\theta} + \theta = F(\theta) x$$



**RAIDEURS AJOUTEES : INSTABILITES DYNAMIQUES**

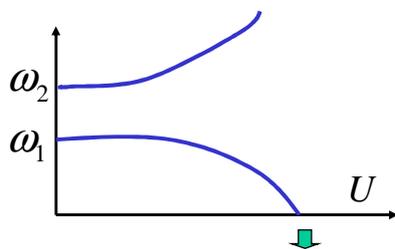
**MOUVEMENT BI-PARAMETRIQUE**

$$\underline{\xi}(\underline{X}, t) = q_1(t) \varphi_1(\underline{X}) + q_2(t) \varphi_2(\underline{X})$$

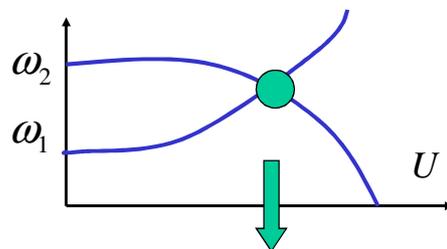


$$m_1 \ddot{q}_1 + k_1 q_1 = C_Y f_1^0 + C_Y K_{11} q_1 + C_Y K_{12} q_2$$

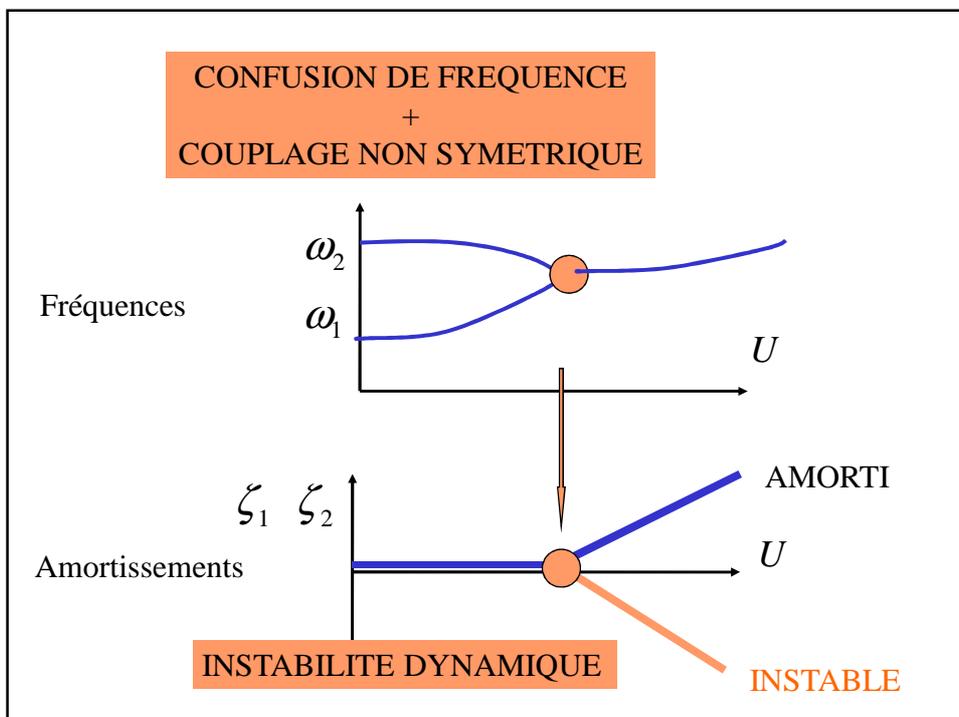
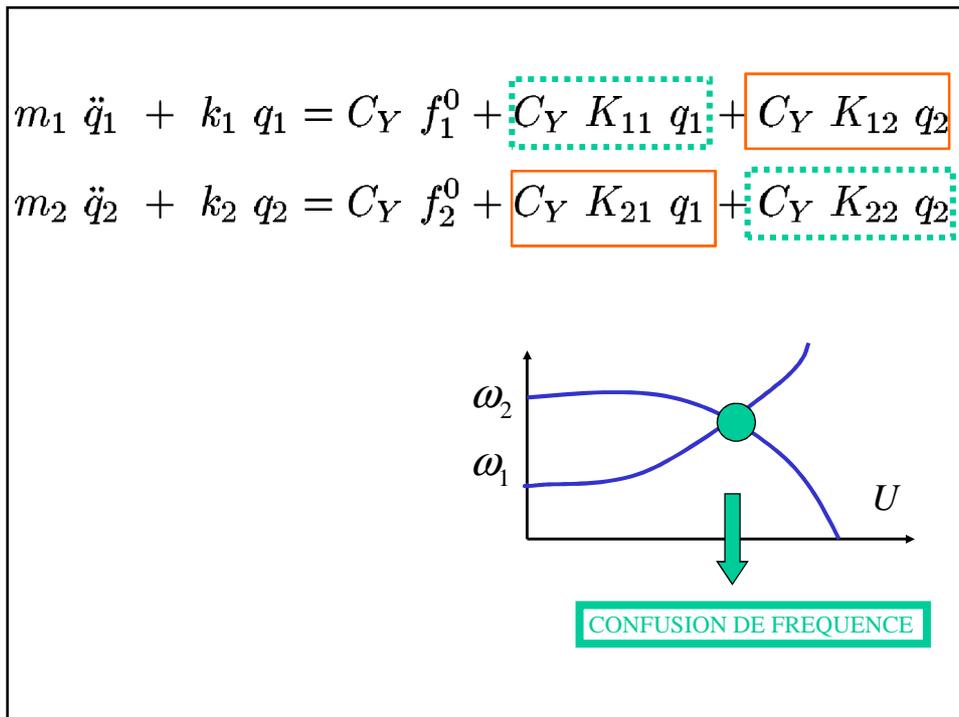
$$m_2 \ddot{q}_2 + k_2 q_2 = C_Y f_2^0 + C_Y K_{21} q_1 + C_Y K_{22} q_2$$



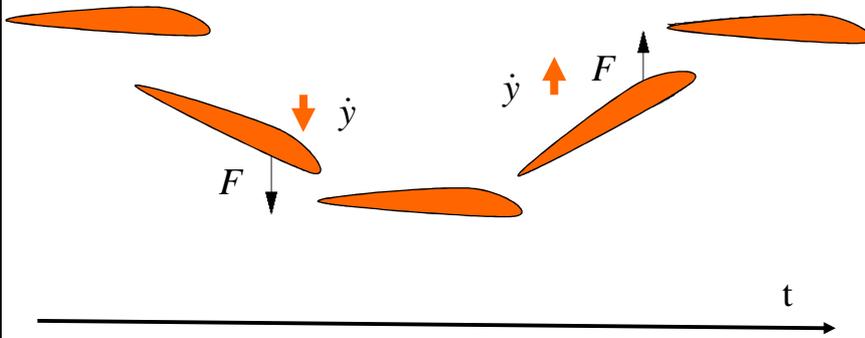
INSTABILITE STATIQUE



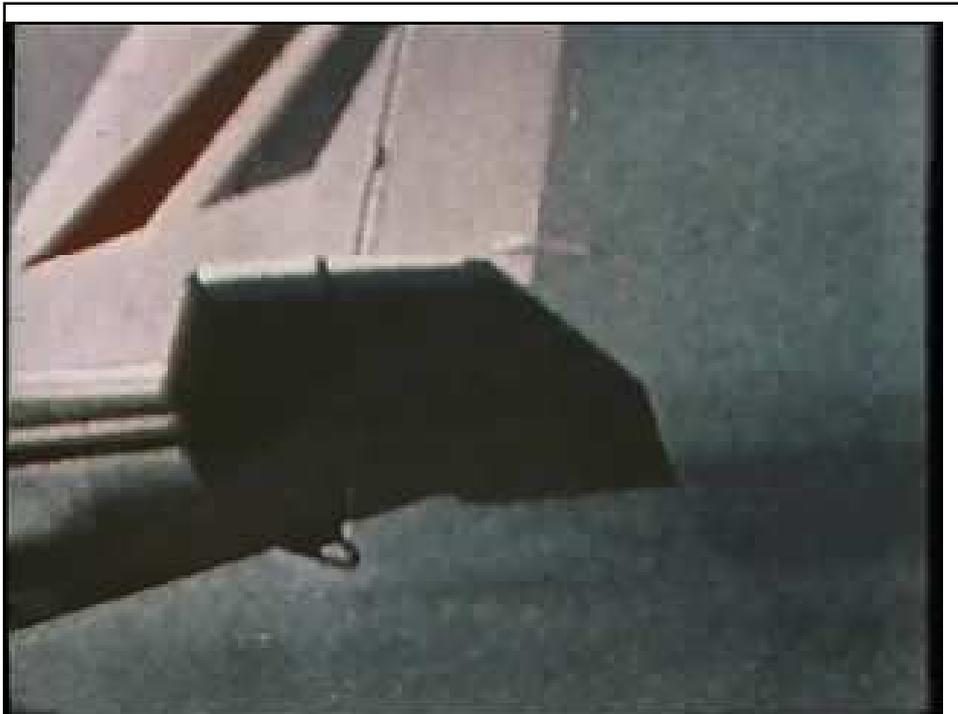
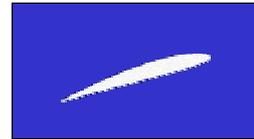
CONFUSION DE FREQUENCE

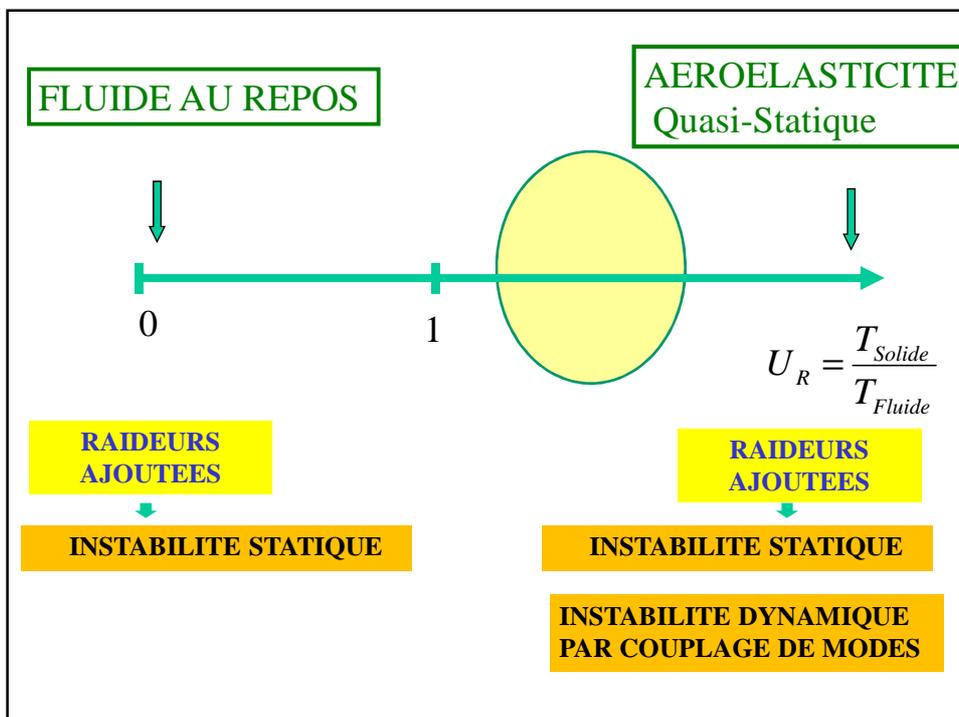
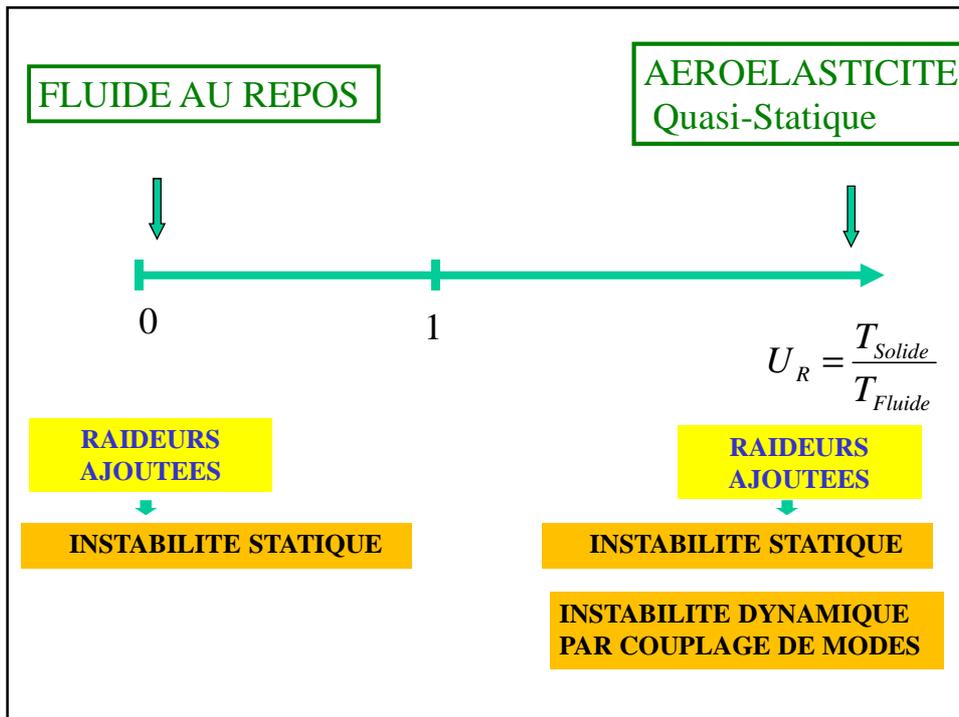


« mode INSTABLE »



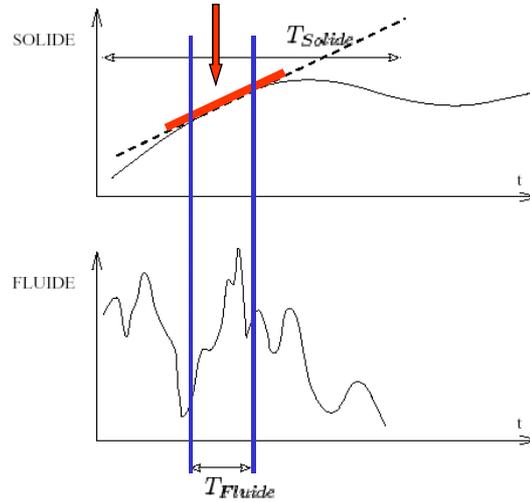
MOUVEMENT PERMETTANT  
D'EXTRAIRE DE L'ENERGIE  
DE L'ECOULEMENT





## AEROELASTICITE PSEUDO-STATIQUE

Vitesse constante



Solide mono-paramétrique

Position  
et Vitesse

Effort

$$F(R_E, F_R, q, \dot{q}) \quad \text{Nouveau}$$

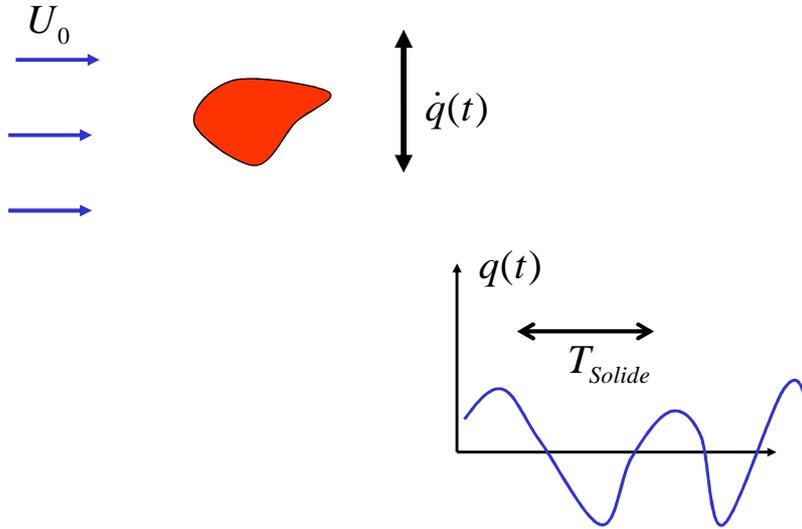
$$f_{FS} = f_0 + q(t) \frac{\partial f}{\partial q} + \dot{q}(t) \frac{\partial f}{\partial \dot{q}}$$

Raideur

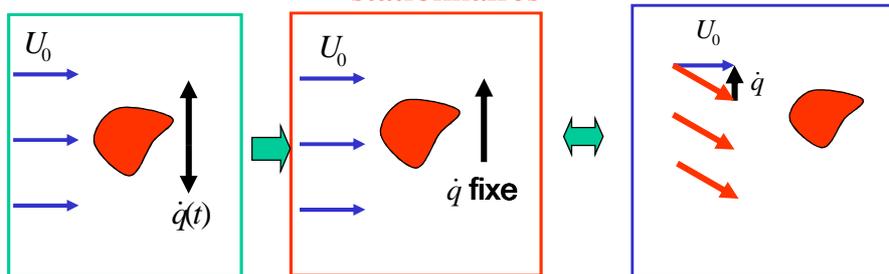
Amortissement  
> 0 ou < 0

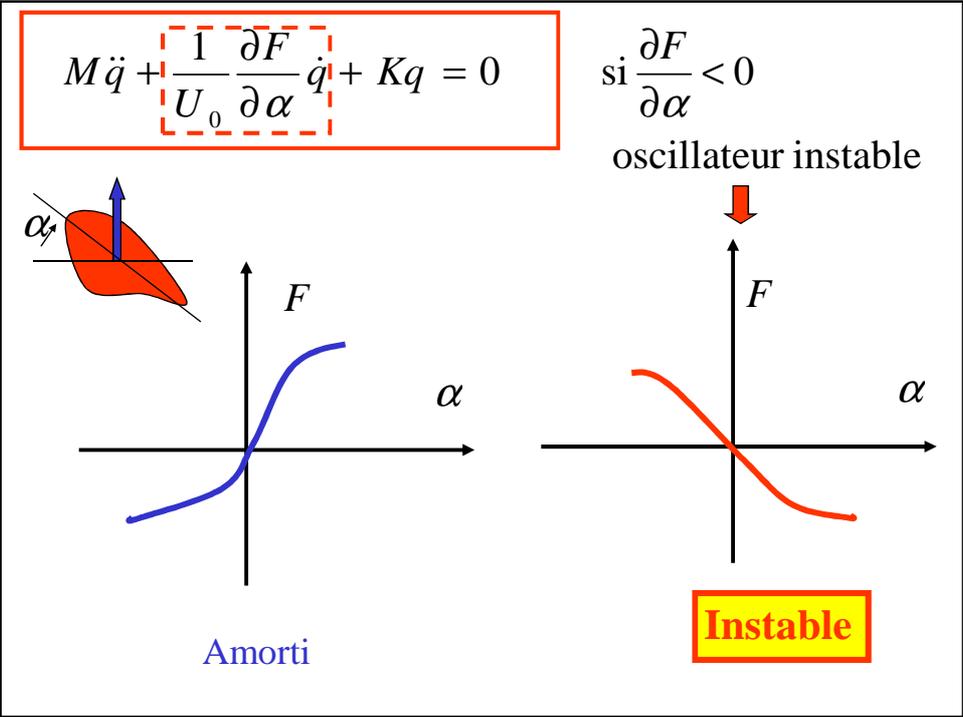
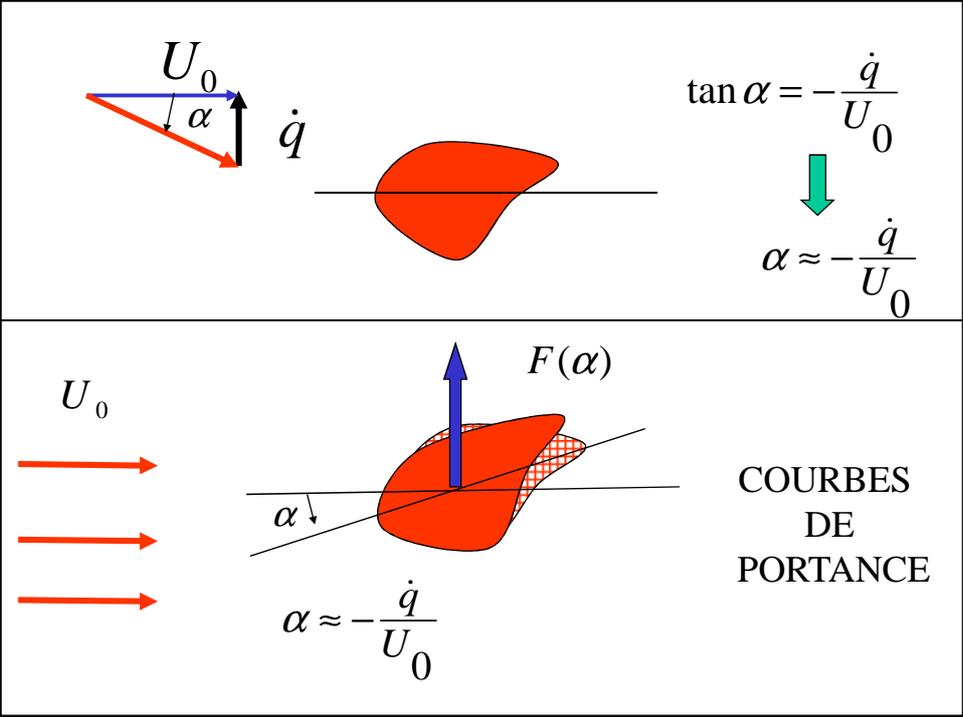
**AMORTISSEMENT AJOUTE :  
INSTABILITE DYNAMIQUE**

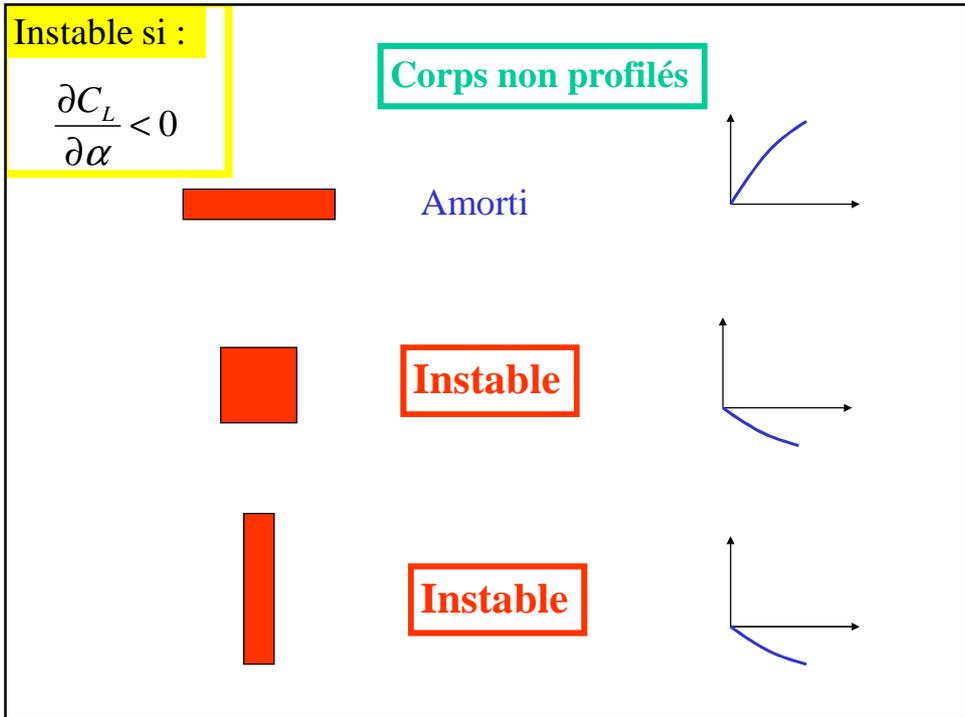
INSTABILITE PAR CRISE DE PORTANCE



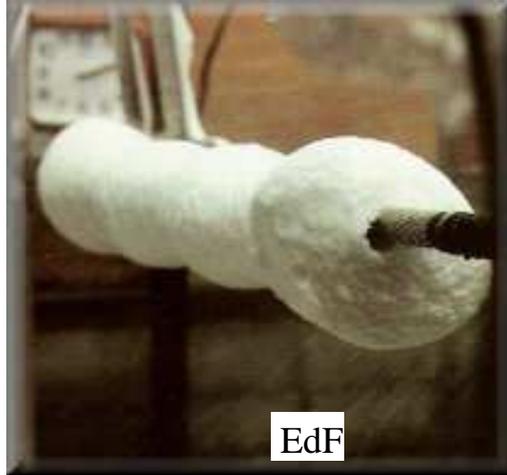
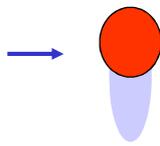
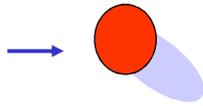
**Succession de problèmes  
stationnaires**





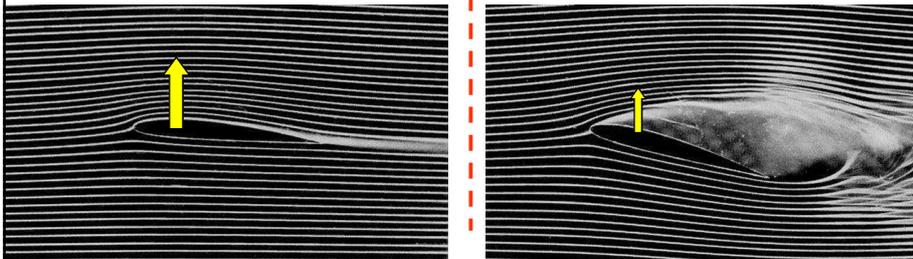
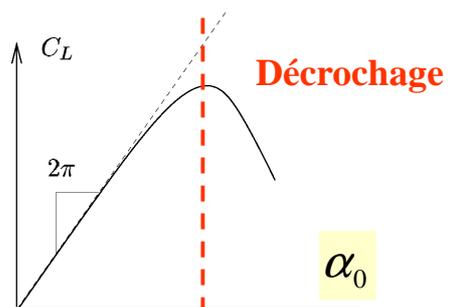


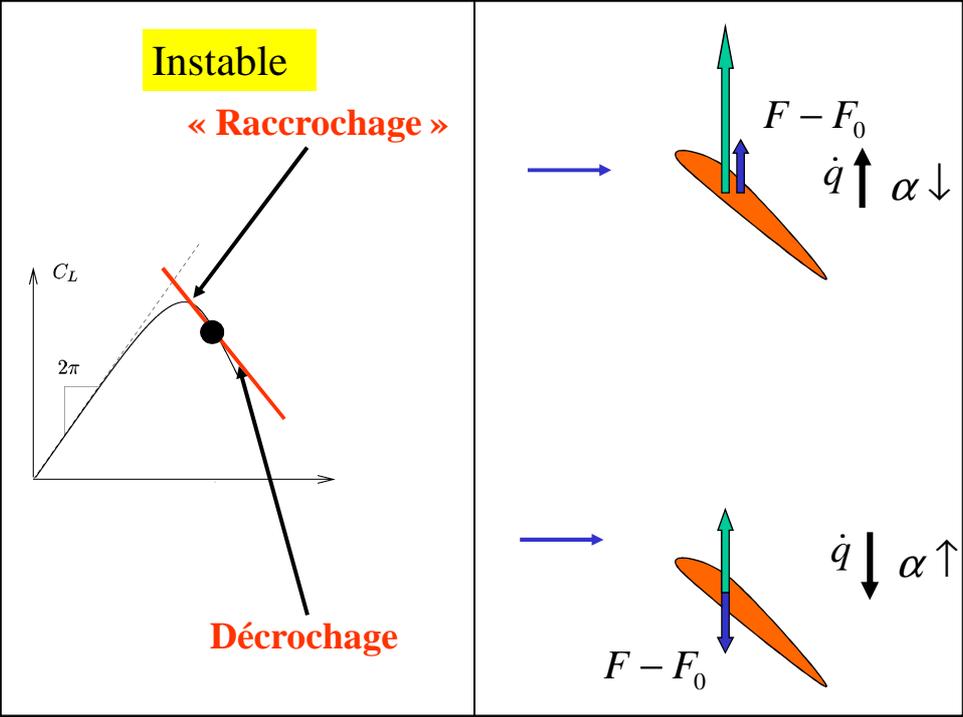
Vent et glace : stable



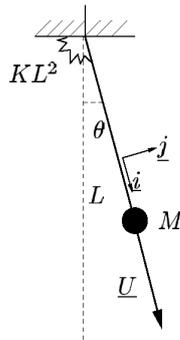
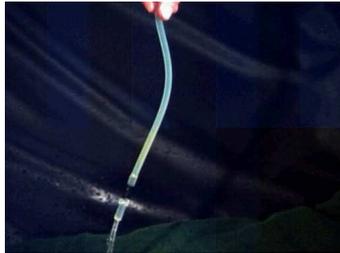
Glace puis vent : instable

Corps profilés : flottement de décrochage

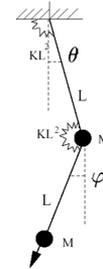




## INSTABILITE DU TUYAU D'ARROSAGE



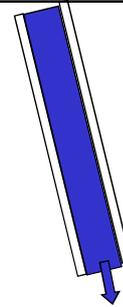
1 DDL



2 DDL

### 1DDL, AEROELASTICITE QUASI-STATIQUE

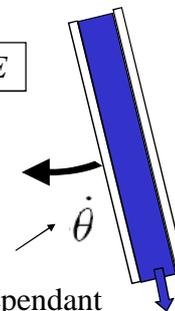
Effort fluide nul  $\ddot{\theta} + \theta = 0$



### 1DDL, AEROELASTICITE PSEUDO-STATIQUE

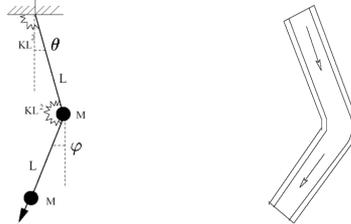
$$\ddot{\theta} + \mathcal{M}U_R\dot{\theta} + \theta = 0$$

Amortissement de Coriolis



Indépendant du temps

2 DDL , AEROELASTICITE QUASI-STATIQUE

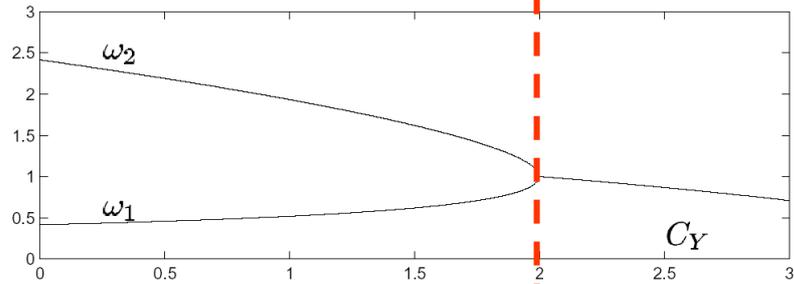


$$\begin{aligned}
 m_1 \ddot{q}_1 + [k_1 + C_Y(\sqrt{2} - 1)] q_1 &= +C_Y(\sqrt{2} + 1) q_2 \\
 m_2 \ddot{q}_2 + [k_2 - C_Y(\sqrt{2} + 1)] q_2 &= -C_Y(\sqrt{2} - 1) q_1
 \end{aligned}$$

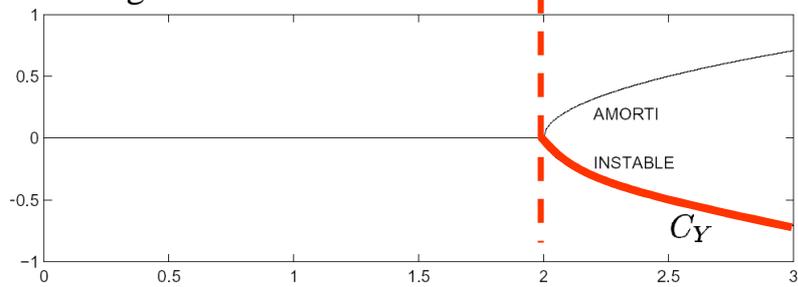
↓  
RAIDEUR

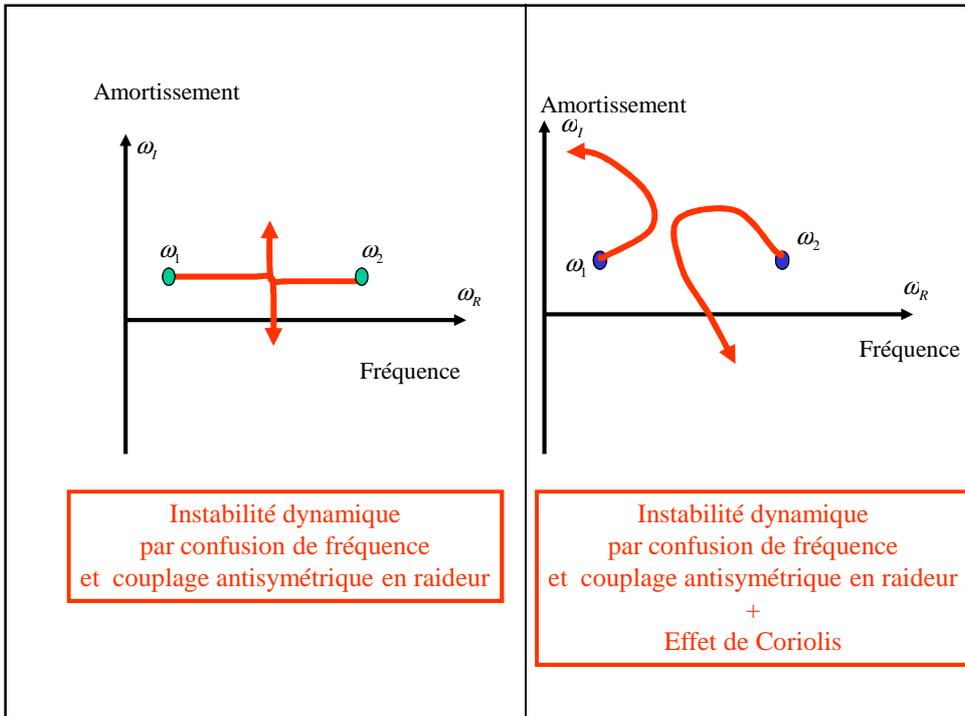
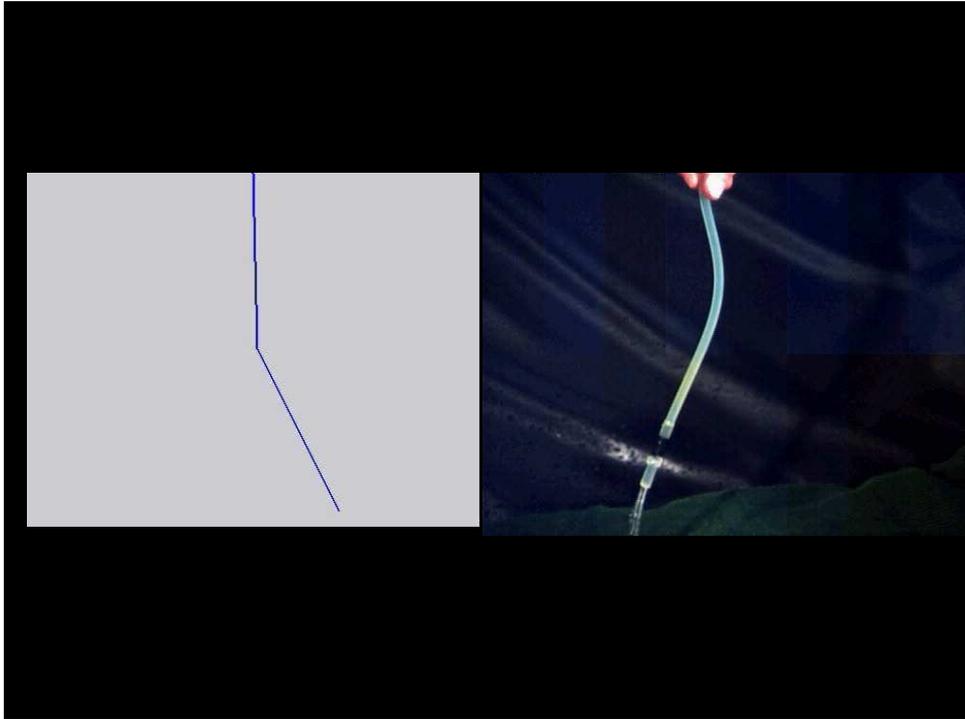
↓  
COUPLAGES EN RAIDEUR

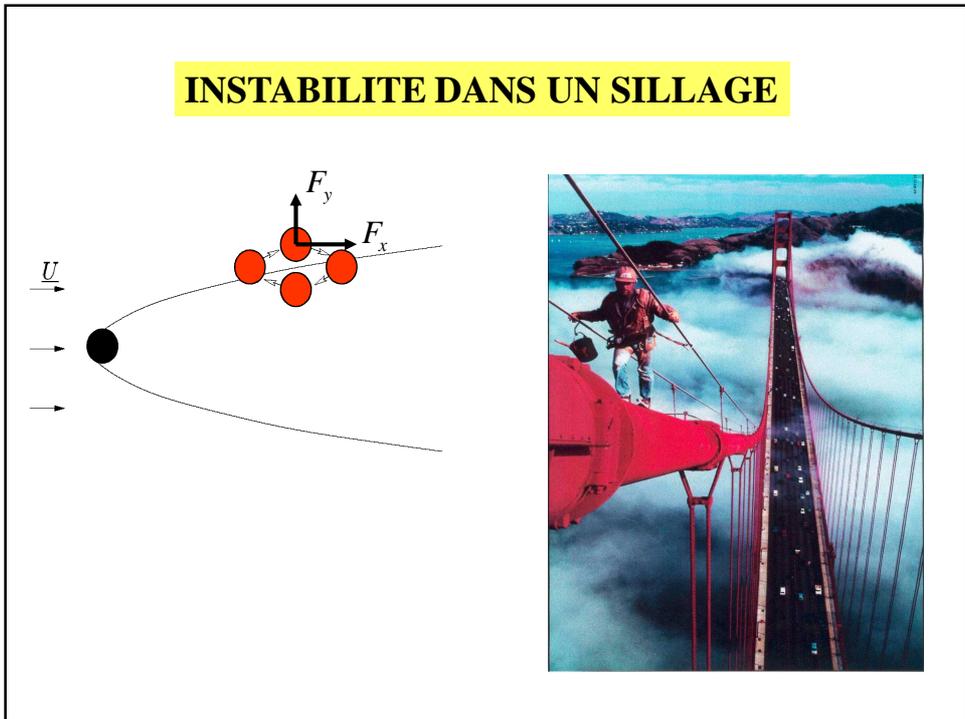
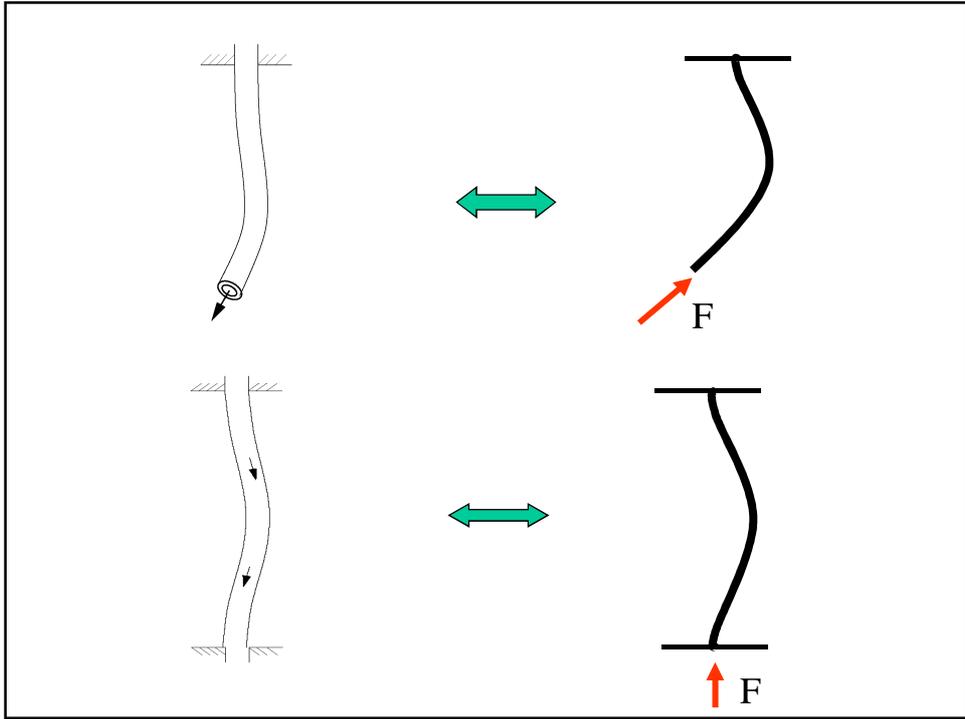
Partie Réelle



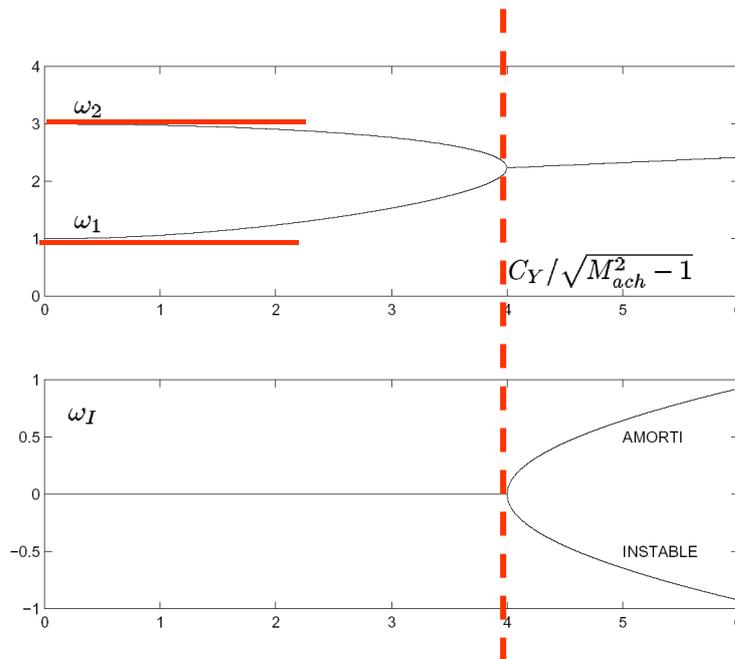
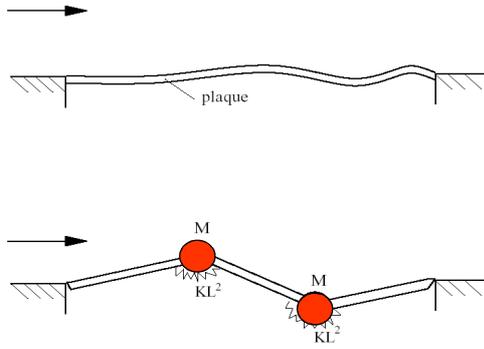
Partie Imaginaire



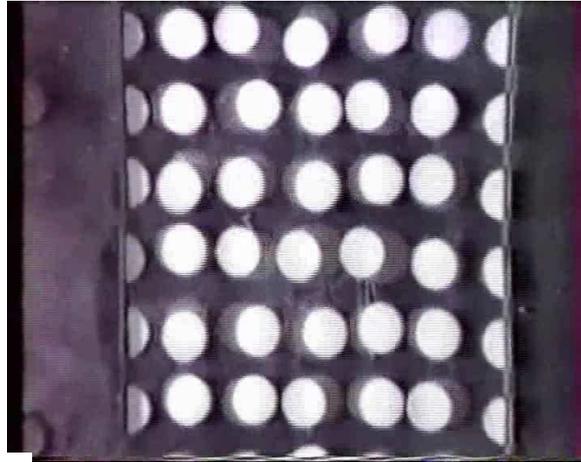




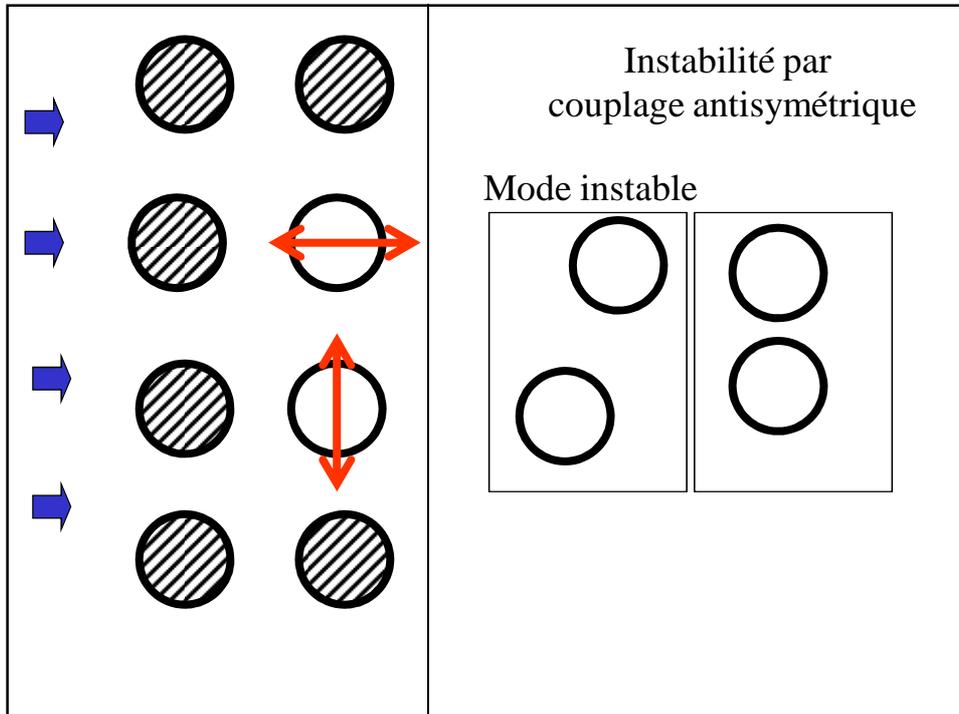
# INSTABILITE DE PANNEAU

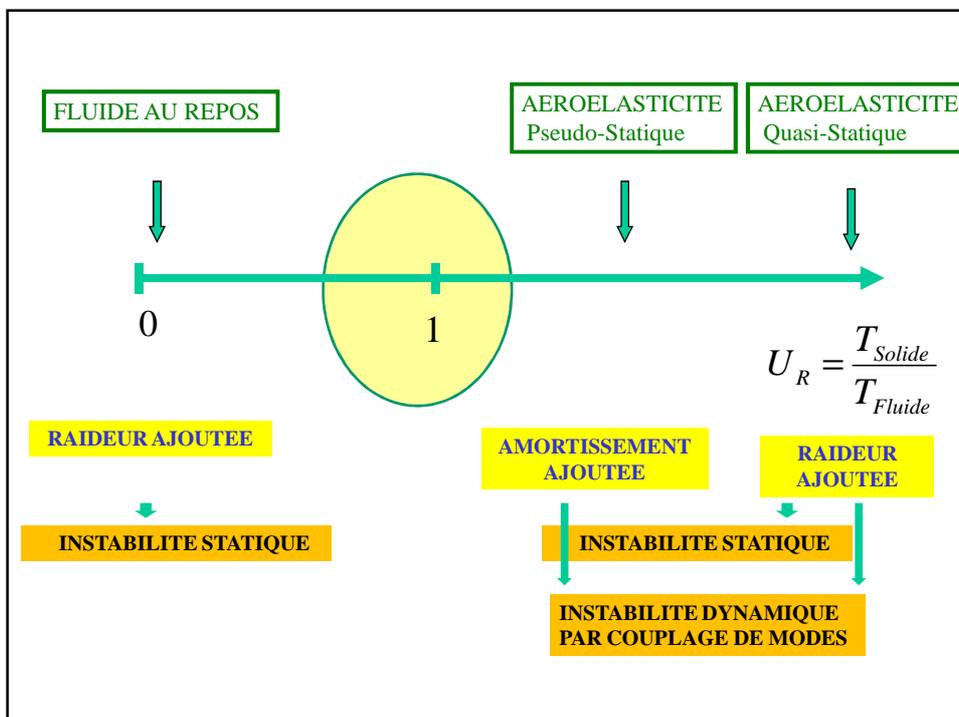
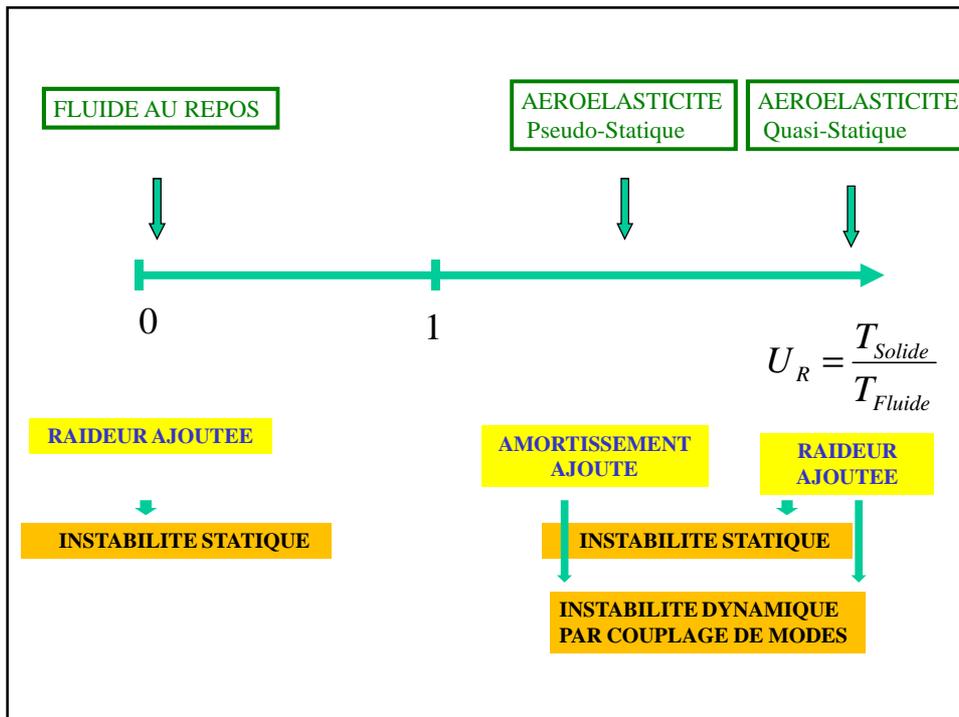


INSTABILITE DE FAISCEAUX DE TUBES  
DANS LES ECHANGEURS NUCLEAIRES



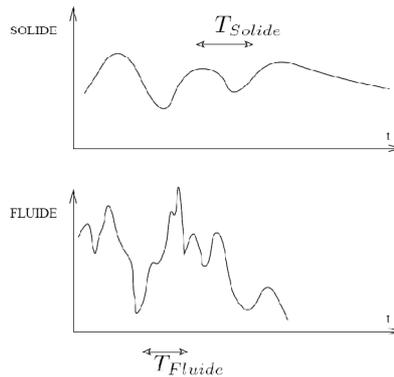
AECL



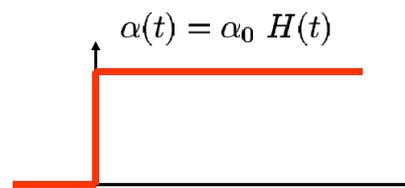
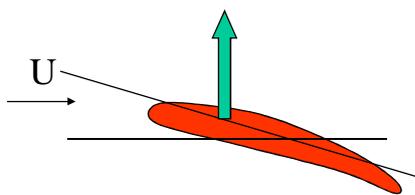


## COUPLAGES FORTS

$$\frac{T_{solide}}{T_{fluide}} = \mathcal{O}(1)$$



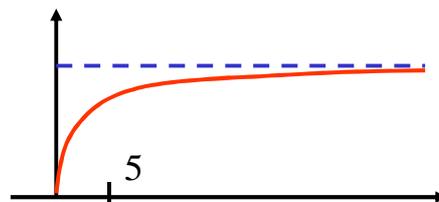
## EFFETS INSTATIONNAIRES SUR LES PROFILS PORTANTS



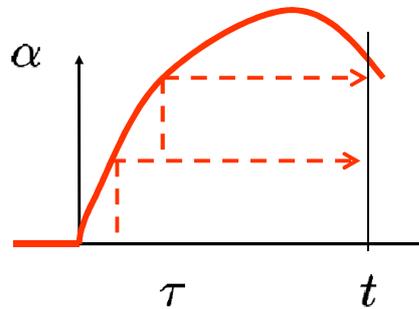
Calculs écoulement  
potentiel fluctuant  
(Theodorsen 1935 !)

$$\underline{F}^I(t) = \underline{F}_0(1 - e^{-\beta U_R t})$$

$$\beta \simeq .2$$



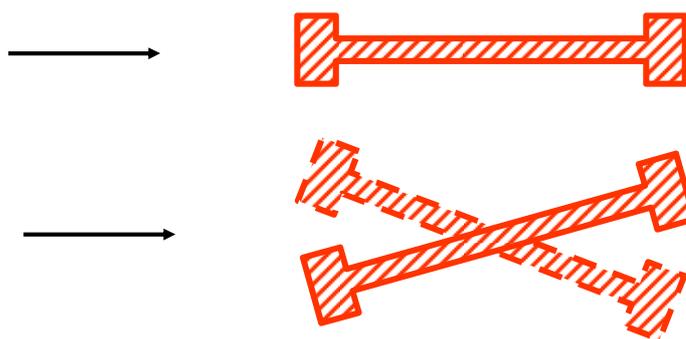
Solution générale (petits mouvements)



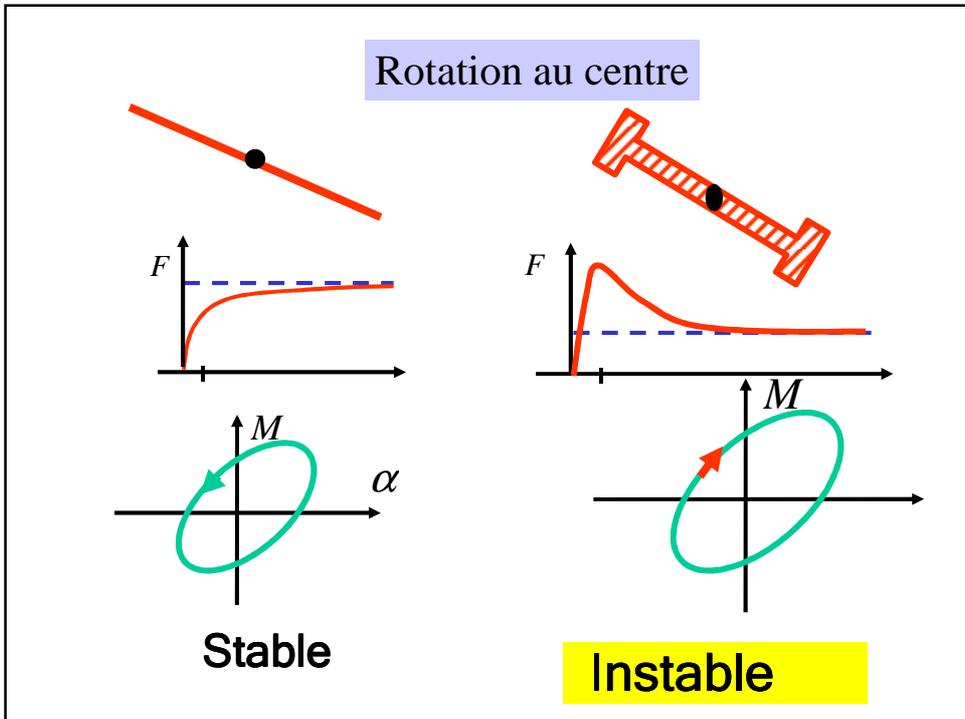
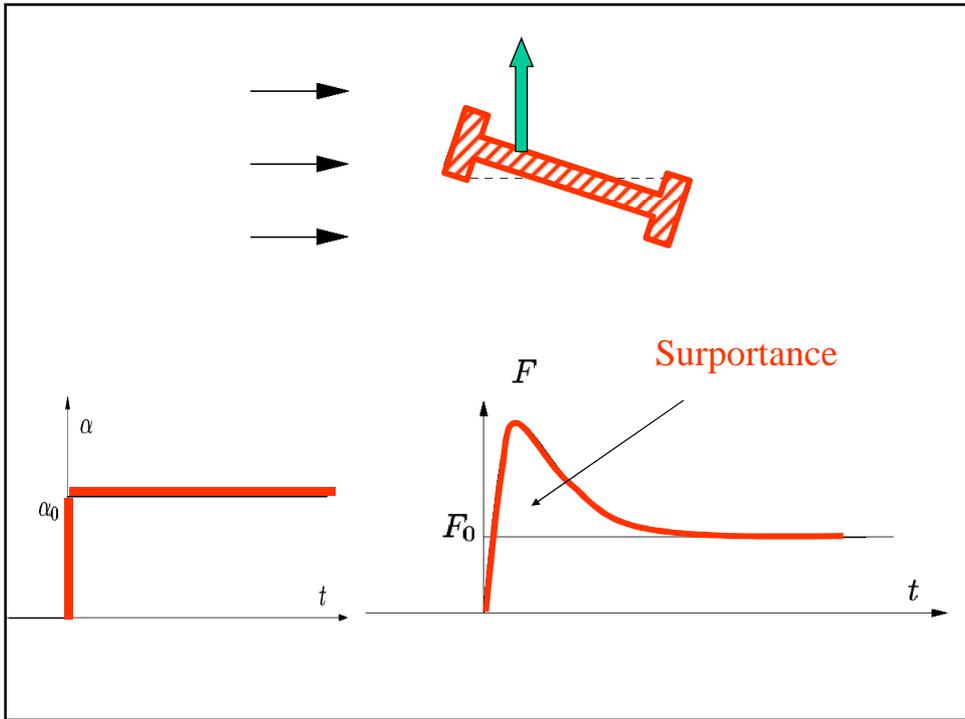
$$\underline{F}(t) = \int_0^t \dot{\alpha}(\tau) \frac{1}{\alpha_0} \underline{F}^I(t - \tau) d\tau.$$

*Convolution*

Pont de Tacoma



$$U_R = \frac{T_{Solide}}{T_{Fluide}} \approx \frac{5_s}{(10_m / 10_{m/s})} \approx 5$$





Un cas complet : la corde fluide



$$(\mathcal{M}U_R^2 - 1) \frac{\partial^2 y}{\partial x^2} + 2\mathcal{M}U_R \frac{\partial^2 y}{\partial x \partial t} + (1 + \mathcal{M}) \frac{\partial^2 y}{\partial t^2} = 0$$

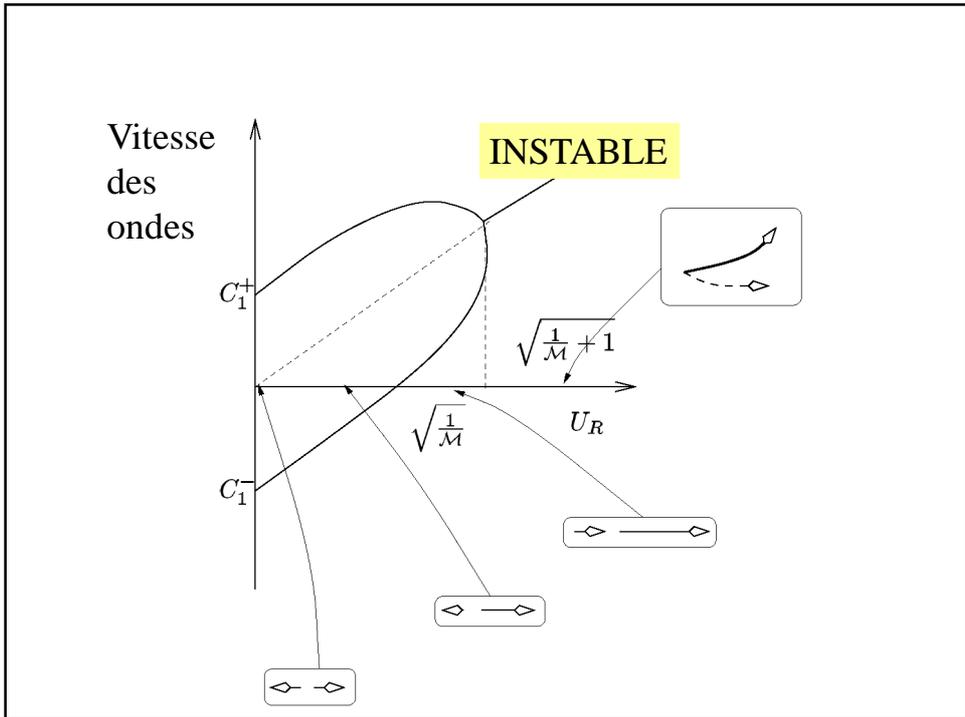
↑  
Raideur  
aéroélastique

↑  
Coriolis

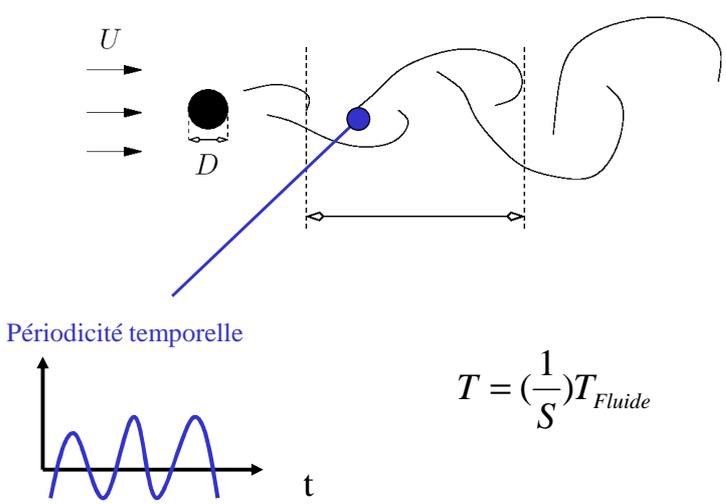
↑  
Masse ajoutée

0

$U_R$

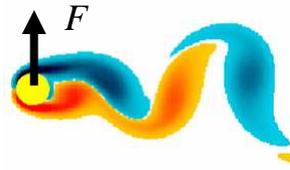


Autre échelle de temps dans la dynamique du fluide ?

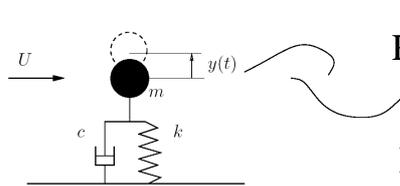


Portance fluctuante

$$F = \frac{1}{2} \rho U^2 D C_T \sin 2\pi S \frac{Ut}{D}$$



Réponse forcée d'oscillateur



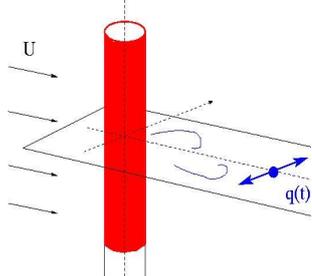
Résonance à  $U_R = \frac{1}{S}$

Effets de corrélation spatiale,..

Couplage sillage/mouvement : un modèle simple

Oscillateurs

Sillage  
 $q(t) = F(t) / |F|$  portance

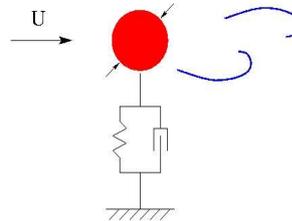


$$\Omega = S_T U_R$$

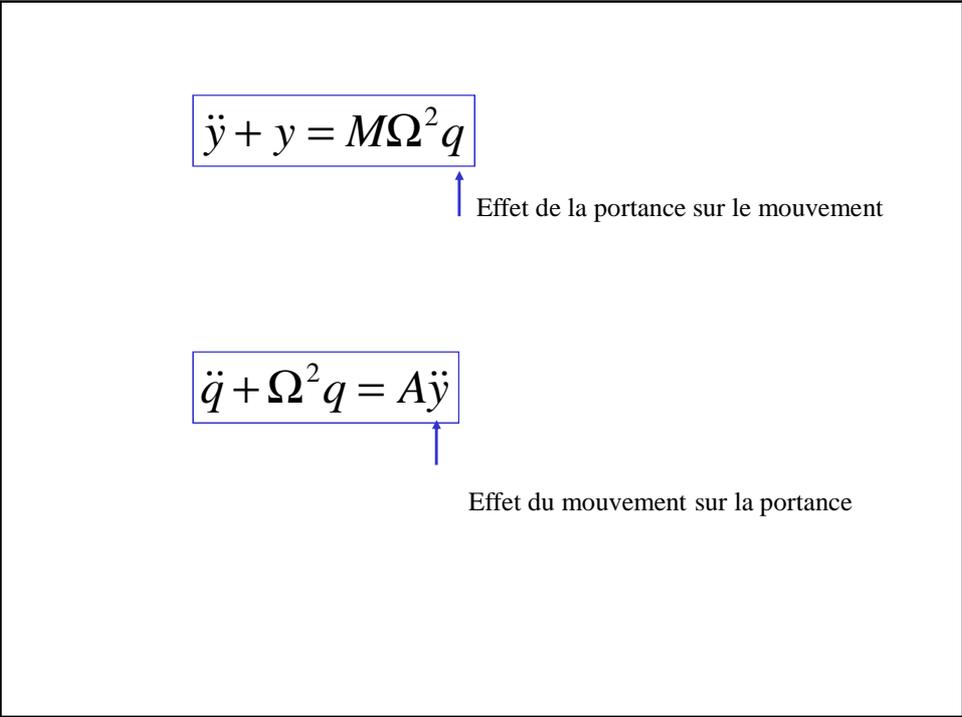
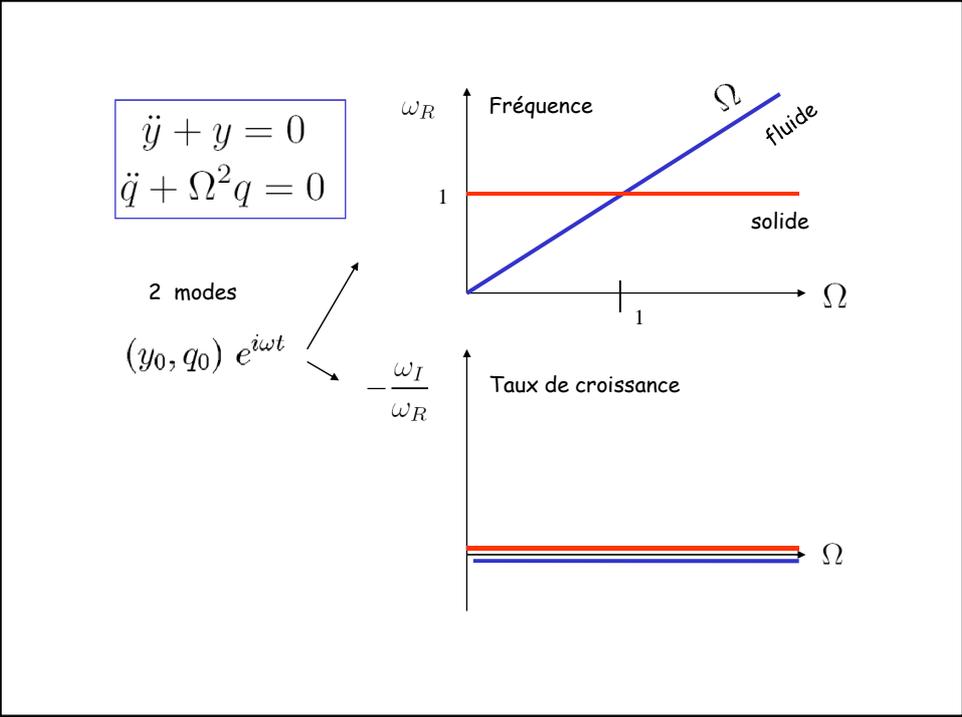
$$\ddot{q} + \Omega^2 q = 0$$

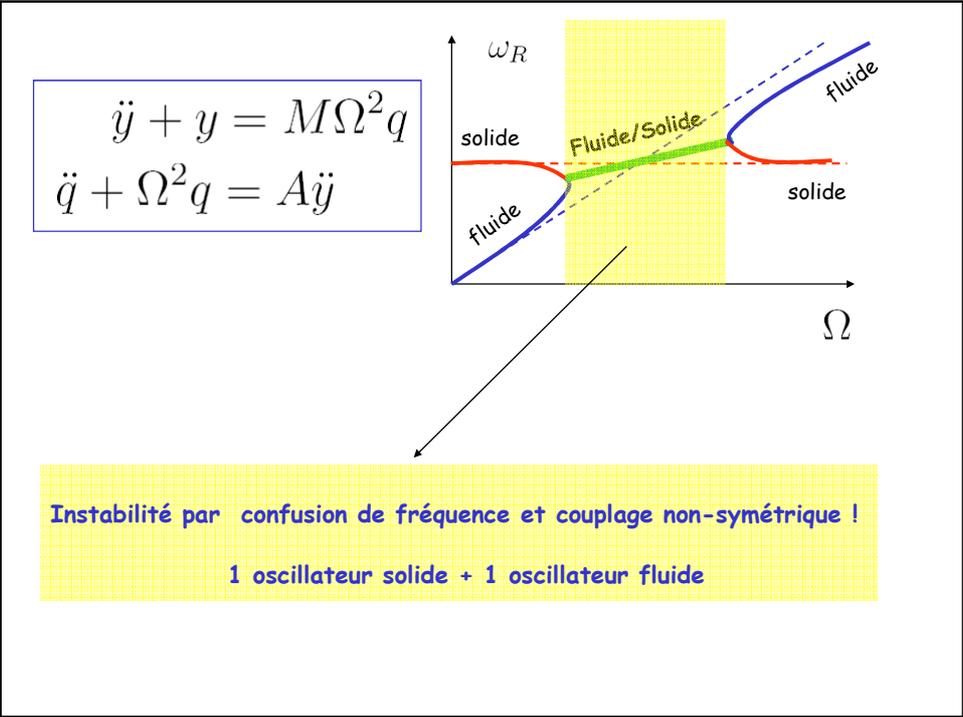
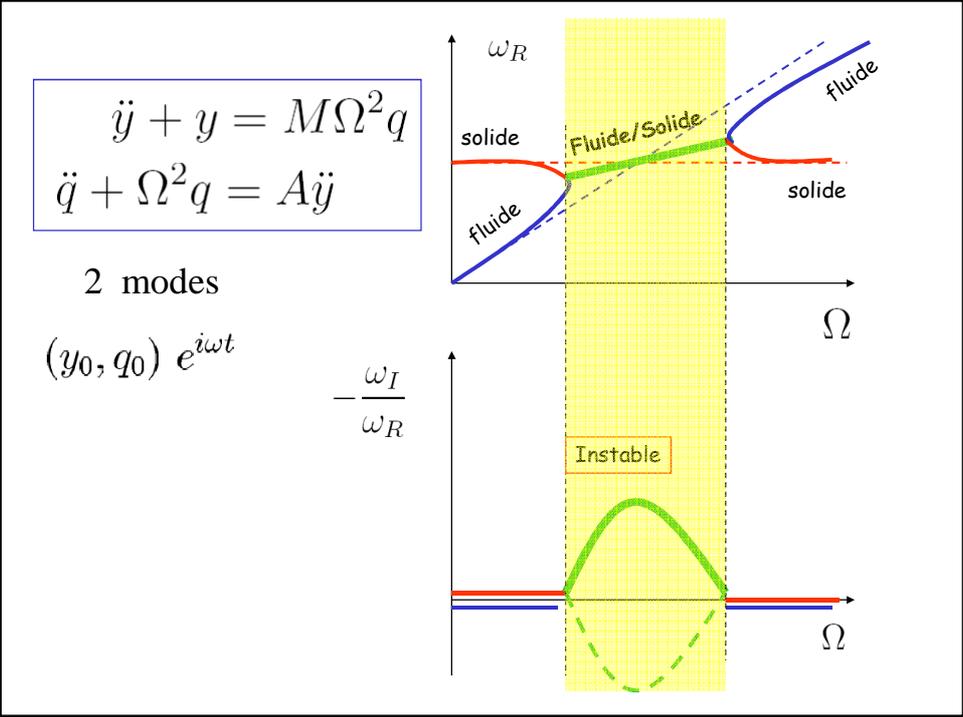
Fréquence croissant avec la vitesse U

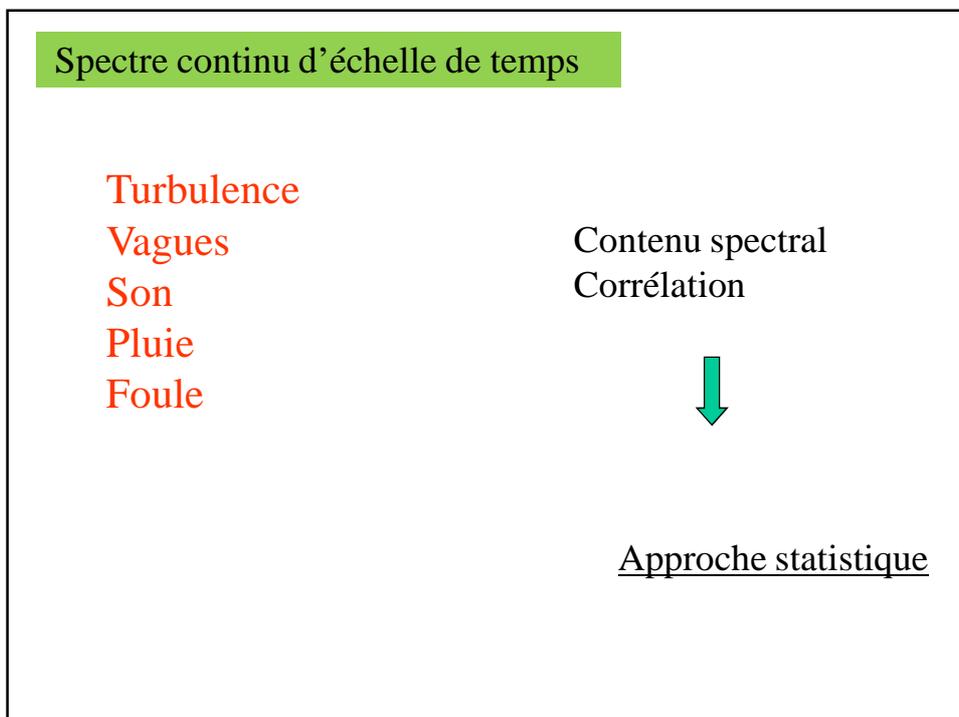
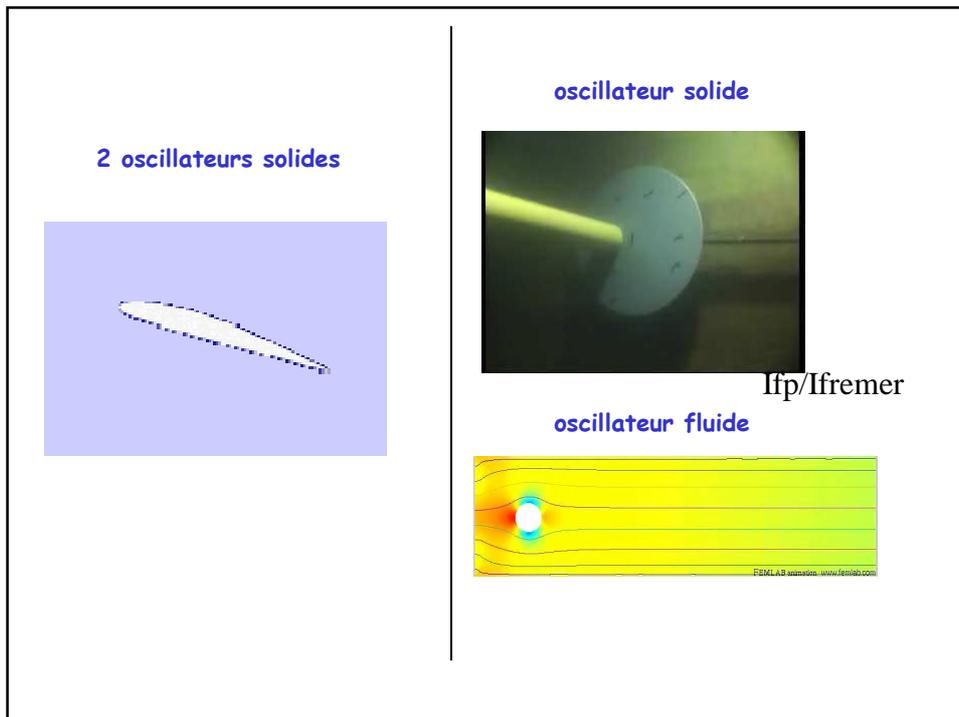
Structure



$$\ddot{y} + y = 0$$

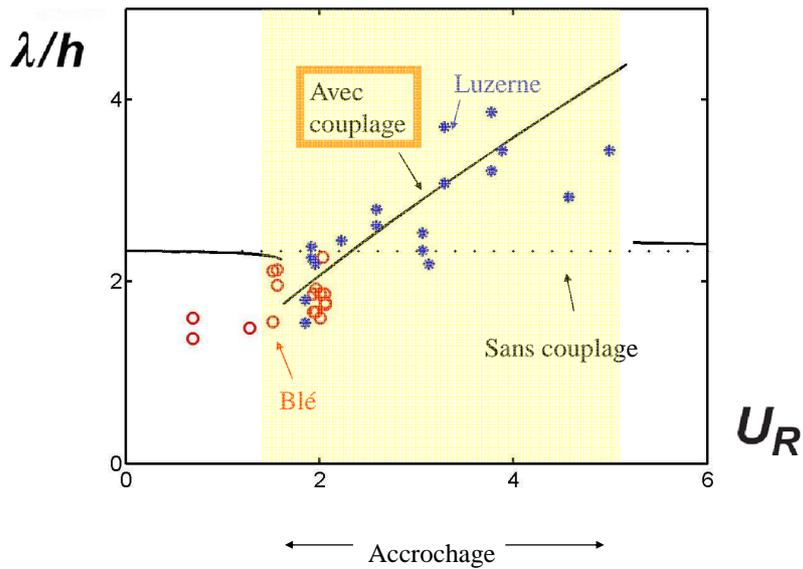
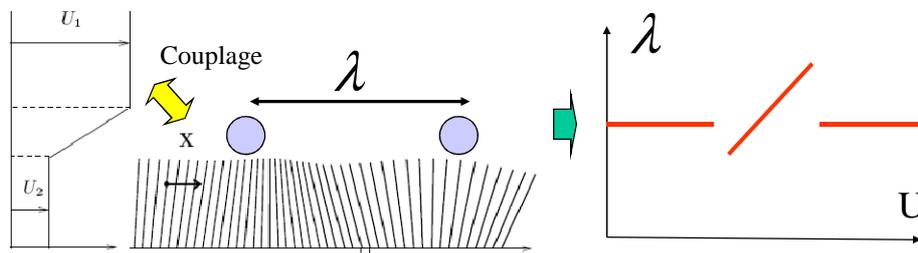




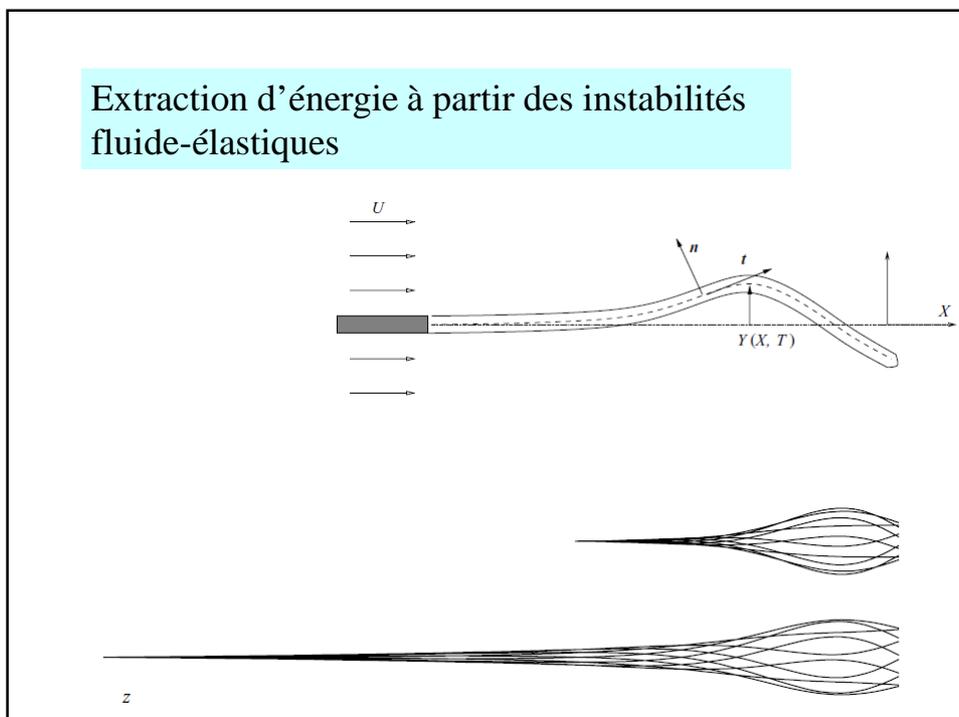
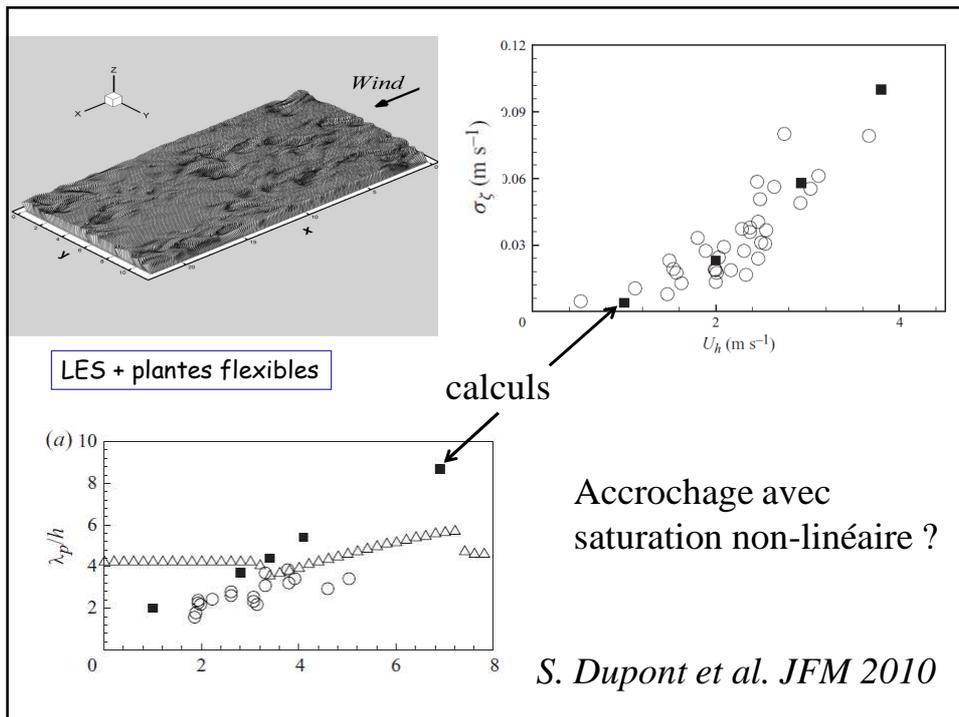


## QUELQUES PROBLEMES OUVERTS

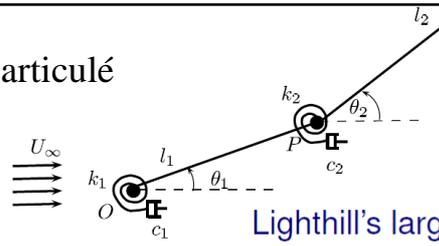
Couplage entre instabilité d'écoulement et comportement élastique



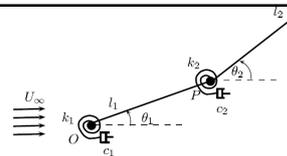
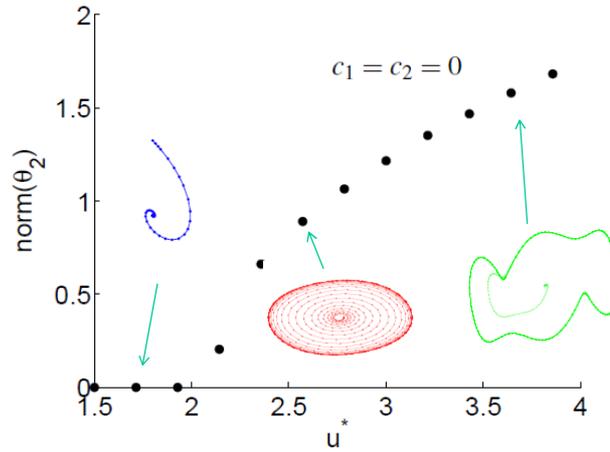
*Py, de Langre & Moulia (2006)*



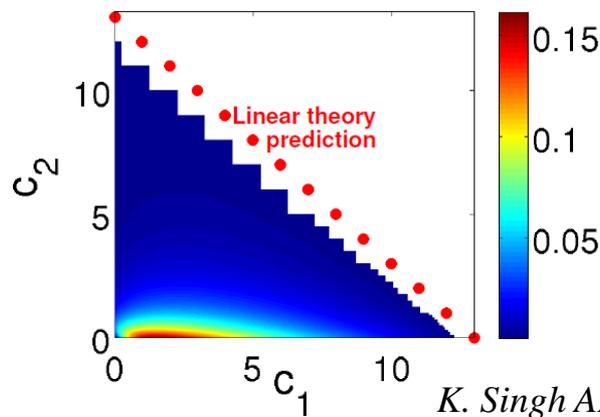
### Modèle bi-articulé



Lighthill's large amplitude theory

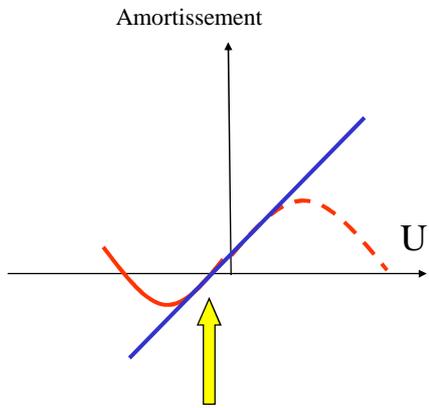
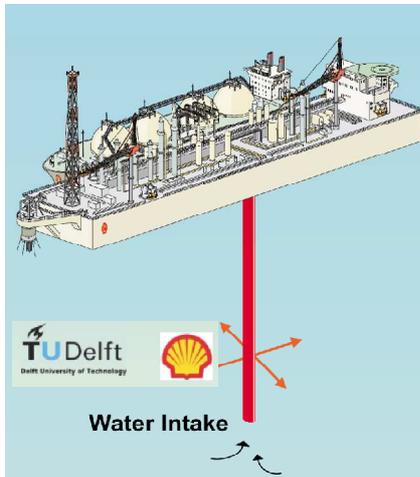


Puissance extraite 
$$\mathcal{P} = \frac{1}{2T} \int_0^T (c_1 \dot{\theta}_1^2 + c_2 (\dot{\theta}_2 - \dot{\theta}_1)^2) dt$$



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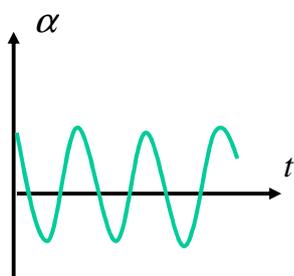
## Le tuyau aspirant !



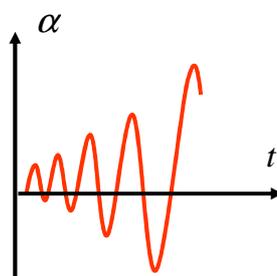
INSTABILITE PAR EFFET DE CORIOLIS INVERSE ??

$$\ddot{\theta} - \mathcal{M}U_R\dot{\theta} + \theta = 0$$

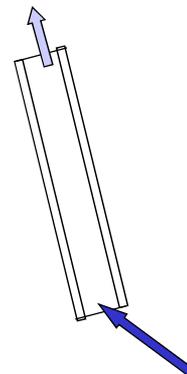
FAUX ??

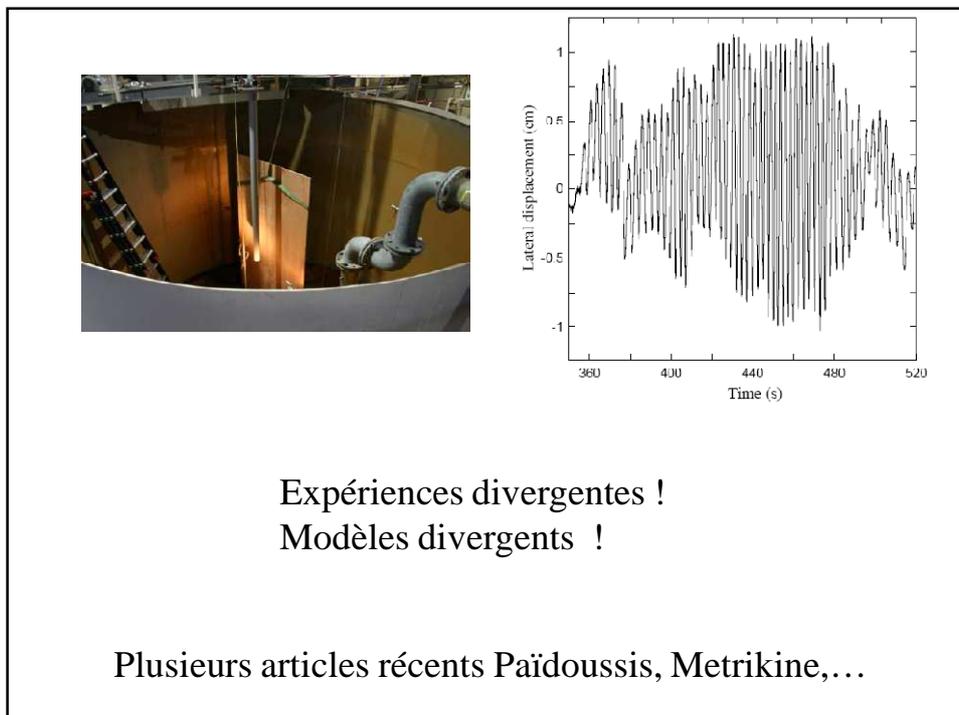
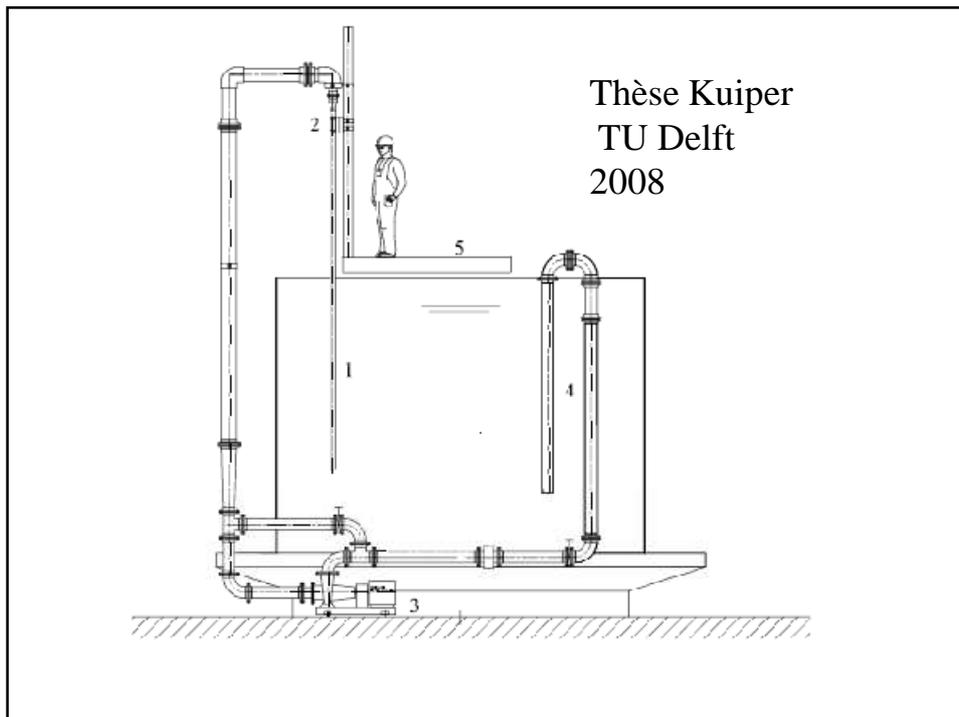


$U_R = 0$



$U_R \uparrow$





## Conclusions

Beaucoup d'outils classiques mais  
beaucoup de problèmes ouverts !