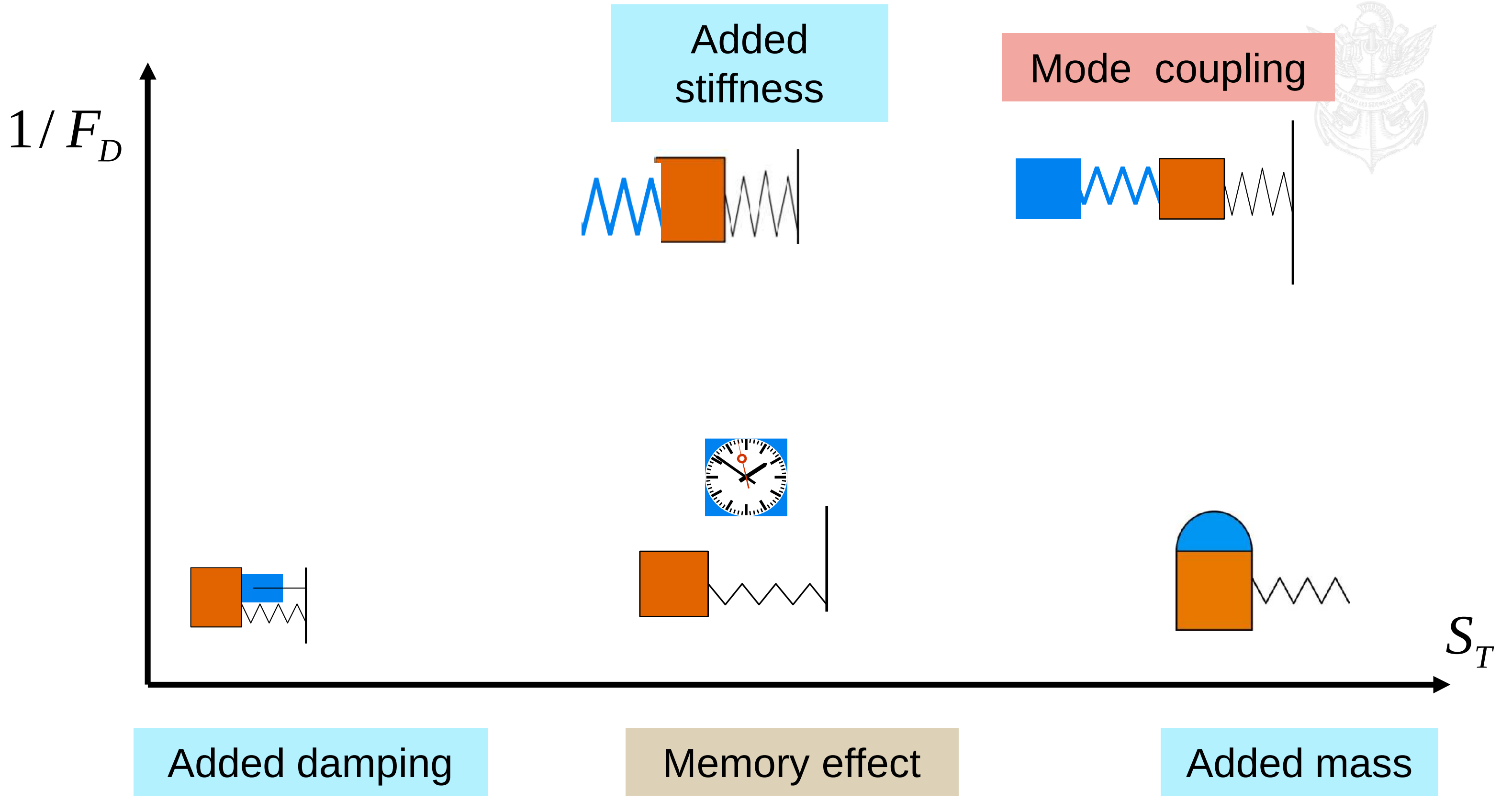
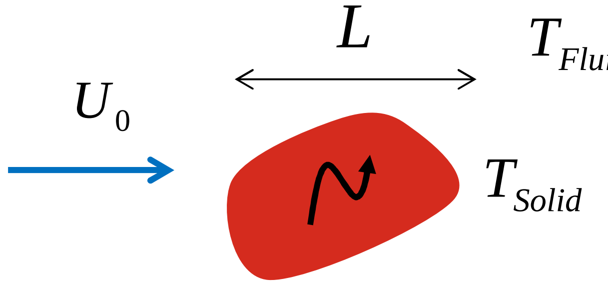
COUPLINGS


Added stiffness
Mode coupling
$1/F_D$
S_T
Added damping
Memory effect
Added mass

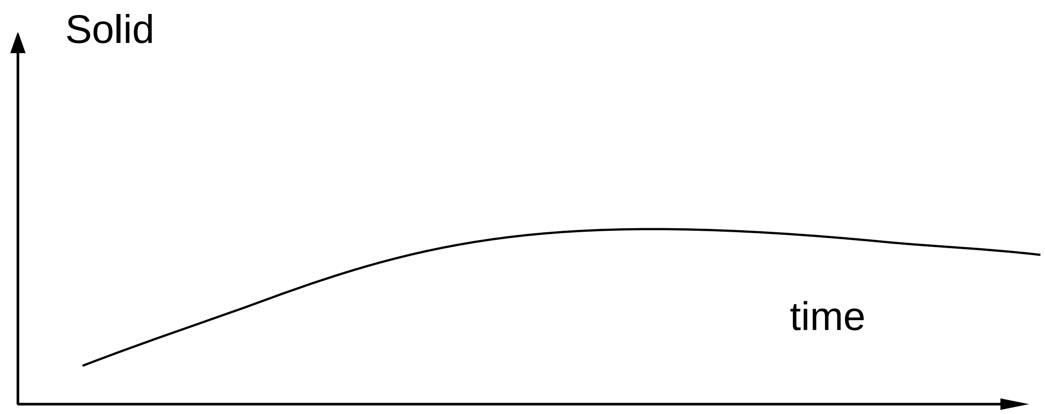
FLOW-INDUCED OSCILLATION OF A PLANE EMPENNAGE

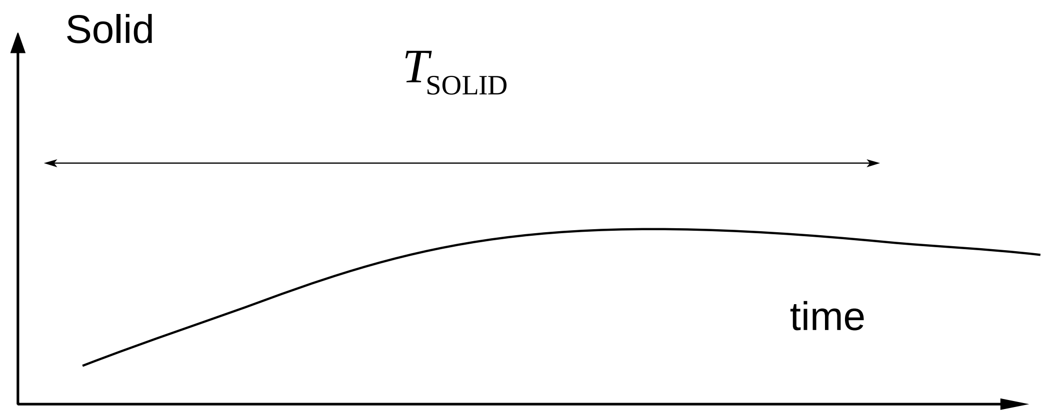
HIGH REDUCED VELOCITIES

$$U_R = \frac{T_{SOLID}}{T_{FLUID}} >> 1$$

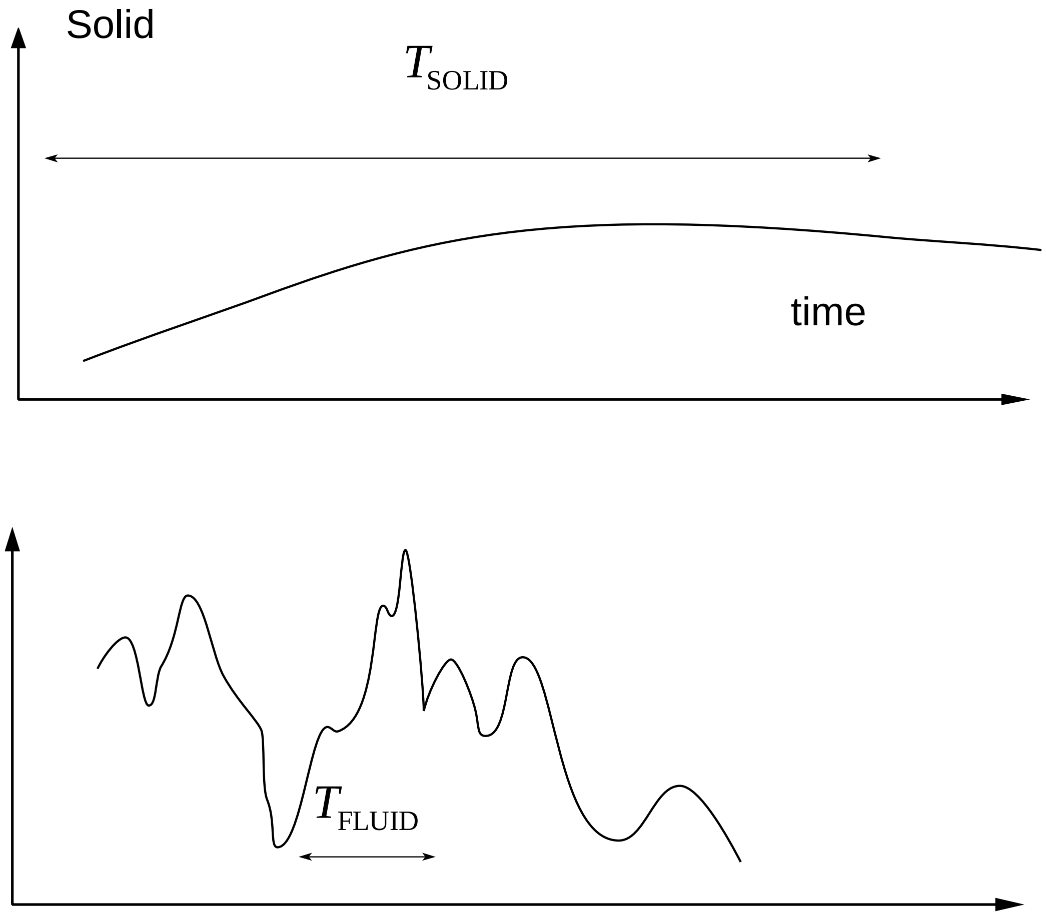


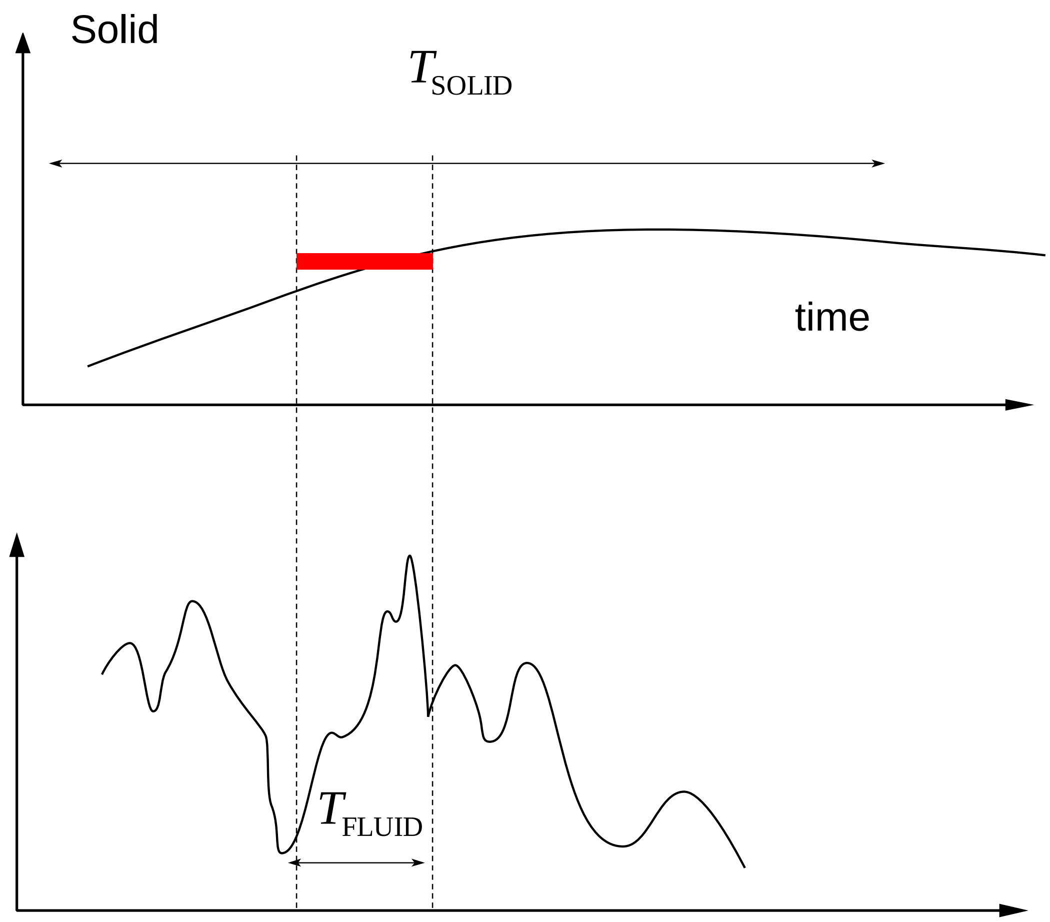
$$T_{Fluid} = L / U_0$$


Solid
time



Solid
T_{SOLID}
time


Solid
T_{SOLID}
time
T_{FLUID}


Solid
T_{SOLID}
time
T_{FLUID}

HIGH REDUCED VELOCITIES

$$U_0 \approx 100 \text{ m/s}$$

$$L \approx 1 \text{ m}$$

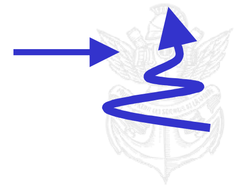
$$T_{Fluid} = L / U_0 \approx 0.01 \text{ s}$$

$$T_{Solid} \approx 1 \text{ s}$$

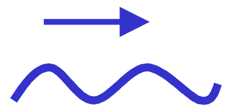
$$\boxed{\mathrm{U}_R = \frac{T_{\mathrm{SOLID}}}{T_{\mathrm{FLUID}}} \approx 100}$$

DIMENSIONLESS NUMBERS

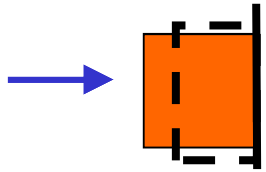
Reynolds $$R_E = \frac{\rho U_0 L}{\mu}$$



Froude $$F_R = \frac{U_0}{\sqrt{gL}}$$

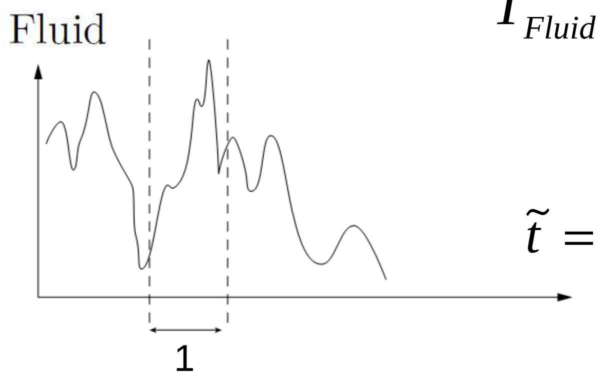


Cauchy $$C_Y = \frac{\rho U_0^2}{E}$$



DIMENSIONLESS VARIABLES

Dimensionless time based on the fluid velocity



$$T_{Fluid} = L / U_0$$

$$\tilde{t} = t / T_{FLUID}$$

Dimensionless velocity and pressure

$$\underline{\tilde{U}} = \frac{\underline{U}}{U_0} \qquad \tilde{p} = \frac{p}{\rho U_0^2}$$

DIMENSIONLESS EQUATIONS

FLUID

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

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

SOLID

$$\underline{\bar{\xi}}(\underline{x},t) = Dq(t)\underline{\varphi}(\underline{x})$$

$$U_R^2\frac{\partial^2 q}{\partial \tilde{t}^2} + q = f_{FS}$$

INTERFACE

$$\underline{\tilde{U}} = \frac{\partial \underline{\xi}}{\partial \tilde{t}}$$

$$C_Y \int_{\partial\Omega_{FS}} \left\{ \left[-\tilde{p}\underline{\underline{I}} + \frac{1}{R_E}\left(\nabla\underline{\tilde{U}} + \nabla^t\underline{\tilde{U}}\right)\right].\underline{n} \right\}.\underline{\varphi}\, dS = Df_{FS}$$

BOUNDARY CONDITIONS

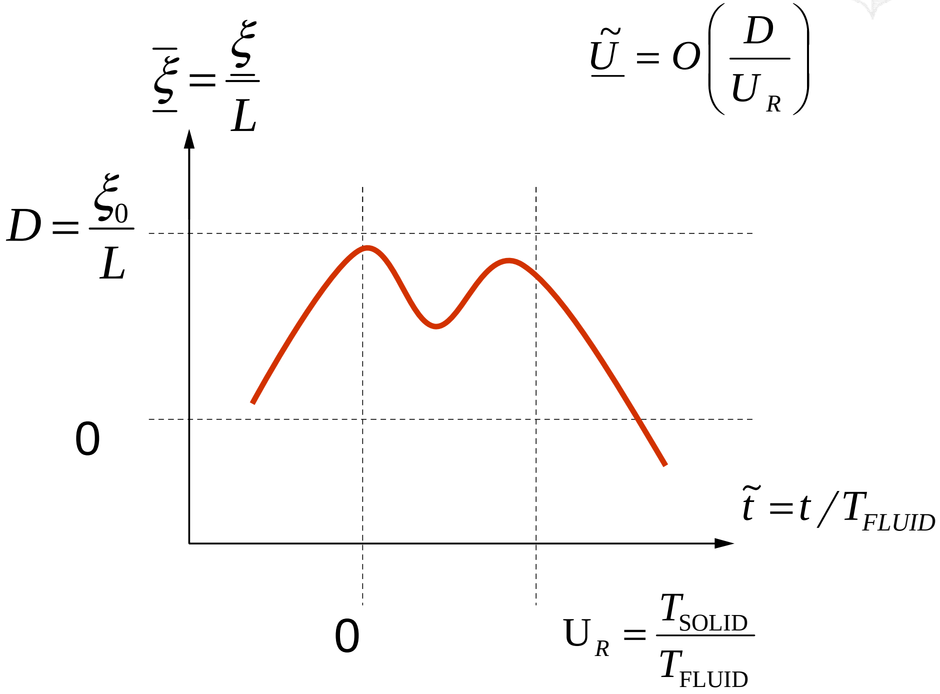
$$\underline{U} = O\left(U_0\right)$$

$$\underline{\tilde{U}} = O\left(\frac{U_0}{U_0}\right) = O(1)$$

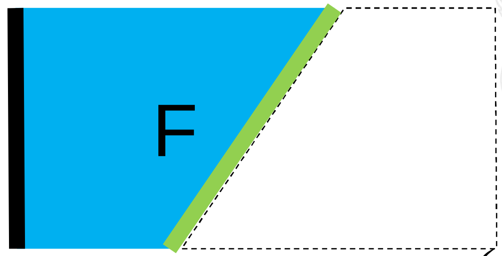
BOUNDARY CONDITIONS

$$\underline{\tilde{U}} = \frac{\partial \underline{\bar{\xi}}}{\partial \tilde{t}}$$

$$\underline{\tilde{U}} = O\left(\frac{D}{U_R}\right)$$



THE ASSUMPTION OF LARGE REDUCED VELOCITY



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

$$\underline{\tilde{U}} = O\left(\frac{D}{U_R}\right)$$

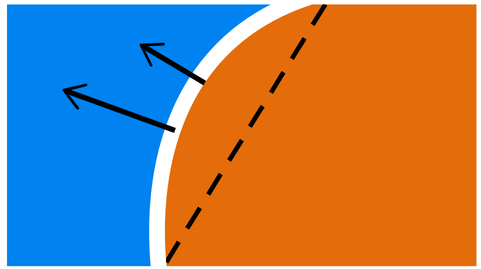
If $U_R >> D$

The solid velocity is neglected

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

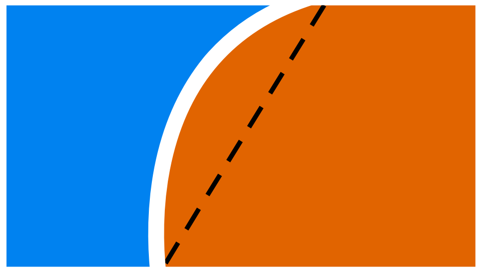
QUASI-STATIC AEROELASTICITY

General case



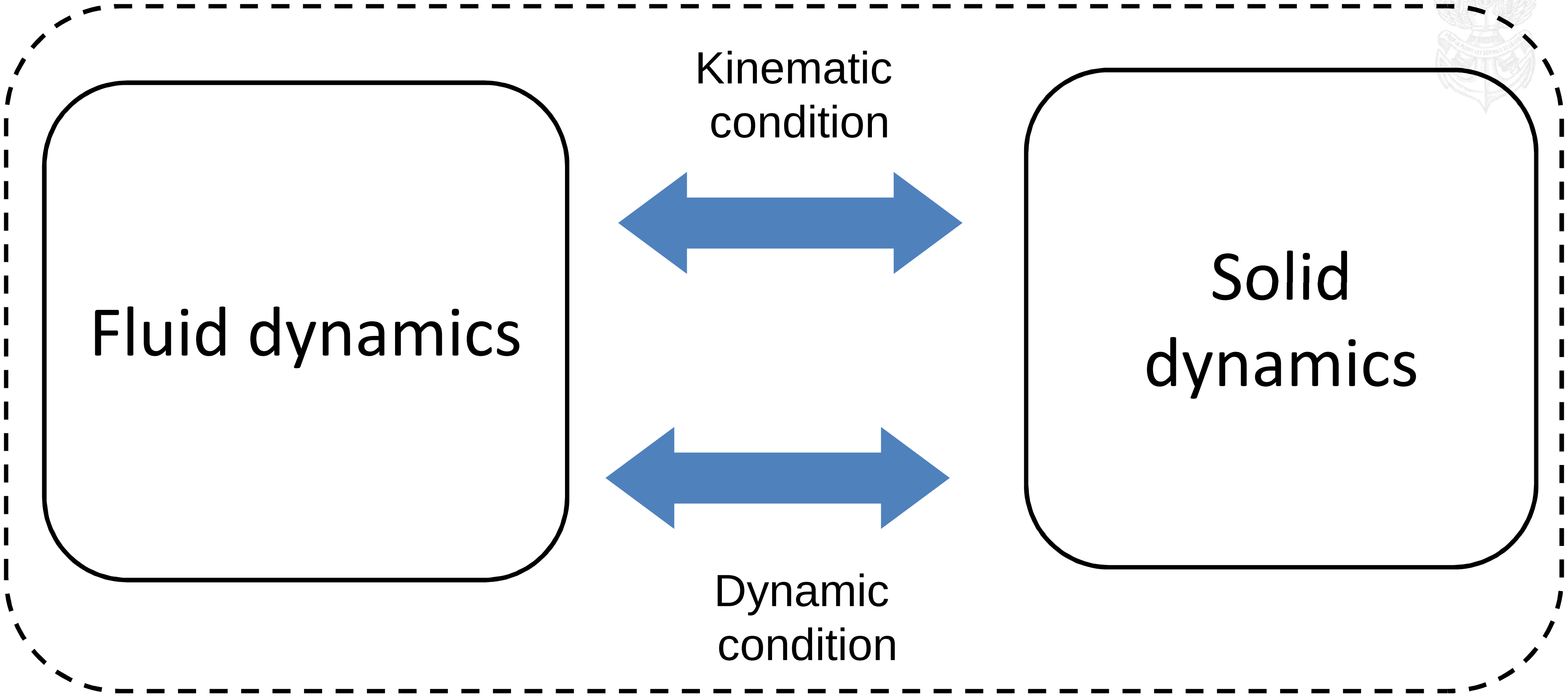
Deformation and velocity

Quasi-static aeroelasticity

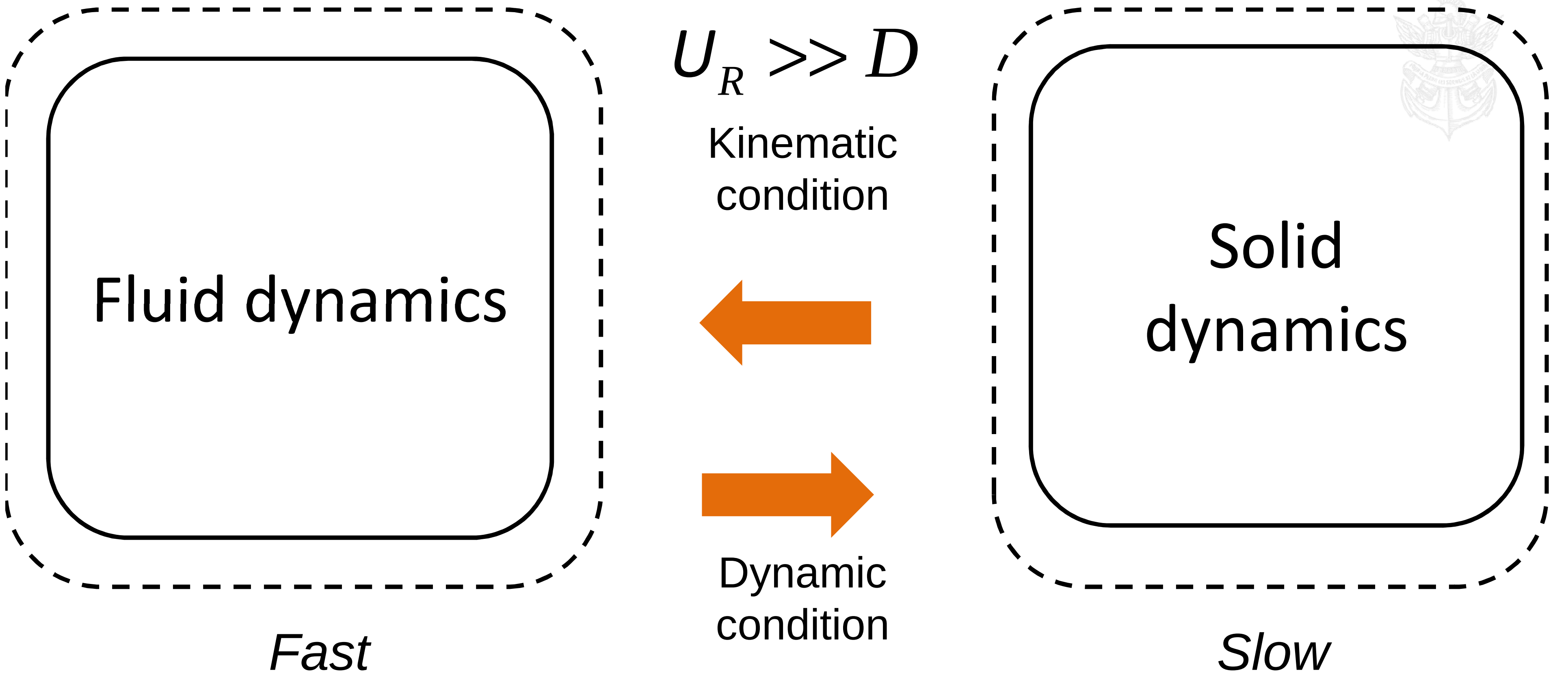


Deformation **but no velocity**

GENERAL CASE



QUASI-STATIC AEROELASTICITY



QUASI-STATIC AEROELASTICITY

Problem 1

Problem 2