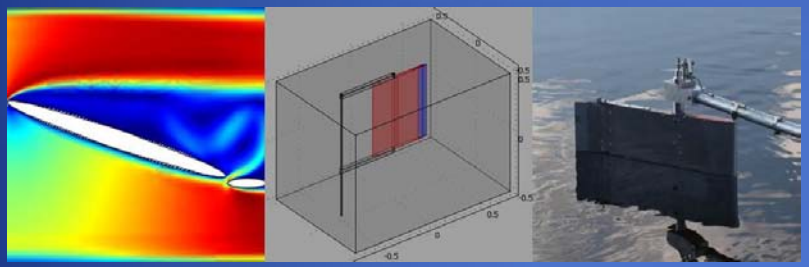
Presented at the COMSOL Conference 2010 Boston

Modeling an Oscillating Hydrofoil for Hydrokinetic Power Generation

A Hydro-foil energy converter



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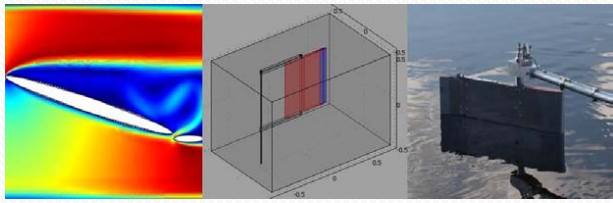
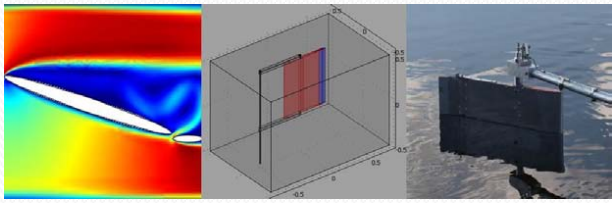


- Mechanism of the Controlled Hydrofoil
- Prototype
- Mathematical Model
- Foil motion
- 2D static model and results
- Challenges in 2D transient model
- Pros and cons for 3D model

Controlled Hydrofoil

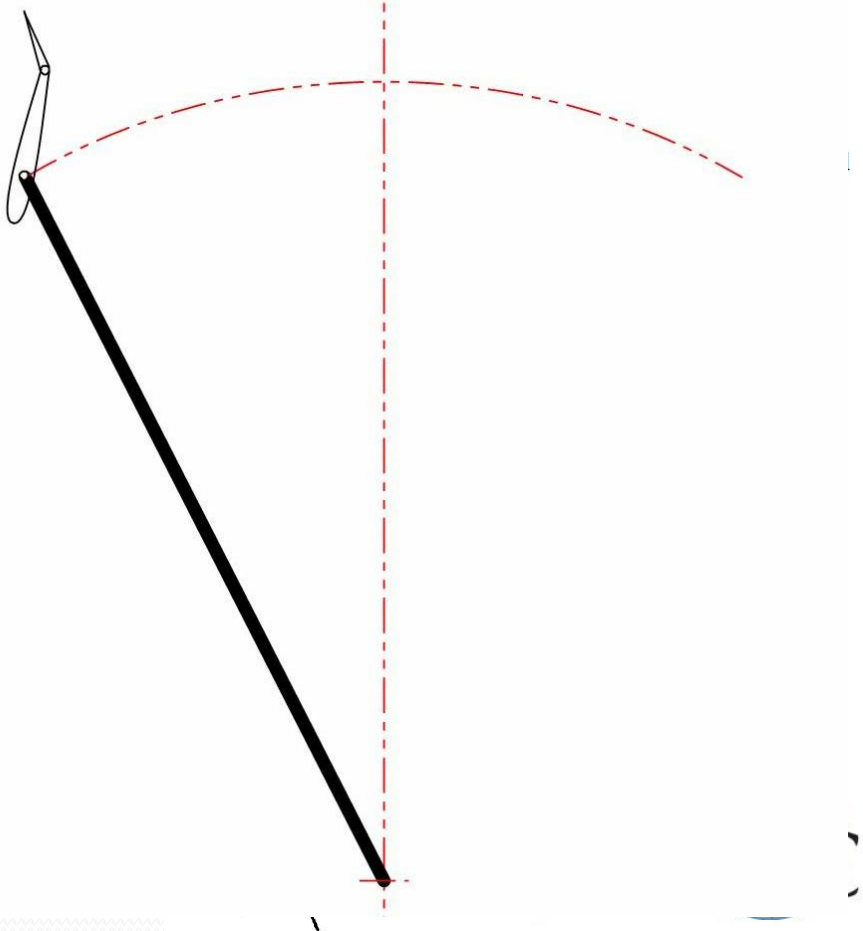


- **How it works?**

Trim flap
- Control system actuator

Hydrofoil
- Water force

Osci.Be



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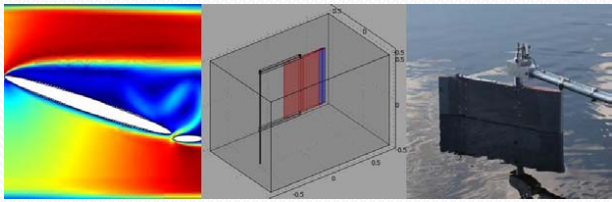
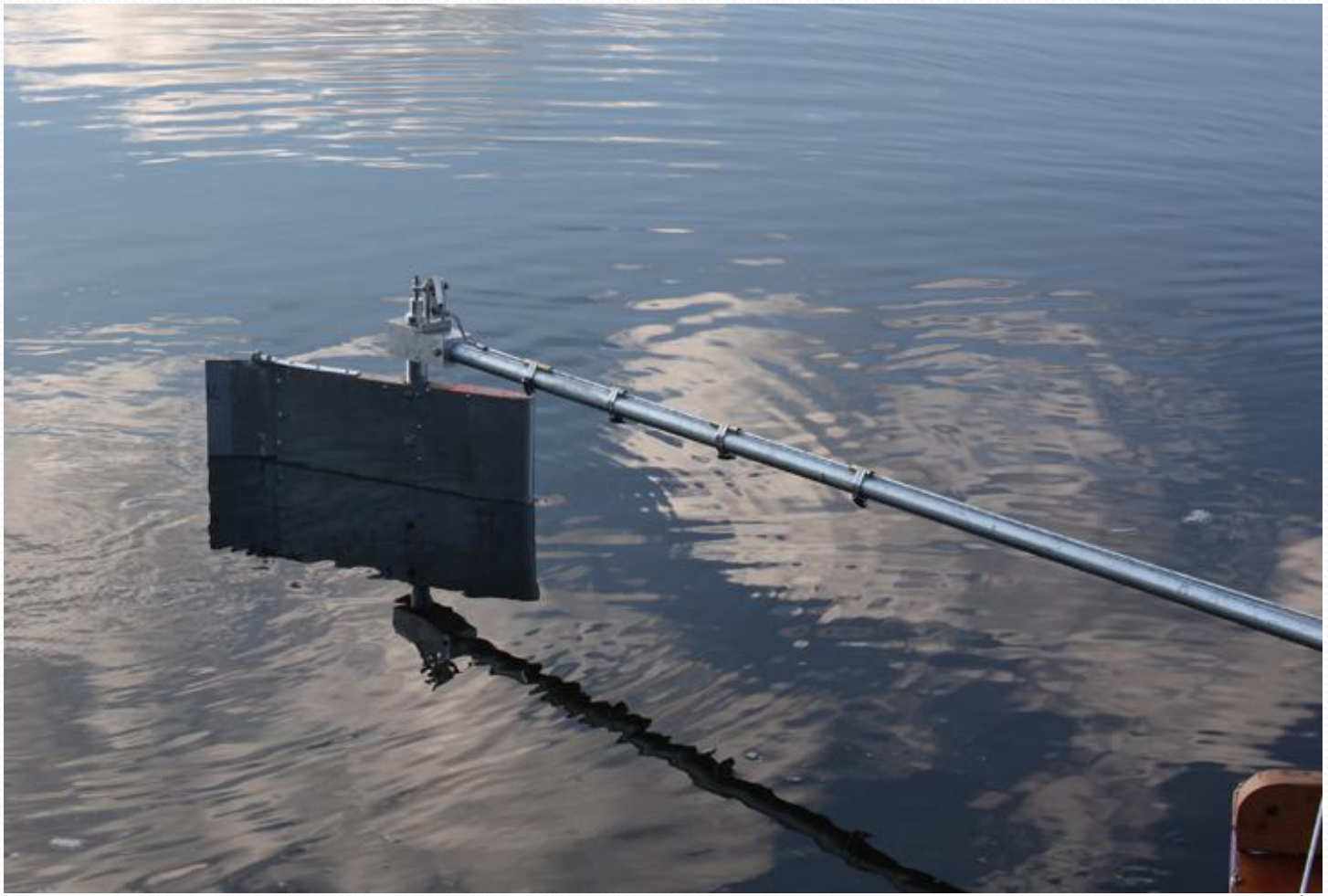
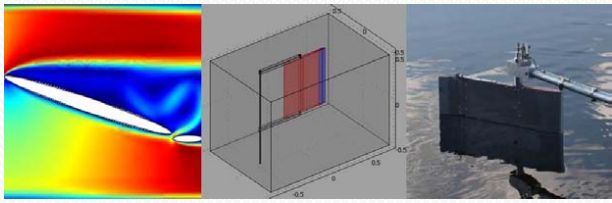
Hydrofoil Prototype





Mathematical Model



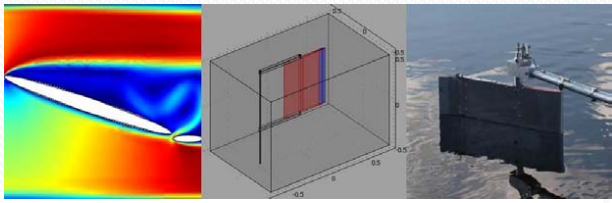
- Differential Equations for flowing water

  Navier-Stokes Equation:

$$\rho \frac{D\mathbf{V}}{Dt} = -\nabla p\mathbf{I} + \nabla \mu \left[\nabla \mathbf{V} + (\nabla \mathbf{V})^T \right] + \rho \mathbf{g} \qquad \text{In } \Omega \text{ for t } \in [0,T]$$

  - ρ –fluid density
  - p –pressure
  - μ –fluid viscosity
  - $\mathbf{V}$ –fluid velocity
  - $\mathbf{g}$ –gravity of Earth

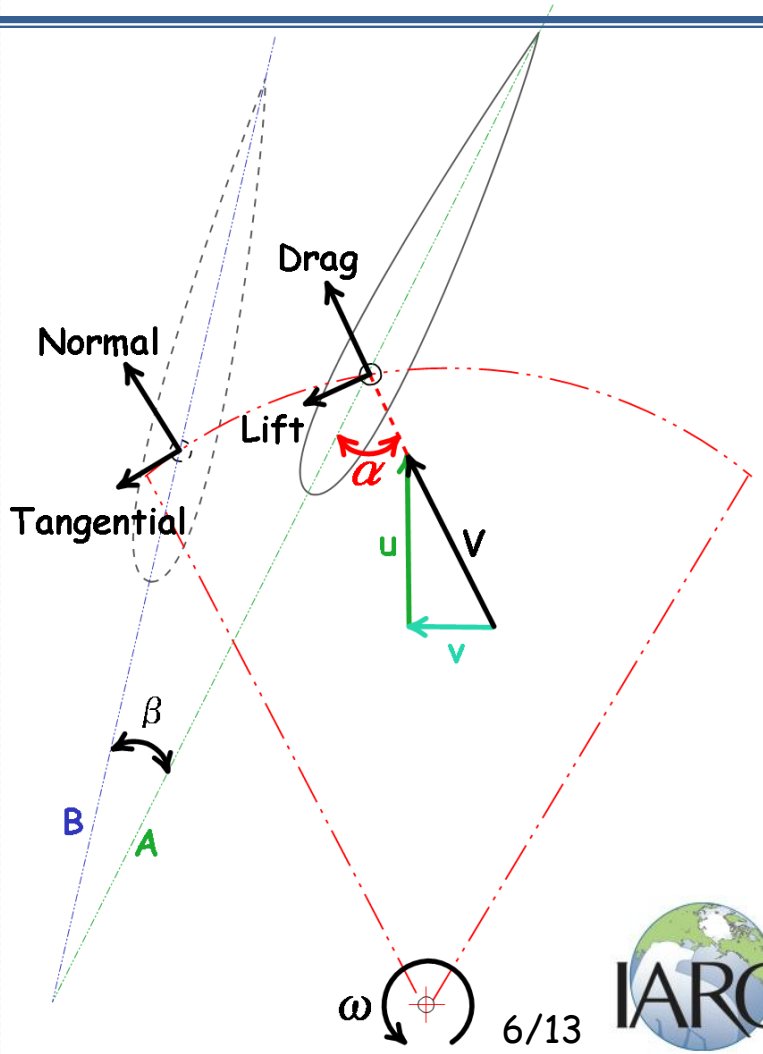
Mathematical Model



- **Analysis of the foil motion**
  - Harmonic transverse motion
  - Harmonic angular motion
  - With same period **T**
- **Quantification of forces**

$$L = \frac{1}{2}\rho \bar{V} S C_L \qquad D = \frac{1}{2}\rho \bar{V} S C_D$$

$$T = L(\cos\gamma) + D(\sin\gamma)$$



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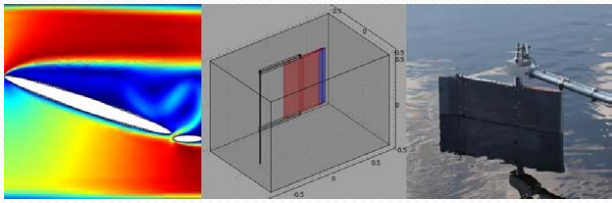
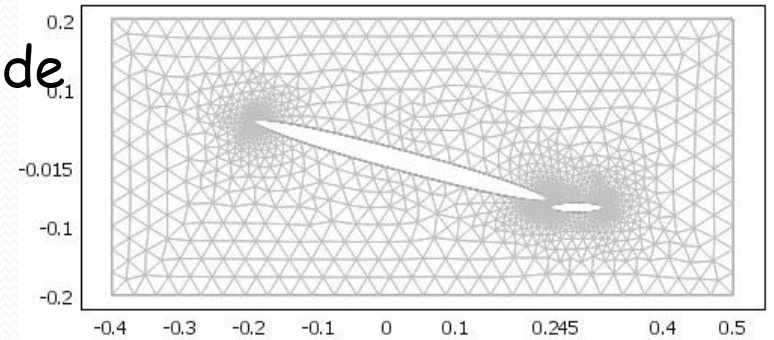
Foil Model in COMSOL

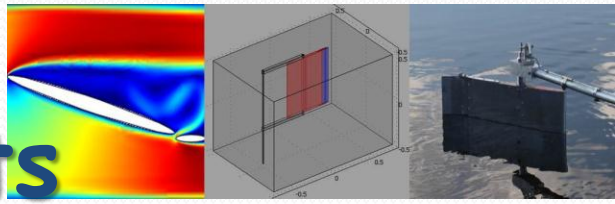


- **2D static Model**
  - **Goal**
    - Analyze the total static force acting on the foil
    - How different velocities affect the fluid force on the foil
    - Whether it generates enough force to drive PMG
  - **Application mode**
    - Incompressible NS application mode
  - **Boundary conditions**
    - No Slip wall, inlet velocity, outlet
  - **Solver**
    - Parametric solver

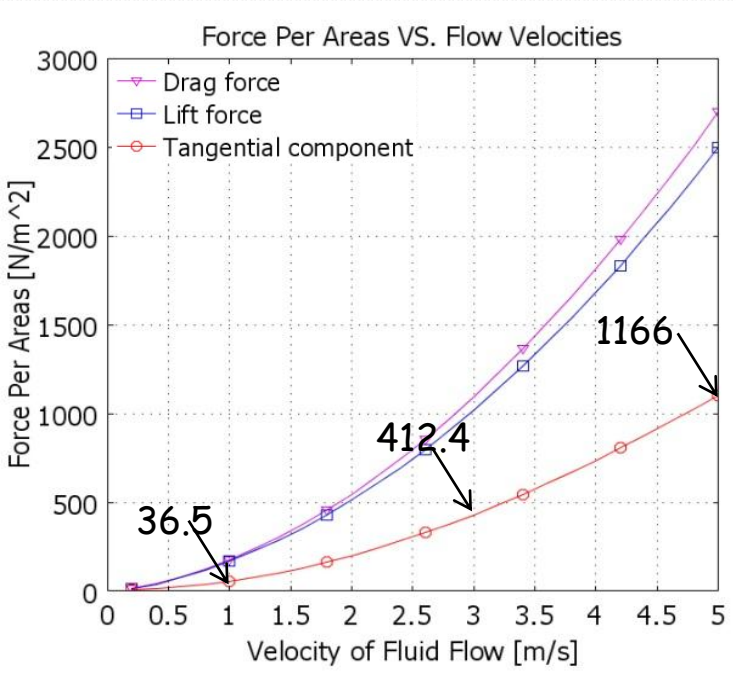


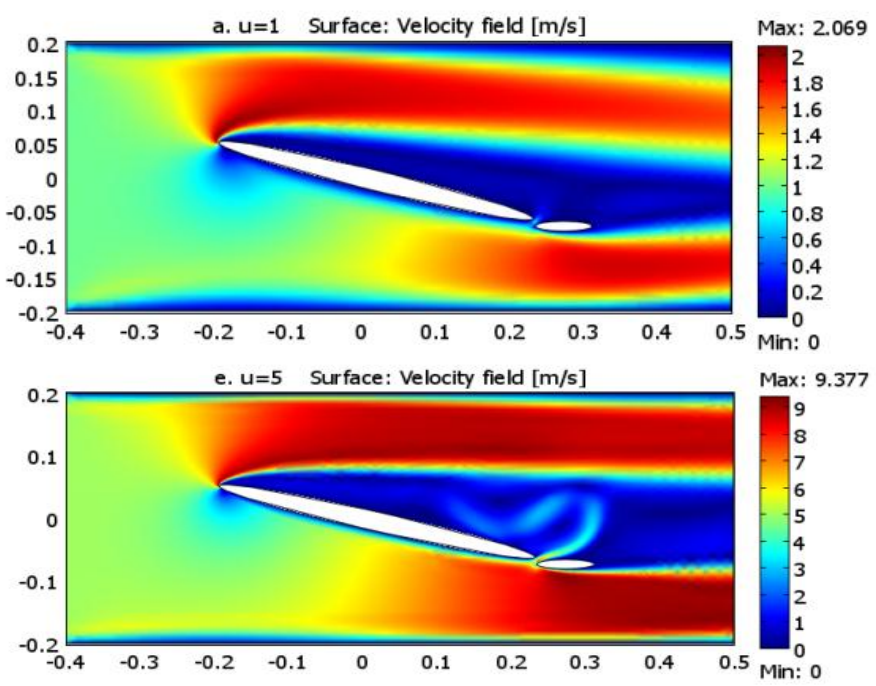
Mesh of 2D geometry model

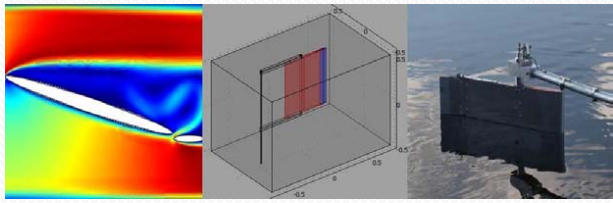
2D Static Modeling Results



- Velocity distribution of the flow pass the foil
- Lift force, drag force, and the combination of the two to drive the rod







Results Analysis

- 1 m/s → 36.5 N/m²
- 3 m/s → 412.4 N/m²
- 5 m/s → 1166 N/m²

S = 0.63m²

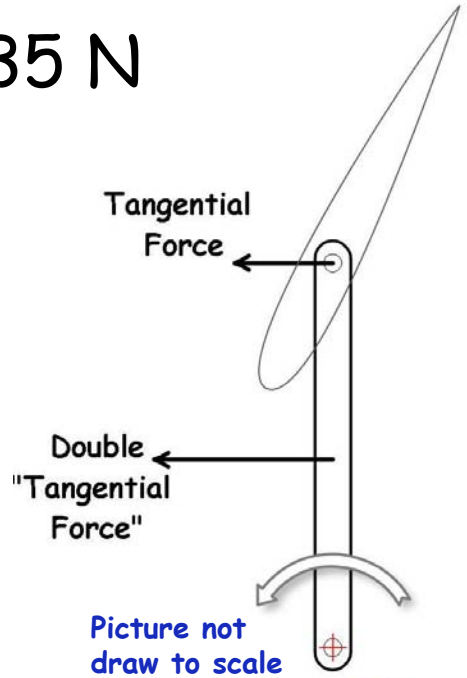
- 23 N
- 260 N
- 735 N

- **Commercial PMG (eg. Ginlong)**

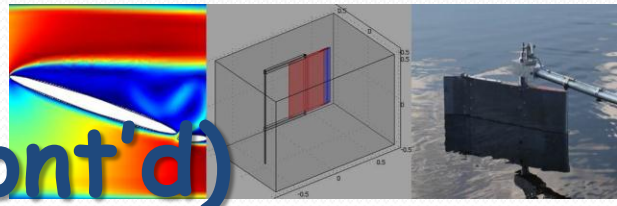
- 500 Watts require 14.8 N·m
- 30 Kilowatts require 3300 N·m

- **Direct drive Power generator**

  Easier to drive

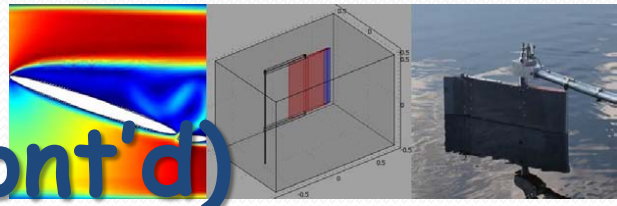


Foil Model in COMSOL (cont'd)

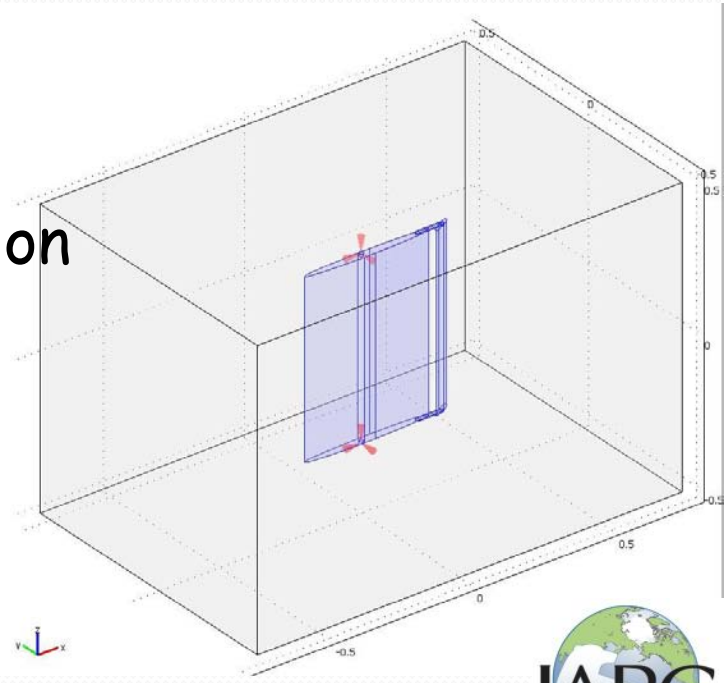


- **2D transient Model (Unfinished)**
  - **Goal**
    - Analyze transient motion of the foil
    - Estimate the output power in one oscillating period
  - **COMSOL application mode**
    - Predefined Fluid Structure Interaction mode
    - Rotating machinery mode
  - **Challenges**
    - How to model 3 relative moving frames
    - Optimize solving time

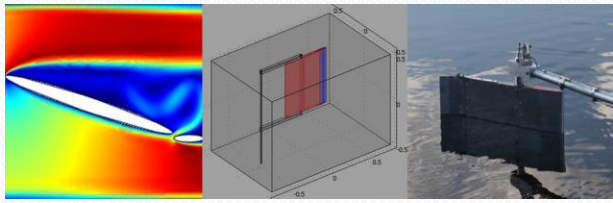
Foil Model in COMSOL (cont'd)



- **3D Model (optional)**
  - ☑ Better visualization of the model
  - ☑ Provides more data
  - ☒ Convergence problem
  - ☒ Involving more boundary condition
  - ☒ Structure mechanics coupling



Future Challenges



- 3 relative free motions in 2D transient model
- Couple the Structure mechanics in 3D model
- Convergence problem in 3D model
- Integrate with Simulink control system

Questions….