Etude de la performance énergétique d'un houlomoteur à différentiel de pression

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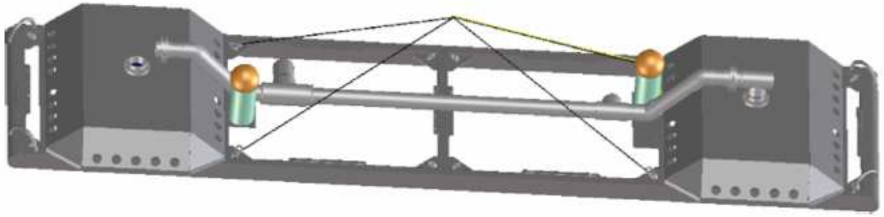
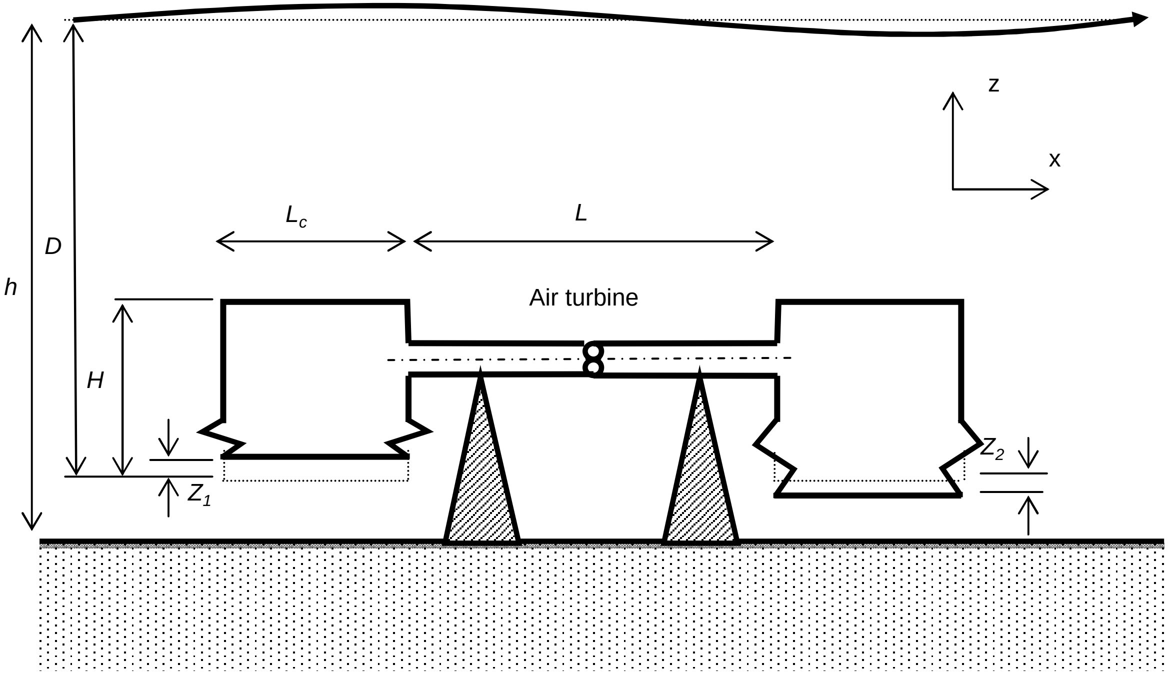
M3 Wave WEC



- Width = 8 m
- Length of volume = 8 m
- Distance between volume = 30 m
- Submergence (bottom) = 9 m
- Water depth = 10 m

> Aim of the study: what is the energy performance of this device?

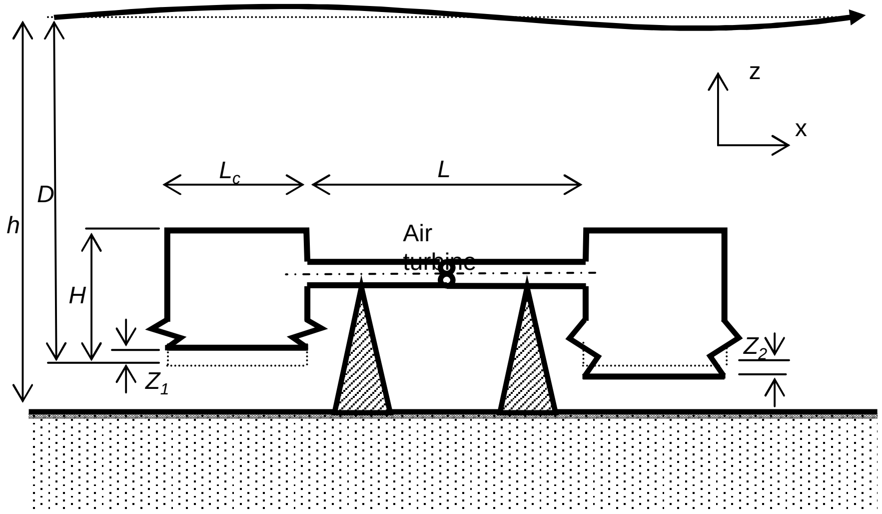
Equation du mouvement



Modelling assumptions

- •The WEC structure is bottom fixed. There are no rigid body motions, only deformations
- •Mode shape is a piston mode (may be achieved using a bellow).
- •Deformations and waves are small so that linear theory is applicable.
- •The front and back volumes are identicals.
- •Compression is isothermal and quasi-static.
- •Pressure and volume variation are small so that equations for the inner flow can be linearized.
- •Pressure drop through the turbine is proportional to mass rate

Equation du mouvement



$$\left\{\begin{array}{l}
\sum_{j=1}^{2} A_{1j}\ddot{\tilde{Z}}_j + \sum_{j=1}^{2} B_{1j}\dot{\tilde{Z}}_j + \tilde{p}_1 S + (\boxed{K +} (\rho-\rho')gS)\tilde{Z}_1 = F_{ex,1} \\
\sum_{j=1}^{2} A_{2j}\ddot{\tilde{Z}}_j + \sum_{j=1}^{2} B_{2j}\dot{\tilde{Z}}_j + \tilde{p}_2 S + (\boxed{K +} (\rho-\rho')gS)\tilde{Z}_2 = F_{ex,2} \\
\dot{\tilde{p}}_1 - \frac{S\dot{\tilde{Z}}_1}{\chi_T V_S} + \frac{\tilde{p}_1}{\chi_T V_S \boxed{B_{PTO}}} - \frac{\tilde{p}_2}{\chi_T V_S \boxed{B_{PTO}}} = 0 \\
\dot{\tilde{p}}_2 - \frac{S\dot{\tilde{Z}}_2}{\chi_T V_S} - \frac{\tilde{p}_1}{\chi_T V_S \boxed{B_{PTO}}} + \frac{\tilde{p}_2}{\chi_T V_S \boxed{B_{PTO}}} = 0
\end{array}\right.$$

Membrane stiffness and PTO damping coefficient can be optimized

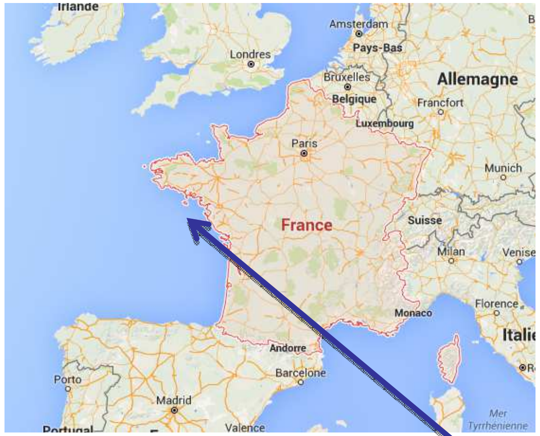
Mean absorbed power regular waves →

$$\bar{p} = \frac{1}{2\boxed{B_{PTO}}}|\tilde{p}_2 - \tilde{p}_1|^2$$

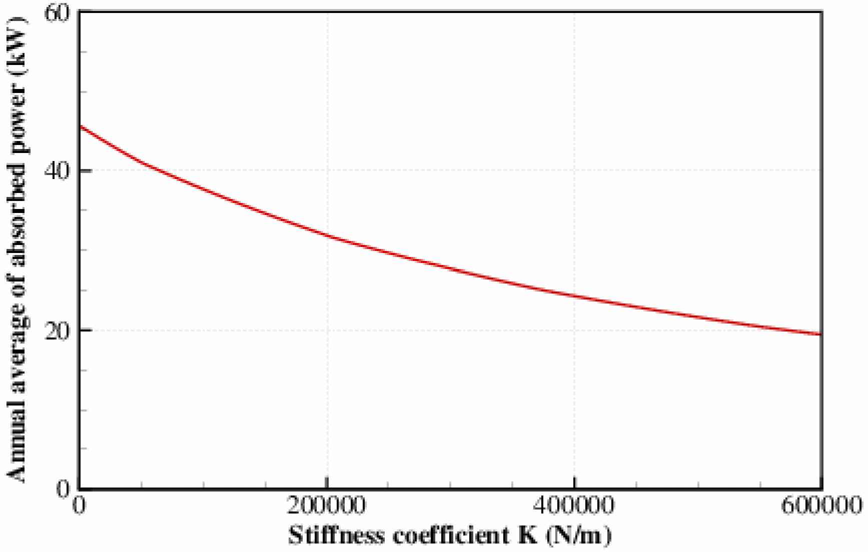
Annual average absorbed power →

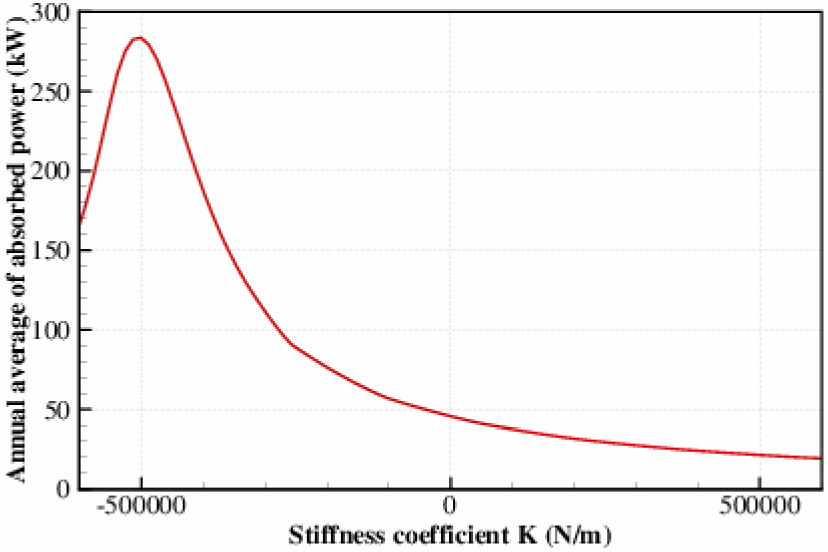
$$\bar{P} = \int_0^\infty S_h(f)\bar{p}(f)df$$

annual power as function of PTO and membrane stiffness

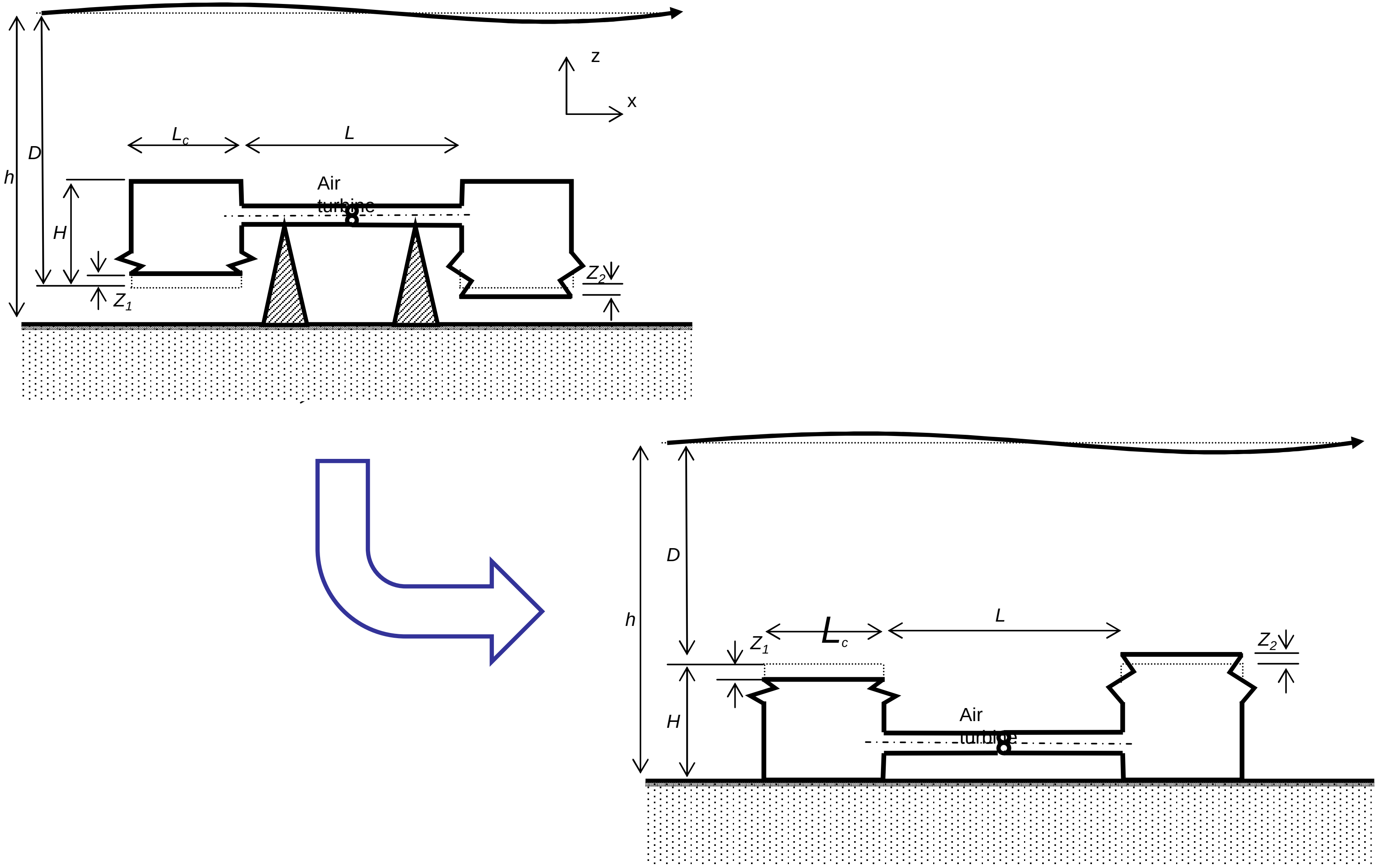


- Mean annual absorbed power for synthetic site close to Yeu island site (J = 16.8 kW/m)
- Inner fluid is air (2,4kg/m^3)
- With 0 membrane stiffness, mean power ~ 45kW
- Increasing membrane stiffness decrease power
- Reducing stiffness increases mean power → **system is too stiff**





Variante: membrane on the top



Equation du mouvement

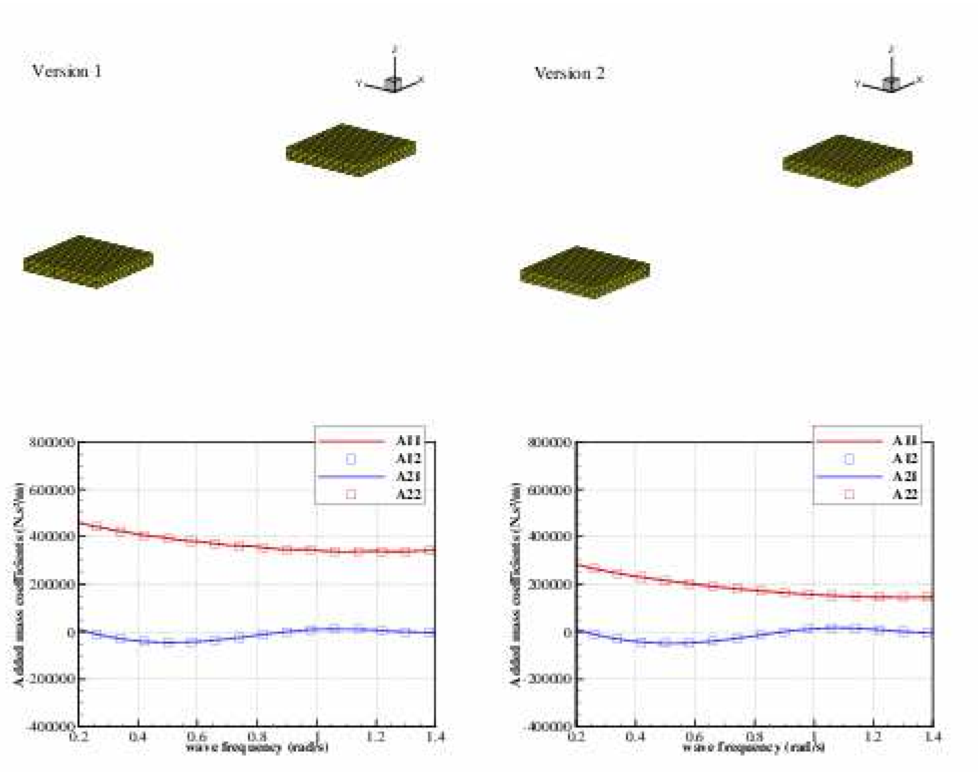
Version 1

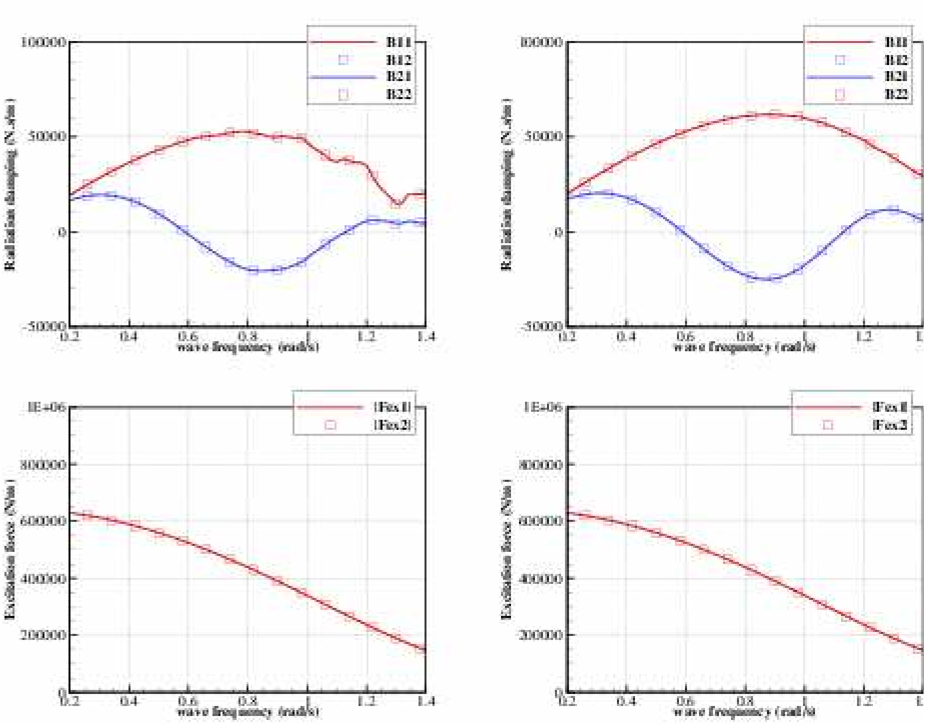
$$\left\{\begin{array}{l}
\sum_{j=1}^{2} A_{1j}\ddot{\tilde{Z}}_j + \sum_{j=1}^{2} B_{1j}\dot{\tilde{Z}}_j + \tilde{p}_1 S + (K + (\rho - \rho')gS)\tilde{Z}_1 = F_{ex,1} \\
\sum_{j=1}^{2} A_{2j}\ddot{\tilde{Z}}_j + \sum_{j=1}^{2} B_{2j}\dot{\tilde{Z}}_j + \tilde{p}_2 S + (K + (\rho - \rho')gS)\tilde{Z}_2 = F_{ex,2} \\
\dot{\tilde{p}}_1 - \frac{S\dot{\tilde{Z}}_1}{\chi_T V_S} + \frac{\tilde{p}_1}{\chi_T V_S B_{PTO}} - \frac{\tilde{p}_2}{\chi_T V_S B_{PTO}} = 0 \\
\dot{\tilde{p}}_2 - \frac{S\dot{\tilde{Z}}_2}{\chi_T V_S} - \frac{\tilde{p}_1}{\chi_T V_S B_{PTO}} + \frac{\tilde{p}_2}{\chi_T V_S B_{PTO}} = 0
\end{array}\right.$$

Version 2

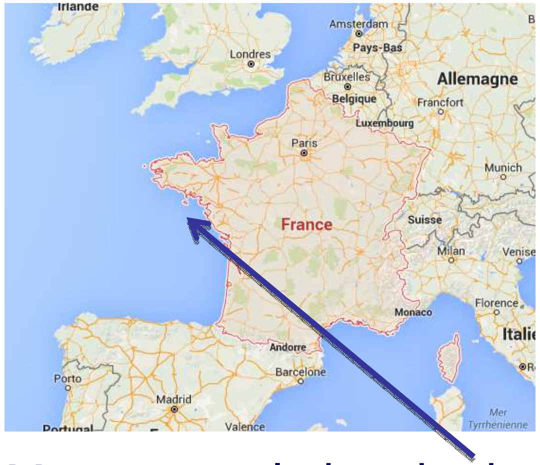
$$\left\{\begin{array}{l}
\sum_{j=1}^{2} A_{1j}\ddot{\tilde{Z}}_j + \sum_{j=1}^{2} B_{1j}\dot{\tilde{Z}}_j - \tilde{p}_1 S + (K \boxed{-} (\rho - \rho')gS)\tilde{Z}_1 = F_{ex,1} \\
\sum_{j=1}^{2} A_{2j}\ddot{\tilde{Z}}_j + \sum_{j=1}^{2} B_{2j}\dot{\tilde{Z}}_j - \tilde{p}_2 S + (K \boxed{-} (\rho - \rho')gS)\tilde{Z}_2 = F_{ex,2} \\
\dot{\tilde{p}}_1 \boxed{+} \frac{S\dot{\tilde{Z}}_1}{\chi_T V_S} + \frac{\tilde{p}_1}{\chi_T V_S B_{PTO}} - \frac{\tilde{p}_2}{\chi_T V_S B_{PTO}} = 0 \\
\dot{\tilde{p}}_2 \boxed{+} \frac{S\dot{\tilde{Z}}_2}{\chi_T V_S} - \frac{\tilde{p}_1}{\chi_T V_S B_{PTO}} + \frac{\tilde{p}_2}{\chi_T V_S B_{PTO}} = 0
\end{array}\right.$$

Coefficients hydrodynamiques

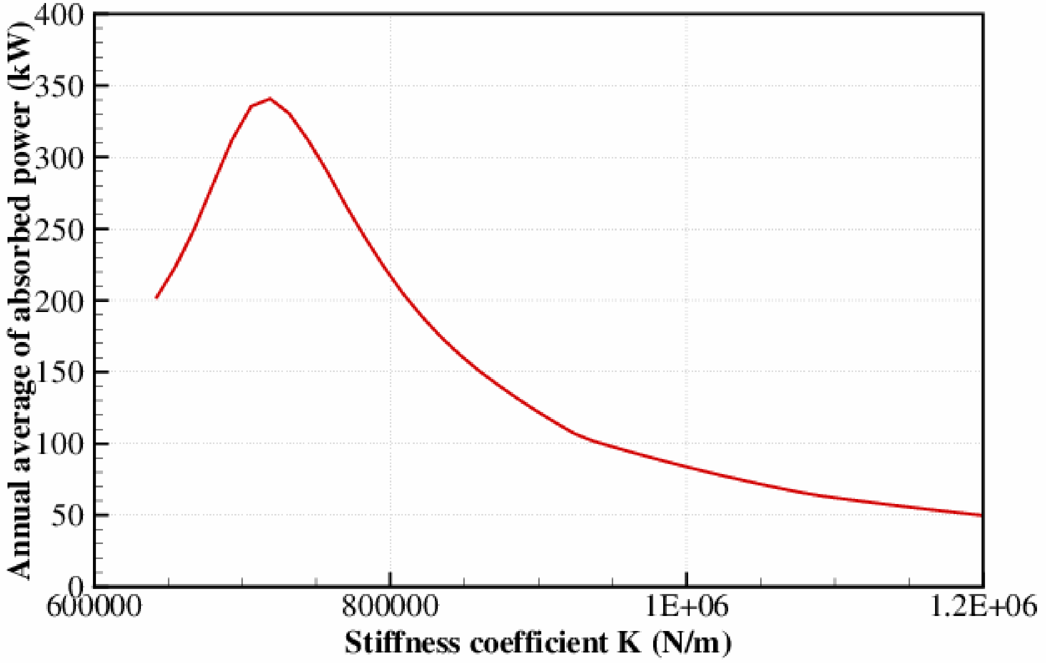




annual power as function of PTO and membrane stiffness

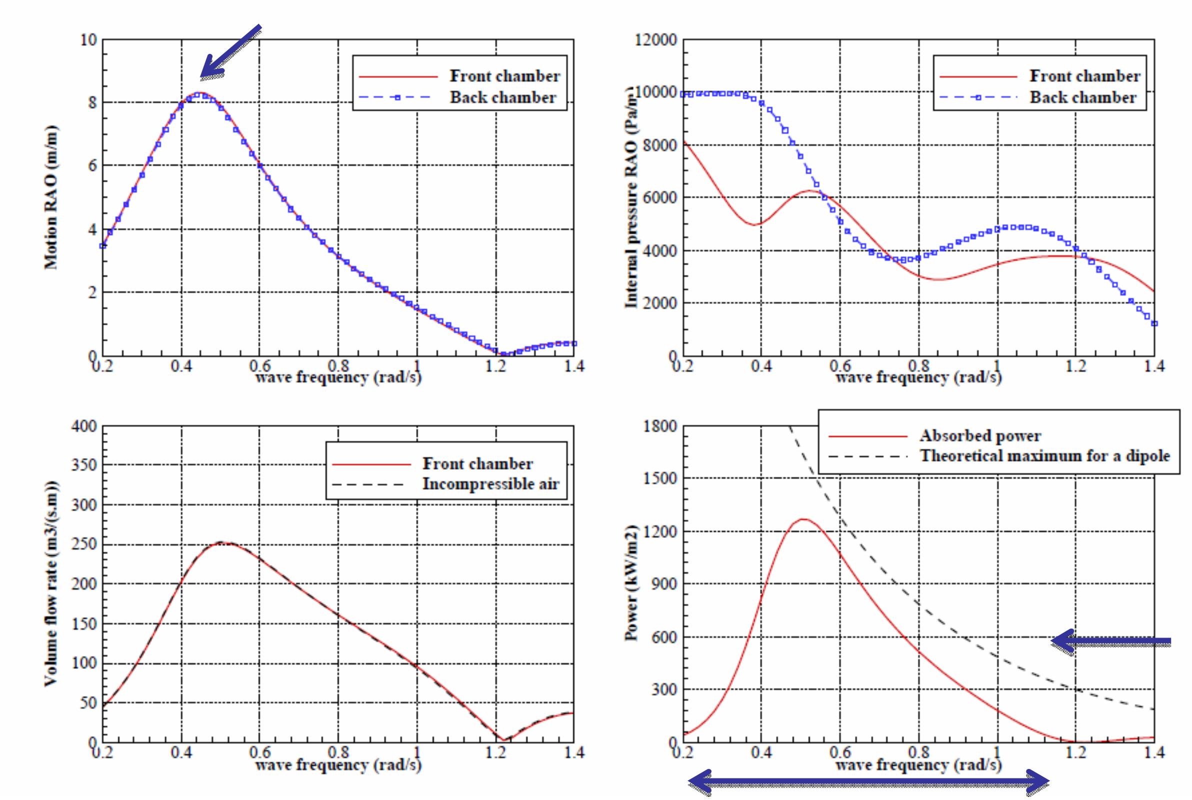


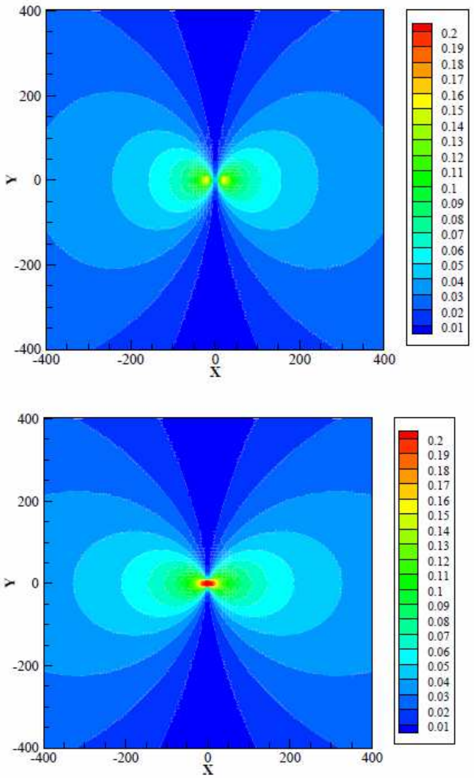
- Mean annual absorbed power for synthetic site based on Yeu island site data (J = 16.8 kW/m)
- Inner fluid is air (2,4kg/m^3)
- With membrane stiffness = 110% of hydrostatic stiffness, mean power ~ 350kW



RAO & power function

Amplitude is not realistic



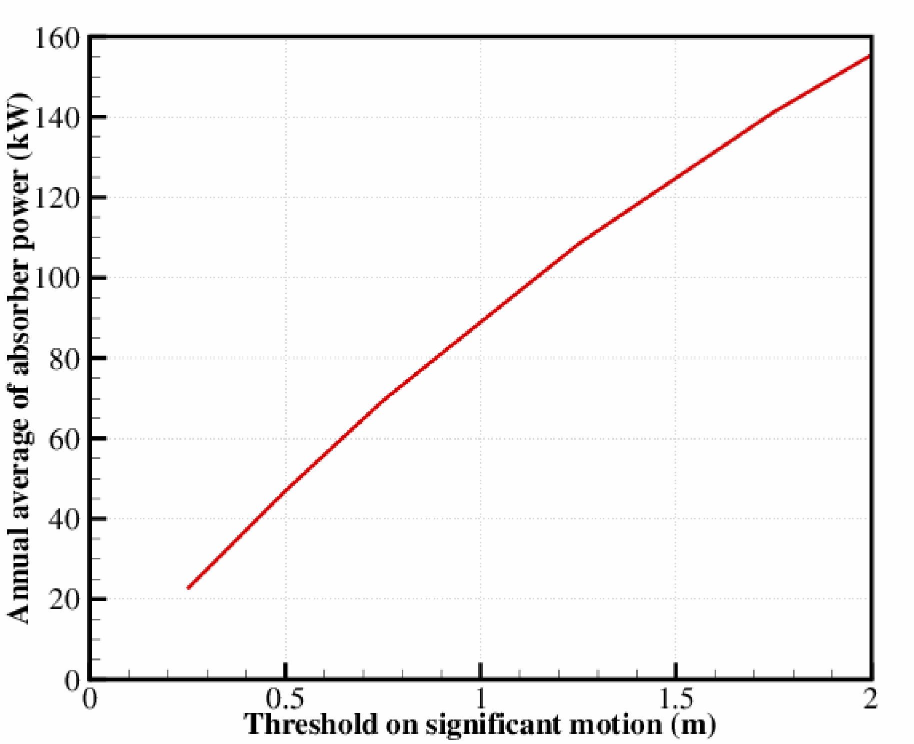


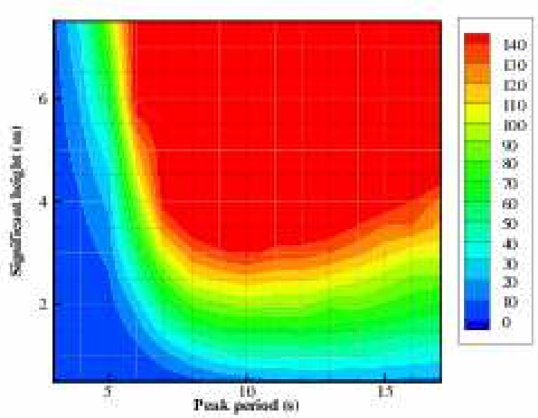
Theoretical maximum for dipole

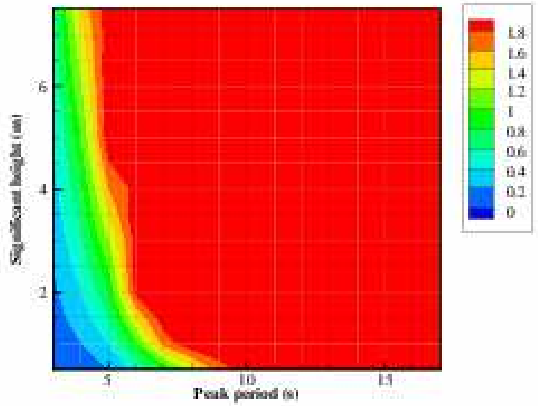
Great bandwidth

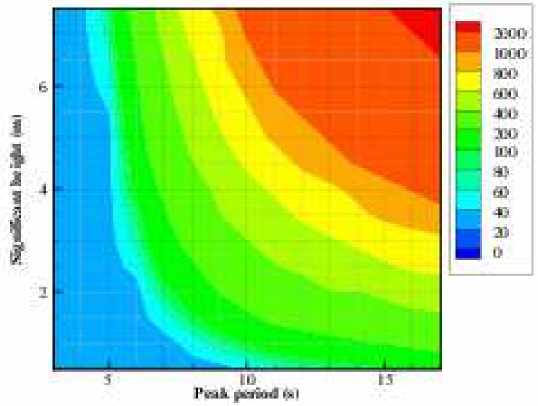
Taking into account motion constraint

Power as function of motion constraint (Z_{mx})



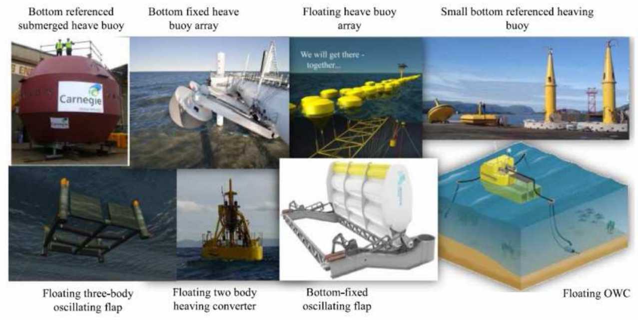




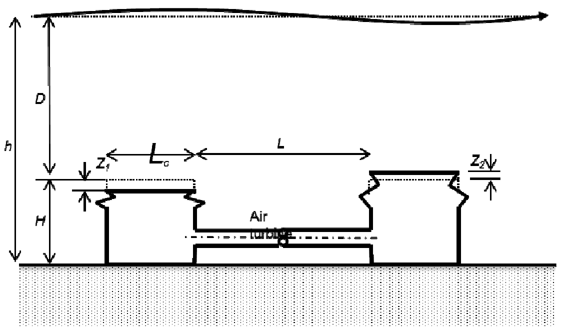


Motion constraint $Z_{mx} < 1$m
Rated power = 150kW
Mean annual absorbed power = 83kW
Capacity factor = 55%

Comparison to the NumWEC benchmark



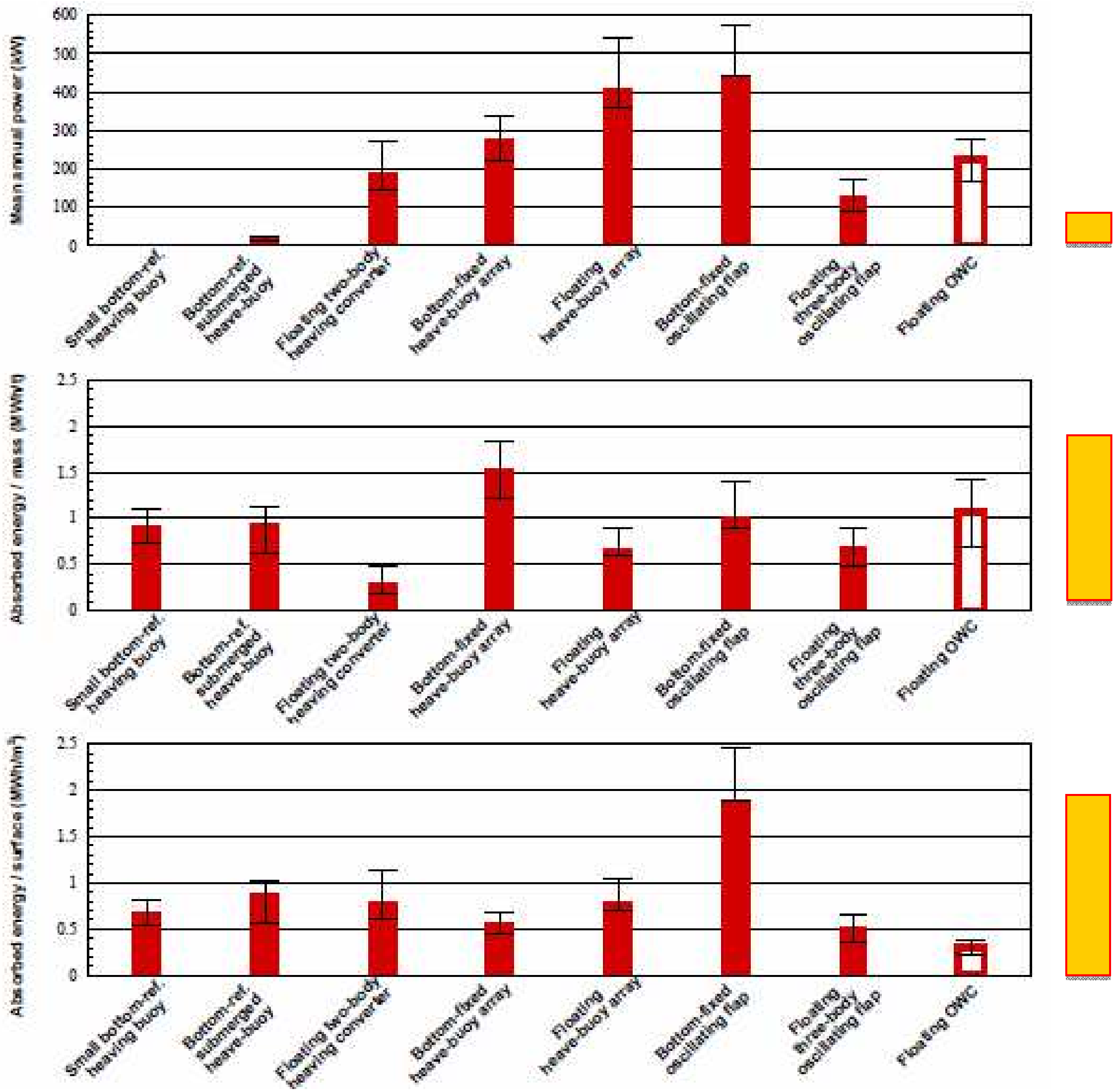
VS



Mean annual absorbed power = 83kW

E/V = 1,9 MWh/m3 (>> 1,6 at best in NumWEC study)

E/S = 1,8 MWh/m2 (~ 1,8 at best in NumWEC study)



Conclusions

- > Bottom-fixed pressure-differential wave energy device
- > Variant with membrane on top is much more efficient than with membrane on the bottom
  - Mainly due to tuneable resonant frequency
- > It requires membrane stiffness (may be achieved by pretensioning the membrane or by using bellows)
- > For this device, performance measures are greater than the best other technologies. Capacity factor is greater than 50%

- > Perspectives
  - Geometry optimization
  - Energy losses in internal flow
  - Efficiency of air turbine
  - Membrane stiffness
  - Protection from coastal erosion (→EMACOP)
  - Sediment transport
  - Installation, operation and maintenance

Merci de votre attention!

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> Publications:

- A. Babarit, F. Wendt, Y-H. Yu, J. Weber, « Investigation on the energy performance of a pressure differential wave energy converter », submitted to Applied Ocean Research