Power Vision Engineering

Draft tube modelling for prediction of pressure fluctuations on prototype

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3-4 juin 2015

SHF – Machines hydrauliques et cavitation
Cetim Nantes
74 route de la Jonelière
France

SHF

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  - ✓ Eigenmodes
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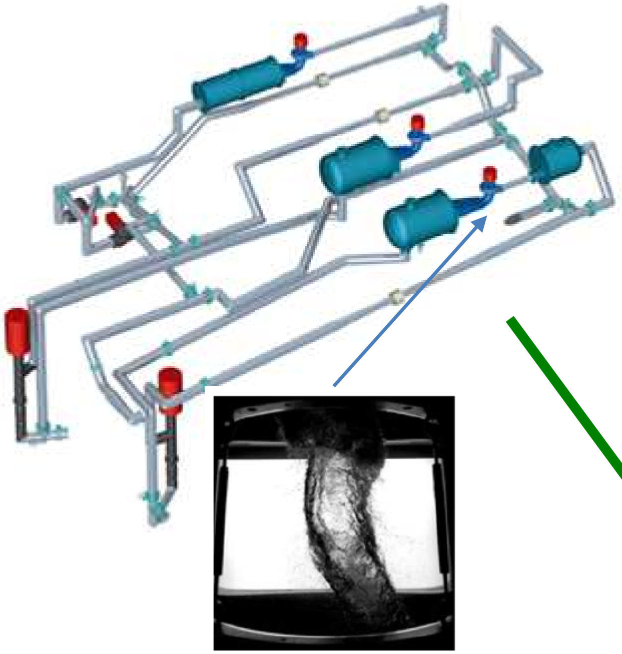
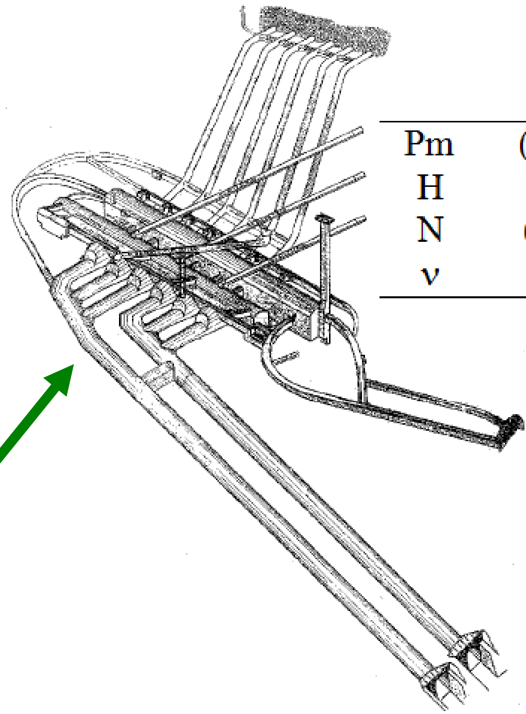
Problematic

Reduced scale model



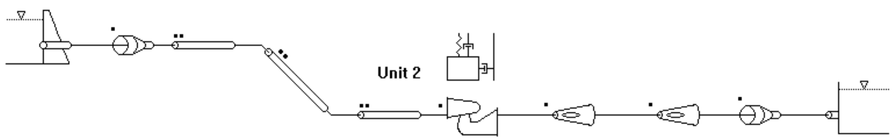
Direct transposition of pressure fluctuations

Prototype

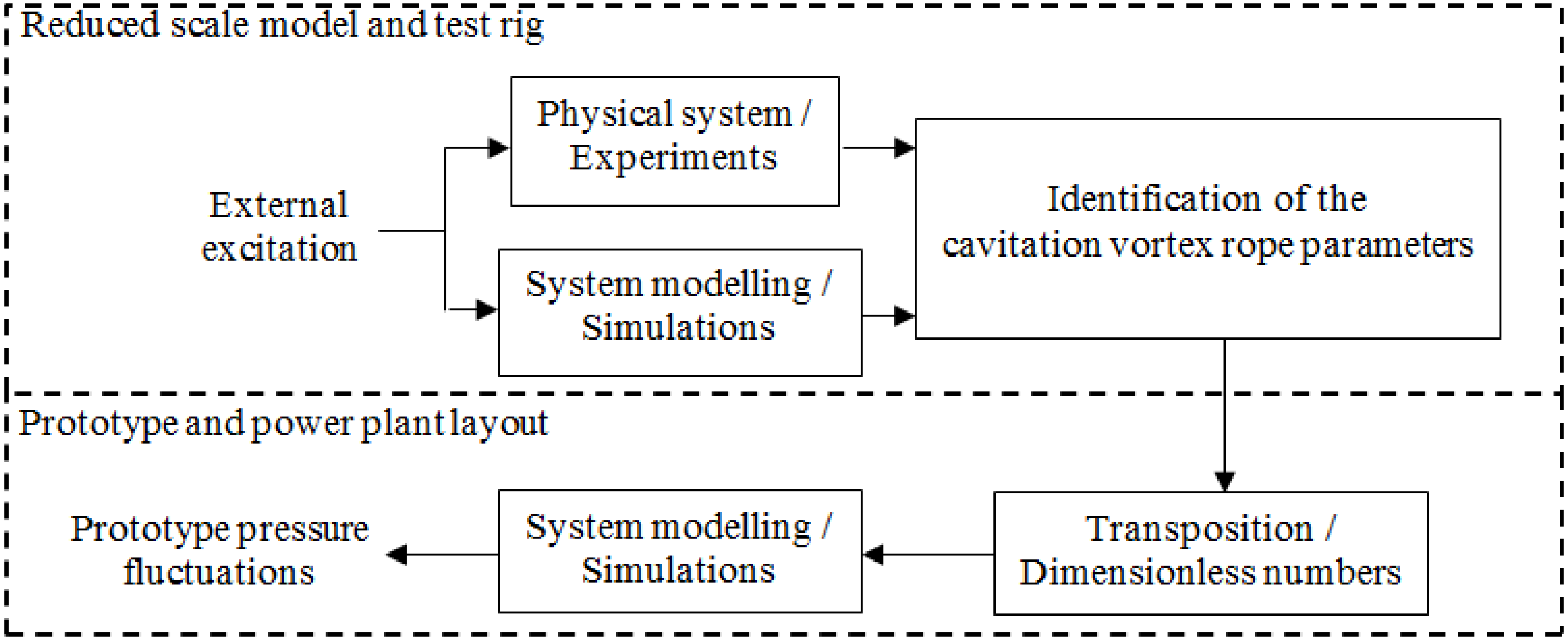


Pm	(MW)	444
H	(m)	171
N	(rpm)	128.6
ν	(-)	0.29

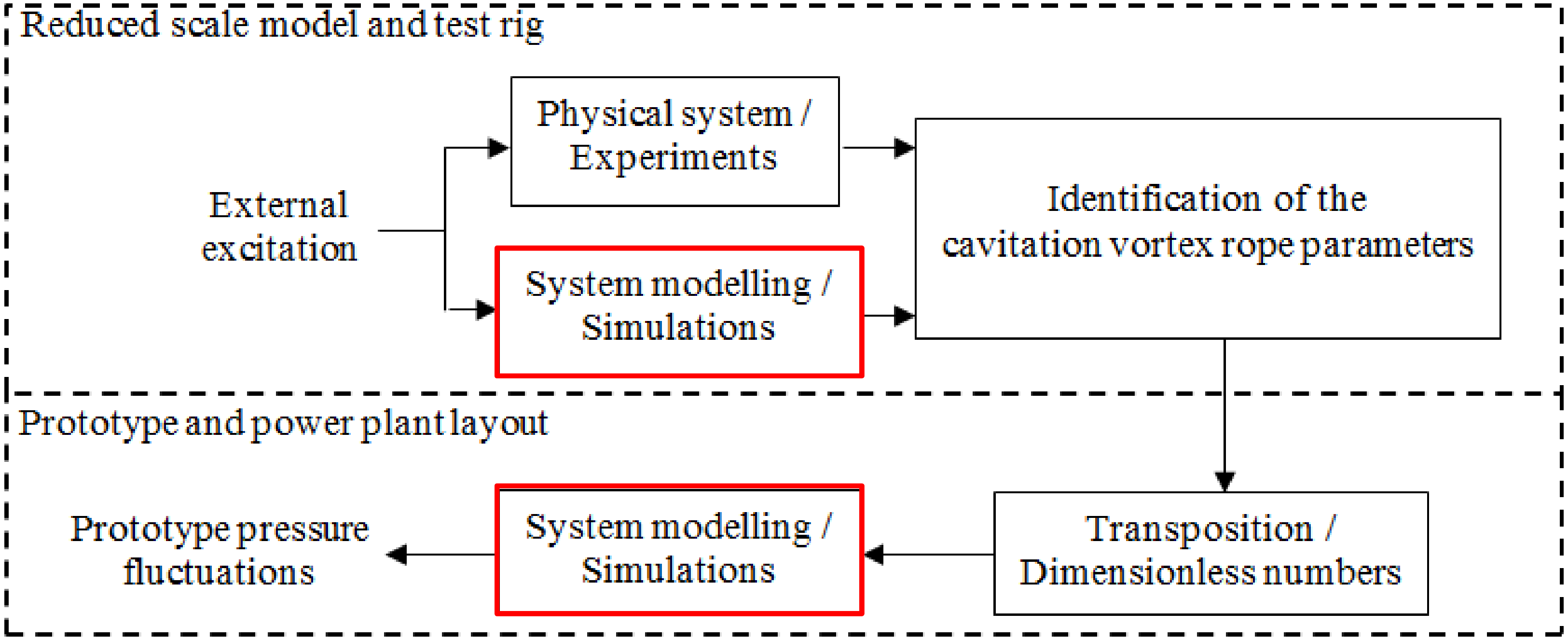
1D simulation model



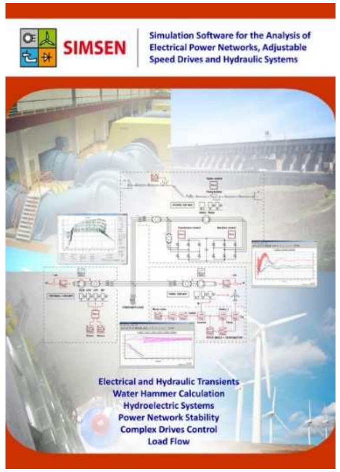
Methodology



Methodology



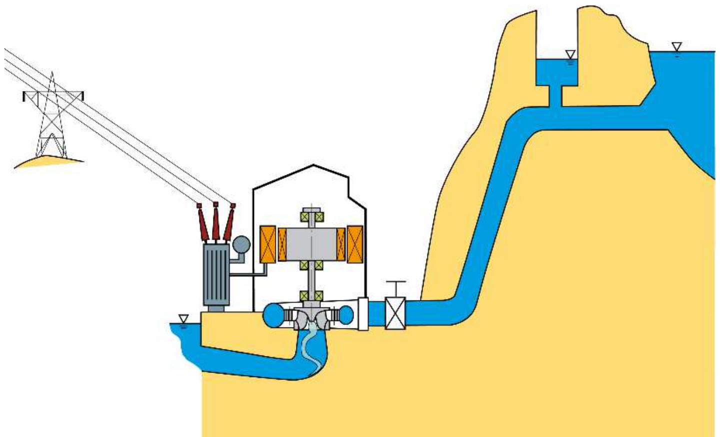
SIMSEN



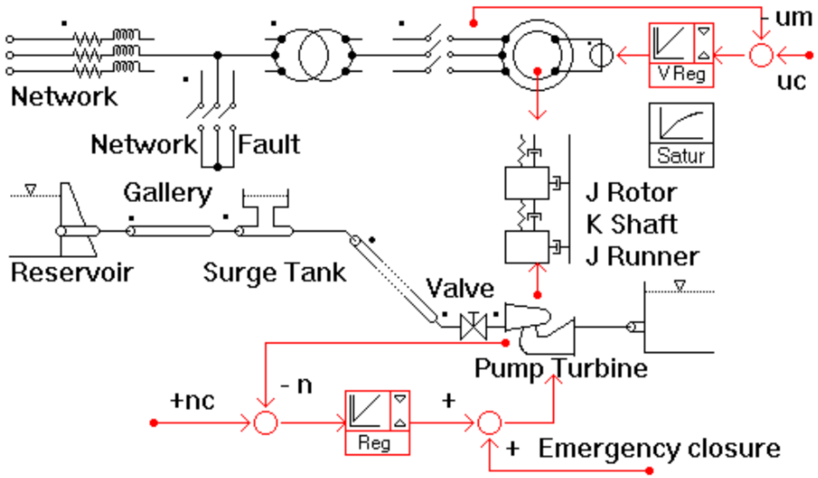
- SIMSEN software:
  - ✓ Hydraulic circuit
  - ✓ Electrica installations
  - ✓ Rotating inertias
  - ✓ Control system

SIMSEN

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE



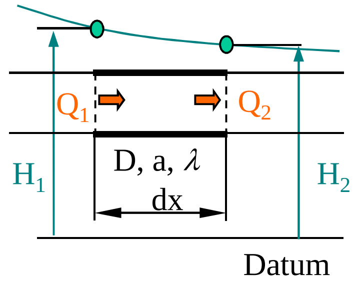
Modeling from water to wire



1D Modelling

- Piping system modelling:

✓Mass and momentum equation:



$$\frac{\partial H}{\partial t} + \frac{a^2}{gA}\frac{\partial Q}{\partial x} = 0$$

Storage

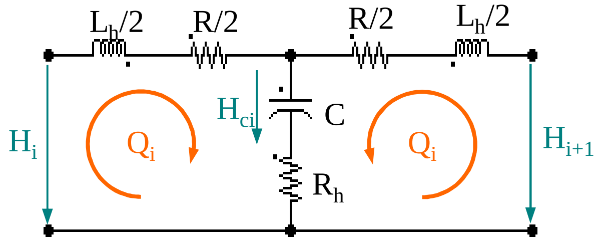
$$\frac{\partial H}{\partial x} + \frac{1}{gA}\frac{\partial Q}{\partial t} + \frac{\lambda |Q|}{2gDA^2} Q = 0$$

Losses

Inertia

✓Electrical analogy:

- (Bergeron, 1950; Paynter, 1953)



$$\frac{\partial U}{\partial t} + \frac{1}{C_e}\frac{\partial I}{\partial x} = 0$$

$$\frac{\partial U}{\partial x} + L_e \frac{\partial I}{\partial t} + R_e I = 0$$

1D Modelling

- Turbine characteristic:

Dimensionless factors:

Unit speed factor:

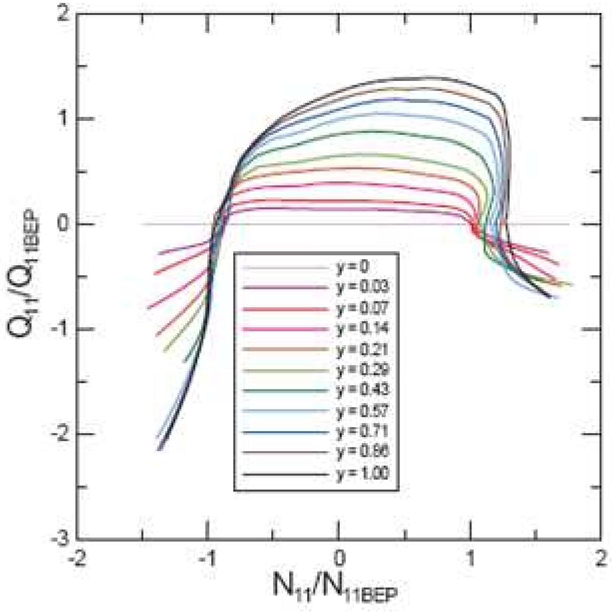
$$N_{11} = \frac{N \cdot D_{ref}}{\sqrt{(E/g)}}$$

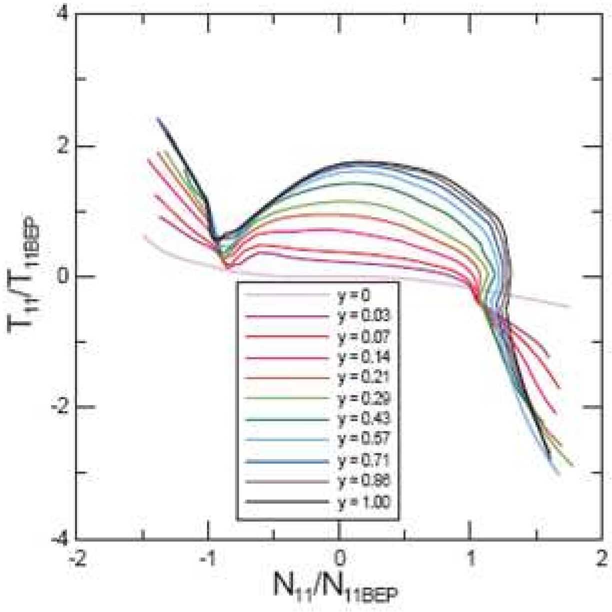
Unit discharge factor:

$$Q_{11} = \frac{Q}{D_{ref}^2 \cdot \sqrt{(E/g)}}$$

Unit torque factor:

$$T_{11} = \frac{T}{D_{ref}^3 \cdot E/g}$$

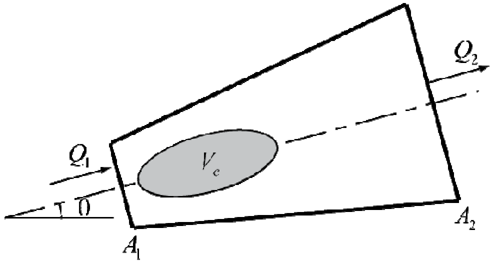




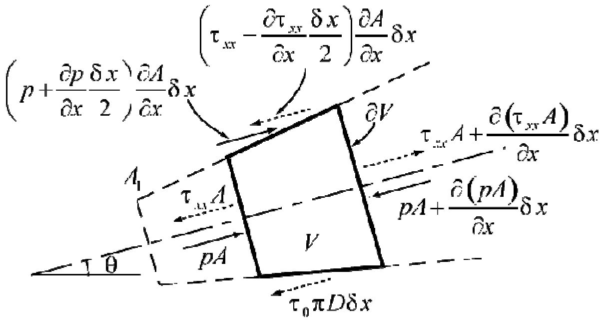
1D Modelling

- Cavitation draft tube flow

S.Alligné, C. Nicolet, Y. Tsujimoto, F. Avellan, *Cavitation Surge Modelling in Francis Turbine Draft Tube*, In Publication process for Journal of Hydraulic Research, 2014



$$V_c = f(Q_1, h, Q_2) \rightarrow Q_1 - Q_2 = \chi_1 \frac{dQ_1}{dt} + C_c \frac{dh}{dt} \leftarrow \begin{cases} C_c = -\dfrac{\partial V_c}{\partial h} = \dfrac{gAdx}{a^2} \\ \chi_1 = -\dfrac{\partial V_c}{\partial Q_1} \end{cases}$$



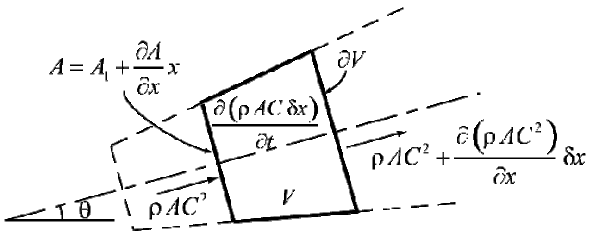
$$\frac{1}{gA}\frac{\partial Q}{\partial t} + \boxed{\frac{Q}{gA^2}\frac{\partial Q}{\partial x}} \boxed{- \frac{Q^2}{gA^3}K_x} + \frac{\partial h}{\partial x} + \frac{\tau_0 \pi D}{\rho g A} \boxed{- \frac{\mu''}{\rho g A}\frac{\partial^2 Q}{\partial x^2}} + S_h = 0$$

Convective terms (New)

Divergent geometry (Tsujimoto et al.)

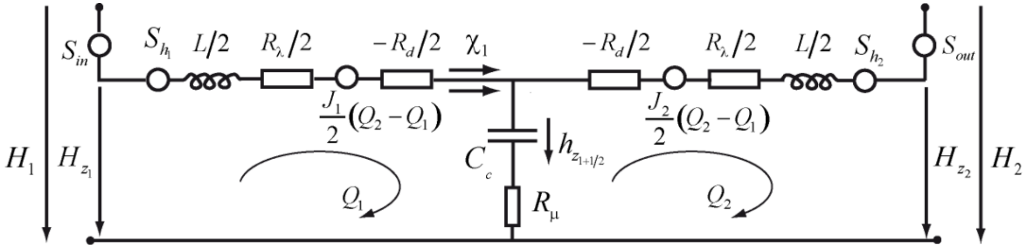
$$K_x = \frac{\partial A}{\partial x}$$

Dilatation viscosity (Pezzinga et al.)



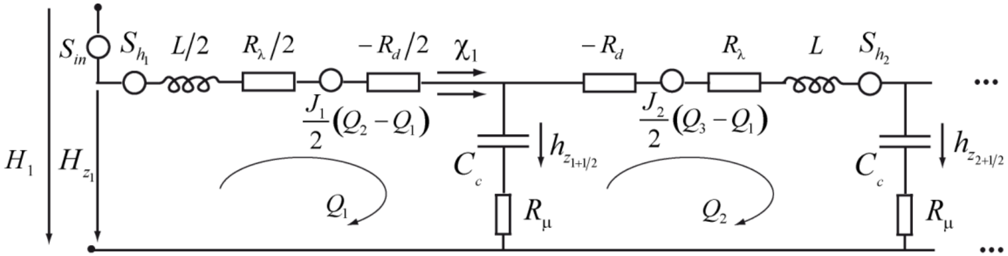
1D Modelling

- Cavitation draft tube flow:
  - ✓Lumped model

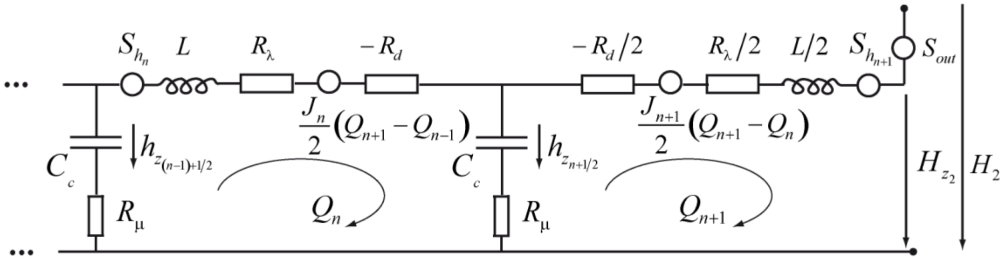


Nb=1

  - ✓Distributed model



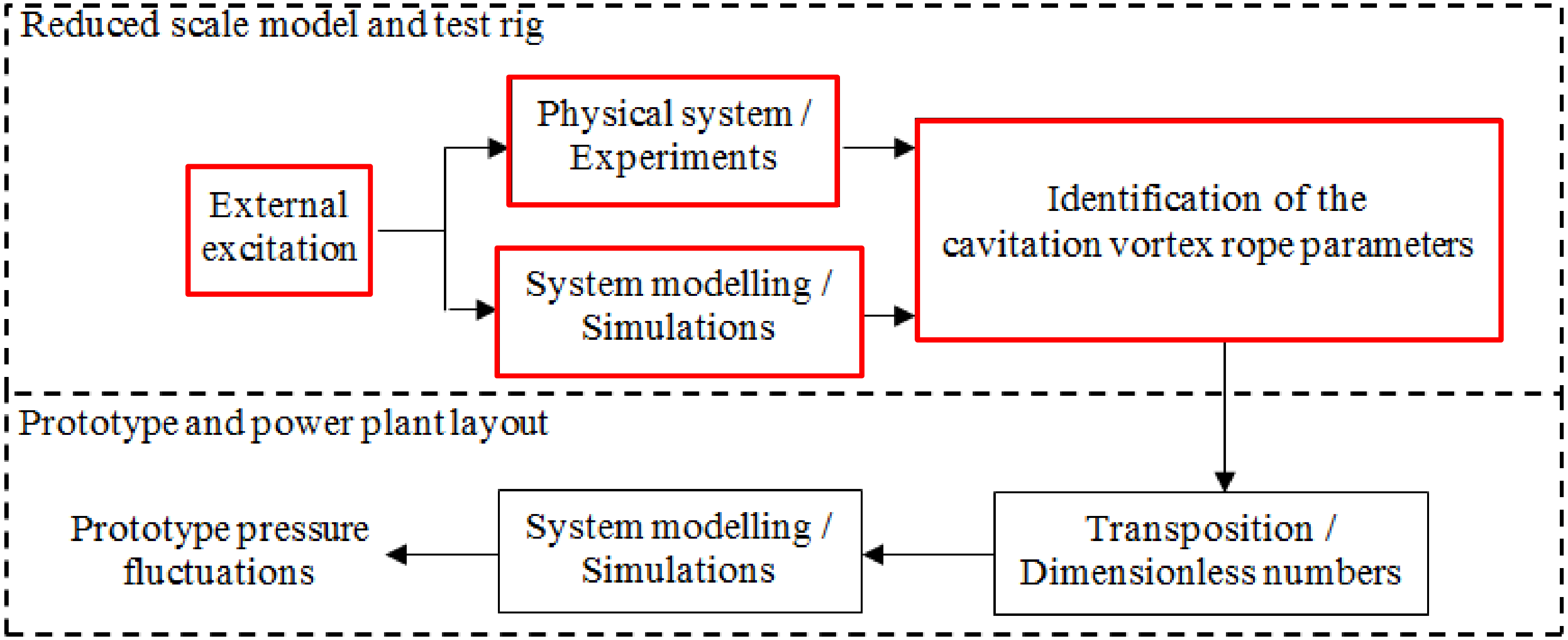
Nb=32



1D Modelling

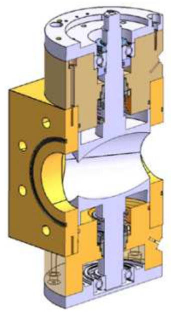
- Draft tube model parameters:
  - ✓ Wave speed a
  - ✓ Second viscosity μ'' : dissipation induced by the phase change during cavitation volume fluctuations
  - ✓ Excitation source S_h : induced by the vortex rope
  - ✓ *Mass flow gain factor* χ_1*: not considered*
- Effect of parameters:
  - ✓ a and μ'' influence damping $\alpha(a,\mu'')$ and frequency $f(a,\mu'')$ of eigenmodes
  - ✓ The excitation source S_h is external to the system

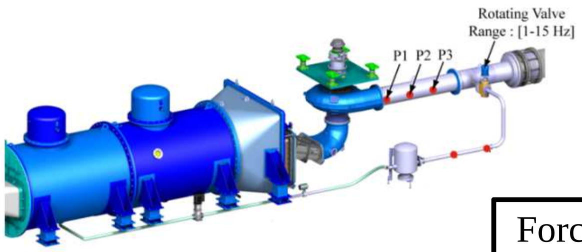
Methodology

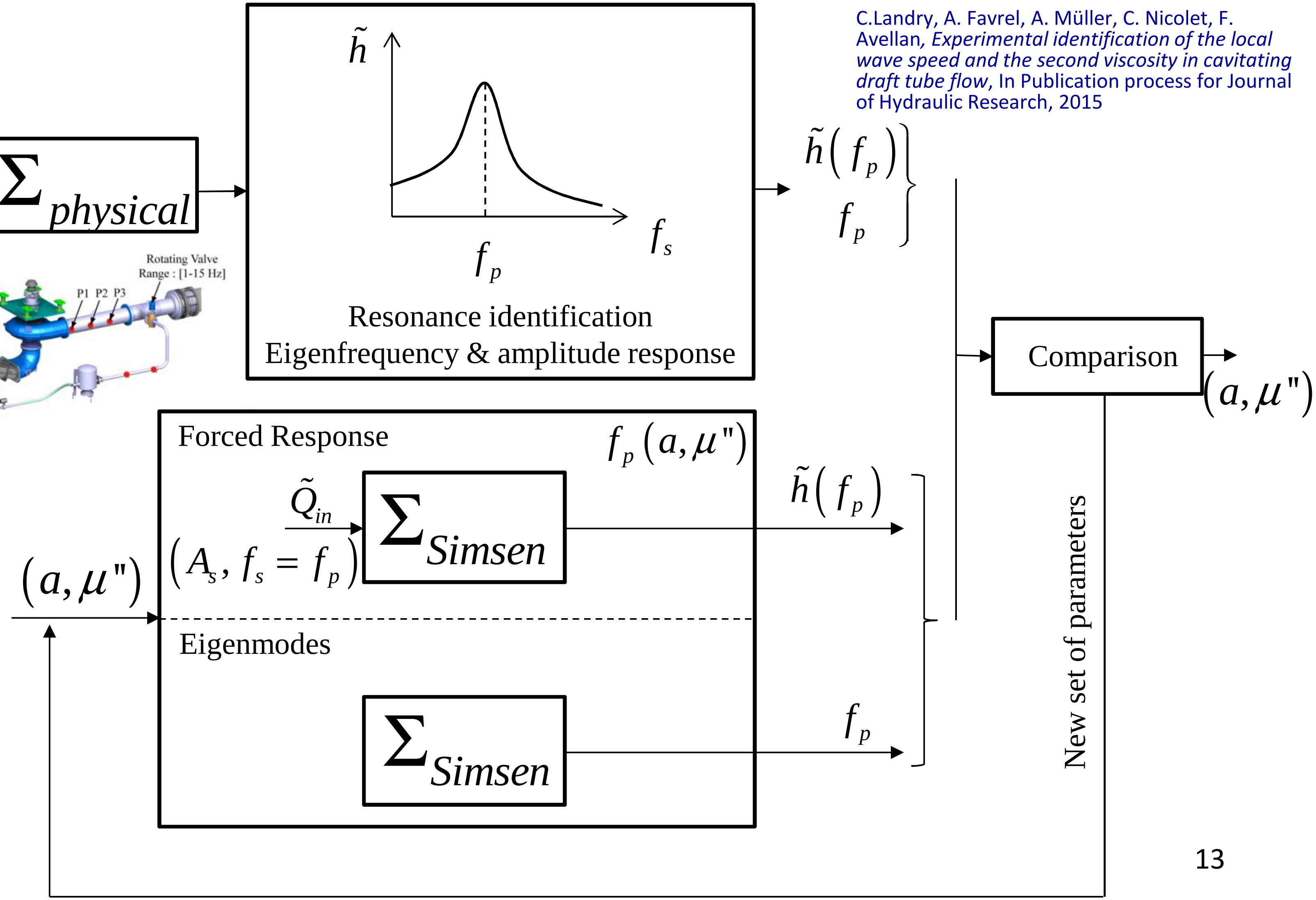


Identification of a & μ''

C.Landry, A. Favrel, A. Müller, C. Nicolet, F. Avellan, *Experimental identification of the local wave speed and the second viscosity in cavitating draft tube flow*, In Publication process for Journal of Hydraulic Research, 2015

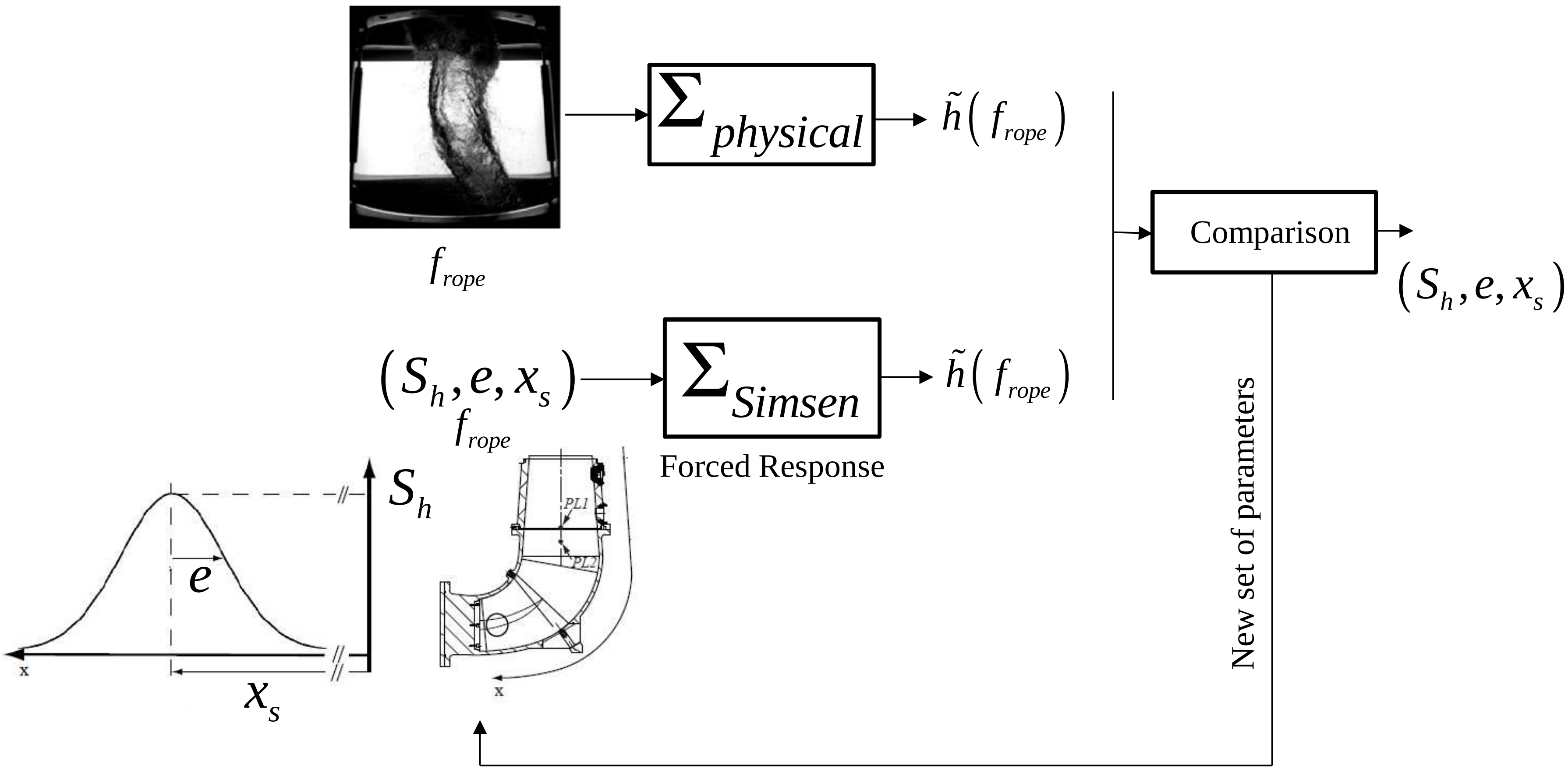




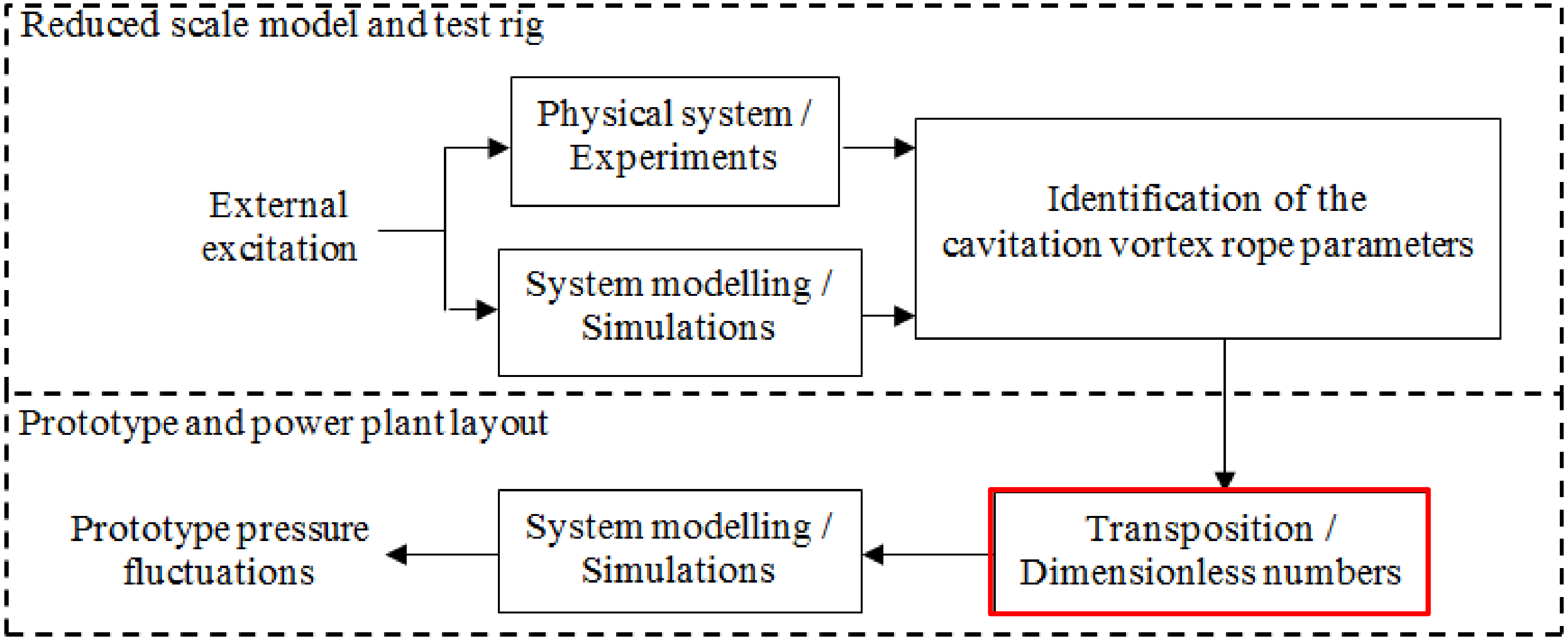


Identification of S_h

C.Landry, EPFL Thesis N°6547, 2015



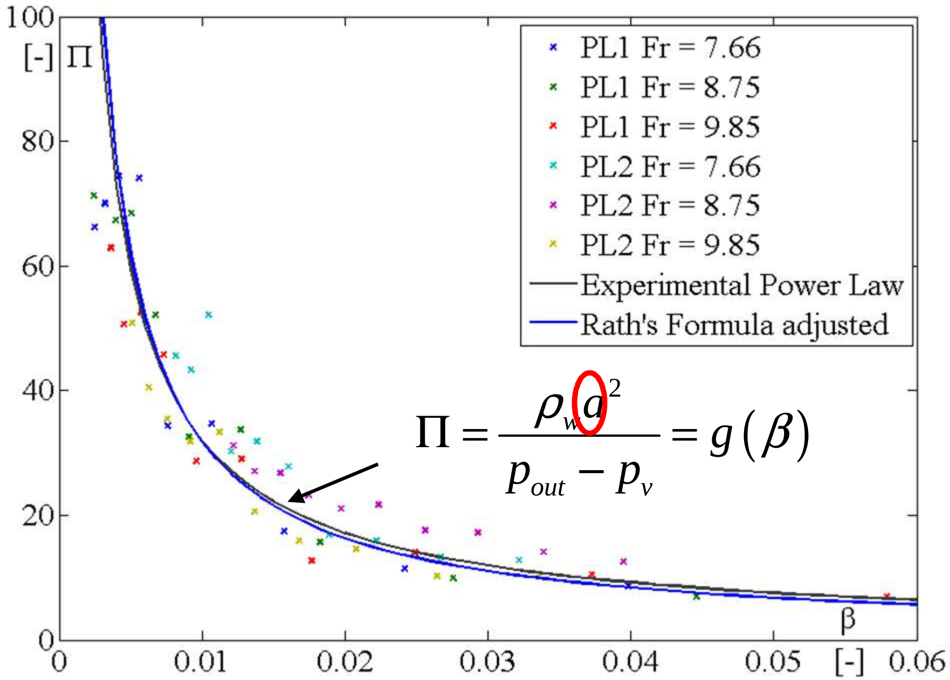
Methodology

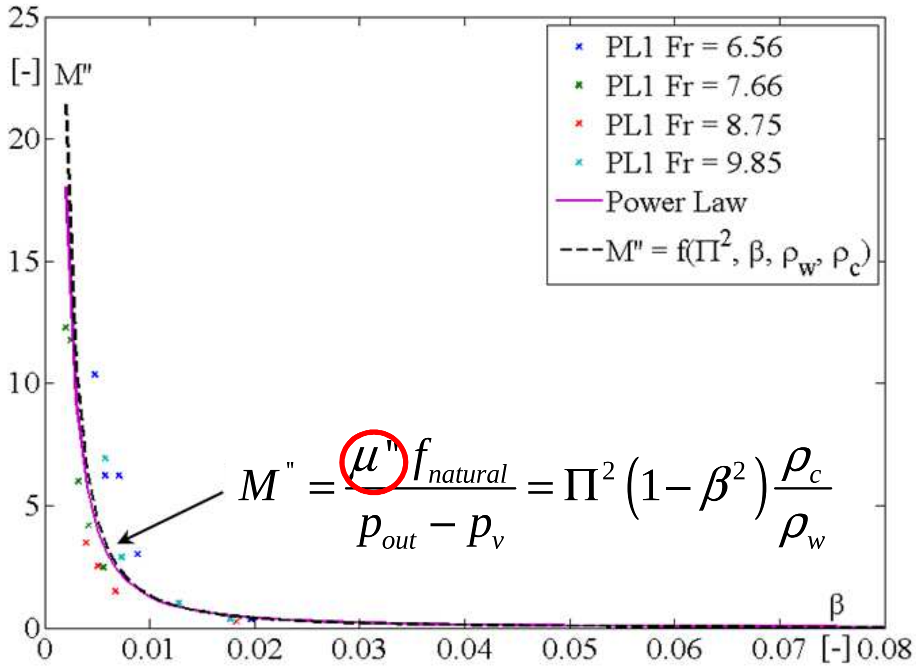


Dimensionless Numbers

C.Landry, A. Favrel, A. Müller, C. Nicolet, F. Avellan, *Experimental identification of the local wave speed and the second viscosity in cavitating draft tube flow*, In Publication process for Journal of Hydraulic Research, 2015

- Wave speed a and μ'' second viscosity

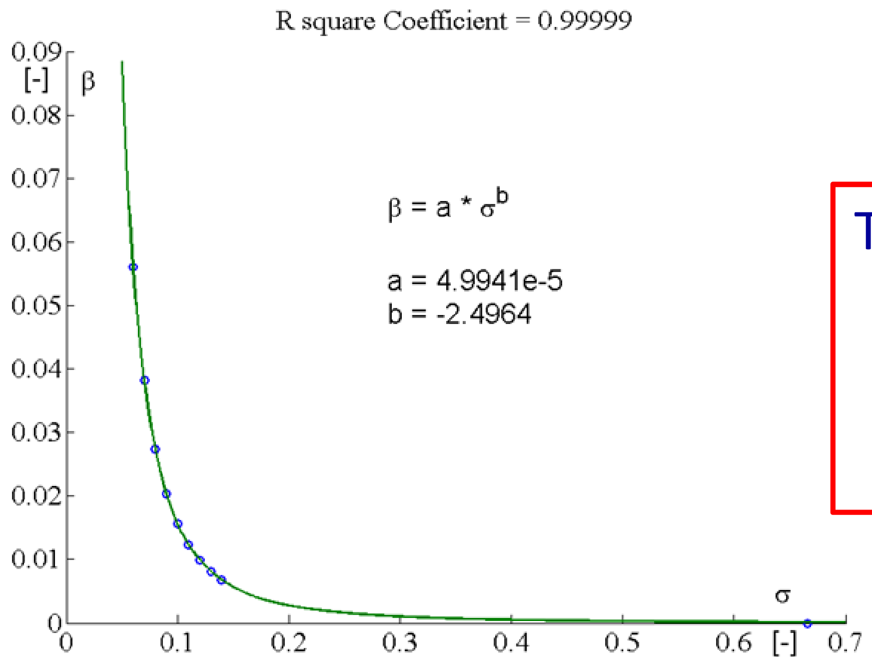




Cavitation Mapping

C. Landry, EPFL Doctoral Thesis N°6547, 2015

$$\beta(\sigma)_{n_{ED},Q_{ED},Fr}$$



Transposition Law

$$\beta^P = \beta^M$$

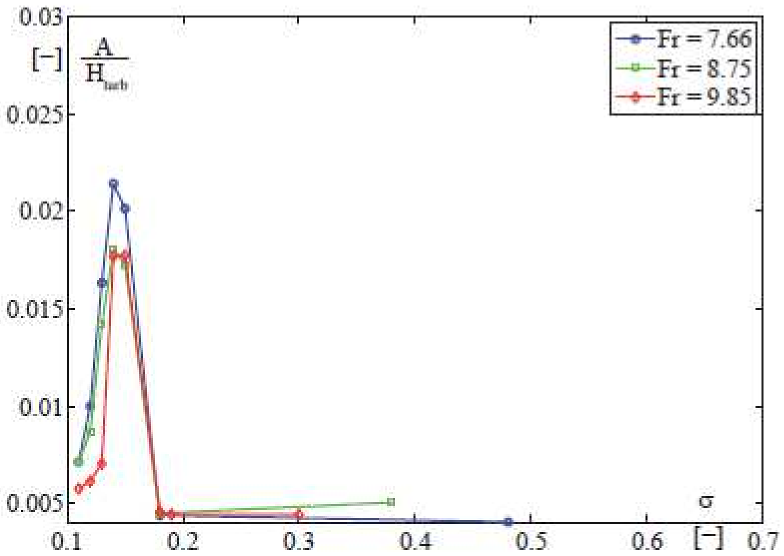
Froude similitude respected !

Excitation Source Mapping

C.Landry, EPFL Thesis N°6547, 2015

$$S_h(\sigma)_{n_{ED}, Q_{ED}, Fr}$$

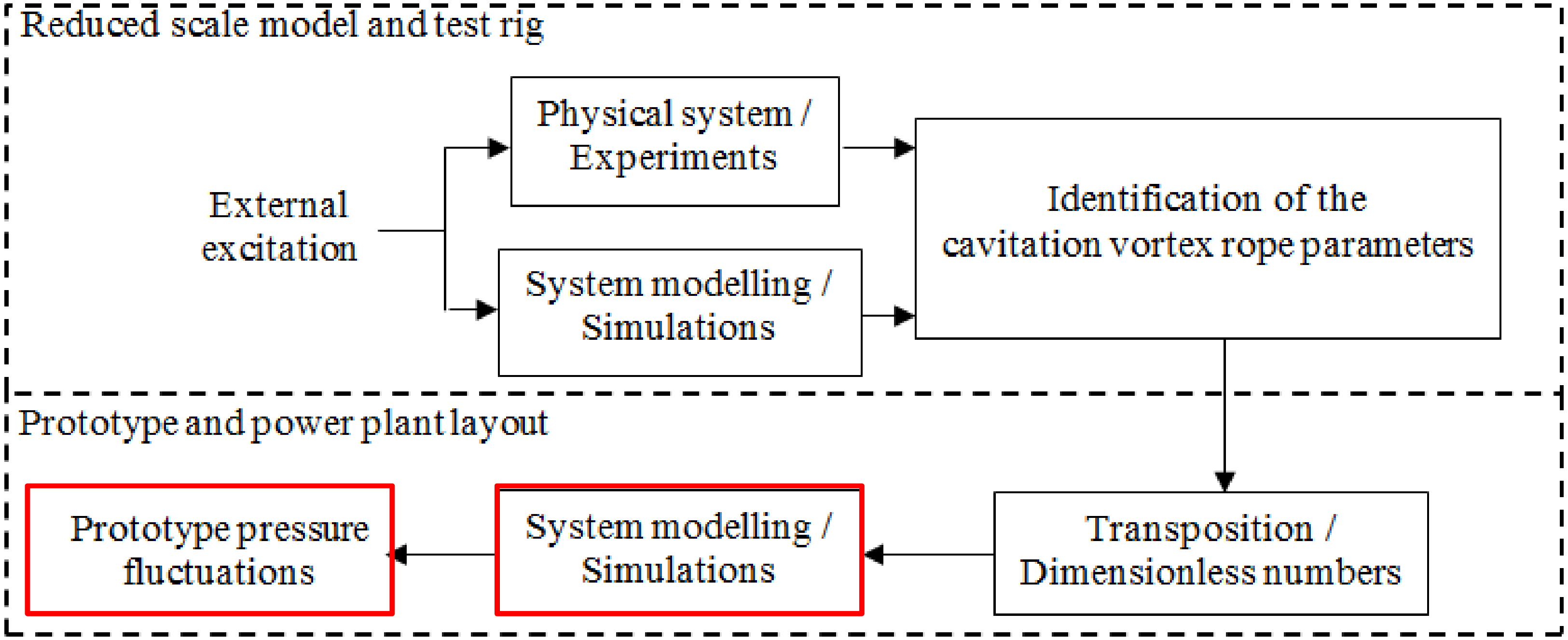
Transposition Laws



$$\begin{cases} S_h^P = S_h^M \left(\dfrac{H_{ref}^P}{H_{ref}^M} \right) \\ e^P = e^M \left(\dfrac{D_{ref}^P}{D_{ref}^M} \right) \\ x_h^P = x_h^M \left(\dfrac{D_{ref}^P}{D_{ref}^M} \right) \end{cases}$$

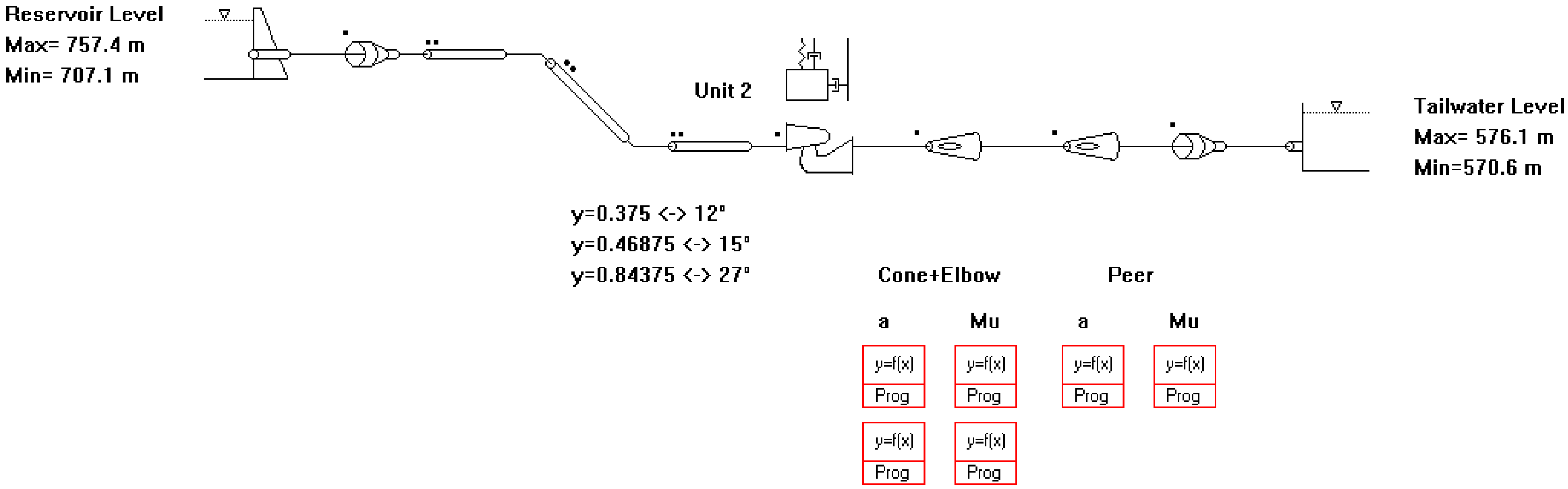
Froude similitude fulfilled!

Methodology



Prototype - 1D Modelling

- SIMSEN System model



$$\left.\begin{matrix} n_{ED}, Q_{ED} \\ Fr \\ \sigma \end{matrix}\right\} \rightarrow \beta \rightarrow \begin{cases} \Pi = \dfrac{\rho_w a^2}{p_{out} - p_v} = g(\beta) & \rightarrow a(t) \\ M'' = \dfrac{\mu'' f_{natural}}{p_{out} - p_v} = \Pi^2 \left(1 - \beta^2\right) \dfrac{\rho_c}{\rho_w} & \rightarrow \mu''(t) \end{cases}$$

Prediction of eigenmodes

- DT parameters and predicted eigenmodes

	Distributed Model		Lumped Model
	Constant Para.	Variable Para.	
σ (–)	0.11		0.108
Void Frac.β (–)	0.0124		0.0128
a (m/s)	76.9	55 – 100	75.7
μ" (Pa.s)	3.06E+05	1.5E+05 – 5.7E+05	3.12E+05
$\alpha 1$ (s^{-1})	-0.40	-0.38	-0.40
f1 (Hz)	0.65	0.63	0.6
Unstable eigenmodes	No	No	Yes

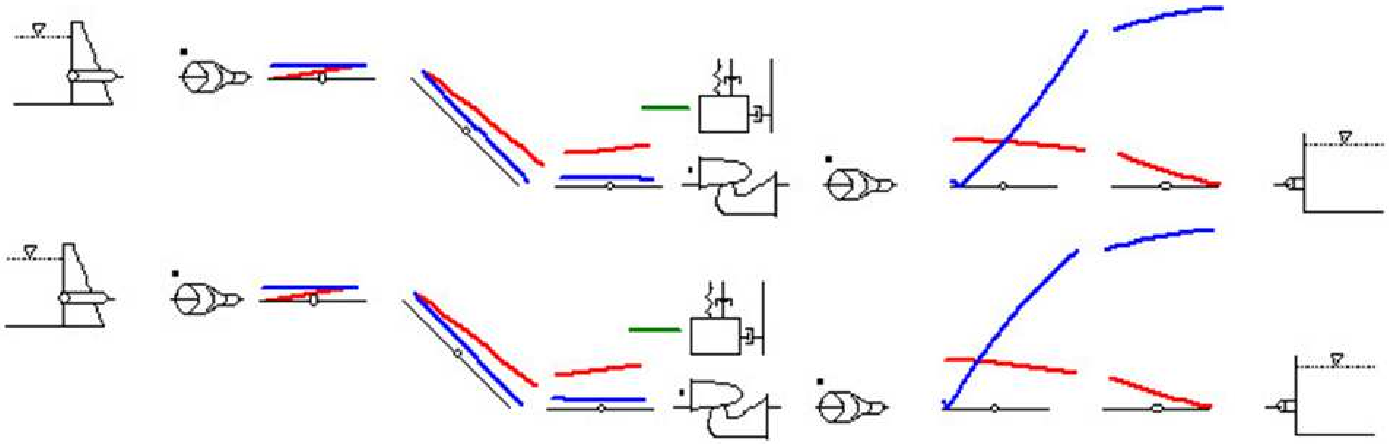
✓Unstable eigenmodes with lumped model

Prediction of eigenmodes

- Shape of pressure and discharge 1st eigenmode

Distributed
Constant Parameters

Distributed
Variable Parameters



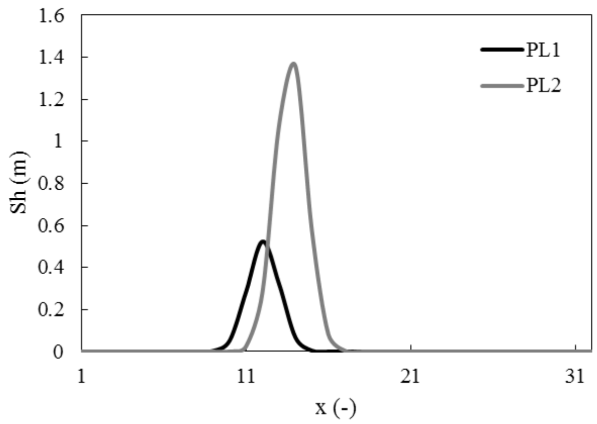
✓Small changes on eigenmodes shapes

Prediction of pressure fluctuations

- 2 investigated OP
  - ✓Eigenmodes

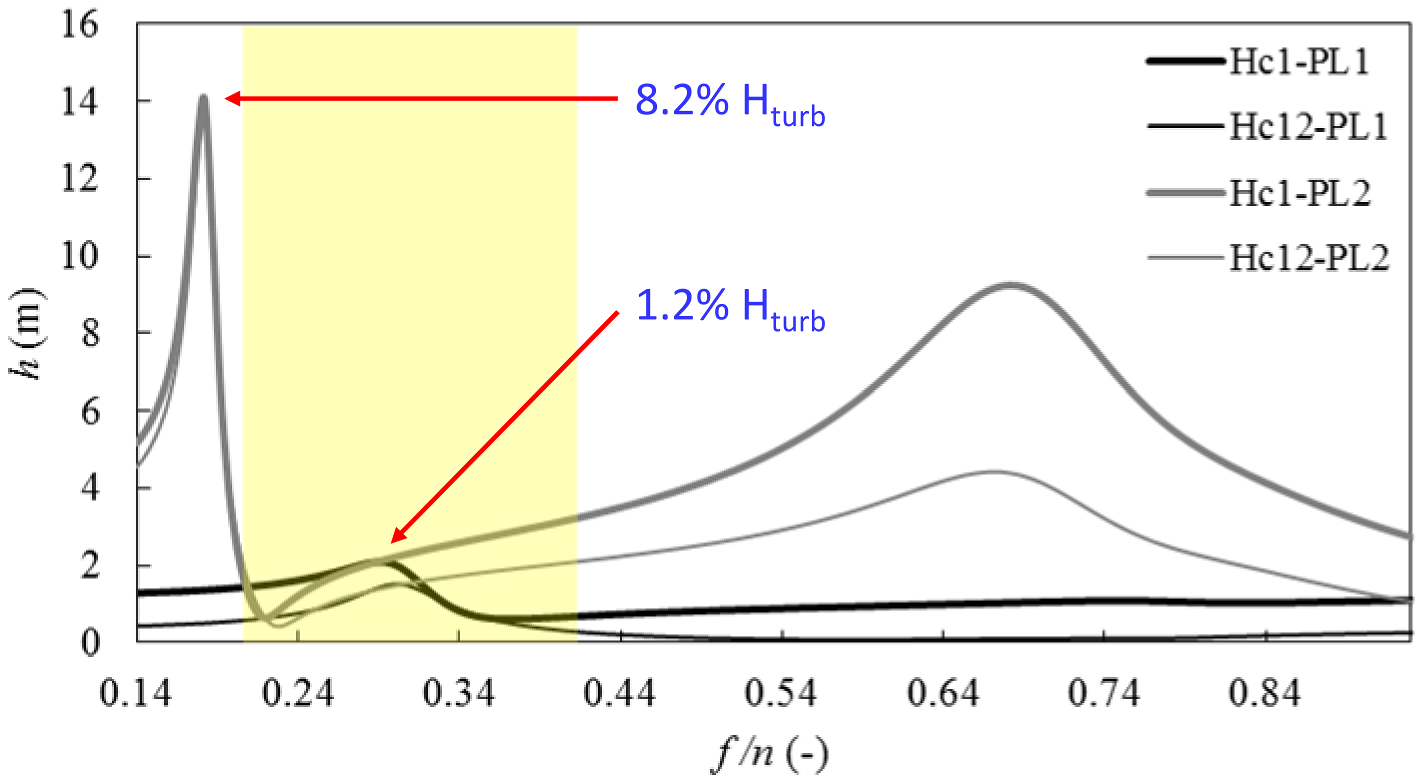
	PL1	PL2
σ (–)	0.11	0.11
β (–)	0.0124	0.0421
a (m/s)	76.9	45.3
μ" (Pa.s)	3.06E+05	6.14E+04
α1 (s^{-1})	–0.40	–0.10
f1 (Hz)	0.65	0.39

  - ✓Excitation source



Prediction of pressure fluctuations

- System response



Conclusions

- Methodology applied for transposition of pressure fluctuations on reduced scale model to prototype:
  - ✓ Prediction of different amplitudes as function of the OP
  - ✓ Froude similitude should be respected $\beta^P = \beta^M$
  - ✓ Mass flow gain factor neglected
    - Second campaign planned
    - Could change predicted amplitudes
- Measurements on prototype scheduled for validation

HYPERBOLE

HYdropower plants PERformance and flexiBle Operation towards Lean integration of new renewable Energies

European Commission

SEVENTH FRAMEWORK PROGRAMME

LMH Laboratory for Hydraulic Machines

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

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Hes·so VALAIS WALLIS

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Universität Stuttgart

Merci pour votre attention!

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