Computations of cavitating flow on hydrofoils

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OUTLINE

- **Introduction**
- **Modelling**
- **Problem Setup**
- **Results**
- **Conclusions**

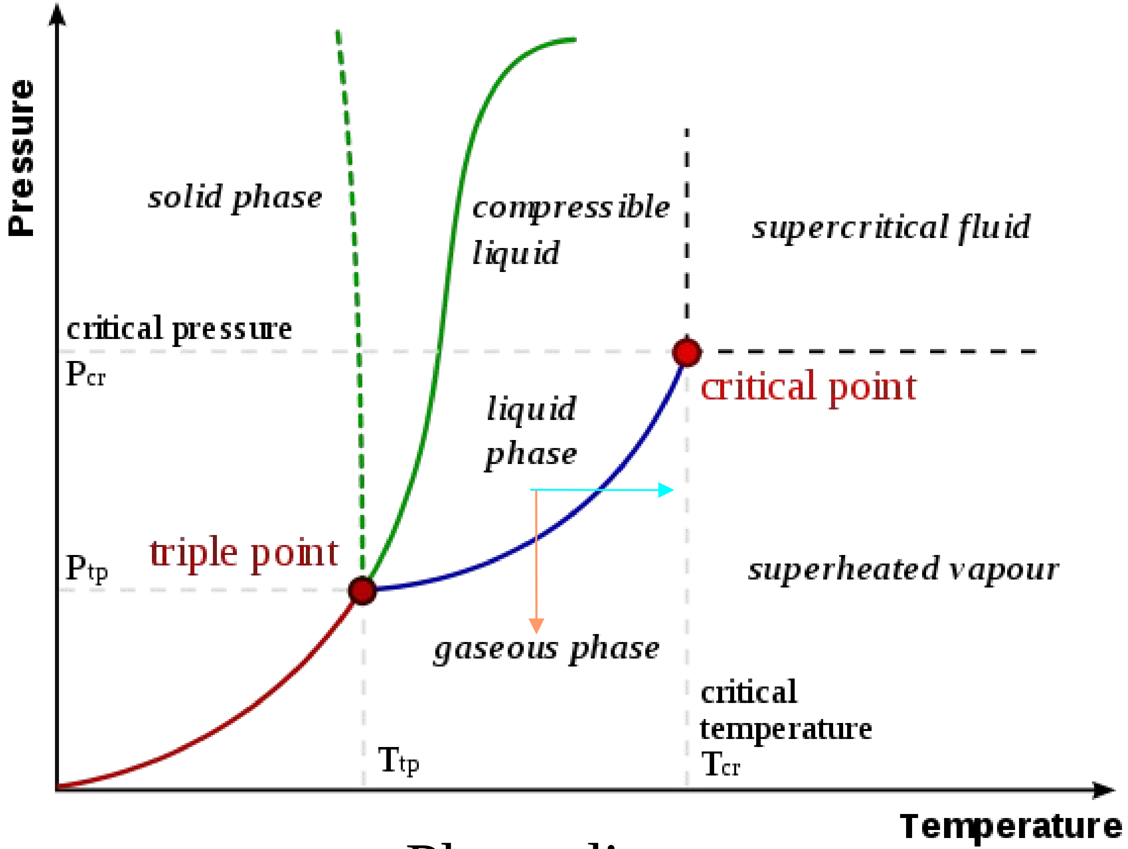
INTRODUCTION

- Cavitation
  - what is it?
  - where does it occur?
  - different types of cavitation
  - why do we want to understand it?

INTRODUCTION

Cavitation - what is it?

Definition : Formation of vapor cavities in a liquid due to pressure drop.



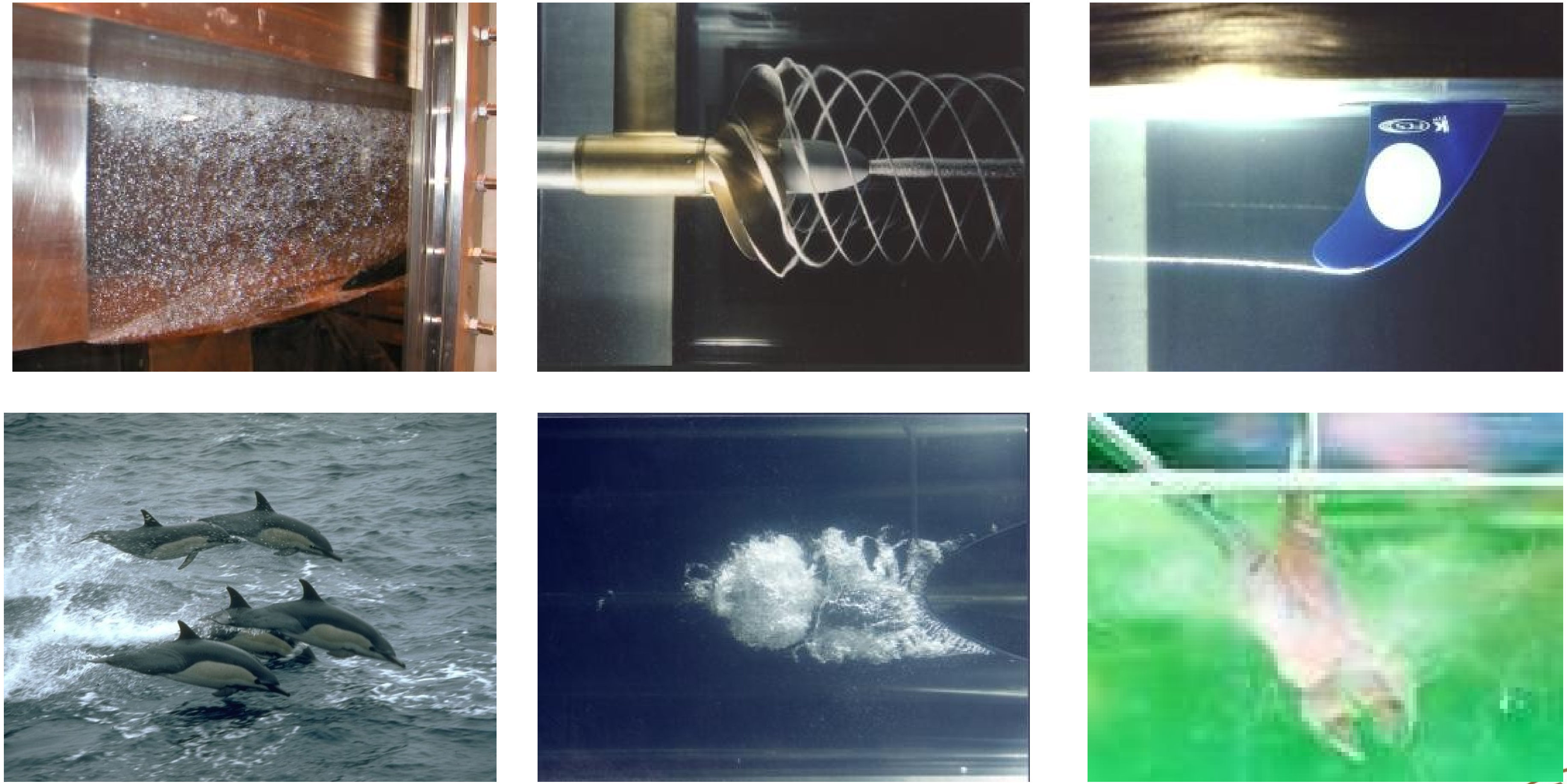
Boiling

Cavitation

Phase diagram

INTRODUCTION

Cavitation – where does it occur?



INTRODUCTION

Cavitation – different types of cavitation

$$\sigma = \frac{p_\infty - p_v}{\frac{1}{2}\rho u_\infty^2}$$

σ_c

$\sigma < \sigma_c$ $\downarrow$

(a) Travelling bubble

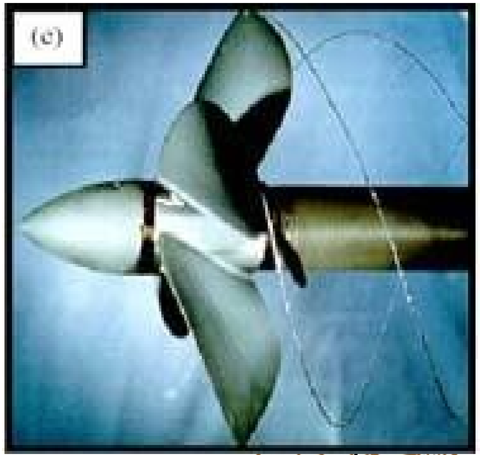
Attached cavitation

- Sheet cavitation (c)

-Cloud cavitation (b)

(d) Supercavitation

(e) Vortex cavitation



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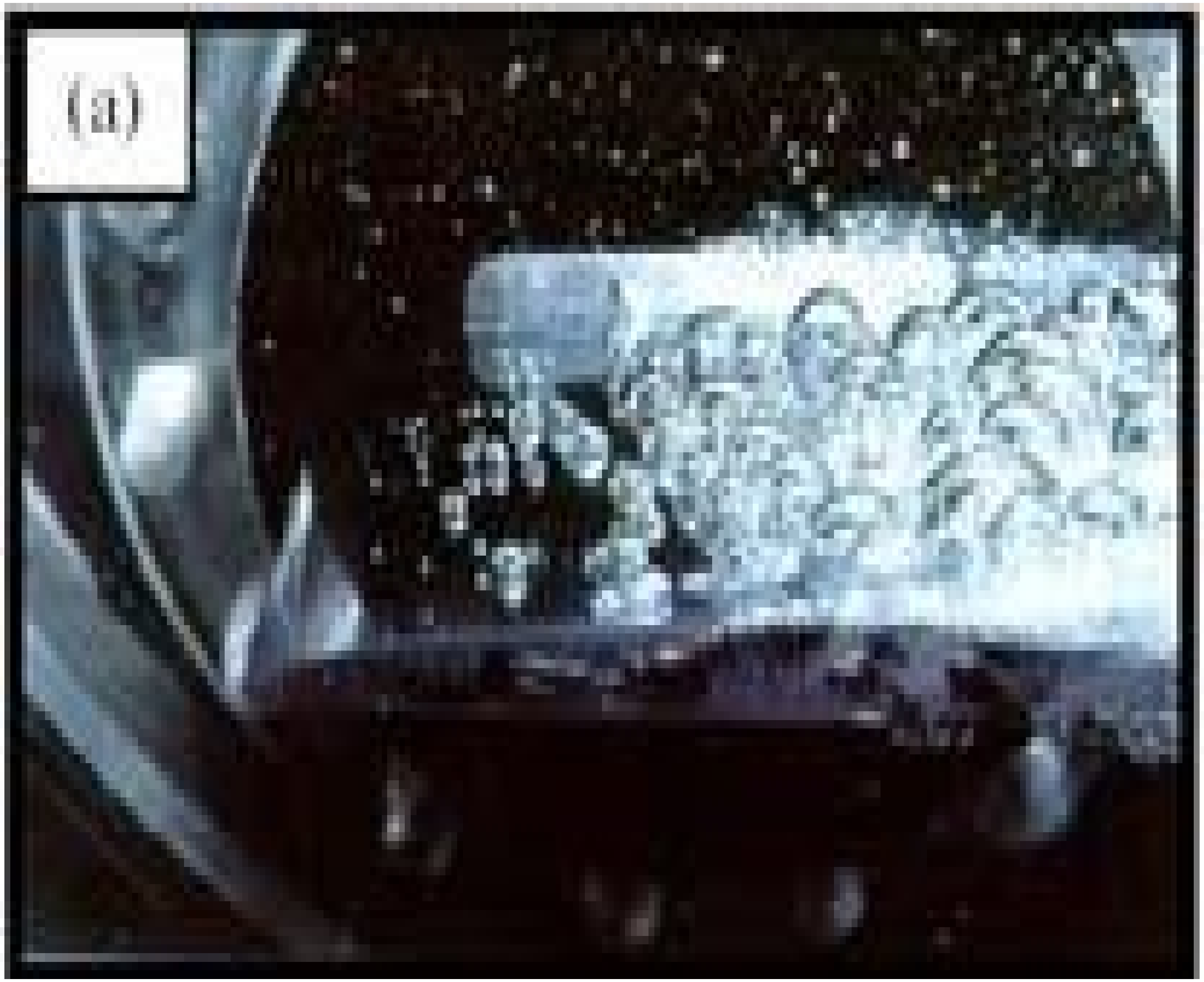

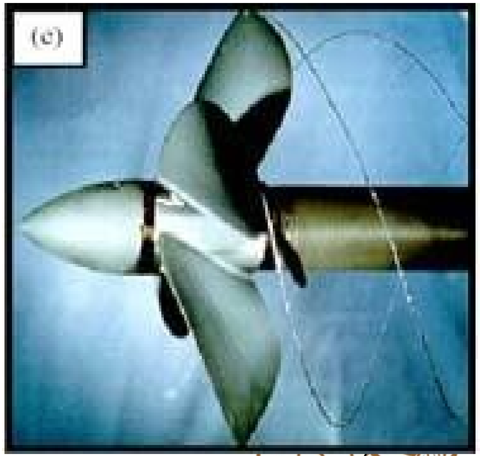

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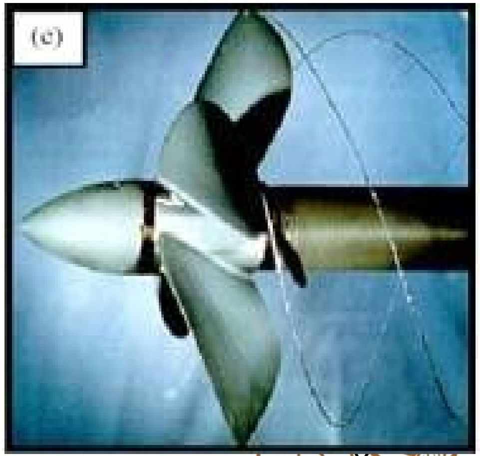

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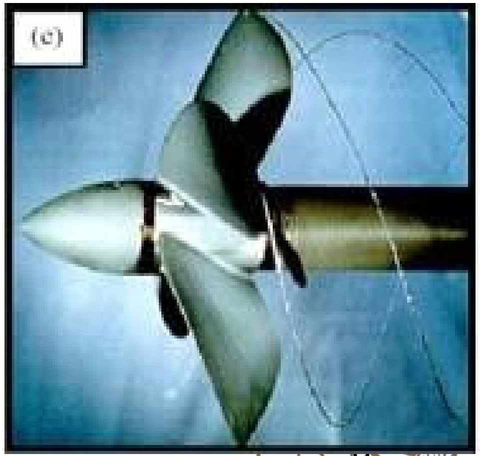

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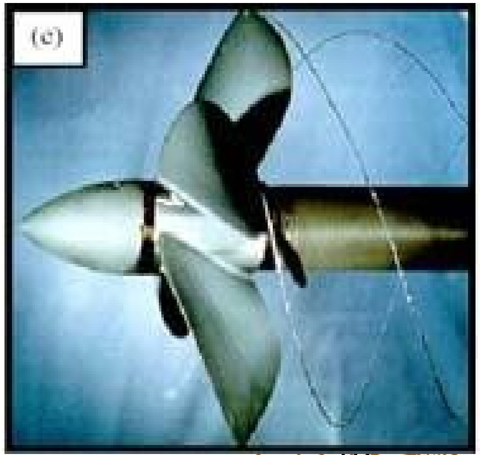

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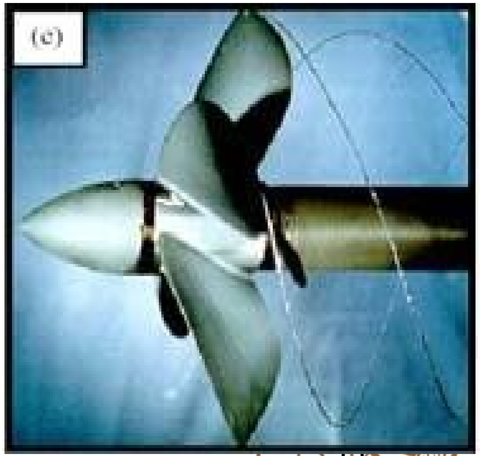

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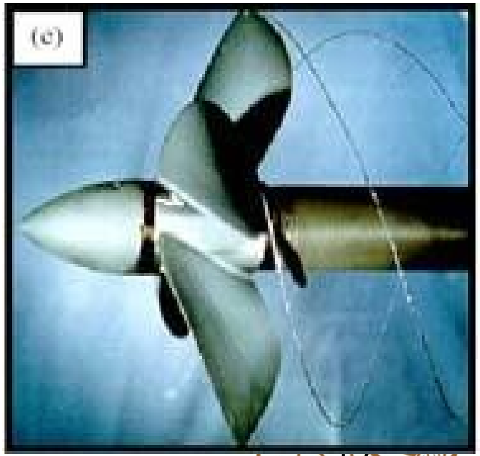

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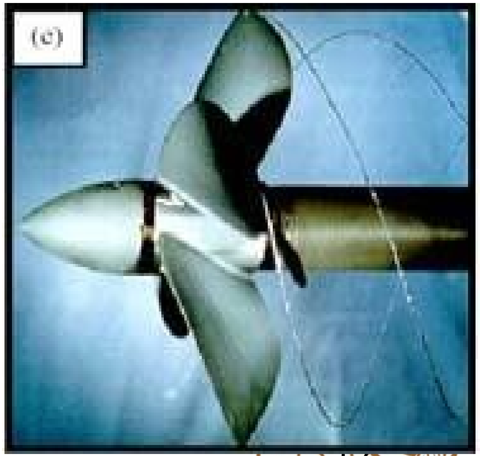

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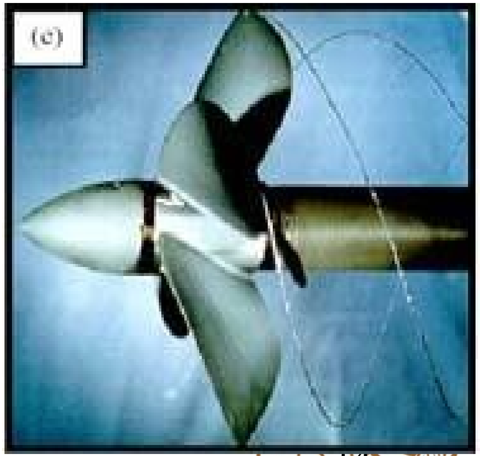
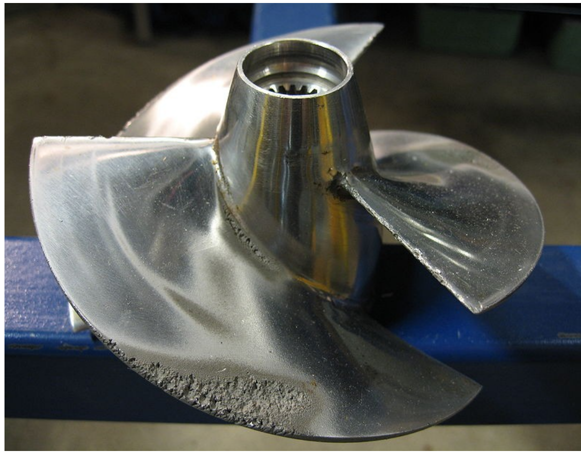


INTRODUCTION

Cavitation – why do we want to understand it?



- Negative effects :
  - noise,
  - vibration,
  - material damages (erosion due to the collapse)
  - performance reduction

Understand cavitation inception and evolution

→ avoid (at least control and reduce) these effects

- Difficult to predict because it depends on
  - flow conditions
  - water nuclei
  - surface roughness

MODELLING

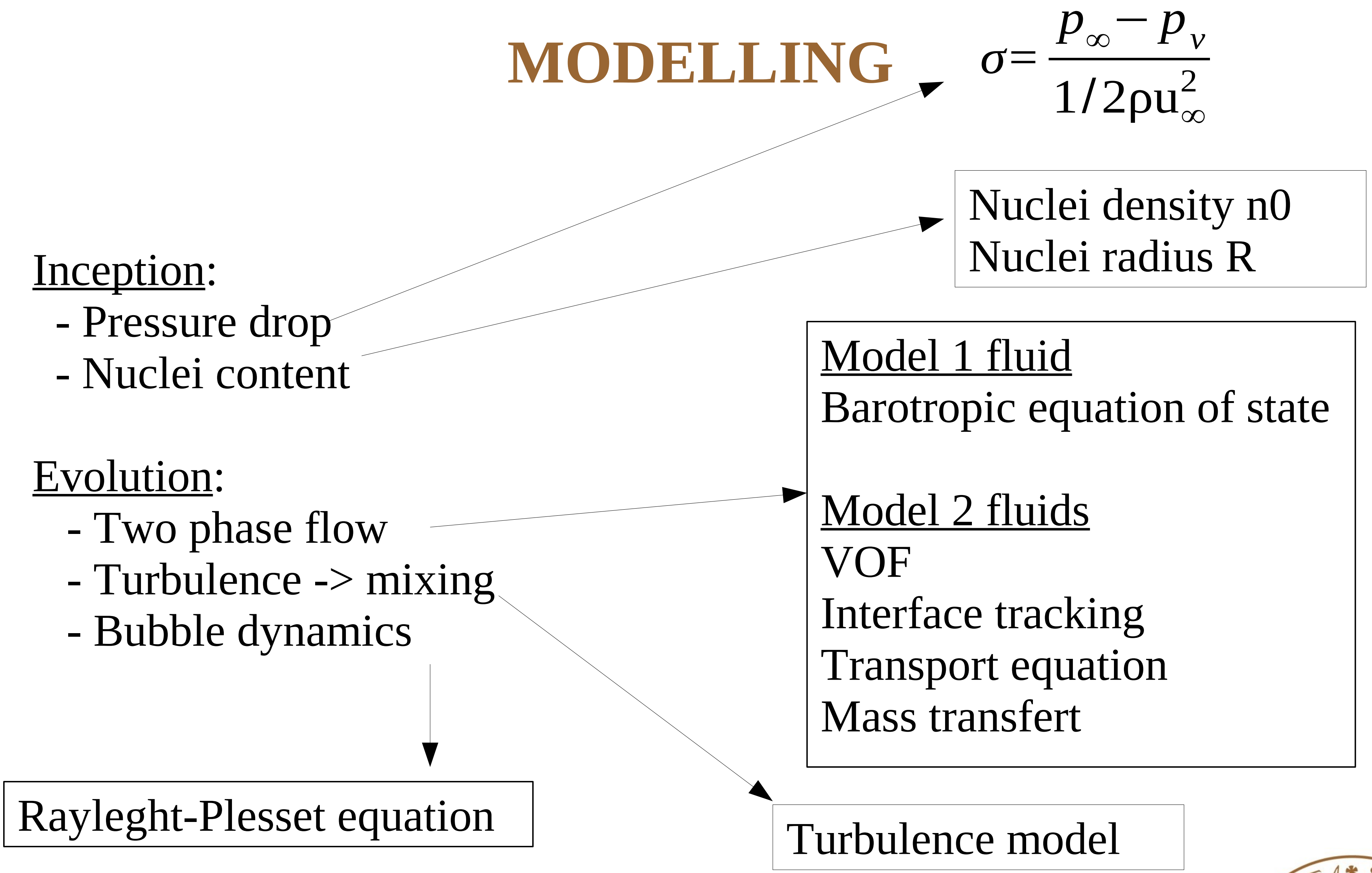
<ins>Inception</ins>:

- Pressure drop
- Nuclei content

<ins>Evolution</ins>:

- Two phase flow
- Bubble dynamics
- Turbulence -> mixing

MODELLING



$$\sigma = \frac{p_\infty - p_v}{1/2\rho u_\infty^2}$$

Nuclei density n0
Nuclei radius R

Inception:
- Pressure drop
- Nuclei content

Evolution:
- Two phase flow
- Turbulence -> mixing
- Bubble dynamics

Model 1 fluid
Barotropic equation of state

Model 2 fluids
VOF
Interface tracking
Transport equation
Mass transfert

Raylegh-Plesset equation

Turbulence model

$$\rho\left(R\ddot{R} + \frac{3}{2}\dot{R}^2 + 4\nu\frac{\dot{R}}{R}\right) = p_v - p(t) - \frac{2S}{R} + \left(\frac{2\gamma}{R_0} - (p_v - p_0)\right)\left(\frac{R_0}{R}\right)^{3\Gamma}$$

MODELLING

Sauer Model

VOF ---> vapor volume fraction α

$$\rho = \rho_v \alpha + \rho_l (1 - \alpha)$$
$$\mu = \mu_v \alpha + \mu_l (1 - \alpha)$$

$$\frac{\partial \alpha}{\partial t} + \nabla . (\alpha \vec{u}) = \boxed{\frac{\dot{m}}{\rho_l}}$$

Mass transfer rate = creation of vapour $\dot{m}^{+}$
+ destruction of vapour $\dot{m}^{-}$

$$\frac{\partial \rho}{\partial t} + \nabla . (\rho \vec{u}) = 0$$

$$\rho \frac{\partial \vec{u}}{\partial t} + \rho (\vec{u} . \nabla \vec{u}) = -\nabla p + \mu \nabla^2 \vec{u} - \boxed{\sigma \kappa \frac{\nabla \alpha}{|\nabla \alpha|}}$$

MODELLING

Sauer Model

VOF ---> vapor volume fraction α

Vapor= small spherical bubbles

$$\rho=\rho_v\alpha+\rho_l(1-\alpha)$$

$$\mu=\mu_v\alpha+\mu_l(1-\alpha)$$

$$\alpha=\frac{n_0 . \frac{4}{3}\pi R^3}{1+n_0 . \frac{4}{3}\pi R^3}$$

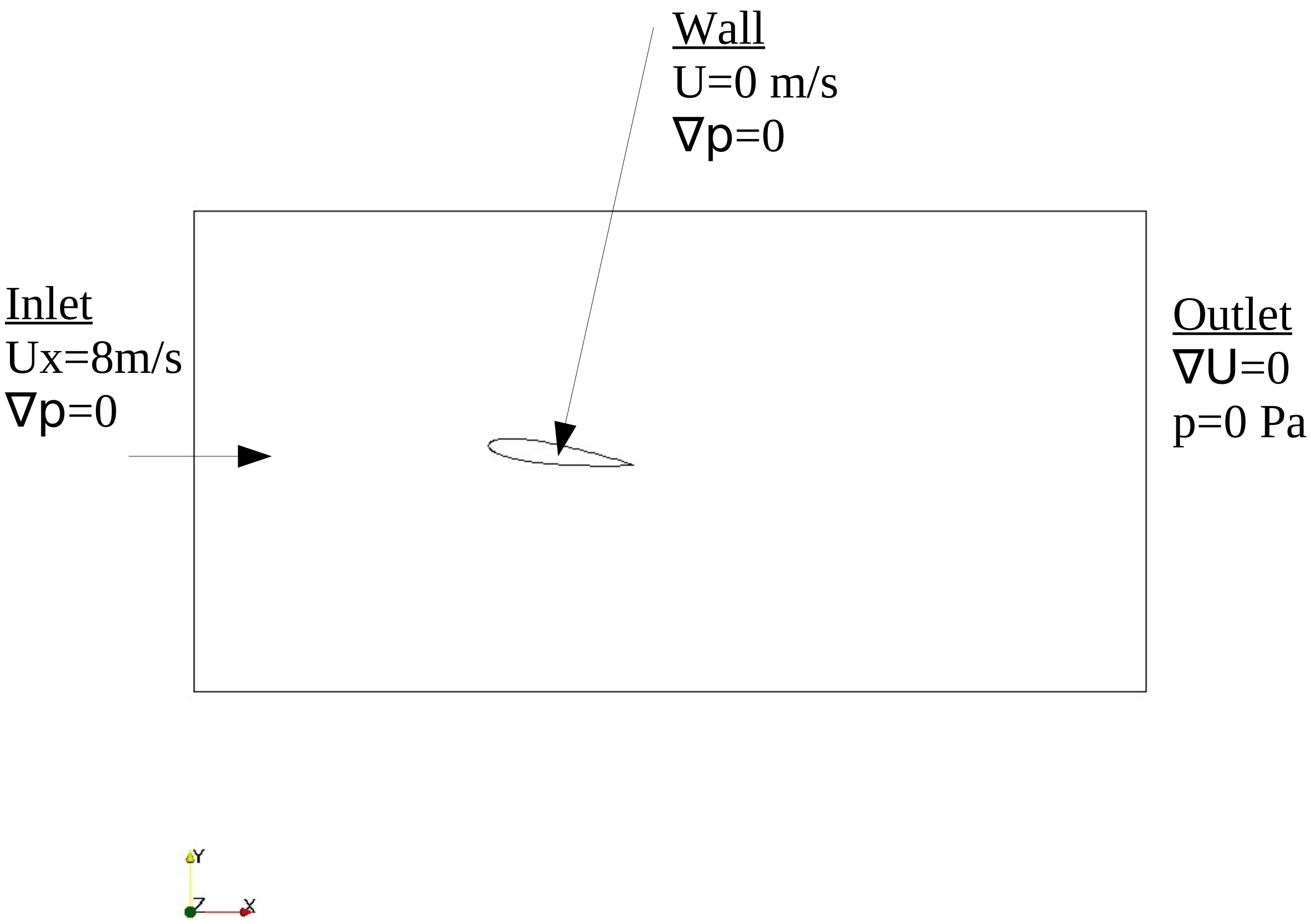
$$\frac{dR}{dt}=\sqrt{\frac{2}{3}\frac{p(R)-p_\infty}{\rho_l}}$$

$$\frac{\partial\alpha}{\partial t}+\nabla.(\alpha\vec{u})=\boxed{\frac{\dot{m}}{\rho_l}} \quad \longrightarrow \quad \frac{d\alpha}{dt}=(1-\alpha)\frac{n_0 . \frac{4}{3}\pi R^2\dot{R}}{1+n_0 . \frac{4}{3}\pi R^3}$$

$$\frac{\partial\rho}{\partial t}+\nabla.(\rho\vec{u})=0 \longrightarrow \nabla.\vec{u}=\frac{-1}{\rho}\left(\frac{\partial\rho}{\partial t}+\vec{u}\,\nabla.\rho\right)=\frac{-1}{\rho}\frac{\partial\rho}{\partial t}=\frac{\rho_l-\rho_v}{\rho}\frac{\partial\alpha}{\partial t}$$

$$\rho\frac{\partial\vec{u}}{\partial t}+\rho(\vec{u}.\nabla\vec{u})=-\nabla p+\mu\nabla^2\vec{u}-\boxed{\sigma\kappa\frac{\nabla\alpha}{|\nabla\alpha|}}$$

PROBLEM SETUP



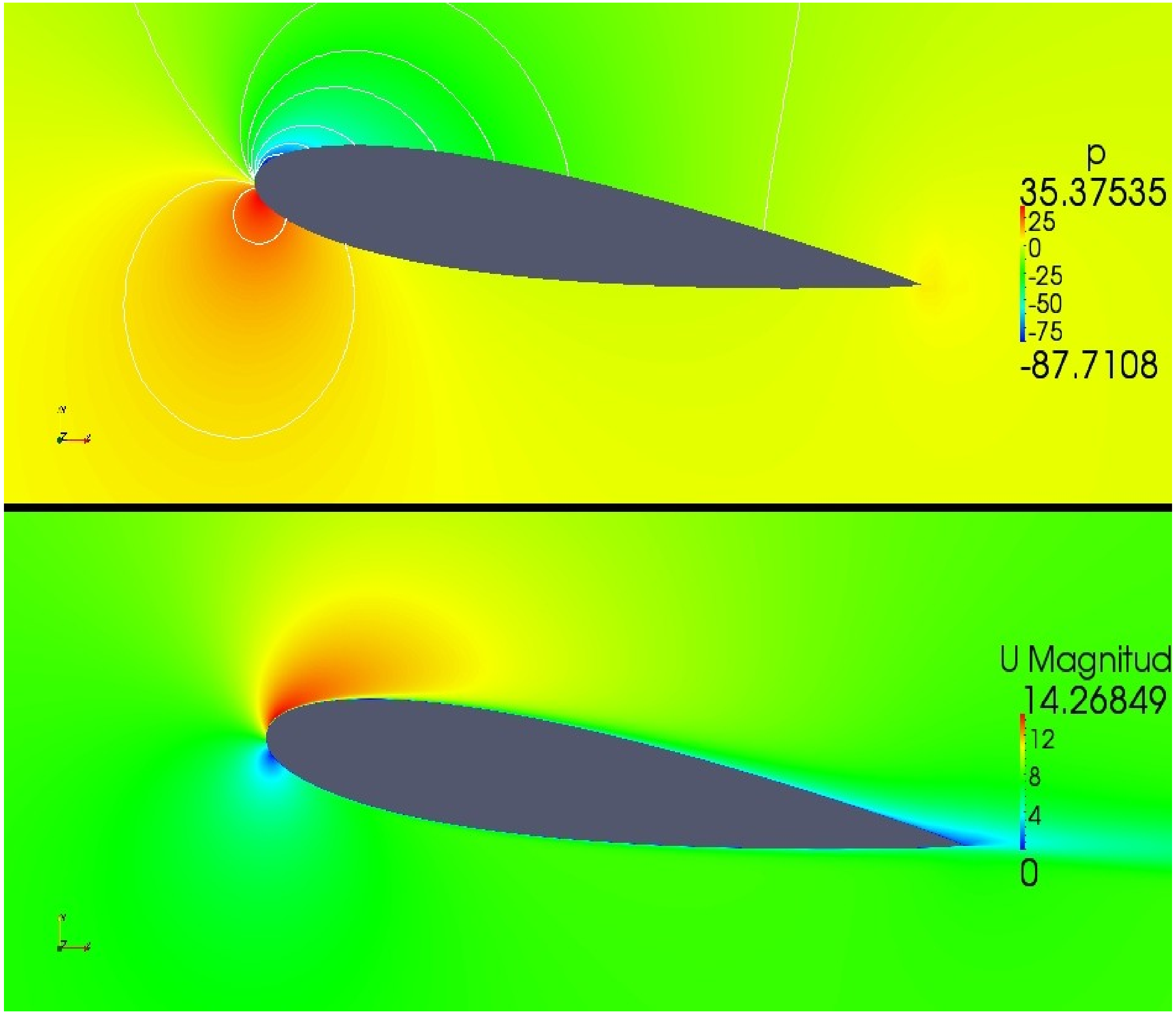
Wall
U=0 m/s
∇p=0

Inlet
Ux=8m/s
∇p=0

Outlet
∇U=0
p=0 Pa

Naca0015 profile (chord length=0.15m , angle of attack=8°)
2D geometry (1m*0.5m)
Re=1.2 $*10^6$

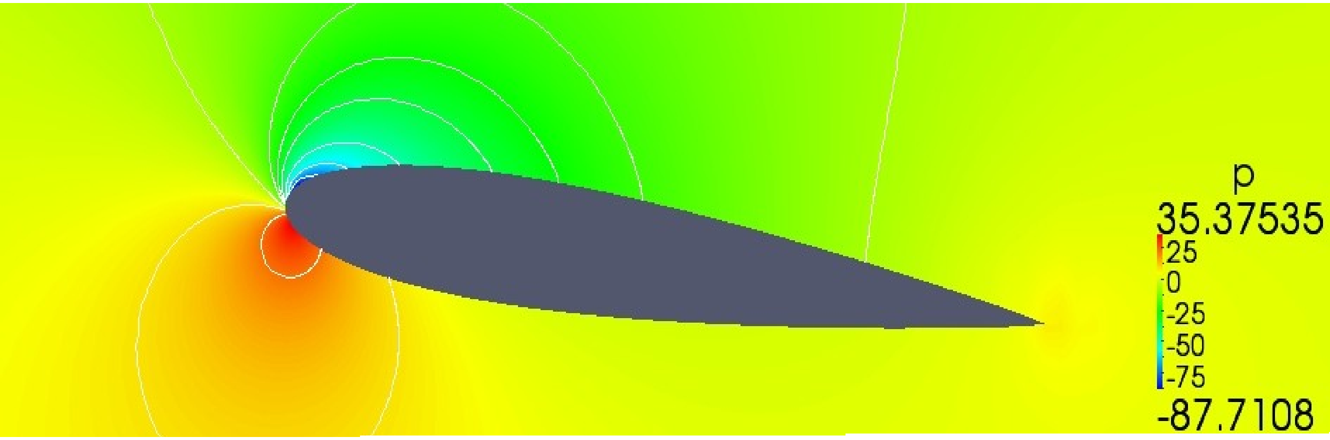
RESULTS

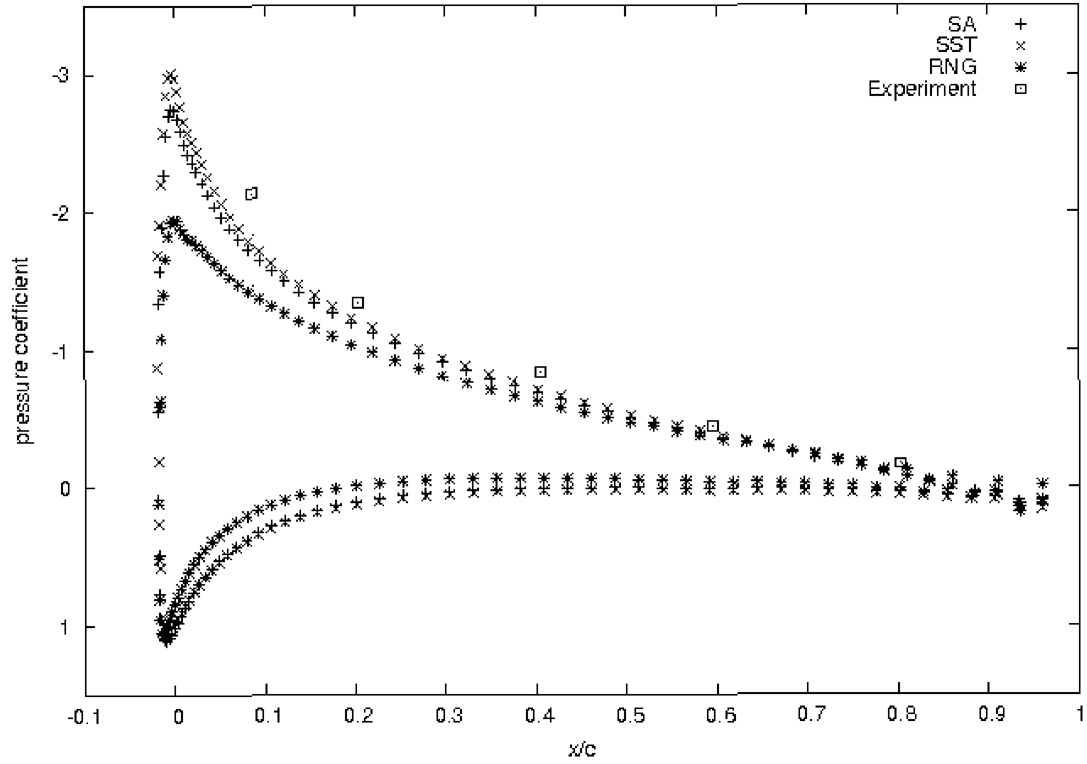


-Spallart Allmaras model

-Wall function (y+= 30)

RESULTS





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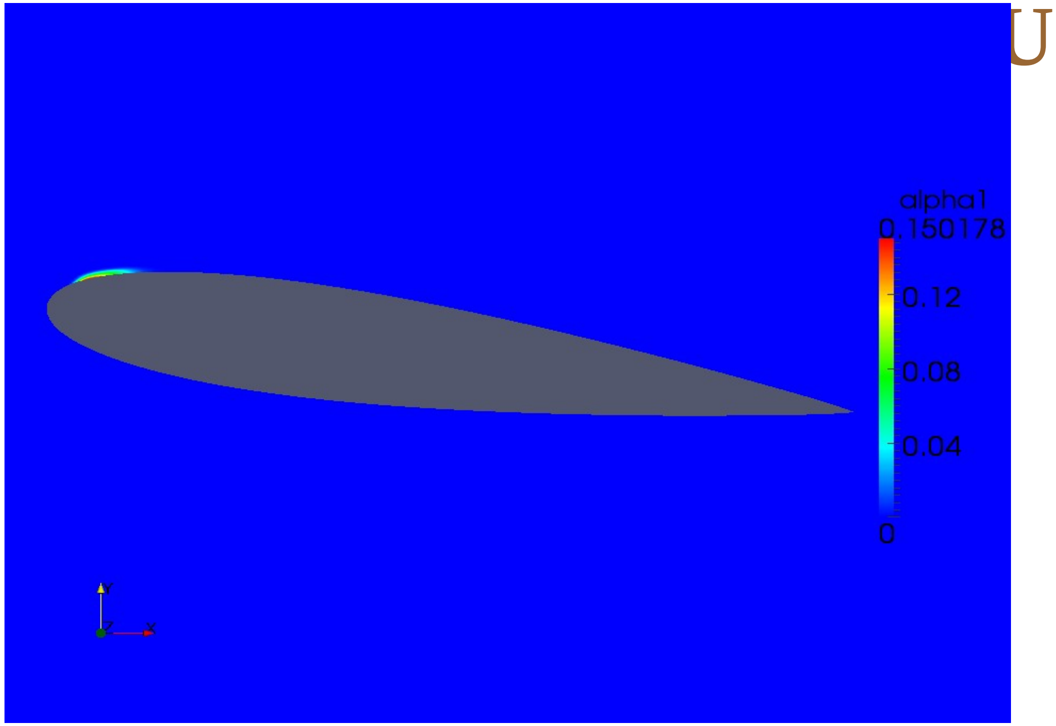
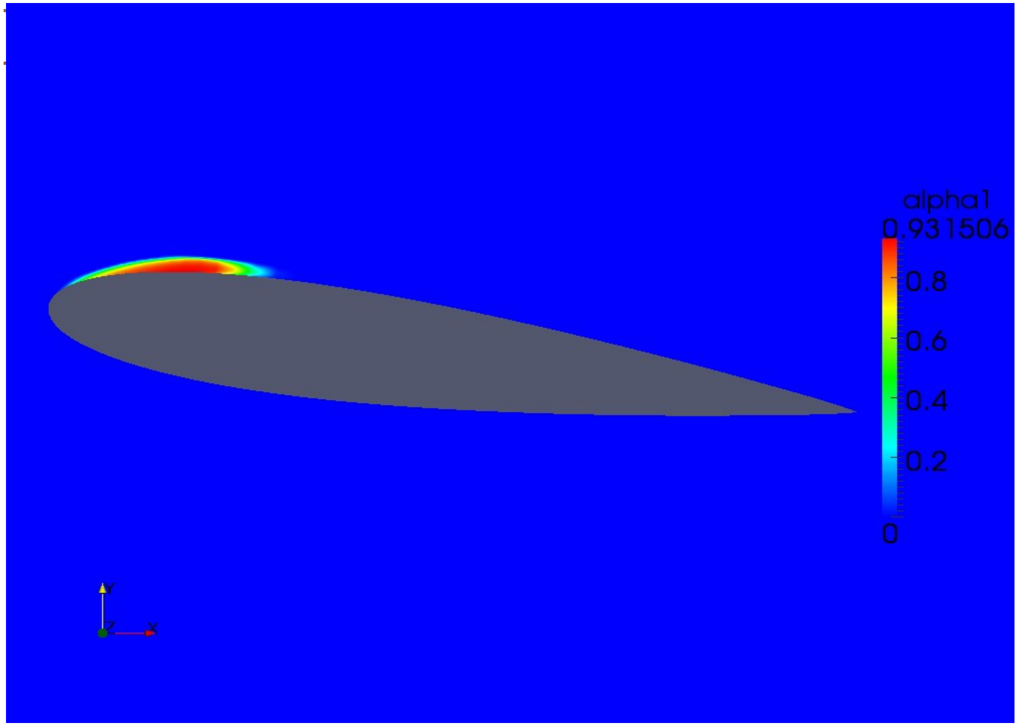
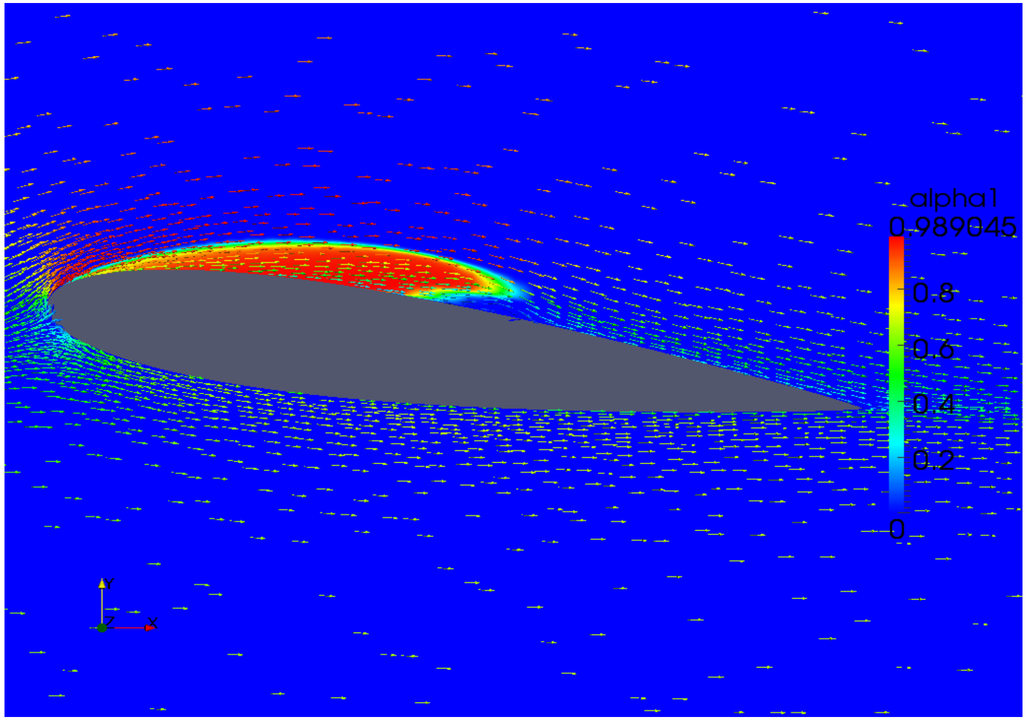

alpha1
0.150178
0.12
0.08
0.04
0
Y
Z
X


alpha1
0.931506
0.8
0.6
0.4
0.2
0
Y
Z
X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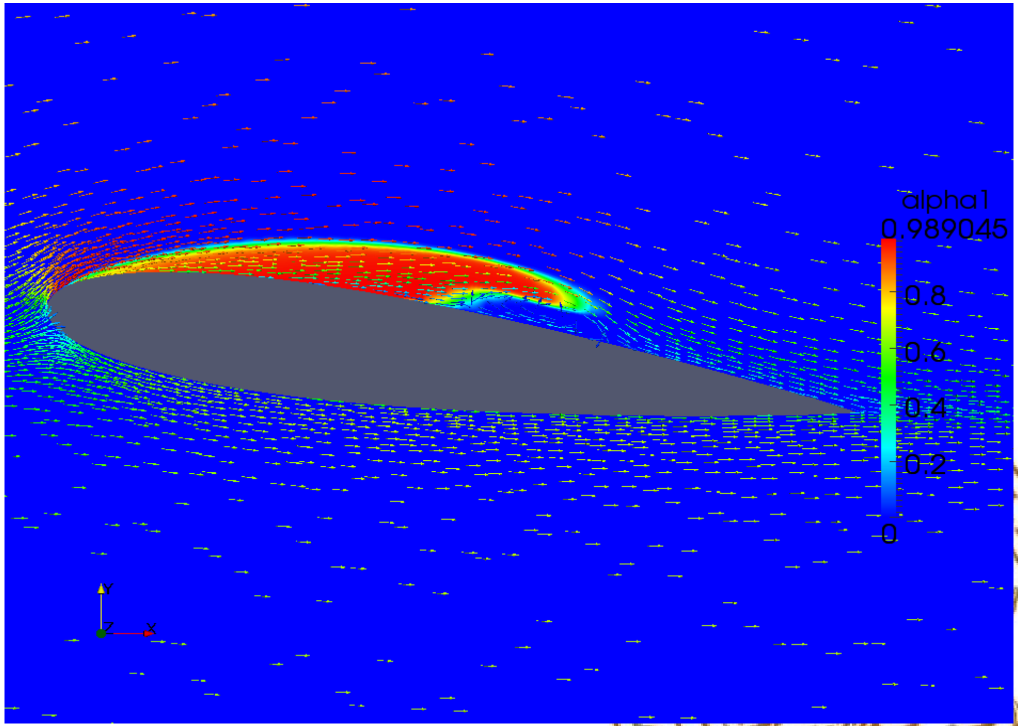
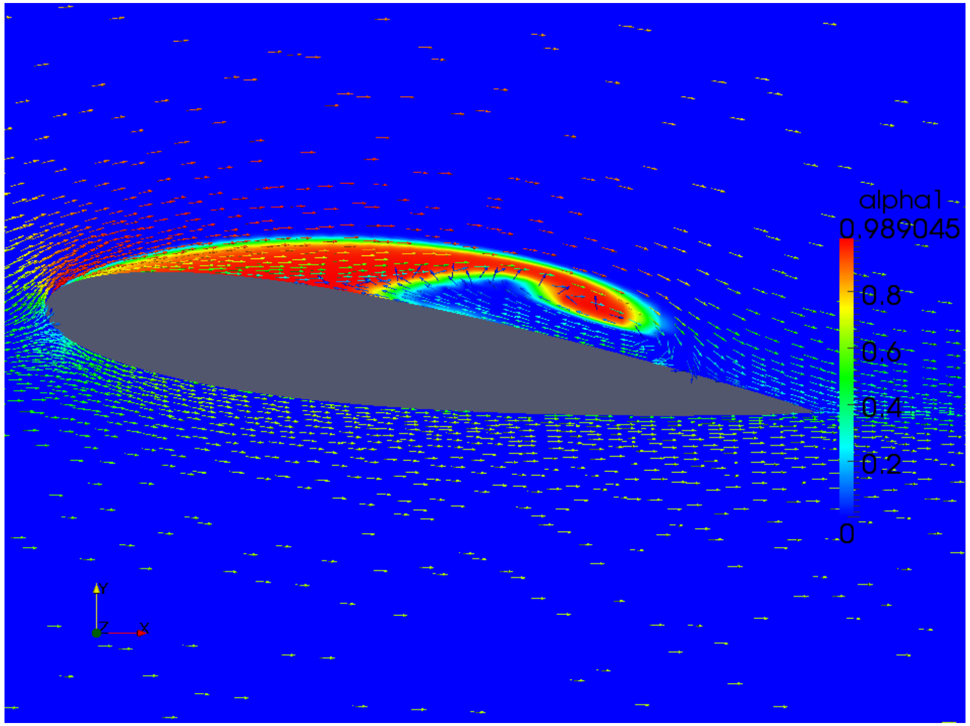
0.8
0.6
0.4
0.2
0
Y
Z
X


alpha1
0.989045
0.8
0.6
0.4
0.2
0
Y
Z
X


alpha1
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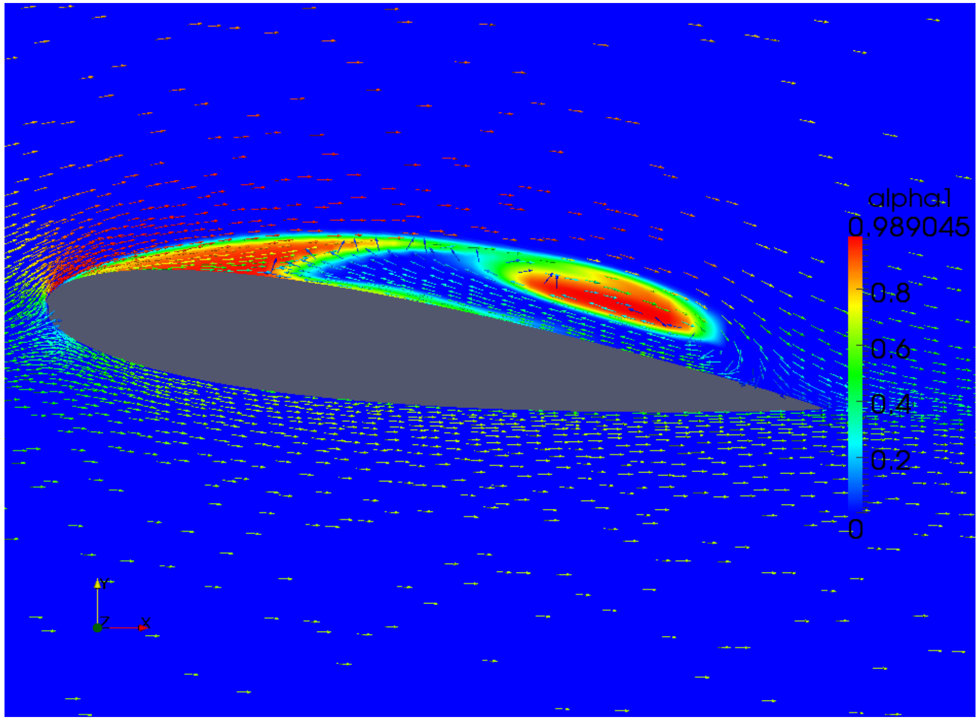
0.8
0.6
0.4
0.2
0
Y
Z
X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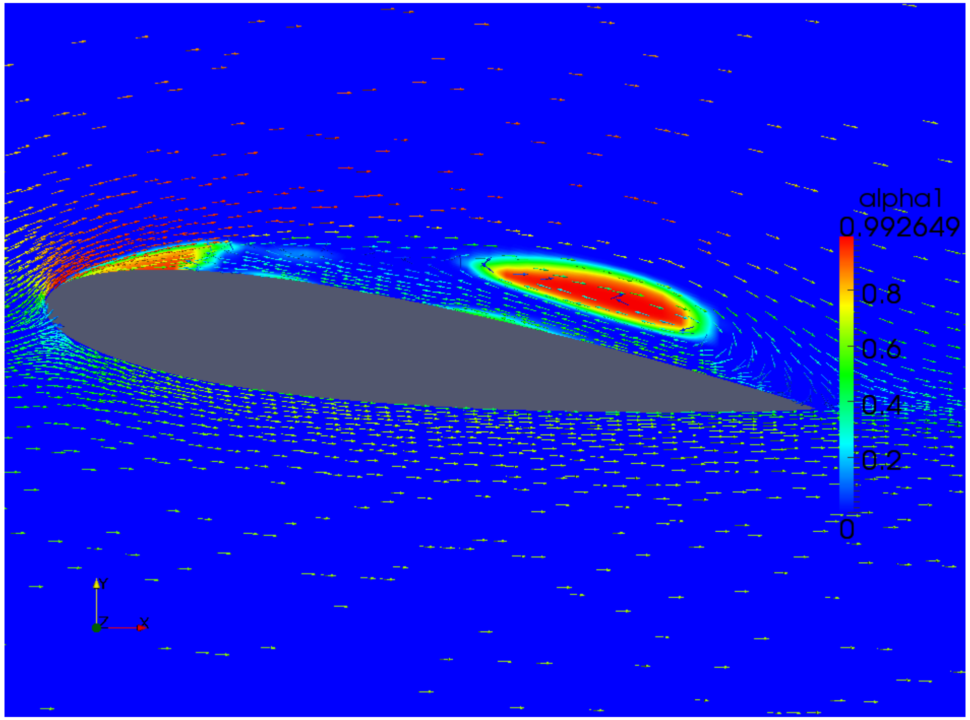
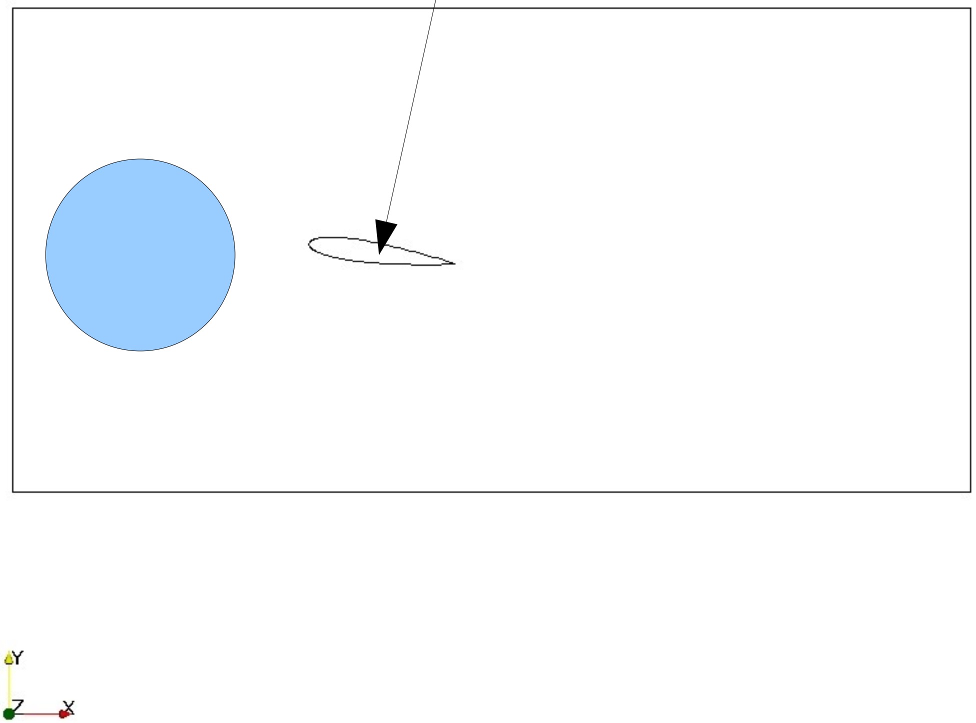
0.989045
0.8
0.6
0.4
0.2
0
Y
Z
X


alpha1
0.992649
0.8
0.6
0.4
0.2
0
Y
Z
X

PROBLEM SETUP

Wall
U=0 m/s
∇p=0

Inlet
Ux=8m/s
∇p=0

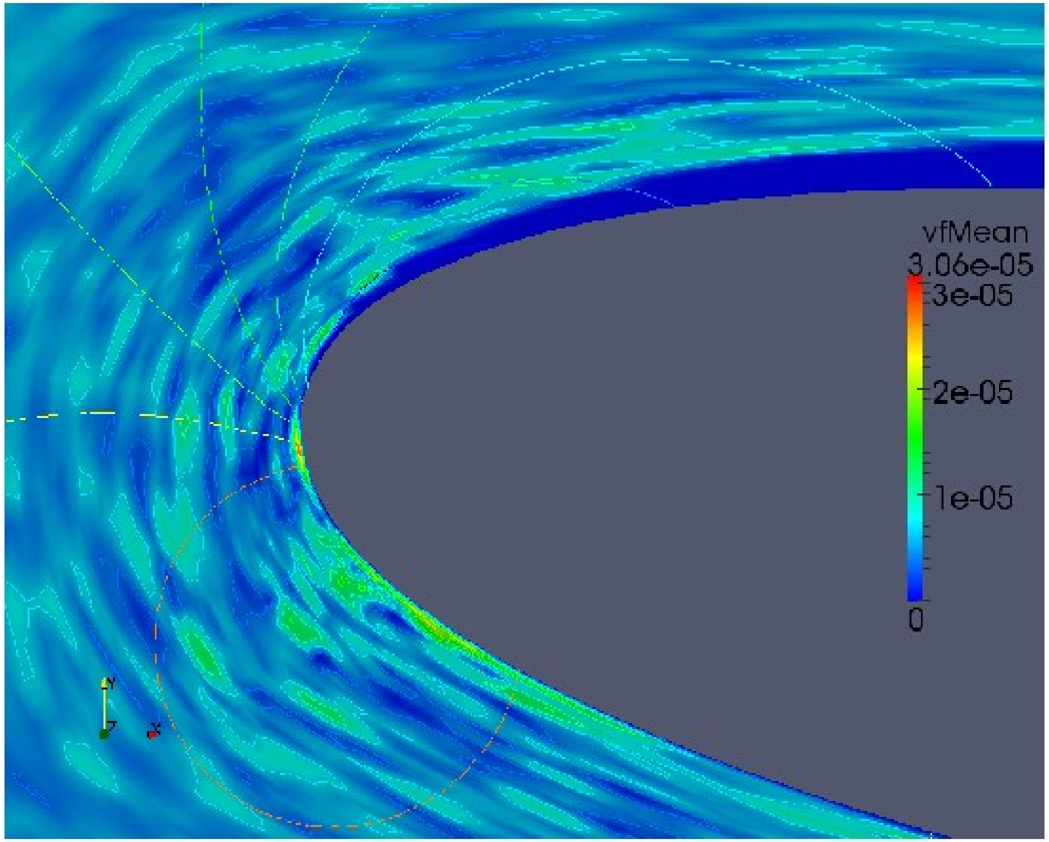


Outlet
∇U=0
p=0 Pa

Injection
50 or 500 particles / time step
Dp=0.1,1,10 or 50µm
Up=0

Solution method
LPT one way coupling

RESULTS



Statistical average of the nuclei concentration over 40 periods

<u>Dense</u>

-at the point of impact (collision)

-in the low pressure area (close to the leading edge and **above** the suction side)

<u>Very diluted</u>

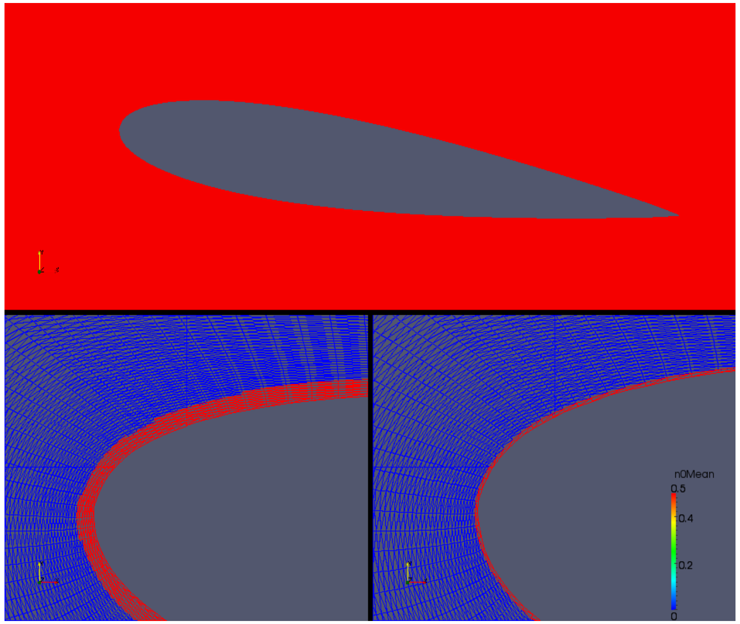
in the boundary layer of the suction side

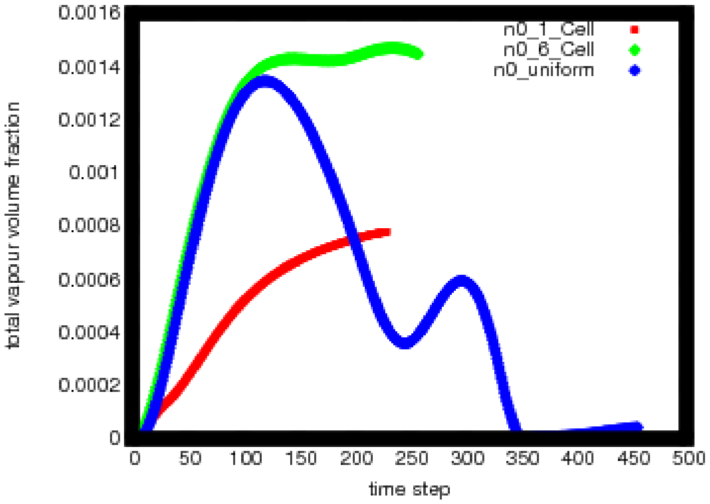
→Nuclei concentration don't explain cavitation inception

→ Importance of the surface rugosity ?

PROBLEM SET UP

Non uniform distribution of the nuclei concentration:
-nuclei on the boundary layer (thickness = 6 cells)
-nuclei on the first cell close to the surface





CONCLUSION

Cavitation is a complex phenomena which
- involve multiphase flow, phase transition, no symmetry (need to simulate in 3D), turbulence, instabilities, chock waves, bubbles dynamic, fluid quality, surface rugosity...
- and occurs in complex geometry

No empirism free cavitation model
No comprehensive capabilities to model development of a type of cavitation to an other.

Rather good results for the prediction oh sheet cavitation. Improvement would be achieved if we take account for the influence of the fluid quality, the surface rugosity and the turbulence.

Thank you

short about LPT

$$\frac{d\vec{x}_p}{dt} = \vec{u}_p$$

$$m_p \frac{d\vec{u}_p}{dt} = F_D = -m_p \frac{\vec{u}_p - \vec{u}}{\tau_p}$$

$$Re_p = \frac{D_p \left| \vec{u}_p - \vec{u} \right|}{\nu}$$

$$Stk = \frac{\tau_p}{fluid\,time\,scale}$$

Movie LPT ST<<1 and St>>1