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Mass transfer cavitation model with variable density of nuclei

Aurélia Vallier[1], Håkan Nilsson[2] and Johan Revstedt[1]

[1]Fluid Mechanics/Energy Sciences, LTH Lund University, SE-221 00 Lund, Sweden

[2]Applied Mechanics/Fluid Dynamics, Chalmers University of Technology, SE-412 96 Gothenburg, Sweden

Introduction

The performance of the mass transfer cavitation model of Sauer is investigated using a varying nuclei concentration.
The Sauer model assumes a uniform nuclei distribution despite measurement of the non-homogeneous nucleus population. Here the nuclei density is studied and a non-homogeneous nuclei distribution in a modified Sauer model is implemented. We study how the increased cavitation nuclei density in regions of low pressure affects the inception and development of cavitation.

The simulations are performed on a hydrofoil NACA0015 at angle of attack of 8° with the open source C++ library OpenFOAM.

Nuclei distribution

The nuclei in the liquid phase are modeled by particles injected in front of the hydrofoil and tracked with a Lagrangian Particle Tracking method.
A random walk model is used to include the effect of turbulent dispersion.

The LPT computations yield to a non uniform nuclei distribution.
The unsteady distribution is time averaged over 50 flow-through periods in order to obtain convergence in mean.
The average nuclei density is sampled on the vertical line (colored in white on Figure 2) that crosses the cell with the lowest pressure value (the contour of pressure are colored in black on Figure 2).

- Sensitivity to turbulent dispersion
Figure 1 shows the particle density on the sample line, from computations with and without random walk model. When turbulent dispersion is accounted for, the nuclei distribution is very dense on the surface of the hydrofoil while there is no nuclei on the first 0.2 mm near the surface without turbulent dispersion. Furthermore the oscillations away from the surface are damped.

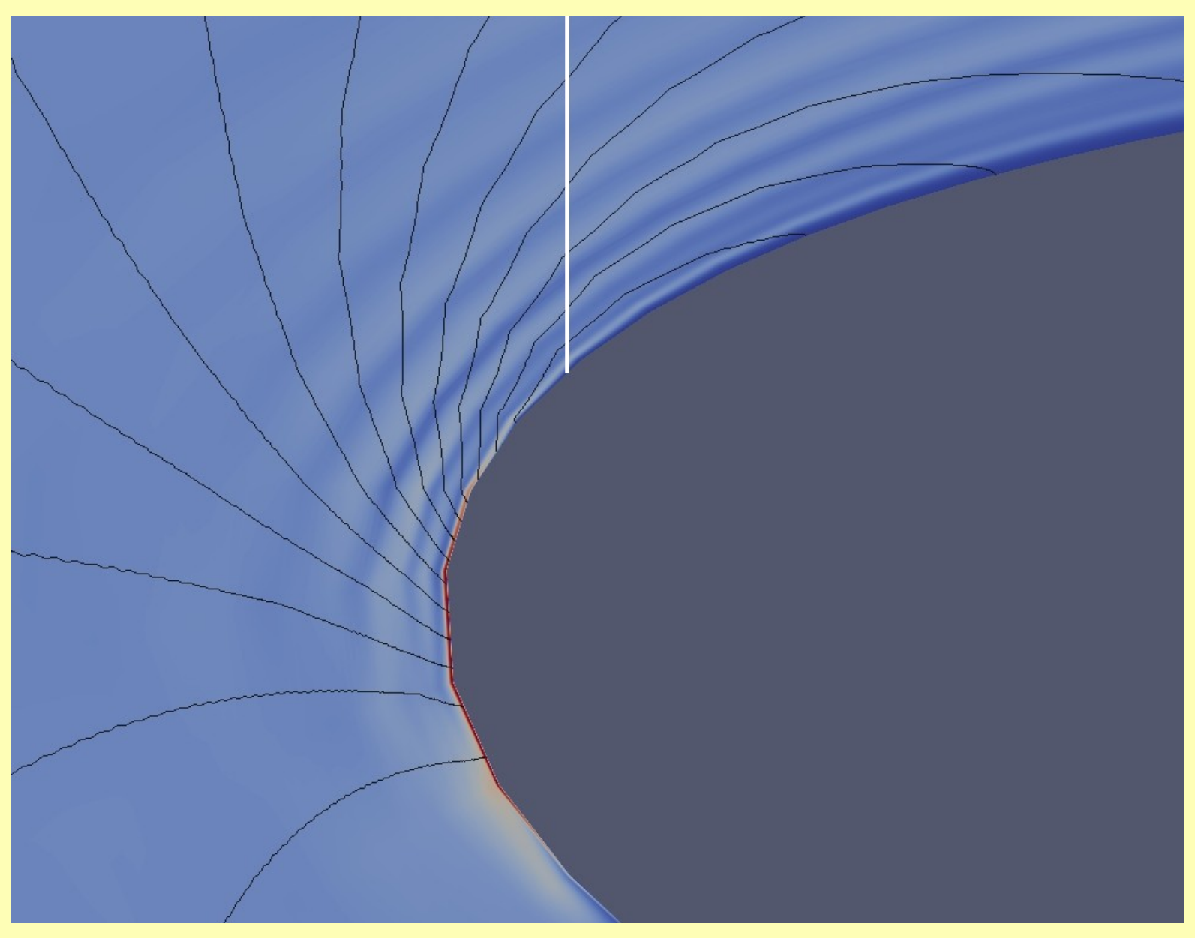

Figure 2. Averaged nuclei distribution near the leading edge for D=1 μm.

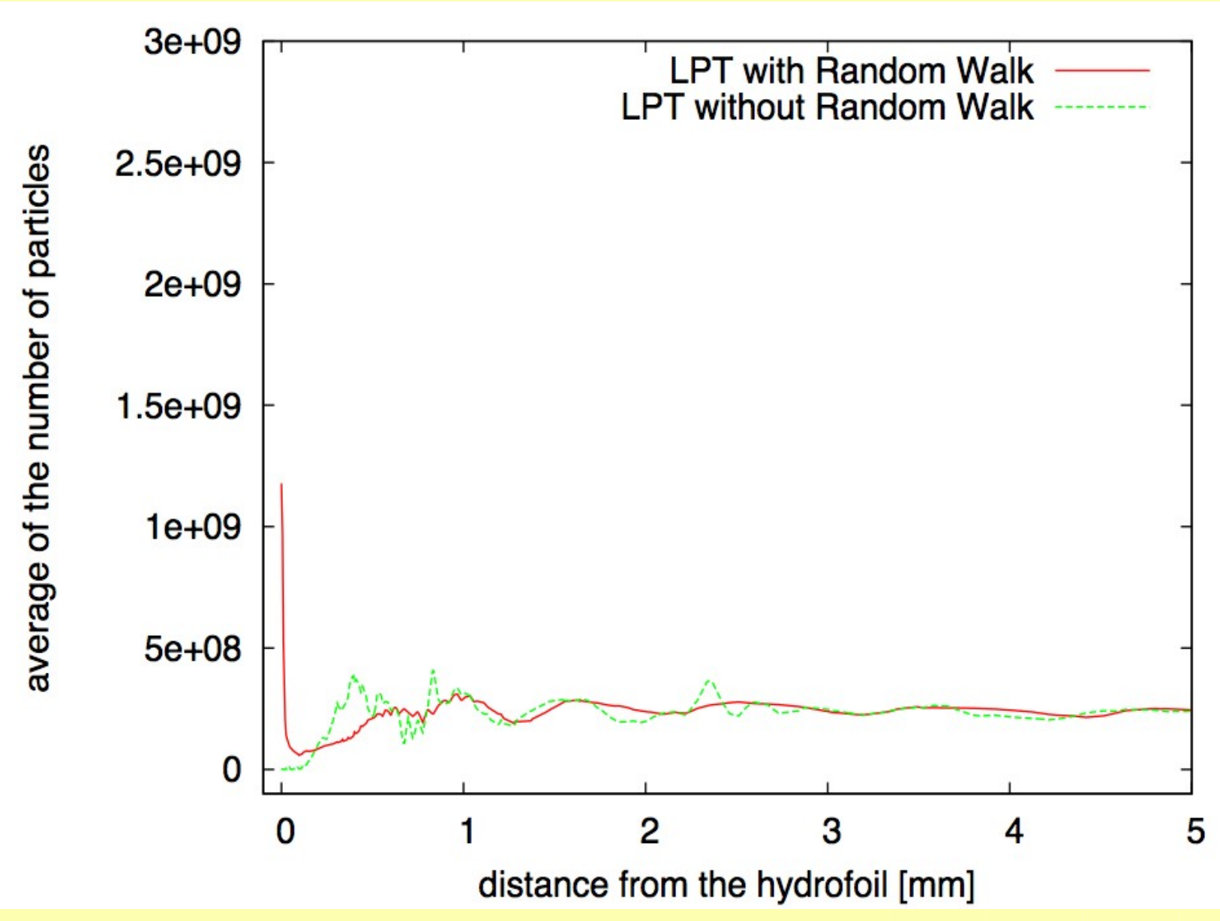

Figure 1(*). Averaged nuclei distribution on the sample line for D=50 μm, with and without turbulent dispersion.

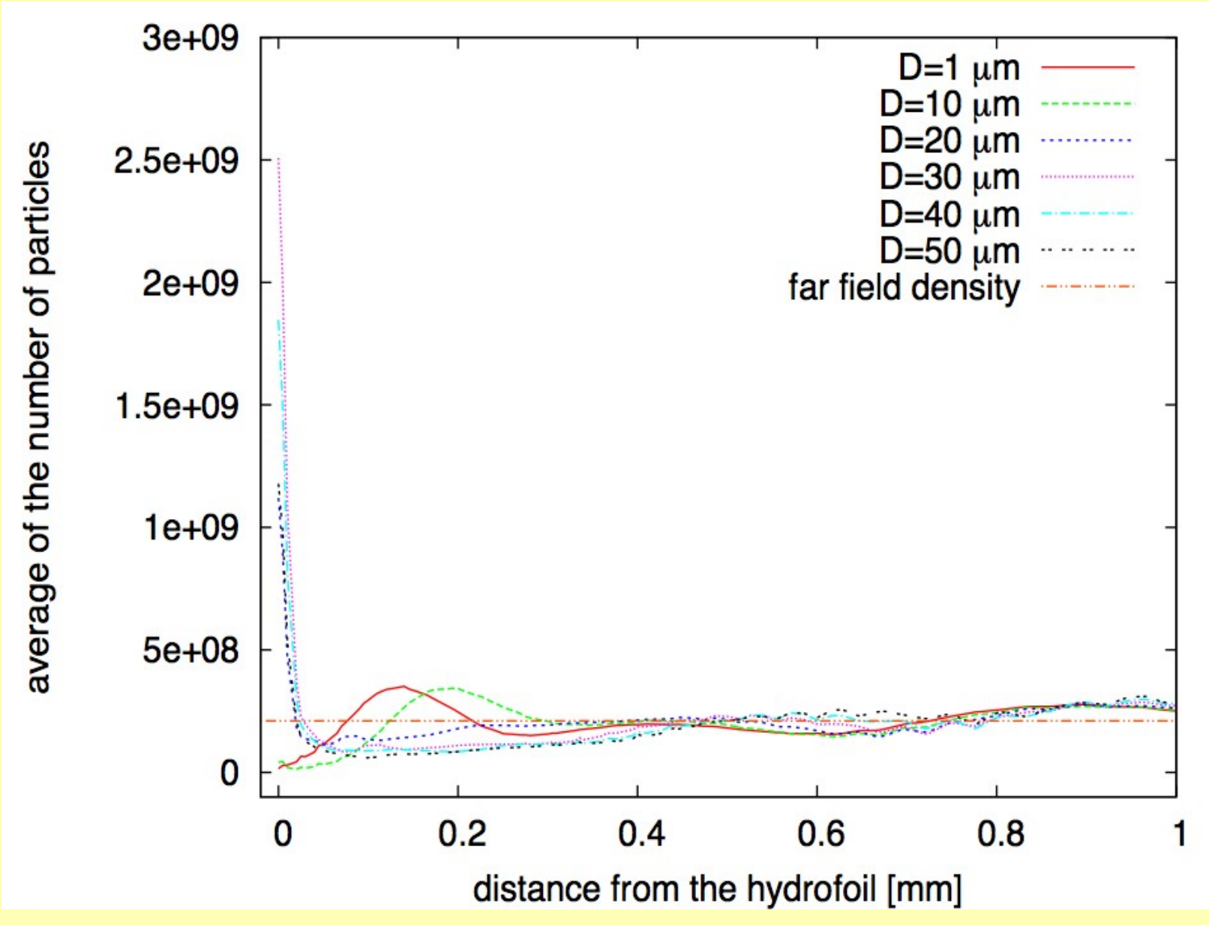

Figure 3(*). Averaged nuclei distribution on the sample line for different nuclei sizes.

- Sensitivity to particle size.
Figure 2 shows the average nuclei density for the smallest nuclei size.
The averaged density is highest at the stagnation point (colored in red) because the nuclei rebound against the wall and reside a longer time in this region of low velocity.
Nuclei are not present on average in a layer close to the hydrofoil (colored in dark blue).
In Figure 3, the nuclei density for different nuclei sizes are sampled on the sample line. It shows that the dark blue layer without nuclei corresponds to a nuclei content lower than the far field density (which is 2.1e8). This layer is thicker (0. 5 mm instead of 0.1 mm) for nuclei larger than 10 μm .
For large nuclei, the distribution is very dense on the surface, exactly in the low pressure cells.
For small nuclei, the high density is located from 0.1 to 0.3 mm away from the surface, and the peak is much lower.

Sauer model with non uniform nuclei distribution

	δ_N=0.5	δ_N=1	δ_N=2	δ_N=4
N=10^2	case 1	case 2	case 3	case 4
N=10^4	case 5	case 6	case 7	case 8

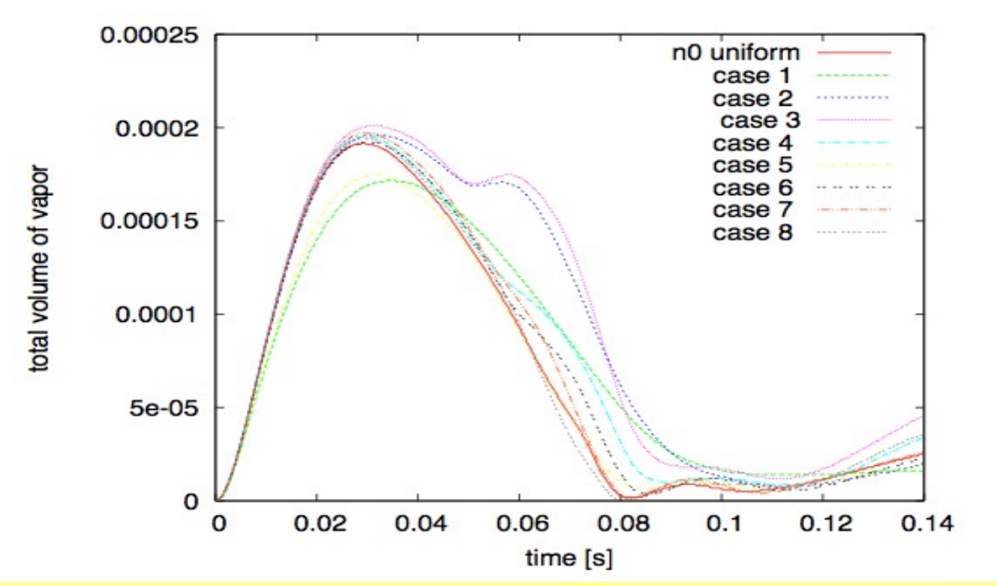

Figure 4. Total volume of vapor for cavitating flow with different nuclei distributions.

The Sauer model assumes a homogeneous nuclei distribution, and a value of 1e8 is generally used. Here we take advantage of the previous results and assume that the nuclei concentration N is high (N=1e8) in a layer attached to the surface and low (N=1e2 or N=1e4) everywhere else. The thickness of the layer δ_N varies from 0.5 to 4 mm.

With the thinnest layer, the nuclei content is too low to enable the cavity to grow sufficiently. The production of vapor is lower during cavitation inception compare to the uniform case (Figure 4). In all other cases, the cavitation inception is entirely similar to the uniform case.

However the development of the cavity is always sensitive to the nuclei distribution. Figure 5 shows the cavitation process for different cases.
The re-entrant jet is thinner (as thick as δ_N) and faster, it beaks the attached cavity at a position closer to the leading edge. Thus the remaining attached cavity is shorter and the cloud is more stretched. The attached cavity is linked to the cloud by a thin layer of vapor which generates a second smaller and fuzzier cloud for the cases 2 and 3.
This is the reason why the total volume of vapor increases at t=0.06 for these cases in Figure 4.

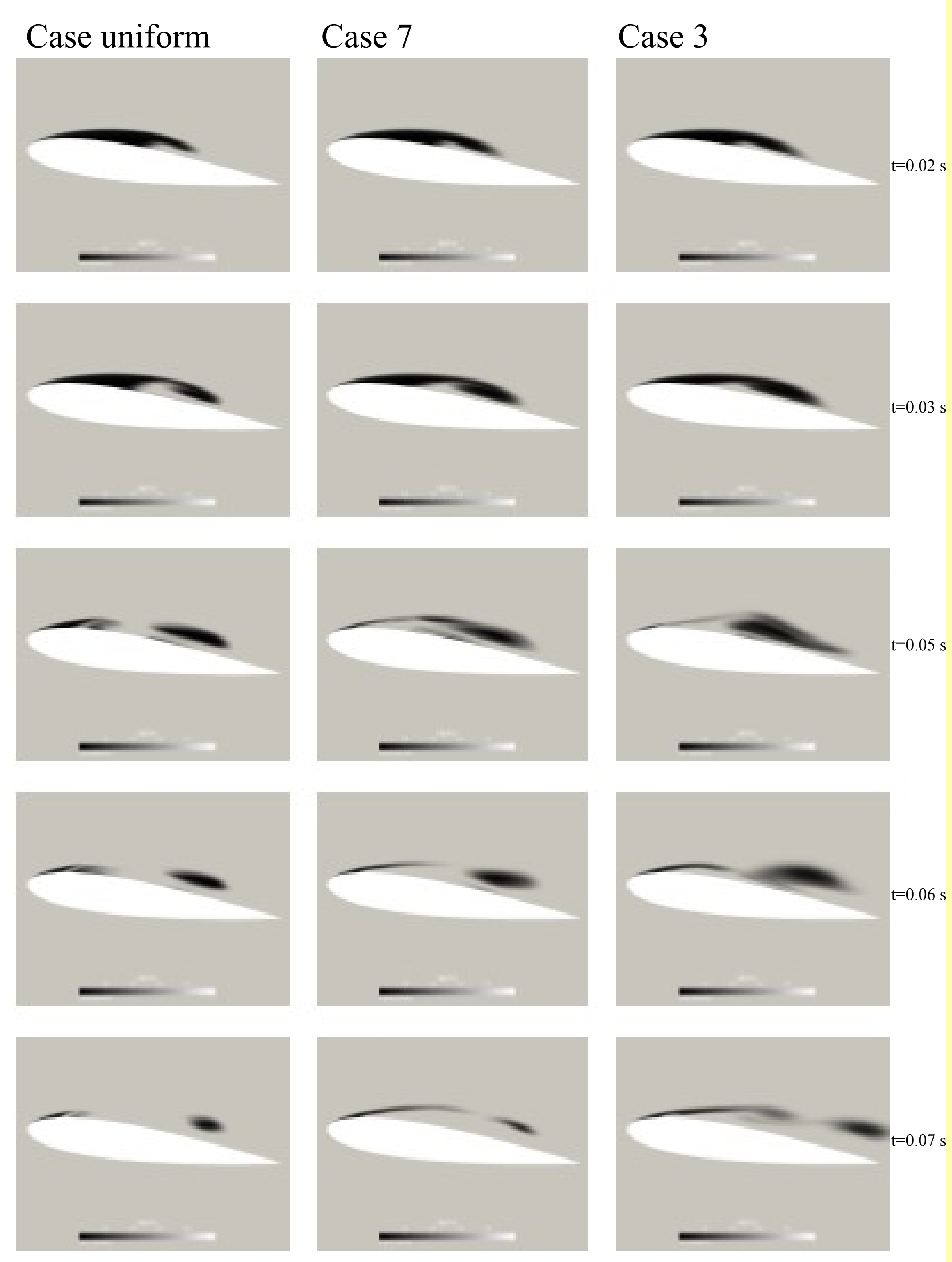

Figure 5. Instantaneous plot of the vapor volume fraction for different nuclei distributions.

Conclusions

We studied the nuclei distribution over a NACA0015 hydrofoil. It was shown that turbulent dispersion and the particle size influenced the nuclei distribution. The distribution of larger nuclei is very dense on the surface at the lowest pressure point, while smaller particle have a more homogeneous distribution and are not present on the surface.

The Sauer model was modified to take into account this non uniform nuclei density. Only for δ_N=0.5 mm, the inception of cavitation was affected. For all cases, the attached cavity was shorter, the re-entrant jet was faster and thinner, and the cloud was stretched. A thin layer of vapor linked the attached cavity and the cloud of vapor. These features emphasize the importance of the nuclei distribution when modeling cavitation inception and developement.

Acknowledgments

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(*) Erratum The pictures 6 and 8 in the articles erroneously display the sampled instantaneous values instead of the average. The pictures presented here (1 and 3) are corrects.