Reduction of Pressure Fluctuation on Hydrofoil NACA 0015 Using Cavitation- Bubble Generator

Submitted by

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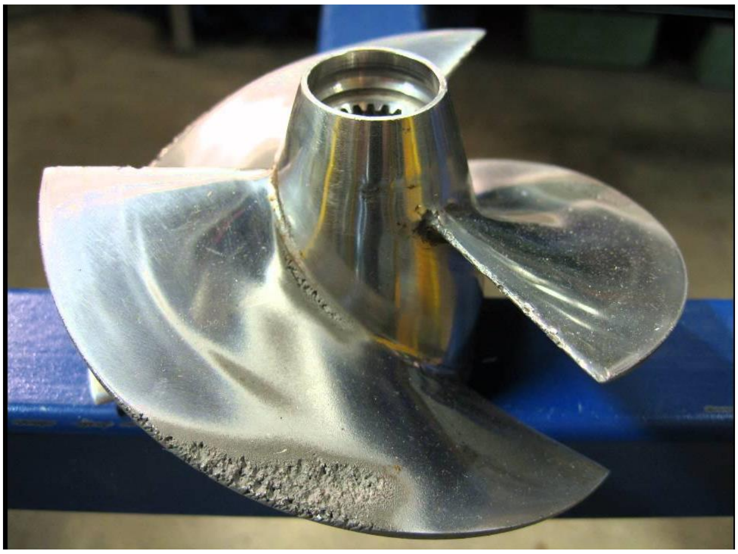
ABSTRACT

Cavitation is the formation, increment and rupture of bubble in liquid. Cavitation occurs in the region in which local pressure decreases below the vapour pressure of the liquid. The sudden rupture of bubble causes the release of high energy and the narrow water jet. This process causes cavities on the surface of hydrofoil. Hydrofoil is used in many instruments like turbine, Propeller etc. Cavitation reduces the efficiency and the working range of the hydrofoils and so the instrument. The aim of the project is to reduce cavitation on the hydrofoil NACA0015 using a passive cavitation controller. I have also presented the effect of the position and size of the passive cavitation controller on the cavitation on the suction side of the hydrofoil. I have used OpenFoam-v7 for the simulation of the case. I have used “interPhaseChangeFoam” solver.

1. INTRODUCTION

Cavitation is the very common, destructive problems associated with fluid flow. This problem occurs when there is chance of pressure drop below vapour pressure of liquid. when cavitation occurs on the solid surface, it creates dentations on the surface, sound, shocks etc. Cavitation can be seen on the surface of pipe, turbine, propeller etc. The dentations on the surface reduces the efficiency of machines. Consequently, maintenance expenses and efforts are increased. Bubbles are formed in the zone which pressure is lesser than the saturate pressure. The bubbles move toward high pressure zone. On reaching the high-pressure zone the bubbles bursts. The sudden collapse on the bubbles generate large pressure on the surface which further creates dentations on the surface. It also creates noise and the collapse is so sudden that shock is formed. Hence, it has become important to control cavitation by different methods like adding passive appendage, active methods etc.

In this project, I have used Hydrofoil NACA 0015 as the solid body on which cavitation will be studied. I have used hydrofoil because this shape is commonly found in propeller, turbine and these are highly affected by cavitation. I have focused only on the suction side of the hydrofoil. Cavitation becomes more devastating due to its periodic nature. Cavitation repeats its nature again and again. Due to this periodicity, the pressure on the suction side changes and this periodicity has to be controlled to reduce the cavitation problem on the suction side. In this project, I have used the concept of artificial cavitation generator to reduce the periodicity of pressure variation on the suction side. This process can be used to reduce the periodicity of cavitation within certain range or at a certain point on the suction side by using one passive appendage. The location and the size of the appendage plays an important role in controlling cavitation. I have also shown the effect of the location and size of the appendage on the cavitation.



Submarine propeller Cavitation (source: Wikipedia)

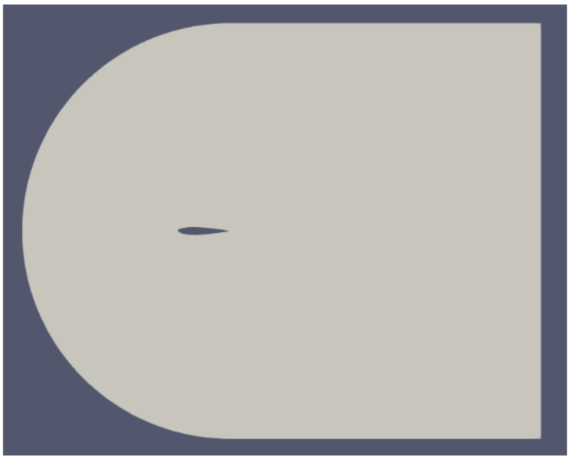
To obtain the correct physics, it is important to have correct combination of cavitation and turbulence model. I have used Sauer and schnerr cavitation model with k-omega turbulence model. This combination gives good results (M. Lopez et al.,2017[1]). There are two major challenges for capturing the correct physics of the cavitation. Firstly, there should be the correct combination of the number of bubbles/nuclei and number of nodes in the computational domain. This plays crucial role in capturing the cavitation on the surface of the hydrofoil.

2. CASE SETUP

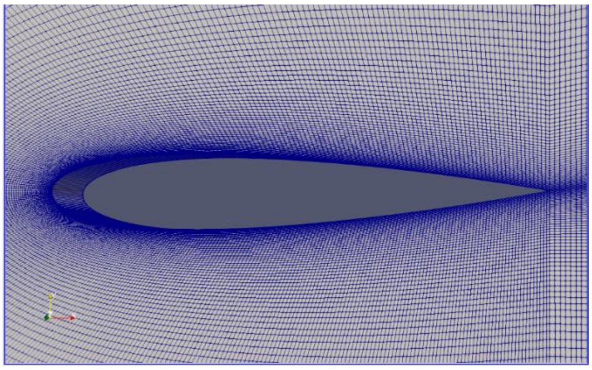
I have simulated 4 cases to locate the best position of the appendage to control cavitation at 0.3c, where c is the chord length; I have also the effect of size of the appendage on cavitation. I have simulated the following cases:
Case 1: Without appendage.
Case 2: With appendage at 0.295c of height 0.0015 m.
Case 3: With appendage at 0.295c of height 0.0025 m.
Case 4: With appendage at 0.181c of height 0.0015 m.
The initial and boundary conditions are same for all the four cases, only there is a difference in the blockmeshDict file, i.e. location and size of appendage on the suction side.

2.1 Meshing

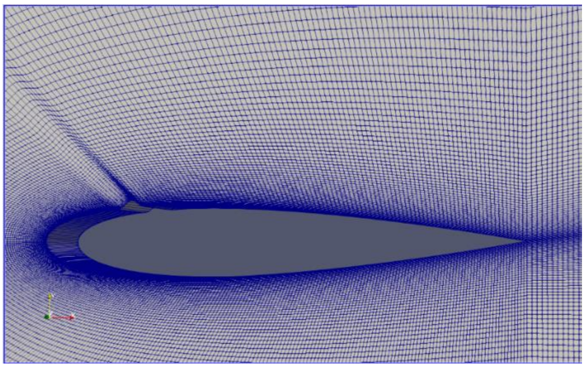
The total length of the computational domain is 10c and breadth is 8c. The radius of semicircle is 4c, and 190000 hexahedral meshes.



Computational Domain



Meshing for aerofoil without appendage



Meshing for aerofoil with appendage

2.2 Initial Conditions

Table 1 shows the initial conditions of all the four cases respectively. Since, this is 2-dimensional simulation so the boundary and initial conditions are empty on front and back surfaces.

S. No.	Quantities	Values
1	K	Inlet: turbulentIntensityKineticEnergyInlet; intensity = 2%; value =0.018
		Outlet: zeroGradient
		Airfoil: krqWallFunction
		Top and bottom: krqWallFunction
2	Omega	Inlet: turbulentMixingLengthFrequencyInlet
		Outlet: zeroGradient
		Airfoil: zeroGradient
		Top and bottom: zeroGradient
3	alpha. water	Inlet: fixed value = 1
		Outlet: zeroGradient
		Airfoil: zeroGradient
		Top and bottom: zeroGradient
4	Phi	Inlet:zeroGradient
		Outlet: internalField
		Airfoil: zeroGradient
		Top and bottom: zeroGradient
5	Phi_rgh. orig	Inlet: zeroGradient
		Outlet: fixedValue (20300 m^{-1} s^{-2})
		Airfoil: zeroGradient
		Top and bottom: zeroGradient
6	U. orig	Inlet: fixedValue (7.9695 m/s, 0.69724 m/s, 0 m/s)
		Outlet: zeroGradient
		Airfoil: no slip
		Top and bottom: zeroGradient

Table 01: Initial Conditions

Table 02 shows some of the constant properties that I have used for the simulation of all the four cases.

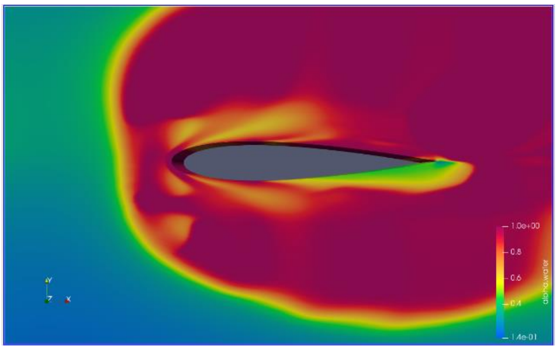
S. No.	Parameters	Values
1	Saturation pressure	2300 pa
2.	Sigma	1.2
3.	Schnerr and Sauer Coefficients	n = 10e12
		dNuc = 1e-5
		$C_c = 1$
		$C_v = 1$

Table 02: Constant properties

3. RESULTS

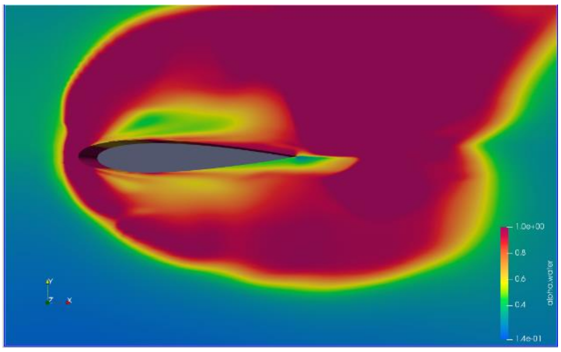
3.1 Validation

I have tried to capture the physics of originating, propagating and scattering of cavitation sheet on the aerofoil; and I present the physics of cavitation flow over aerofoil as the validation work (Case 1) for this project, and I have used V. H. Hidalgo et. al,2013[2] to compare my results.

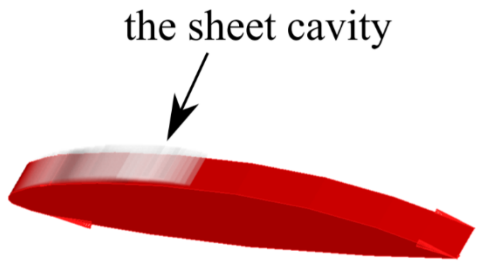


Cavitation begins from the front of the aerofoil
(at 0.004 s)

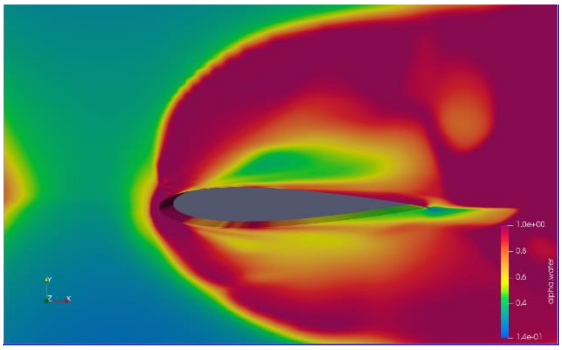
Cavitation sheet starts from the front of the aerofoil
(V. H. Hidalgo et. al,2013[2])



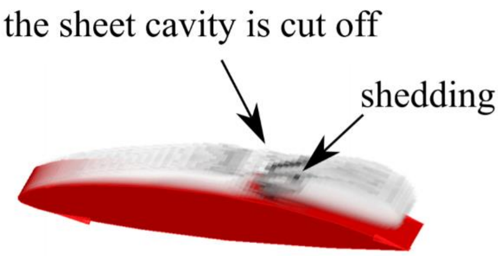
Development of cavitation along the suction side
(0.076 s)



Development of cavitation along the suction side
(V. H. Hidalgo et. al,2013[2])



Cavitation sheet cuts off
(0.089 s)



Cavitation sheet cuts off
(V. H. Hidalgo et. al,2013[2])

1. Without Appendage

Cavitation on the suction side of the aerofoil has been shown in figure 2 to figure 7 at different time. It can be seen from the figures that the cavitated area on the suction side vary with time, and the cavitation at a position also varies and keeps repeated after certain interval of time which is the most deleterious effect of the cavitation.

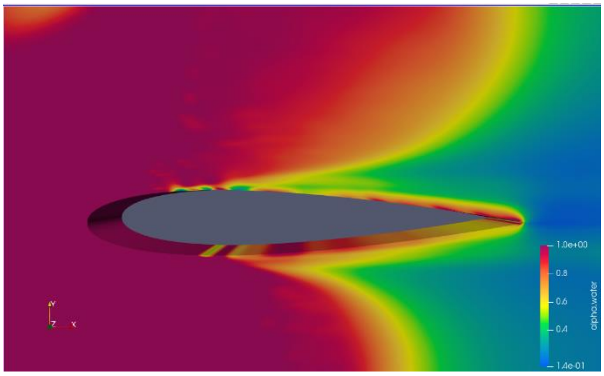


Fig. 02: Cavitation at 0.03 s

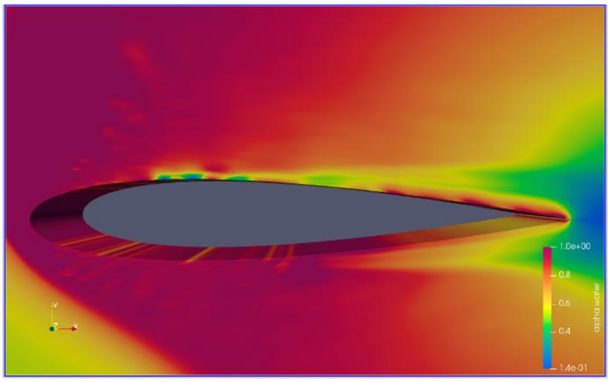


Fig. 03: Cavitation at 0.04 s

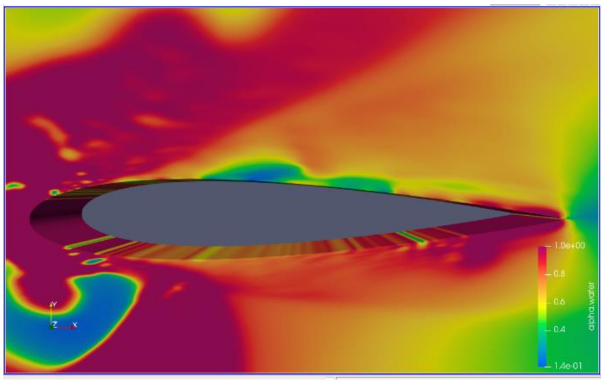


Fig. 04: Cavitation at 0.05 s

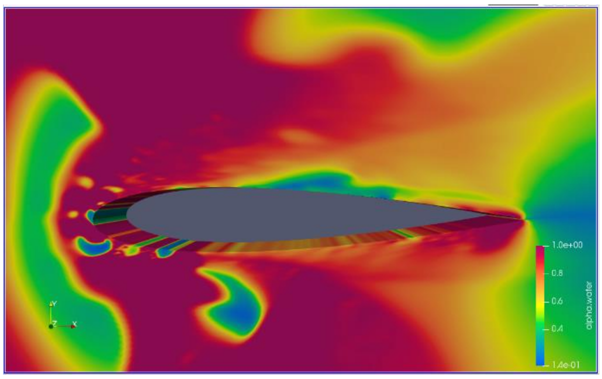


Fig. 05: Cavitation at 0.067 s

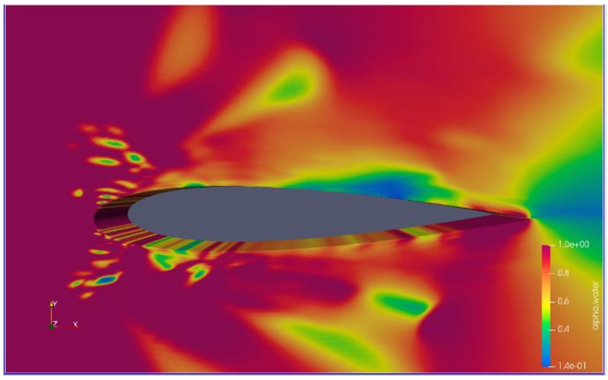


Fig. 06: Cavitation at 0.0798 s

Case 2. With Appendage at 0.295c of height 0.0015 m

The appendage has been added at 0.295c on the suction side of the aerofoil. It has vertical height of 0.0015 m. Through figure 8 to 12, It can be seen that the cavitation is more stabilized, especially just behind the appendage. The variation has been stopped so the detrimental effects of the cavitation has also been reduced.

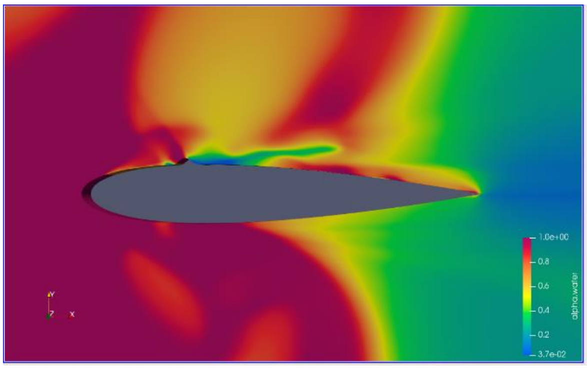


Fig. 08: Cavitation at 0.03 s

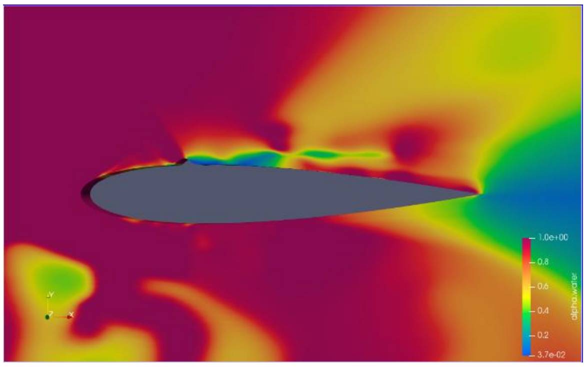


Fig. 09: Cavitation at 0.04 s

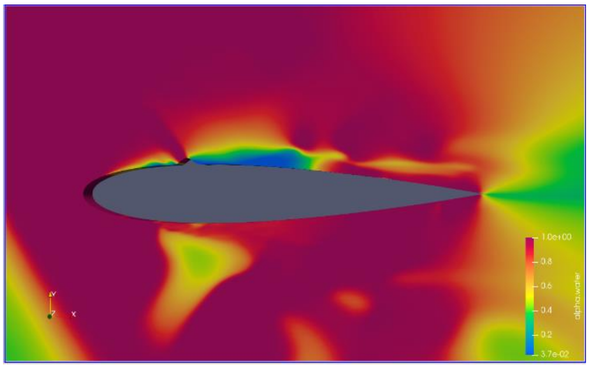


Fig. 10: Cavitation at 0.05 s

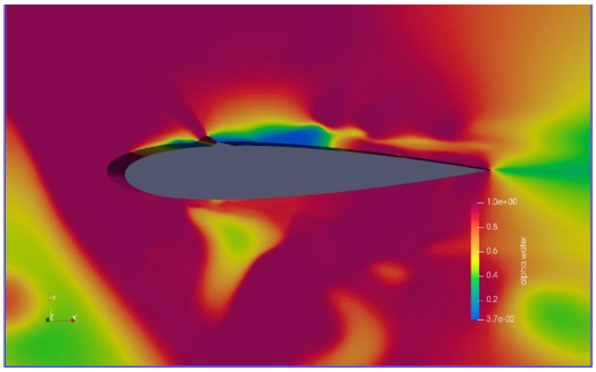


Fig. 11: Cavitation at 0.067 s

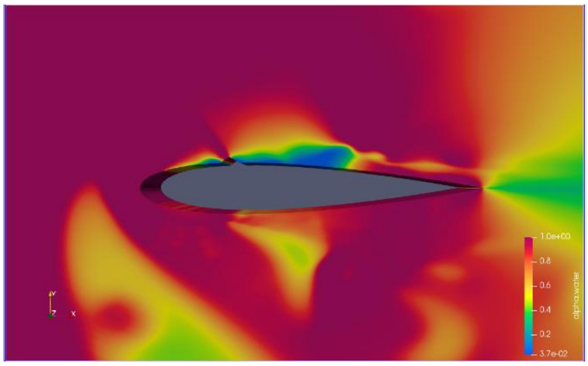


Fig. 12: Cavitation at 0.0798 s

Case 3. With Appendage at 0.295c of Height 0.0025 m

This case has been simulated to show the influence of size of an appendage on cavitation. The appendage has been added at 0.295c on the suction side of the aerofoil. It has vertical height of 0.0025 m. Through figure 13 to 17, It can be seen that the cavitation is more stabilized, especially from appendage to the tail along the suction side. The variation of cavitation has been almost stopped for longer length than that of the previous case so the detrimental effects of the cavitation has also been reduced.

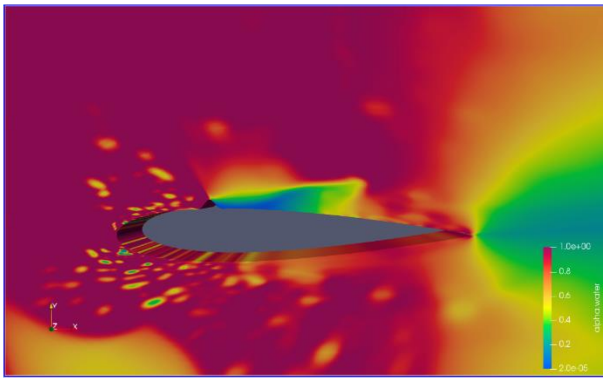


Fig. 13: Cavitation at 0.03 s

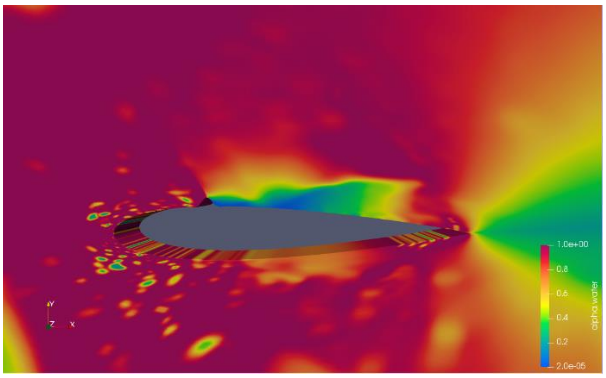


Fig. 14: Cavitation at 0.04 s

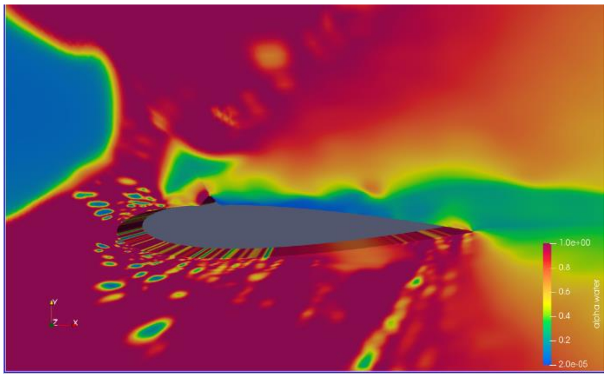


Fig. 15: Cavitation at 0.05 s

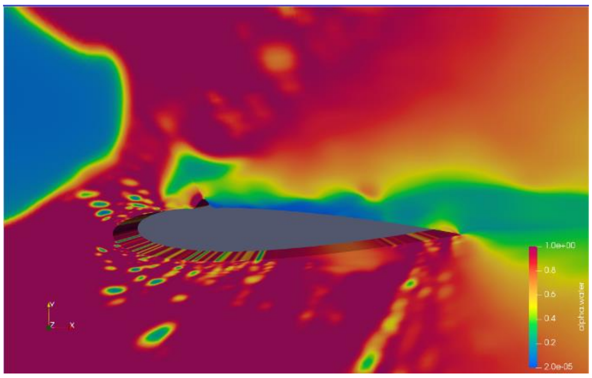


Fig. 16: Cavitation at 0.067 s

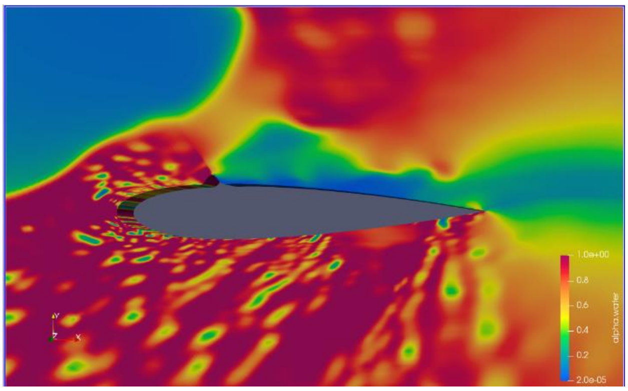


Fig. 17: Cavitation at 0.0798 s

Case 4. With appendage at 0.18c of height 0.0015 m

This case has been simulated with the aim to show the influence of position of appendage on cavitation. The 0.0015 m appendage has been added at 0.18c. Clearly, it can be understood from figure 18 to 22 that the cavitation pattern is different than that of case 2. The appendage at 0.18c of height 0.0015m, for the conditions given, reduce the pressure fluctuation on the suction side of the foil.

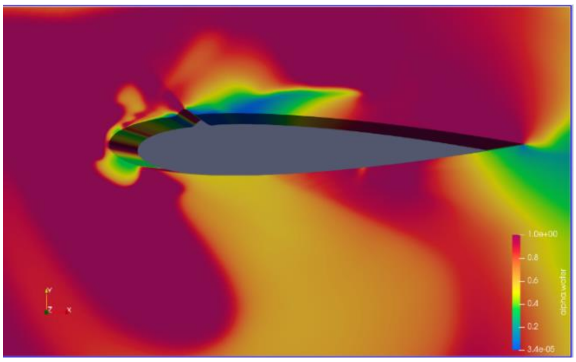


Fig. 18: Cavitation at 0.03 s

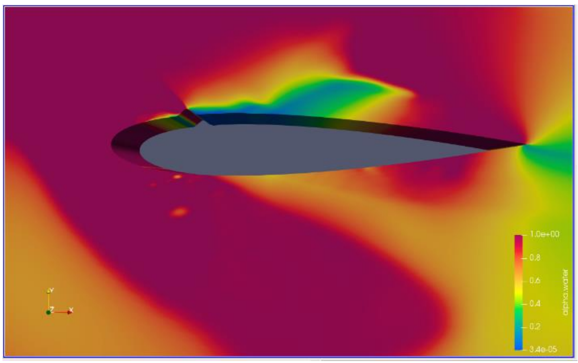


Fig. 19: Cavitation at 0.04 s

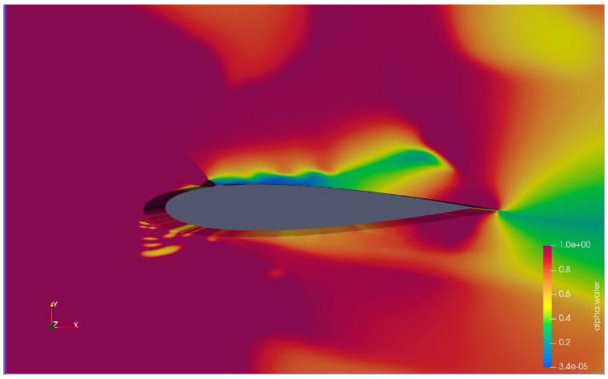


Fig. 20: Cavitation at 0.05 s

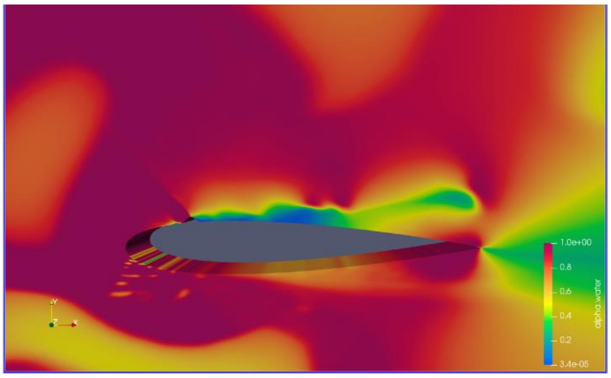


Fig. 21: Cavitation at 0.067 s

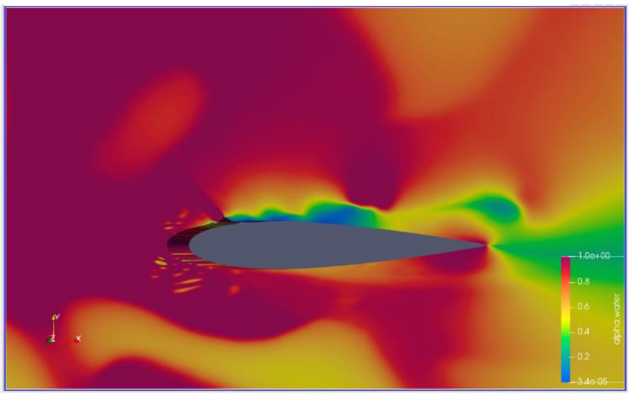


Fig. 22: Cavitation at 0.0798 s

4. CONCLUSION

It can be inferred that adding an appendage reduces the periodicity of pressure fluctuation (figure 6 to 22) . As I am concerned about the cavitation at 0.3c of the aerofoil on the suction side, so in my opinion the appendage at 0.295c of height 0.0015 m is better than the first case: In third case, the appendage creates permanent cavitation in the whole area behind the appendage in the suction side, even in the places where it was not required. I find second case and fourth case equally suitable for generating artificial cavitation at 0.3c but due to the size of appendage in fourth case is smaller so it creates very thin layer of artificial cavitation; so, I find the case the appendage location and size in second case the most suitable for my problem setup.

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