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Super-Cavitating Flow Around Two-Dimensional Conical, Spherical, Disc and Stepped Disc Cavitators

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Abstract. A super-cavitating object is a high speed submerged object that is designed to initiate a cavitation bubble at the nose which extends past the aft end of the object, substantially reducing the skin friction drag that would be present if the sides of the object were in contact with the liquid in which the object is submerged. By reducing the drag force the thermal energy consumption to move faster can also be minimised. The super-cavitation behavioural changes with respect to Cavitators of various geometries have been studied by varying the inlet velocity. Two-dimensional computational fluid dynamics analysis has been carried out by applying k-ε turbulence model. The variation of drag coefficient, cavity length with respect to cavitation number and inlet velocity are analyzed. Results showed conical Cavitator with wedge angle of 30º has lesser drag coefficient and cavity length when compared to conical Cavitators with wedge angles 45º and 60º, spherical, disc and stepped disc Cavitators. Conical cavitator 60ºand disc cavitator have the maximum cavity length but with higher drag coefficient. Also there is significant variation of supercavitation effect observed between inlet velocities of 32 m/s to 40 m/s.

1. Introduction
Cavitation occurs when the local pressure falls below the liquid vapour pressure. Any object moving underwater will reduce the local pressure around the body which can fall below the liquid saturation pressure causing Cavitation. If the velocity of the object increases further, then supercavitation occurs. Supercavitation can envelope the moving body inside a large continuous cavity bubble. This will reduce the drag force between the object and the fluid allowing the object to move faster [2]. In the present work we have chosen Cavitators of different geometry, which are conical (30º, 45º, 60º), spherical, disc and stepped disc Cavitators. A two-dimensional computational analysis [5, 7] is performed on all the axisymmetric Cavitators by varying the inlet velocity starting from 24 m/s to 40 m/s. At all these velocities drag coefficient and cavity length are obtained for all the Cavitators and then the results are validated [3]. And the results are plotted for the variation of drag coefficient, cavity length with respect to the changes in inlet velocity and cavitation number. Cavitation number σ is defined by

$$\sigma = \frac{P_{ref} - P_{sat}}{\frac{1}{2}\rho_l U^2} , \qquad (1)$$

where p_{ref} is the reference pressure of the liquid, p_{sat} is the saturation or vapour pressure of the liquid, ρ_l is the liquid density and U is a characteristic velocity of the flow [1].

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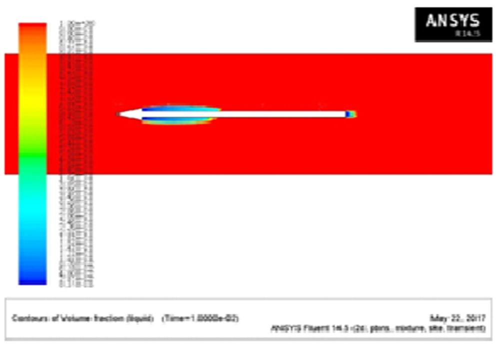
2. Modelling

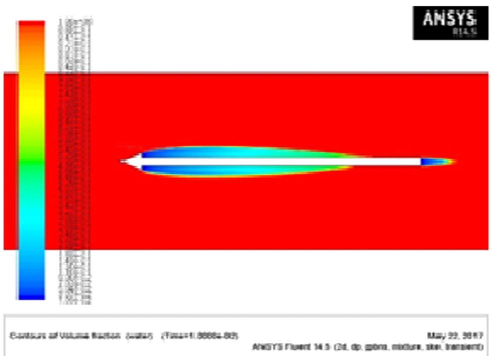
Axisymmetric models were created and meshed with the help of Ansys work bench. We have taken six different geometries like conical Cavitators (30^o, 45^o, 60^o), spherical, disc and stepped disc. The base diameter d and the length of the tails for each model is same which are 26 mm and 400 mm respectively. The supercavitation behaviour is studied by k-ε turbulence model [4], unsteady and a multiphase flow model [6]. Boundary conditions given are the inlet velocity, pressure outlet and adiabatic no-slip condition at the walls. The fluids are assumed to be water and water vapour with dynamic viscosities of 0.001Pa.s and 1.26×10^{-6} Pa.s respectively. Analysis is done to in terms of volume fraction, static pressure which will help us in comparing the values of drag coefficient (C_d) and cavity length (L_c) for selected Cavitators.

3. Results and Discussions

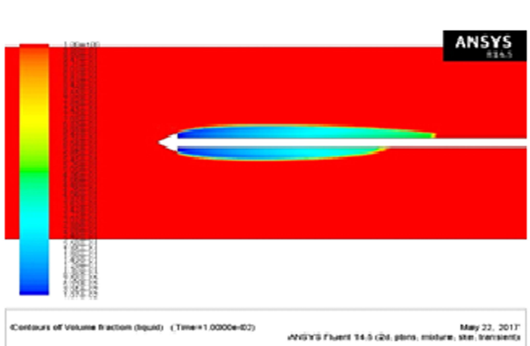
The volume fraction (percentage by volume) is one way of expressing the composition of a mixture with a dimensionless quantity. The volume fraction analysis is done to closely observe the physical behaviour of supercavitation. The supercavitation bubble contains water vapour. The analysis is done at different inlet velocities (24 m/s, 28 m/s, 32 m/s, 36 m/s, 40 m/s) and it is found that the supercavitation effect is found more significant between 32 m/s to 40 m/s and henceforth we are just showing the result at 40 m/s for the sake of comparison and the nature of supercavitation.



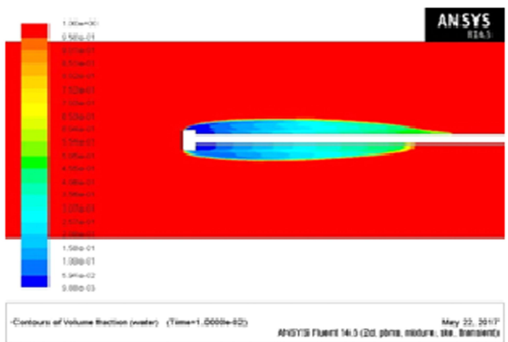
(a) Conical cavitator 30^o



(b) Conical cavitator 45^o

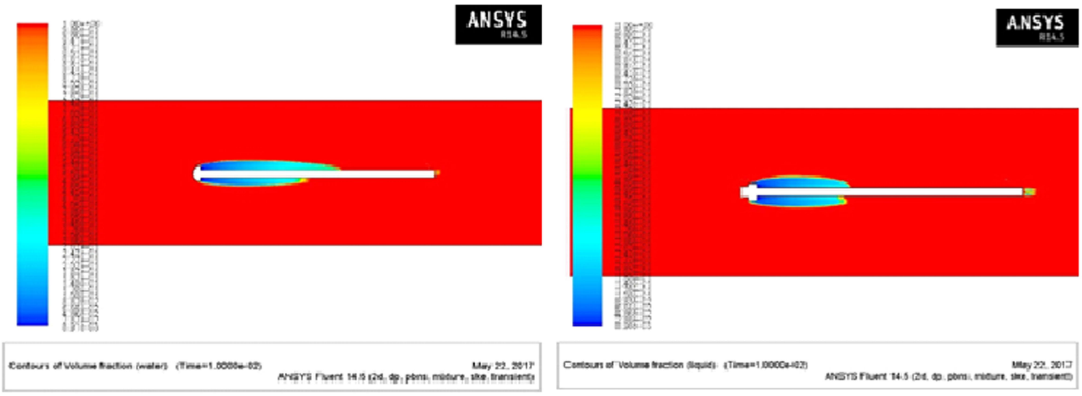


(c) Conical cavitator 60^o



(d) Disc cavitator

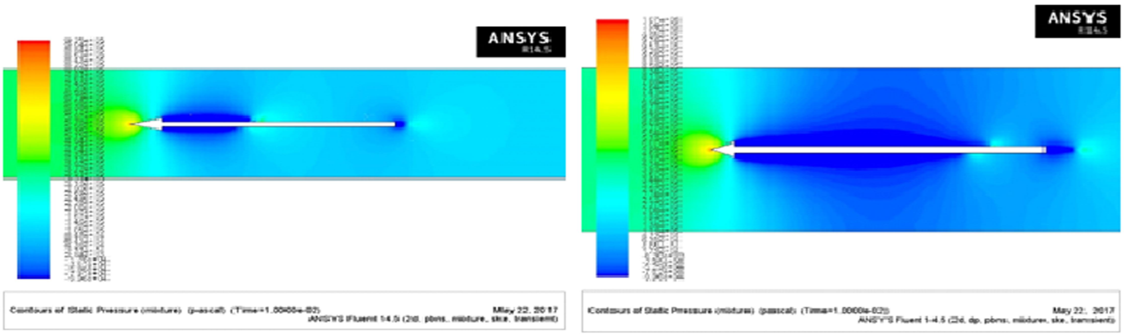
Figure 1. Volume fraction variations for conical and disc Cavitators



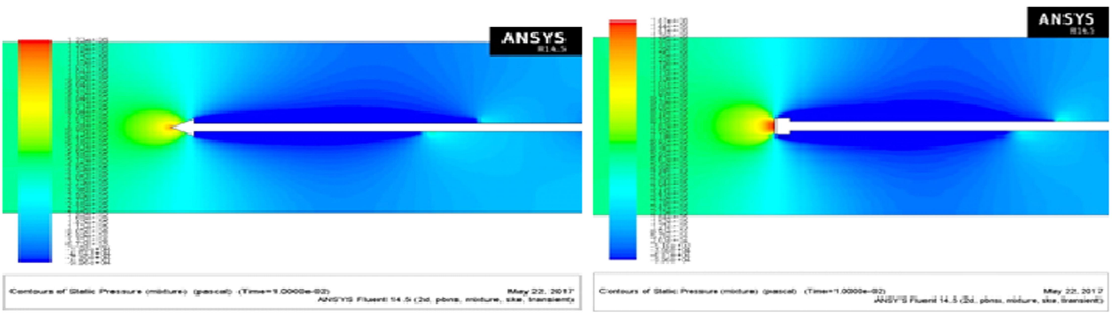
(a)Spherical Cavitator (b) Stepped disc cavitator

Figure 2. Volume fraction variations for spherical and stepped-disc Cavitators

The cavity bubble is prominently visible for all the Cavitators as a large blue cavity, shown in figure 1 and figure 2 indicating the natural supercavitation effect. For the computational analysis, the saturation pressure at a depth of 500 m below sea level is calculated to be 1.74 ka. The static pressure variation is plotted for all the Cavitators selected, as shown in figure 3**.**



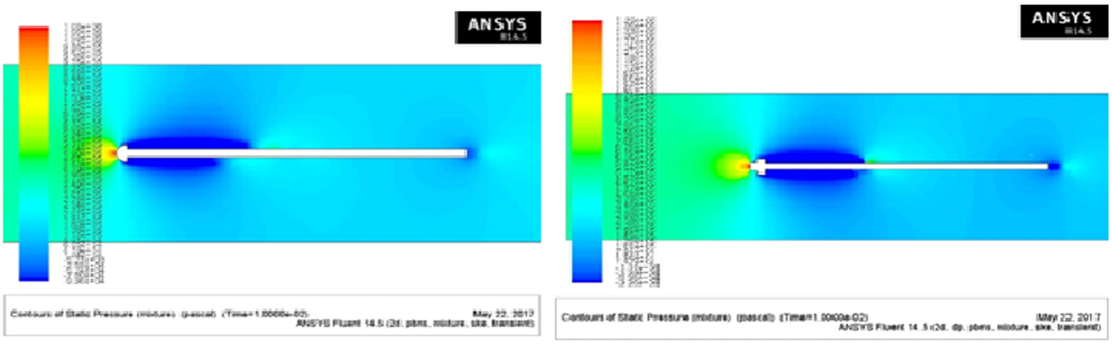
(a)Conical cavitator 30^{o} (b) Conical Cavitator 45^{o}



(c) Conical Cavitator 60^{o} (d) Disc Cavitator

Figure 3. Static Pressure variations for Conical and Disc Cavitators.

The static pressure goes down up to -9.94e+04 kPa for conical cavitator 30°, -9.96e+04 kPa for the rest of Cavitators i.e., for conical (45° & 60°), disc, spherical and stepped disc Cavitators, shown in figure 3 and figure 4.



(a) Spherical Cavitator (b) Stepped-disc Cavitator

Figure 4. Static Pressure variations for Spherical and stepped-disc Cavitators.

The most important parameter in this study is drag coefficient which is been plotted towards the cavitation number. The obtained results, as shown in the figure 5 are in good agreement with the reference paper [3] where they have investigated natural supercavitation flow behind the Cavitators comparing both numerical and experimental results for 30°, 45° and 60° Conical Cavitators. The results have shown that drag coefficient decreases as the cavitation number decreases. In this work we have added disc, spherical and stepped-disc Cavitators along with the conical Cavitators which also showed the same variation.

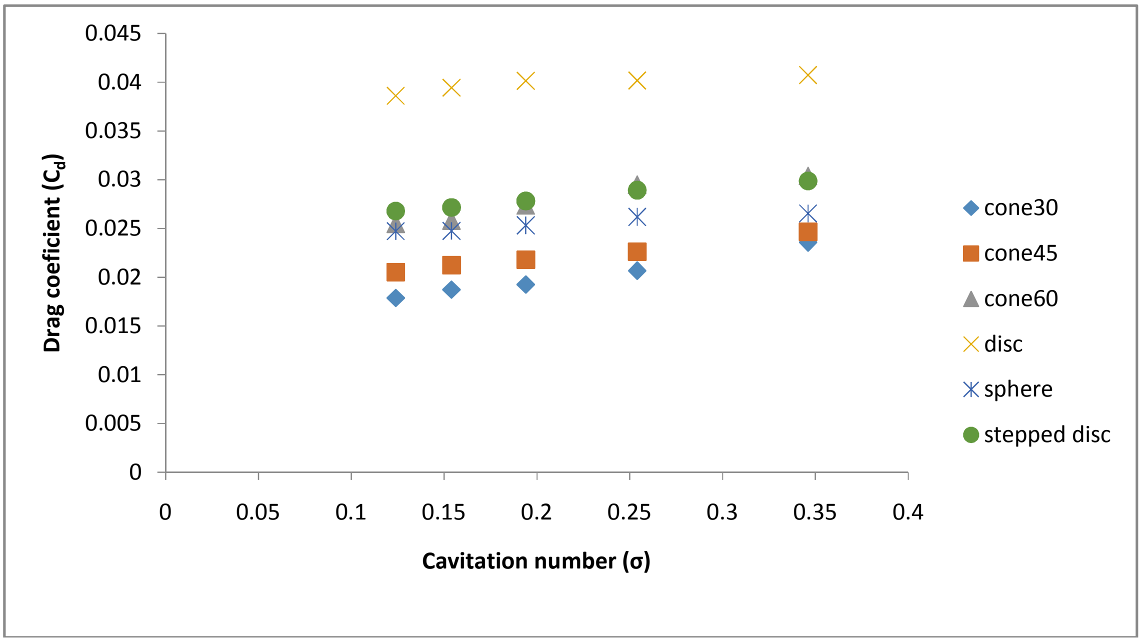


Figure 5. Variation of drag coefficient with respect to cavitation number

The other parameter which is equally important in this study is cavitation length. For simplicity and to express any physical dimension in terms of a basic unit we have defined the cavity length L_c and cavity diameter D_c in terms of d. Lc/d and Dc/d are the ratio of cavity length and cavity diameter to the cavitator diameter. And both are non-dimensional terms. Figure 6 shows the variation of ratio of cavitation length (L_c/d) with respect to cavitation number. We can see the cavitation length (L_c) decreases as the cavitation number increases. The results show that cavitation length is dependent on cavitation number, Cavitator wedge angle and the cavitator geometry.

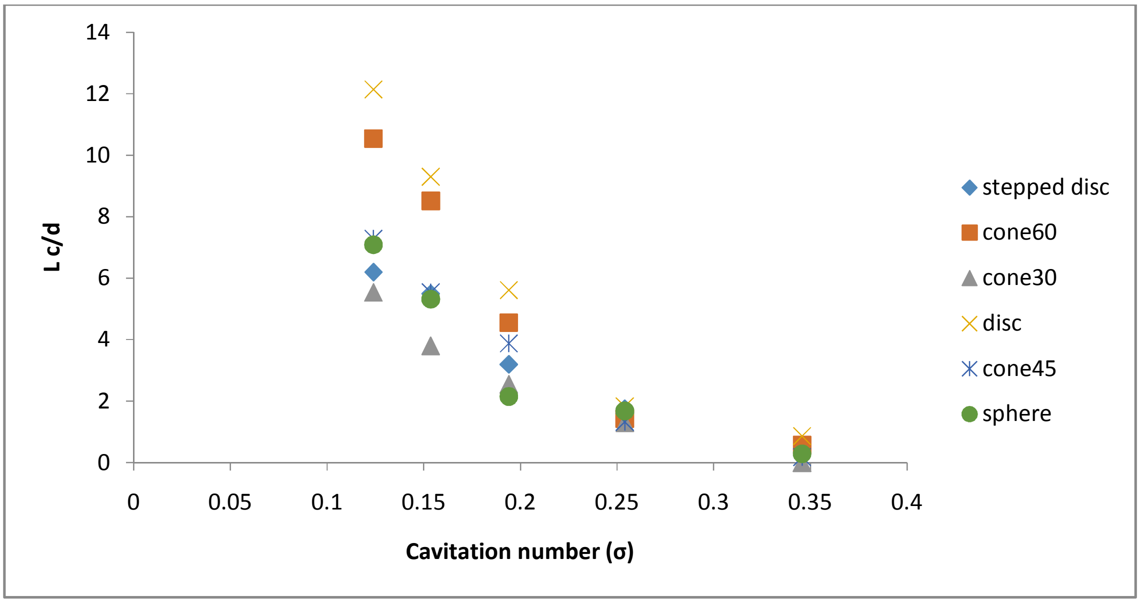


Figure 6. Cavity length ratio variation for different Cavitators relative to cavitation number

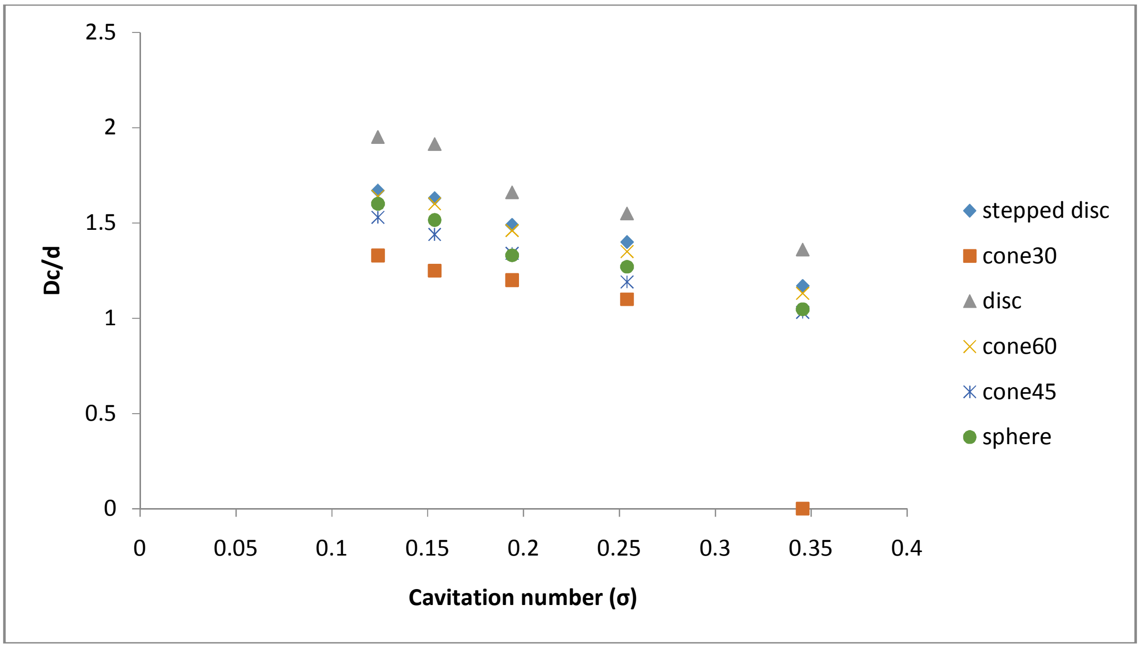


Figure 7. Variation of cavity diameter ratio at different cavitation numbers

Figure 7 shows that the maximum cavity diameter is almost constant as the cavitation number decreases.

4. Conclusion and Future Scope

For conical Cavitators, cavity length is directly proportional to the wedge angle and also the drag coefficient increases by raising the wedge angle. Supercavitation effect is significant between the inlet velocities of 32 m/s to 40 m/s. Conical cavitator 30^o shows lesser drag coefficient when compared to other wedge angle Cavitators at a given cavitation number and inlet velocity but cavity length is more for 60^o conical cavitator. Out of all the Cavitators selected disc cavitator shows more cavity length but with highest drag coefficient. Drag coefficient is observed to decrease as the cavitation number decreases for all the cavitator geometries. With the decrease in drag coefficient one can save the energy consumption to maintain a given speed of an object. The scope for future can be optimization [5] of Cavitators for a lesser drag coefficient and more cavity length. Flow control of ventilated air and their influence on drag reduction in super-cavitating flow can be studied. Other turbulence models can be applied which can result in a better accuracy. Grid independence study can also be made for reducing computational time and accuracy [10, 11]. One can also study the influence of turbulent drag-reducing additives which will decrease the surface tension coefficient resulting in a cavity of large size in length and diameter [9].

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