A New Family of Dual-Mode Super-Cavitating Hydrofoils

Stefano Brizzolara
Innovative Ship design lab, i-Ship, Department of Mechanical Engineering
Massachusetts Institute of Technology, Cambridge, MA 02139, USA, stebriz@mit.edu

ABSTRACT
This paper presents a new type of super-cavitating hydrofoil section designed to have optimal performance both in super-cavitating conditions and in pre-cavitating conditions (including transitional regime). The main hydrodynamic characteristics are given in terms of lift drag and cavity shape at different angles of attack and cavitation numbers. The optimum performance is reached through a particular design philosophy illustrated in the paper which is intensely based on multi-phase URANSE flow simulations, using a bubble dynamic cavitation model to follow the generation and evaporation of the vapor phase in the fully turbulent unsteady viscous flow.

The new profile family, initially created for hydrofoil crafts, may result useful also for applications on super-cavitating or surface-piercing propellers.

Keywords
Super-Cavitation, unconventional hydrofoils, RANSE.

1 INTRODUCTION
Super-cavitating hydrofoils are of interest for a variety of different applications, generally related with production of lift at super- to ultra-high speeds in water: dynamic support surfaces of super-high speed hydrofoil crafts, support or active control surfaces of super-ventilated underwater or surface crafts and of course super-cavitating and surface piercing propellers.

The interest of the author on super-cavitating hydrofoils has been recently revived in occasion of an ONR Global BAA about the design of an ultra-high speed unmanned craft, presented in. The project brought to the aero/hydrodynamic CFD based design of a family of innovative, autonomous surface vehicles (patented in Brizzolara, 2014), an example of which is presented in Figure 1. The ASVs run as SWATH ships in hullborne mode at low speeds, but are designed to reach 120 knots in foilborne mode, when they fly fully supported by two pairs of super-cavitating surface piercing hydrofoils and by the wing in ground type superstructure.

The design of the hydrofoil required special attention: very few studies exist in the literature about surface-piercing (SP) hydrofoils working in super-cavitating (SC) or ventilated conditions. For this reason extensive experimental and numerical studies were conducted first to characterize the hydrodynamic performances of a first design of the hydrofoil wing (Brizzolara, 2011) and then to optimize them in a subsequent project focused on numerical methods for design and analysis (Brizzolara, 2013) culminated with a second version, much more stable than the first.
the linear theory of Tulin-Burkhart (1955), valid in the asymptotic limit of zero cavitation number (infinite cavity length). V.E. Johnson (1961) extended this first order theory considering higher terms in the conformal mapping method used to solve the potential flow around the hydrofoil, leading to the definition of new shapes with higher efficiencies (lift over drag): the so called Johnson’s three and five terms profiles. These were the years (’60s to ’80s) of the greatest development in hydrofoil craft design in the US. After that period, the interest on Super-Cavitating (SC) hydrofoils moved on SC propellers; the emphasis was primarily on the analyses of super or partially cavitating hydrofoils to be used as propeller blade sections, i.e. with rather thin thickness to chord ratio, as opposed to thicker ones used in hydrofoils crafts. A large body of research, in this field, was developed at MIT, culminating with the development of a potential flow panel method for the analyses of partially and supercavitating hydrofoils (Kinnas & Fine, 1991; Lee et al., 1992). The method was then extended to the analyses of SC hydrofoils and propellers in 3D (Kinnas, 2001). Mishima & Kinnas (1996) also proposed an inverse design method of SC propeller blade sections, combining the boundary element method with a variational problem to find the optimum shape of the face of 2D profiles, for a given lift coefficient and single cavitation number. Again considered profiles in this case were very thin and limited to propeller blade sections only. More recently, new interest has been shown in the study of unconventional profiles for supercavitating hydrofoils to be used in very high speed sailing boats or fast ships (Pearce & Brandner, 2007), but the design by optimization method resembles that first introduced by Kinnas years before.

In the following, we will first introduce the new design philosophy and then supply information about the main topological feature of the new SC-hydrofoil family and then describe the main hydrodynamic characteristics of a prototype of this family.

3 ANATOMY OF THE NEW SC-HYDROFOIL

The sketch of Figure 2 presents the main geometric elements of the new family of SC hydrofoils, named SCSB. The composite profile shape is made of six topologically different elements:
- a) main face profile
- b) main back profile
- c) tail face profile
- d) tail back profile
- e) back cavitator
- f) face cavitator

Functionally, the SCSB hydrofoils can be thought as composed of two main elements: the main body defined by a) and b) and the sharp tail, defined by c) and d). The main body is connected to the tail through two right angle chamfers, also indicated in Figure 2, which act as cavitators (e) (f) to trigger base-cavitation\(^1\) at cavitation indexes higher than the design value or at angles of attack lower than the design one.

At the high-speed operating mode, the SCSB hydrofoil behaves like a conventional SC profile, the tail being immersed inside the cavity that originates at the leading edge on the back and at the edge of the face cavitator (f) at the end of the main face profile (a). An ideal cavity boundary appears as a gray line in Figure 2.

The main face profile (a) is the first element to design. Johnson’s supercavitating hydrofoils theory is used to determine its shape as detailed in the following section. Its length along the horizontal direction is taken as the reference chord length, being the effective chord at supercavitating regime. The main back profile (b) is then designed to stay inside the cavity at design condition, by an iterative procedure based on CFD simulations illustrated in the next section. The back profile line (b) must be far enough from the face line in order to ensure enough local and global structural

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\(^1\) definitions of the different cavitation modes for this type of SC profile are given in Brizzolara & Young (2012) and further analyzed in Young & Brizzolara (2013).
strength and, at the same time, it needs to stay well inside the cavity boundary to ensure stable super-cavitating conditions. Finally, the function of the tail (c) (d) is twofold. It contributes to increase the strength of the hydrofoil, increasing its sectional area and inertia modulus. Additionally, in fully wetted regime, it increases lift, adding effective camber and angle of attack and it reduces the base pressure drag (see section 3). Provided that the tail remains inside the cavity in SC and in base-cavitating conditions of interest, then its shape can be opportunoely adapted to give the right amount of lift in fully wetted conditions.

2 DESIGN PRINCIPLES

The new hydrofoil is design through a combination of CFD analysis methods and theoretical design methods. The design method uses Johnson’s asymptotical theory to determine the face line of the foil and a trial and error procedure uses a series of systematic CFD simulations (Brizzolara & Federici, 2011) to find the shape of the back that is fully enclosed inside the cavity, while ensuring the correct modulus of inertia to the foil.

The main body face of the hydrofoil is designed using Johnson’s method. Johnson uses the same conformal mapping technique first introduced by Tulin-Burkart, to transform the flow in the supercavitating hydrofoil complex plane \( \{Z\} \) into a fully wetted foil in the complex plane \( \{\bar{Z}\} \):

\[
Z = -\sqrt{\bar{Z}} \tag{1}
\]

The potential flow around the fully wetted profile is represented by a continuous vorticity distribution (unknown), according thin profile theory.

A general vorticity distribution \( \Omega(x) \) expressed by means of sine series is considered on the wetted foil:

\[
\Omega(\theta) = 2V \left( A_0 \cot \frac{\theta}{2} + \sum_{i=1}^{\infty} A_n \sin n\theta \right) \tag{2}
\]

Where the classical Glauert coordinate transformation is used to transform the coordinate \( x \) along the chord into an angular coordinate \( \theta \):

\[
x = \frac{1}{2}c \left( 1 - \cos \theta \right) , \quad 0 \leq \theta \leq \pi \tag{3}
\]

Classical thin profile theory is used to solve the flow around the wetted foil in the \( \{\bar{Z}\} \) plane, i.e. to find the expression for the \( A_n \) coefficients of the unknown circulation distribution. Due the conformal mapping, it can be proven that the lift coefficient of the supercavitating hydrofoil (calculated in the \( \{Z\} \) plane) turns out to be equal to the pitch moment coefficient of the fully wetted profile calculated in \( \{\bar{Z}\} \) as a function of the coefficients of the sine series, i.e.:

\[
C_L = C_{LM} = \frac{\pi}{2} \left( A_0 + A_1 - \frac{A_2}{2} \right) \tag{4}
\]

Analogously the drag coefficient of the SC hydrofoil corresponds to the lift coefficient of the wetted foil problem through the following relation:

\[
C_D = \frac{1}{8\pi} \frac{\bar{C}_L^2}{\bar{C}^2} = \frac{\pi}{2} \left( A_0 + \frac{A_1}{2} \right)^2 \tag{5}
\]

The optimum SC hydrofoil camber-line (face shape) is found first assuming a zero incidence angle and a proper reference line (not a chord line) in order to cancel out \( A_0 \) in (2) and consequent also in (4) and (5); and second looking for the values of the \( A_n \) coefficient that are able to maximize the efficiency. The hydrofoil efficiency is defined as the ratio between the lift coefficient (4) and the (inviscid) drag (5), i.e.:

\[
\frac{C_L}{C_D} = \frac{L}{D} = 4 \left( 1 - \frac{A_2}{2 A_1} \right)^2 \frac{\pi}{2C_L} \tag{6}
\]

Hence, finding the maximum efficiency is equivalent to find the maximum value of \([-A_2/A_1]\). The search for the maximum needs to satisfy also the physical condition that the vorticity is positive at any point of the foil (face), in order to avoid cavitation on the face. In fact, the dynamic pressure on the face is directly proportional to the circulation and the cavitation index is zero in this asymptotic method.

Hence, depending on the number of terms retained in the expression for the vorticity distribution (2), one can find different value of maximum efficiency.

Tulin-Burkart profiles are found retaining only the first two terms of the series. For this profile family the max ideal efficiency (at 0 angle of attack) is:

\[
\frac{L}{D}_{TB} = \frac{25 \pi}{4} \frac{1}{2C_L} \tag{7}
\]

The so called Johnson’s three term profile is obtained retaining up to \( A_3 \) in (2) and this leads to a 1.44 times higher efficiency (at the ideal angle of attack equal to 0), in fact:

\[
\frac{L}{D}_{3T} = 9 \frac{\pi}{2C_L} \approx 1.44 \cdot \frac{L}{D}_{TB} \tag{8}
\]

The three terms solution corresponds to the following face shape:

\[
\frac{c}{r} = \frac{A_3}{10} \left( 5 \frac{c}{r} - 20 \left( \frac{c}{r} \right)^3 + 80 \left( \frac{c}{r} \right)^5 - 64 \left( \frac{c}{r} \right)^7 \right) \tag{9}
\]

This is the basic shape used for the face of the new SCSB hydrofoil family presented in this paper.

\[\text{Figure 3 – Example of Tulin-Burkart and Johnson’s three, five terms profiles, all obtained for the same design lift coefficient.}\]
results. To this scope we use an unsteady, fully turbulent, RANSE solver with two phase homogeneous mixture of fluids (VoF) technique and a barotropic phase change model, previously validated in the case of a classic SC hydrofoil (Brizzolara & Federici, 2011) with satisfactory results. All Reynolds realizable k-ε turbulence models with two layer wall functions are used also in this case.

We adopt a naming convention for these new hydrofoils which reports the design lift coefficient and the design angle of attack in fully ventilated conditions ($\sigma_0=0$), after the acronym of the hydrofoil. So for instance $SBSC-42-5$ means that the design lift coefficient $C_L=0.42$ and the design angle of attack is $\alpha=5$ deg.

In this presented example, the intent is to design $SCSB-42-5$ hydrofoil so the face stays the same between the various cases, while the back shape is adapted to the predicted cavity shape. The first tentative design of back shape (indicated as v.1) does not super-cavitate: the cavity on the back does not detach at the leading edge, but it starts at about 0.4c, as better inferred from the plots of the pressure coefficient along the chord given in Figure 5. With reference to this plot, super-cavitating condition is reached when the pressure coefficient over the whole back surface is consistent with the phase change condition used by the cavitation model, i.e.:

$$-C_p = \sigma_0 = 0.05 \text{ in this case} \quad (10)$$

Figure 5 - Pressure distributions on some of the hydrofoils presented in Figure 4.

In version 2, the curvature of the back line has been increased but at the expense of a higher thickness in the forward part of the hydrofoils. This does not solve the problem of cavity detachment at the leading edge; on the other hand of the back starting at mid-chord increases the thickness of the height of the cavity over the aft portion of the back. Version 3 has a generally reduced thickness in the first 20% of the chord (face stays the same), resulting in a concave curvature there which anticipates the detachment of the cavity on the back from about 0.4c to 0.3c. A further thickness reduction of the entrance body of the foil, as realized in version 4 maintaining the concave curvature, is able to achieve the supercavitating condition. The thickness of the foil, though, is very small and the required design strength (inertia modulus) is not met. Version 6 gains some thickness back, representing the limit condition for the location of the back line: the thickness of the cavity over the back surface in this case is quite thin as it may be detected.
From the VoF from Figure 4, as confirmed by the constant pressure coefficient value in the plot of Figure 5. The addition of the tail, through the two discontinuity, transforms the conventional hydrofoil into the new SCSB profile. This modification does not affect the hydrodynamic performance of the SCSB hydrofoil in this regime, but does make a difference in other regimes; in particular in fully-wetted, sub- or partially cavitating conditions (approximately $\sigma_0 > 0.4$).

For example, Table 1 summarizes the numerical results of the CFD calculation, in terms of lift, drag coefficients and efficiency ($L/D$) obtained for four different versions of the hydrofoil and for the same hydrofoils the pressure field calculated in fully wetted conditions is presented in Figure 6.

The presented hydrofoil series also includes a conventional Tulin-Burkart hydrofoil designed to achieve the same lift coefficient at $\sigma_0 = 0.05$, and with similar total inertia modulus. CFD simulations presented in this paper were run for full scale, i.e. for $Re \approx 26M$ in supercavitating conditions and $Re \approx 5.5M$ at takeoff (fully wet conditions).

Evidently, the wedge shaped conventional SC hydrofoils suffer of significant pressure drag due to the flow separation and vortex shedding aft of at the truncated base, as opposed to the SCSB hydrofoil. The difference in flow pattern is evident by the comparison of the streamlines and pressure field plots of Figure 6.

For all the above, the efficiency (lift over drag) of the SCSB hydrofoil is about three times higher than that of conventional super-cavitating hydrofoils: $L/D \approx 18$ of the SCSB-42-5, against $L/D \approx 6$ for the hydrofoil with the same main body (v.6) without tail. Additionally the lift coefficient is about 50% higher. This better performance in sub-cavitating conditions is very useful in order to minimize take-off time of hydrofoil crafts, at the same time minimizing the required thrust or propulsion power (directly dependent on the hydrofoil drag), usually characterized by a relatively high hump.

The optimal performances of SCSB profiles at both operating modes (SC and fully wetted) are also desirable for super-cavitating or surface piercing propeller blades sections. Blades designed with SCSB profile will be more efficient at sub-critical conditions and hence will cause less engine overload at low revolutions or during accelerations.

The added tail and cavitators design can be customized to the particular lift required at the lower operational speed.

### Table 1 – Super-cavitating ($\sigma_0=0.05$) and Sub-cavitating ($\sigma_0=\infty$) hydrodynamic characteristics of some of the hydrofoils considered in the design procedure of SCSB-42-5.

<table>
<thead>
<tr>
<th>Hydrofoil</th>
<th>Super-cavitating Conditions (120 knots)</th>
<th>Sub-cavitating Conditions (take-off)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>v.4</td>
<td>v.6</td>
</tr>
<tr>
<td>CL</td>
<td>Pressure</td>
<td>Shear</td>
</tr>
<tr>
<td>CD</td>
<td>3.4E-02</td>
<td>1.9E-03</td>
</tr>
<tr>
<td>L/D</td>
<td>12.24</td>
<td>12.01</td>
</tr>
<tr>
<td>Notes:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pressure</td>
<td>Shear</td>
</tr>
<tr>
<td>CL</td>
<td>6.0E-01</td>
<td>1.5E-01</td>
</tr>
<tr>
<td>CD</td>
<td>8.2E-02</td>
<td>4.0E-03</td>
</tr>
<tr>
<td>L/D</td>
<td>6.98</td>
<td>5.93</td>
</tr>
<tr>
<td>Notes:</td>
<td>oscillating 0.4-0.7</td>
<td>oscillating 0.4-0.52</td>
</tr>
</tbody>
</table>

Figure 6 - Calculated pressure field and streamlines for some of the hydrofoils considered in the design procedure of SCSB-42-5.
After having described the design principles of the new SCSB hydrofoils, we detail their hydrodynamic performance of one member of the family: SCSB-25-5. This hydrofoil was designed for the ultra-high-speed craft presented in Figure 1, as a variant of the SCSB-42-5 and used a base foil for the fin built and tested in surface piercing conditions at the high-speed free surface cavitation tunnel of TUB. Initial numerical predictions of the fin hydrodynamics were presented in Brizzolara & Villa (2011) as obtained from three phase (vapor, air, water) viscous unsteady RANS simulations and in Young & Brizzolara (2013) with a steady potential flow based panel method, adequately adapted to the particular operating conditions of the fin. Some of the complex physics observed in the experiments were introduced in Brizzolara & Young (2012).

![Image of SCSB-25-5 hydrofoil sections](image)

**Figure 7** – Intermediate (top) and final version (bottom) of the SCSB-25-5 hydrofoil section

The design lift coefficient of the v.9 and v.10, presented in Figure 7, is significantly lower (0.25) than the one (0.42) assumed for the previous series of foils (Figure 4). Since the angle of attack was kept unvaried (5 deg) the overall camber needed for the face line is lower. This in turn offers the possibility to obtain a thicker profile especially in the entrance region near the leading edge, where a sufficient strength is needed against fluttering. The practical indication given by Pearce & Brandner (2007) valid for hydrofoil crafts is met by the SCSB-25-5 profile, v.10 hydrofoil, in Figure 7.

To characterize the performance of the SCSB-25-5 hydrofoil we ran a systematic series of unsteady RANS computations over a large range of cavitation indexes and angles of attack. The global results obtained are the non-dimensional coefficients of lift, drag and center of pressure along the effective cord of the hydrofoil. Additional results relative to the flow field were also extracted, such as the type of cavitation, the nature of its stability and the cavity length in case of super-cavitation.

Within all results obtained, we focus here on a reduced set for sake of brevity. To discuss the effect of the angle of attack on the performance on the SCSB-25-5, in Figure 8 we present the lift and drag coefficient calculated for \(0 \leq \alpha \leq 10\) at \(\sigma_0 = 0.05\) and in Figure 9 the longitudinal position of the center of pressure \(X_{CP}\) (measured along the horizontal and normalized with the chord \(c\)) and the efficiency defined as lift over drag. The \(C_L-\alpha\) curve can be divided in three different regions, distinguished by three different slopes of the curve:

\[a \geq 4.5\]: the hydrofoil is working in steady super-cavitating regime with the cavity forming at the L.E. on the back and at the cavitator on the face. The slope of the \(C_L-\alpha\) curve is very close to the theoretical value \(\pi/2\) (Tulin, 1964);

\(1.0 \leq \alpha \leq 4.5\): the hydrofoil is working in partial cavitating conditions with the back fully wetted from the leading edge to the cavitator and no or partial cavitation on the face. Since the contribution to lift of the back surface is present, as in conventional profiles, the slope of the \(C_L-\alpha\) curve changes and set on the theoretical value from (subcavitating) thin profile theory, i.e. \(2\pi\);

\(a \leq 1.0\): the hydrofoil is working again in steady supercavitating regime but the cavity is on the face side starting from the L.E. over the face cavitator and joining with the cavity on the back forming at the back cavitator.

![Graph of lift and drag coefficients](image)

**Figure 8** - SCSB-25-5, lift and drag coefficient versus angle of attack, at cavitation index \(\sigma_0=0.05\).

![Graph of efficiency](image)

**Figure 9** - SCSB-25-5, Efficiency (lift over drag), at cavitation index \(\sigma_0=0.05\).
The drag also changes trend in the various regimes above listed and in particular, it rises more steeply in the supercavitating regimes than it does in partial or base cavitating regime. The combined result of the two above force components gives the efficiency, presented in Figure 9: it shows a peak around the starting of the supercavitating regime on the back, i.e. around 4.5 deg. This is a confirmation that the design procedure illustrated in the previous section has given optimal results.

Another interesting behavior is found by considering a variation of the cavitation index over a large range starting from the lowest value $\sigma_0=0.05$, corresponding to maximum speed of the craft, to the high end of takeoff speed range, corresponding to about $\sigma_0=0.8$. The angle of attack is fixed at $\alpha=5$ deg. Results are shown in Figure 10 in terms of lift and drag coefficients and in Figure 11 in terms of efficiency. The cavitation patterns obtained at the calculated cavitation numbers are shown in Figure 12. In the range $\sigma_0 \in [0.2: 0.4]$, the URANSE model predicts an unsteady type of sheet cavitation, with the cavity oscillating between a longer and a shorter length: these two extreme conditions are presented by the two pictures included at each unsteady cavitation number.

At $\sigma_0=0.3$ and $\sigma_0=0.4$, also the forces show an unsteady trend with periodic oscillations, similar to that first shown in Brizzolara & Federici (2011) for a conventional SC hydrofoil, so the mean value over several periods is taken for plots in Figure 10. The slight unsteadiness of the cavity noted at $\sigma_0=0.3$ has no effect on the force components that are indeed quite constant with time at this cavitation number.

We conclude with a summary of hydrodynamic performance of the SBSC-25-5 in sub-cavitating regime presented in Table 2. The $C_{L-\alpha}$ curve in this case is practically linear, aligned with the theoretical slope of thin profile theory $2\pi$. High lift coefficient are attained also at 0 degree angle of attack, this is due to the tail shape designed as a rigid flap to help with a rapid take-off at low speeds. As discussed in the previous section, in case of the SCSB-42-5, also the SCSB amount of drag is significantly lower than other conventional SC profile and close to that of conventional NACA profiles. The only difference is caused by the pressure drag induced by the face and back cavitators and by the high curvature of the tail back close to the T.E. that can still be possibly improved.

### Table 2 – SBSC-25-5, hydrodynamic characteristics subcavitating conditions

<table>
<thead>
<tr>
<th>$\alpha$</th>
<th>$C_L$</th>
<th>$C_D$</th>
<th>$L/D$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.340</td>
<td>0.0110</td>
<td>30.9</td>
</tr>
<tr>
<td>3</td>
<td>0.628</td>
<td>0.0180</td>
<td>34.9</td>
</tr>
<tr>
<td>4</td>
<td>0.715</td>
<td>0.0234</td>
<td>30.6</td>
</tr>
<tr>
<td>5</td>
<td>0.817</td>
<td>0.0310</td>
<td>26.4</td>
</tr>
<tr>
<td>6</td>
<td>0.912</td>
<td>0.0423</td>
<td>21.6</td>
</tr>
<tr>
<td>7</td>
<td>1.004</td>
<td>0.0550</td>
<td>18.3</td>
</tr>
</tbody>
</table>

### 5 CONCLUSIONS AND FUTURE WORK

The design principles of a new patented family of supercavitating hydrofoils sections has been described in the paper: it is based on a combined use of classic asymptotic methods and state of the art RANSE solvers with cavitation models. This new family of hydrofoils is able to reach optimal efficiencies both in super-cavitating regimes as well as in fully wetted or base cavitating regimes, on the contrary to conventional super-cavitating hydrofoils with blunt trailing edge that pay a large amount of drag in non-cavitating regimes.

A sample hydrofoil of the family, the SB-25-5, suitable for hydrofoil crafts i.e. having a large inertia modulus and realistic thickness near the leading edge to avoid fluttering, has been presented. Its hydrodynamic characteristics have been illustrated, through a systematic series of CFD simulations at different operating regimes, including super-cavitating, subcavitating and intermediate conditions. Interesting conclusions can be drawn from the results of the systematic CFD simulations with variable angle of attack and cavitation index:
- the design lift coefficient $CL = 0.25$ is reached at the design angle of attack $\alpha = 5 \text{deg}$ and design $\sigma_0 = 0.05$ with an efficiency $L/D > 11$. This is the same level of optimality hence attainable by a 3 terms Johnson SC profile (at the same angle of attack);
- a good level of efficiency is maintained by the SCSB hydrofoil in partial cavitating or fully wetted regimes which reaches $L/D \geq 26$ in subcavitating conditions. This is completely opposite to what happens in conventional SC profiles that pay a lot of pressure drag due to flow separation at the blunt T.E.;
- thanks to the two cavitators placed on the back and on the face of the profile, that resemble a sharply truncated trailing edge, the unsteady cavitating conditions are reduced to a minimum, being confined in a small range of cavitating indexes and angles of attack. For the SCSB-25-5 at $\alpha = 5 \text{deg}$, unsteady force oscillations due to unsteady cavitation are predicted in $0.3 < \sigma_0 < 0.4$.
- Thanks to these desirable hydrodynamic performance, the new SCSB profiles, initially designed for surface piercing lifting surfaces, may offer considerable advantages also for application to high speed propellers, either super-cavitating or surface-piercing.

**ACKNOWLEDGMENTS**

Present paper is a result of studies made thanks to the partial support of the Office of Naval Research Global (Grant N62909-11-1-7007) and US Office of Naval Research (N00014-13-1-0332). Early results obtained by Sara Pruner (2012) on the SCSB hydrofoil are willingly acknowledged.

**REFERENCES**

Figure 12 - Cavitation patterns of the SCSB-25-5 hydrofoil at 5 deg angle of attack for various cavitation indexes $\sigma$. Where more than one picture is shown, it means that the cavity is unstable and that the cavity oscillates periodically between the two reported patterns.