STUDY UPON THE CAVITATION PHENOMENON OF THE PROPELLERS AND AXIAL ROTORS

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Abstract: The main problem of the hydrodynamics of cavitation implosion of a single bubble, consists in pressure and velocity fields determination, including the collapse velocity of the bubble wall.
By analysis the theoretic and experimental phenomenon it establish the implicit function which describes this phenomenon. By application the $\prod$ theorem for this implicit function it finds the criterion equation of phenomenon.
Depending on operating condition various cavitation patterns can be observed on a body surface as travelling bubbles, attached sheet cavitation, shear cavitation or vortex cavitation. Leading edge attached partial cavitation is commonly encountered on rotor blades or on hydrofoil. It corresponds to the case for which a vapor cavity is attached in the vecinity of the leading edge and extends over a fraction of the foil surface. It generally takes places at incidence angles for which a leading edge pressure peak occurs and reduced below the liquid vapor pressure. At the early phases of development, leading edge partial cavitation is steady.

Keywords: *The bubble's implosion, incompressible liquid, the bubble surface, the $\prod$ theorem.*

1. Using the similitude theory on two scales in the experimental study of the cavitation phenomenon

There are situations when the possibilities of accomplishment of the pattern impose exceptions from the complete geometrical similitude, obtaining this way the distorted patterns which have horizontal lengths and vertical lengths reduced to different scales.

Generally, the distorted patterns are imposed when the possibilities of practical accomplishment make impossible the exact conformation of the geometrical similitude between the pattern and the prototype, or when evolution of the phenomenon on the pattern made at a single scale would lead to a laminar movement instead of turbulent one which would make all the experiments difficult.

A random physical phenomenon can be expressed in the most general way through a function of several physical proportions and the establishment of the connection between them is made (when the number of the physical proportions n $\geq$ 5) through theorem $\prod$.

Any homogeneous function of several physical proportions which determine a physical phenomenon can always be reduced to a relation between dimensionless complex proportions of the following formula:

$$\Phi(\Pi_1, \Pi_2, \ldots, \Pi_{n-k}) = 0 \qquad (1)$$

In the theory of similitude this function is called criteria equation and its establishment represents the first phase of the pattern study of a phenomenon.

As it is known the cavitation problems have not yet been solved, theoretically or practically, worldwide, although researches are made to this respect.

If we want to study this phenomenon through the similitude theory, we should previously set the physical proportions that intervene within the evolution of the cavitation phenomenon on the rotor of the axial pumps.

<u>The criteria equation for the cavitation phenomenon produced at the wheels of the axial pumps</u>

After theoretical and experimental researches made until now, it has been established that the cavitation phenomenon at the rotor of the axial pumps has the following implicit function:

$$f\ (\rho, n, D, T, \Delta p, h, d_{max}, g, \eta, v, m, z) = 0 \qquad (2)$$

where:

ρ - water density

n - wheel speed
D - wheel diameter
T - wheel pusher

$\Delta p = p - p_v$ - pressure distribution on the blade

p_v – water vaporization pressure at certain temperature;

h - immersion of the wheel axis on the water surface

d_{max} - maximum thickness of the wheel blade;

g - gravitational velocity g = 9,81 m/s²;
η - water kinetic viscosity ;

v - current velocity through the rotor disk;
m - air volume dissolved in water;

z- number of the wheel blades.

The physical proportions of this implicit function actually represent the physical proportions which this phenomenon depends on.

In order to apply theorem $\prod$ to the implicit function, we first write the dimensional matrix of the variables (number of rotor blades z is the same both as pattern and prototype).

$$\begin{array}{ccccccccccc} \rho & n & D & T & \Delta p & h & d_{max} & g & \eta & v & m \\ \end{array} \qquad (3)$$

$$\begin{array}{c|ccccccccccc} m & -3 & 0 & 1 & 1 & -1 & 1 & 1 & 1 & -1 & 1 & 0 \\ Kg & 1 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 1 & 0 & 1 \\ s & 0 & -1 & 0 & -2 & -2 & 0 & 0 & -2 & -1 & -1 & 0 \end{array}$$

$$\left\{ \left\|\begin{array}{ccccccccccc} -3 & 0 & 1 & 1 & -1 & 1 & 1 & 1 & -1 & 1 & 0 \\ 1 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 1 & 0 & 1 \\ 0 & -1 & 0 & -2 & -2 & 0 & 0 & -2 & -1 & -1 & 0 \end{array}\right\| \right.$$

out of which we obtain the equations system:

$$\left\{\begin{array}{l} -3x_1 + x_3 + x_4 - x_5 + x_6 + x_7 + x_8 - x_9 + x_{10} = 0 \\ x_1 + x_4 + x_5 + x_9 + x_{11} = 0 \\ -x_2 - 2x_4 - 2x_5 - 2x_8 - x_9 - x_{10} = 0 \end{array}\right. \qquad (4)$$

We sort out the main variables of the system:

$$x_1 = -x_4 - x_5 - x_9 - x_{11}$$
$$x_2 = -2x_4 - 2x_5 - 2x_8 - x_9 - x_{10} \qquad (5)$$
$$x_3 = -4x_4 - 2x_5 - x_6 - x_7 - x_8 - 2x_9 - x_{10} - 3x_{11}$$

System (4) is undetermined for solving, so we apply the Cramer rule and we obtain the solution matrix as it follows:

$$
\begin{array}{cccccccccccc}
 & \rho & n & D & T & \Delta p & h & d_{max} & g & \eta & v & m \\
\Pi_1 & -1 & -2 & -4 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\Pi_2 & -1 & -2 & -2 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
\Pi_3 & 0 & 0 & -1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
\Pi_4 & 0 & 0 & -1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
\Pi_5 & 0 & -2 & -1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
\Pi_6 & -1 & -1 & -2 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\
\Pi_7 & 0 & -1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\
\Pi_8 & -1 & 0 & -3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1
\end{array}
\quad (6)
$$

Out of the solution matrix we obtain the following similitude criteria:

$$\Pi_1 = \frac{T}{\rho n^2 D^4}; \Pi_2 = \frac{p - p_v}{\rho n^2 D^2}; \Pi_3 = \frac{h}{D}; \Pi_4 = \frac{d_{max}}{D}; \quad (7)$$

$$\Pi_5 = \frac{g}{n^2 D}; \Pi_6 = \frac{\eta}{\rho n D^2}; \Pi_7 = \frac{v}{nD}; \Pi_8 = \frac{m}{\rho D^3}$$

The criteria equation in which we shall include the number of blades z, shall be as it follows:

$$\varphi(\frac{T}{\rho n^2 D^2}, \frac{p - p_v}{\rho n^2 D^2}, \frac{h}{D}, \frac{d_{max}}{D}, \frac{g}{n^2 d}, \frac{\eta}{\rho n D^2}, \frac{v}{nD}, \frac{m}{\rho D^3}, z) = 0$$

(8)

If we respect the geometrical similitude after a single scale, it is possible that the thickness of the wheel blade and the immersion of its axis to reduce a lot, therefore it is possible that the pattern not to be able to be used for determinations, the results including too many errors.

Because of this, it is more advantageous and safe to create the distorted blade patter (at two scales), which allows more accurate results.

It can be determined the pattern law in the case of similitude at two scales, by randomly choosing the scale of the parallel lengths with the blade diameter and the scale of the parallel lengths with the thickness of the blade.

2. Experimental results and discussions

An investigation of leading edge partial cavitation was performed in Romania (ICEPRONAV – Galați) including the conditions of cavitation inception, the cavitation patterns together with cavity length measurements. The investigation was enhanced by instantaneous wall-pressure measurements using an instrumented blade of rotor equipped with seventeen wall-pressure transducers mounted into small cavities, (fig 1).

a)   b)
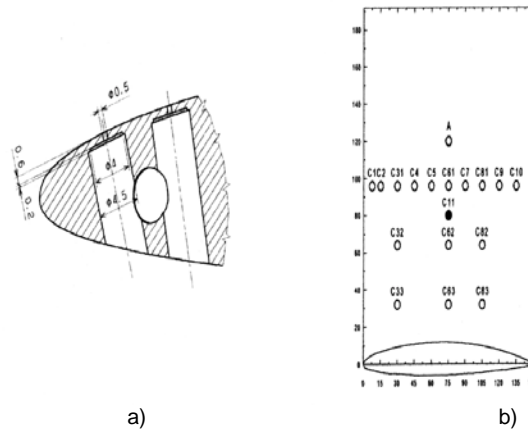
Fig. 1, a) Transducer cavity, b) Location of the pressure transducers, filled symbol is on the pressure side, A referees to an accelerometer, unit in millimeter.
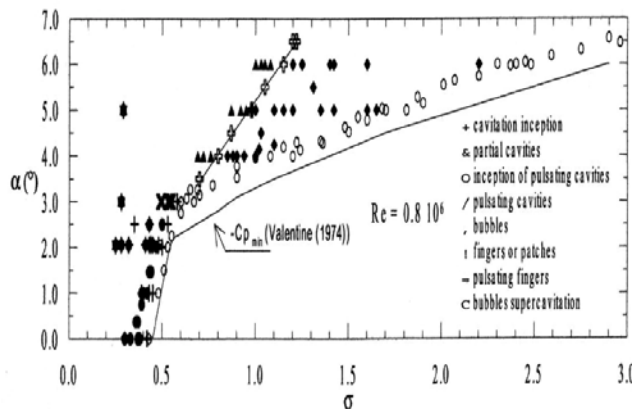

Fig. 2 Experimental results

All the experiments fitted with a 1m long and 0,192 m wide square cross test section. In this device, velocities of up to15 m/s and pressures between 30 mbar and 3 bar can archieved. The designed blade for this project is a 0,191 mm

span two - dimensional cambered foil of the NACA 66. Several experimental results have been obtained. Figure 2 shows the inception conditions and the various patterns detected on the suction side of the foil versus the cavitation number and the angle of incidence. The inception conditions are also

compared to the theoretical values of the opposite of the minimum pressure coefficient on the suction side. Partial cavities of intermediate length (l*lower than about 0,5) have a relatively stable behavior with weak variation of the cavity closure while shedding U-shaped vapor structures in the wake. In that situation the cavity length was measurable (see fig. 3). As shown on fig. 4, the liquid-vapor interface has a glossy aspect over a short distance from the leading edge indicative

of a laminar boundary layer developing on the interface. The extent of the laminar flow was found to be dependent on the velocity (Figures 4.b and 4.c for the same cavitation number but two velocities). Further away the interface becomes wavy and unstable over a large fraction of the cavity length. When the cavity becomes large, typicalli l/c larger than about 0,5, it exhibits a pulsating behavior while shedding larger vapor - filled structures. The transition is relatively well represented by the straight line shown on fig 1.
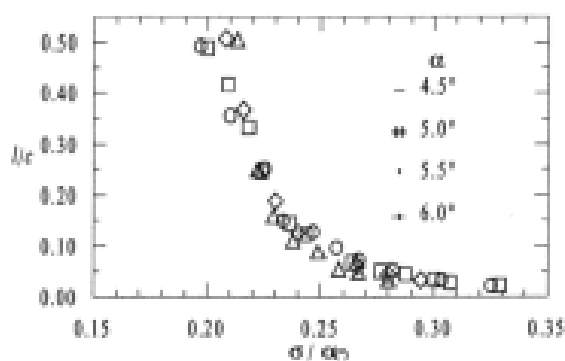
Fig. 3 Cavity length as a function of $\dfrac{\sigma}{\alpha}$ **, Re = $8 \cdot 10^{6}$**
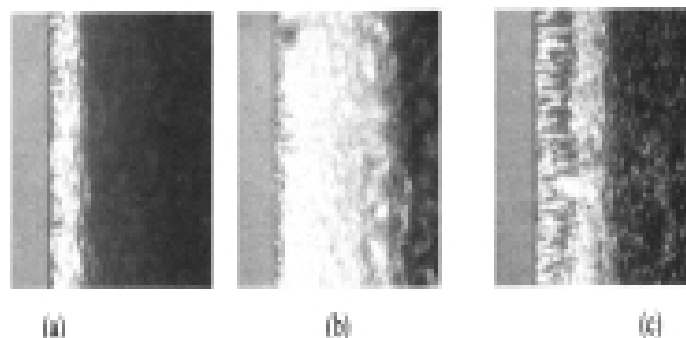
Fig. 4. Photographs of leading edge partial sheet cavitation, NACA 66-12% - 100mm foil, flow is from the left,

α = 6, a) Re = $8 \cdot 10^{6}$, $\sigma = 1,98$, l/c= 0,045 b) Re = $8 \cdot 10^{6}$,σ = 1,31, l/c=0,325. c) Re=$0,4 \cdot 10^{6}$, σ = 1,30, l/c=0,205.

3. Conclusions

Used in distributions, the equations form in the fluid mechanics and the filtration property of the Dirac distribution, several integral formulas regarding the cavitational implosion are obtained. The mathematic pattern, which only describes the fluid movement, can only indicate something about the hydrodynamic effects of the cavitational implosion, the thermal and electrochemical effects, experimentally presented, can be analogously analyzed. After knowing the non dimensional complex numbers which form the criteria equation, before making the pattern of the studied phenomenon we shall establish the connections between the scales of the physical proportions which determine these complex numbers, that is we shall establish the pattern law. Being familiar to the distorted pattern law, we can transfer the proportions results obtained on the pattern, on the prototype.

We notice that not all the similitude criteria have the same importance in the evolution of the cavitation process of the axial pumps blades. The most important criterion, decisive in the cavitation process, is the one in which the vaporization pressure intervenes pv. The cavity lenght does not change significantly, the liquid – vapor interface is smooth and has a glossy aspect along a short distance from the leading edge. At the end of the cavity it breaks partially into small bubbles. As the cavity expands, the liquid – vapor interface become distorted, wavy and unstable yielding to breakup and unsteadiness. At this stage significant variations of the location of the cavity closure point are observed while shedding vapor structures called „cloud" cavitatin. This process induces high - level pressure pulses and is known to be one of the most destructive forms of cavitations.

4. REFERENCES

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