ABSTRACT

A non-linear problem of the cavity flow past a hydrofoil with taking into account the fluid viscosity in the cavity closure region and the surface tension affecting the cavity detachment is considered. The theoretical model is based on the concept of viscous/inviscid interaction between the external inviscid cavity flow and internal turbulent separated flow behind the cavity. The external inviscid flow is solved by constructing the complex potential of the flow, and the wake model is based on the method of integral relationships for separated turbulent flows. The obtained numerical results and experimental data are compared.

KEY WORDS: Cavitating hydrofoil; cavity detachment; complex potential; viscous/inviscid interaction; cavity wake.

INTRODUCTION

As the speed of a body moving in a liquid increases, the pressure on its surface drops to the vapor pressure, the flow separates from the body, and a cavity forms. If the body has a sharp edge, it is at the edge that the pressure reaches a minimum first. In this case, the separation point is fixed, and its location is known. If the body is smooth, the location of the separation point is not known a priori and has to be determined as part of the solution of the problem. In the model of perfect liquid, flow separation from a smooth surface implies zero velocity and zero pressure gradient at the separation point, which is equivalent to the jet curvature being equal to the body surface curvature at the separation point (Brillouin, 1911; Villat, 1914). Abundant experimental evidence shows that in a real liquid cavitation separation takes place downstream of the point predicted by the model of perfect liquid.

The effect of liquid viscosity on the position of the separation point has been studied experimentally, in particular by Arakert & Acosta (1973), Arakeri (1975). It is shown there that boundary layer control allows one to vary the position of the cavitation separation point. In the paper Arakeri (1975) it is shown that cavity detachment is preceded by laminar boundary layer separation. According to the boundary-layer theory, laminar separation may take place if the pressure gradient is positive, i.e. the pressure on the body increases when going toward the cavity detachment point. However, this is in contradiction with the assumption that the cavity pressure is the minimum possible pressure in the flow.

The existence of a laminar boundary layer separation region upstream of the cavity detachment point is verified by Franc & Michel (1985). Tassin Leger & Ceccio (1998) have examined pressure distributions along the NACA 631A012 hydrofoil for the cavitation and the cavitation-free condition, the effect of surface tension and studied the physical properties of the liquid–body contact on cavity detachment. Similar experimental data for the NACA 0009 hydrofoil were presented Laberteaux & Ceccio (2001). According to the experimental data of Tassin Leger & Ceccio (1998), in the presence of cavitation the hydrofoil surface shows two velocity maxima, which correspond to two pressure minima, while in the absence of cavitation there is only one minimum/maximum, and the maximum velocity near the leading edge is greater than on the cavity boundary. This suggests that near the leading edge the pressure on the hydrofoil is lower than the vapor pressure.

To find the velocity distribution in the potential flow near the leading edge, which is necessary for laminar boundary layer calculation, Tassin Leger & Ceccio (1998) used a numerical solution of the problem of potential separation-free flow around the hydrofoil. Although the authors demonstrated the possibility of applying the boundary-layer separation theory to cavity flow, they neither explained the positive pressure gradient paradox nor presented any method for body pressure calculation in the presence of cavitation.

A semi-empirical method for cavity detachment calculation, which includes liquid viscosity and surface tension, has been presented by Amromin & Ivanov (1982). The authors consider a laminar boundary layer near the cavity detachment point and a pressure jump across the cavity boundary caused by the surface tension and cavity curvature. The unknown pressure distribution in the region upstream of the cavity detachment point is approximated by a parabola with the coefficients determined from the boundary conditions.

In this work, a physical model of cavitation separation from a smooth surface is presented. According to this model, cavity formation starts with cavitation nuclei in the boundary layer, whose development requires some time and an ambient pressure lower than the vapor pressure. Not only does the outer potential flow form a pressure gradient in the separation region, but it also limits the size of cavitation bubbles in the boundary layer. If the size of a gas–vapor bubble is