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Title

Flow separation characteristics of supersonic nozzles in water environment

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Abstract

Jet propulsion with supersonic nozzles is one of the main propulsion methods for underwater vehicles [1]. Large nozzle expansion ratio and adapting to a wide depth range are the future development trends of underwater jet propulsion, and the consequent flow separation problem of supersonic nozzles in water environment needs to be paid more attention by researchers. In this paper, a highly visualized experimental system of underwater plane vertical gas jets was established, which can effectively improve the observation of the flow state inside the nozzle and near the outlet. The typical characteristics of gas jet morphology and flow separation in water environment were discussed by conducting jet experiments at different nozzle pressure ratios (NPRs). In order to further reveal the flow field structure during flow separation, the VOF model was used to numerically simulate the flow characteristics of a parabolic nozzle under the condition of high over-expansion in deep water environment, and the pulsation laws of nozzle shock wave, gas-liquid separation point and wall pressure distribution were analyzed. The experimental and simulation results show that the over-expanded supersonic gas jet in water environment has significant unsteady characteristics. The jet flow pattern near the nozzle outlet constantly appears bulging, necking and back-attacking, and the pressure of the flow field outside the nozzle also presents the characteristics of unsteady oscillation. Different from the supersonic nozzles working in the air [2], the flow separation inside the nozzle in water environment also has obvious unsteady characteristics due to the change of the ambient pressure at the nozzle outlet. The position of the flow separation point is not fixed, but shows a reciprocating periodic motion along the nozzle axis, and the volume fraction at the separation point also shows the characteristics of gas-liquid separation. The pressure distribution on the nozzle wall changes suddenly at the point where the shock wave separates. The pressure before the shock wave presents the low-pressure distribution in the conventional nozzle, and after the shock wave, the pressure suddenly increases and tends to the ambient pressure. Due to the instability of gas-liquid interaction, the flow separation in the nozzle is not always symmetrical. The uneven distribution of the separation point and nozzle wall pressure will lead to a skewed macroscopic pattern of the jet, and there may be intermittent side-to-side swings, which will bring serious thrust instability and thrust eccentricity.

References

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