# Experimental Characterisation and Numerical Modelling of Planar Cavitating Venturis

A thesis submitted

in partial fulfillment for the award of the degree of

**Doctor of Philosophy**

by

**Anuja Vijayan**

**Department of Aerospace Engineering**

**Indian Institute of Space Science and Technology**

**Thiruvananthapuram, India**

**March 2024**

# Abstract

A ***cavitating venturi*** is a passive device that uses hydrodynamic cavitating flow to anchor the mass flow rate. The inter-phase interactions impart inherent cavity oscillations in the venturi operation, presenting challenges in understanding its flow behaviour and developing reliable numerical models. The present work aims to experimentally characterise the nature and dynamics of the cavitation zone in planar cavitating venturi and numerically model the cavity behaviour.

An experimental facility has been erected and commissioned for planned experiments under different geometric and operating conditions. Systematic experimentation with a planar cavitating venturi confirms that the re-entrant jet (REJ) causes the cavity oscillations at low cavitation intensity and the combined action of the REJ and the bubbly shock at high cavitation intensity. The present experiments reveal three distinct behaviours of venturi operation. At low cavitation intensity (high cavitation number), the cavity oscillations and the dynamics are governed by the low frequency components corresponding to the global oscillation of the attached cavity. This region is *region* 1. At high cavitation intensity (low cavitation number), the cavity dynamics is governed by high-frequency oscillations due to the cloud cavitation. This region is *region* 3. Both the high and low frequency components dominate the cavity dynamics at the intermediate region (*region* 2), and the frequency response shifts from low frequency to high frequency oscillations. The venturi divergence angle influences the cavity dynamics. In general, as the divergent angle increases, the cavity length decreases, and the oscillation frequency increases. This behaviour is due to the increased flow separation at higher divergence angles. The span of the transition region also reduces when the divergent angle increases. When the divergent angle is very low, the dynamics is characterised by *region* 1 alone. The cavity is stable, with only minor oscillations at the tail-end. The throat configuration significantly affects the cavity dynamics. *Region* 2 is found to be shifting to the high cavitation number regime when the throat width is increased. This behaviour is due to the reduced interaction between the upper and the lower cavity lobes. A similar shift of *Region* 2 to the high cavitation number regime is observed when the throat length is reduced. This is because of the reduced boundary layer thickness, which facilitates stronger and faster re-entrant jets. In a planar venturi with no throat length, a complete absence of *region* 1 is observed. Thus an increase in the throat

width and a reduction in the throat length will push the venturi behaviour more into the cloud cavitation regime.

An assessment of the existing two-dimensional mixture and RANS models has been done using the commercial software ANSYS Fluent. The applicability of the models in reliably predicting the key sizing parameters as the cavity length, the critical and the minimum pressure ratio, the anchored flow rate and the cavity oscillation frequency has been studied. A systematic non-dimensionalisation of the governing equations revealed two important non-dimensional numbers, the inlet Reynolds number, $Re_{in}$ and the scaled non-dimensional pressure gradient, $K$, related to the performance prediction of the existing two-dimensional models. In the range of $Re_{in}$ between $1 \times 10^4$ - $3 \times 10^5$ and $K$ between $1 \times 10^{-1}$ - $5 \times 10^3$, the assessment of predictability indicate reliable cavitation zone length predictions for $Re_{in} > 1 \times 10^5$ and $K < 100$. The inertia-dominated system at higher Re is responsible for better predictability. In this regime of predictability, the mass flow rate and the pressure ratio at anchoring will also show better agreement (within $\pm 10$ %) with the experimental data. Extensive simulations carried out in the present work show that the existing models are insufficient to capture the realistic behaviour of the cavitating venturi. Studies are being undertaken to correctly predict the dynamics using two-fluid models as a continuation of the present work.

A simple one-dimensional model has been constituted as an engineering sizing tool for predicting the integral sizing parameters. The model uses a homogeneous Eulerian flow field closed by the Rayleigh-Plesset equation (implemented by a two-part Euler integration using the local time scale derived from the translational bubble velocity) for the bubble dynamics. The model has been validated for a wide range of operating conditions using the experimental data from five planar venturis with different throat widths and divergent angles. The model predicts the experimentally obtained cavitation lengths within $\pm 10\%$ for small divergent angles and $\pm 25\%$ for large divergent angles. The mass flow rates are also predicted within $\pm 25\%$. The applicability of the model as a typical engineering sizing tool to predict the operating pressure ratios is also checked using the available experimental data in axisymmetric venturis from published literature. The model could predict the experimentally obtained critical pressure ratios and the minimum pressure ratios within $\pm 12\%$ and $\pm 20.7\%$, respectively, for the planar venturis.