Parametrically forced axisymmetric gravity waves and jetting in a circular cylinder

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Abstract: Parametrically forced surface waves commonly known as Faraday waves, can be generated by shaking a container vertically inducing oscillation to the interface of two fluids. The Faraday waves that are sub-harmonically excited have been extensively studied over many decades. Large amplitude gravity waves in axisymmetric and sloshing regime are not yet fully understood. A perfect understanding may facilitate the evaluation of the forces in tank wall and also the heat and mass transfer in liquid propellant tank or other tanks partially filled with liquid experiencing this kind of wave motion. Faraday noticed that the waves formed at the interface have half the forcing frequency. This had been confirmed by the Rayleigh through his experiments. Present work deals with numerical studies of parametrically forced gravity waves in axisymmetric mode in a circular cylinder filled with FC-72 with large liquid depth and compare with the existing results reported in literature.

The computational domain is a cylindrical container of 100mm diameter with FC-72 at bottom and air at top. Moving boundary condition is imposed at the bottom wall and at the wall no slip condition is applied. The simulations have been done in ANSYS 15.0 Fluent using VOF model which helps to track the interface. Both axisymmetric and three dimensional simulations have been carried out for the axisymmetric mode (01) to trace the instability threshold and wave amplitude response. Although three dimensional simulations are performed in the chaotic region and in unstable wave region, validation of axisymmetric simulation for wave breaking and stable wave regions with three dimensional simulations have been done to ensure their axisymmetric nature. The instability thresholds and wave breaking thresholds are plotted from the simulated results which show a good agreement with the reported experimental (Das and Hopfinger 2008) and theoretical results (Hendersen and Miles 1994). When the forcing amplitude crosses the stability threshold, steady state wave amplitude response is observed. Wave amplitude response shows non-axisymmetric behaviour in a small regime below the breaking line and above instability threshold. A notable observation is the presence of different time scales of wave amplitude modulations at different regimes. Wave amplitude modulation exhibits presence of different types of time scales of modulations e.g. slow time scale, period tripling and period quadrupling. In some part of the unstable wave motion (subcritical regime) period tripling (here for amplitude ratio, A/R = 0.005, R is the radius of the container) has been observed whereas some part (supercritical regime) shows period quadrupling behaviour (here at A/R=0.010). At higher frequency it bifurcates into a different mode (asymmetric 31 mode). In the overlap region of two, i.e. 01 and 31 modes, there is a small region where coexistence is observed as shown in the figure 1. When $A>A_{breaking}$, the wave breaking occurs for axisymmetric mode. In the breaking region, exponential growth of amplitude and subsequent breaking occurs with a high velocity jet ejection from the fluid interface due to the inertial collapse as observed by previous investigators [Zeff et al., 2000 and Das and Hopfinger, 2008]. Jet formation occurs both with and without bubble pinch-off. From the simulation results it is observed that calculated jet velocity can be as high as 40m/s. Zeff et al. (2000) found a jet velocity of 52m/s with glycerine water solution as working fluid in a slightly larger container. Figure 2 shows picture of a jet and the evolution of the velocity at a location on the interface along the centreline.

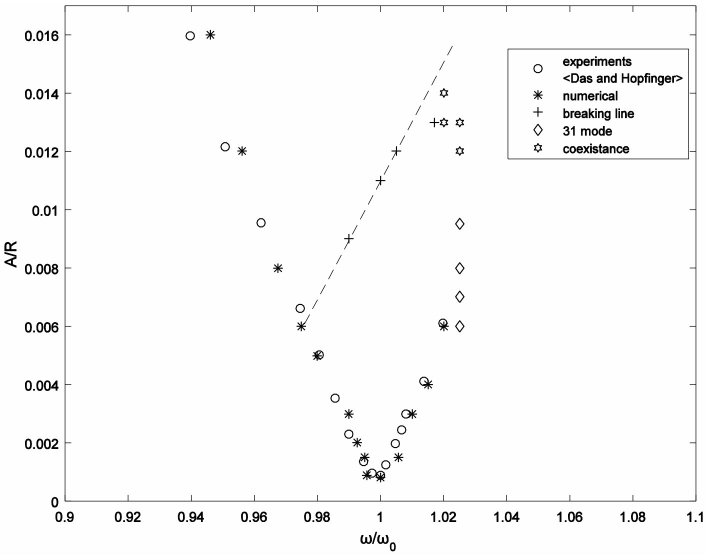

Figure 1. Instability threshold obtained from numerical simulations (*) is compared with experimental results (Das and Hopfinger 2008). + shows the region where the wave grows exponentially and breaks. The symbols × and ◊ show the regions for 31 mode and coexistence of 31 and axisymmetric modes respectively. The wave mode for the latter is initially axisymmetric and then coexists with the 31 mode. ω_0 is the natural frequency of 01 mode.

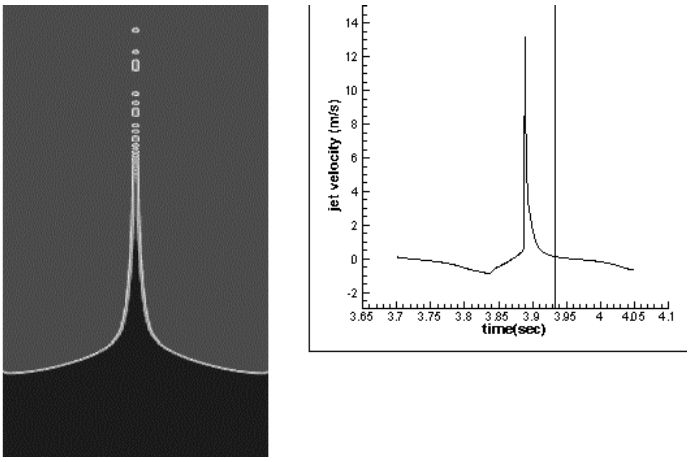

Figure 2. A high velocity Jet issuing out of the interface (A/R=0.0168, ω/ω_0=0.995). Jet velocity has been probed at the interface. Plot on the right shows the velocity as a function of time and vertical solid line indicates the time at which jet is shown on left. A is forcing amplitude and R is the radius of container.

References

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