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ENHANCEMENT OF HYDRODYNAMIC FLOW NOISE RADIATION BY THE REGULATION OF AIR BUBBLES IN A TURBULENT WATER JET

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An experiment is performed to show that the near-field hydrodynamic radiated flow noise (generated by a turbulent submerged water jet) is enhanced when the turbulent flow is modified to become a two-phase flow containing air bubbles. Acoustic intensity spectra, in the frequency band between 5Hz and 7000Hz, are measured using a digital spectrum analyzer from signals generated by a hydrophone placed at the position of $Z=4D$ and $R=4D$. Here, Z and R are the axial and radial positions from the nozzle exit, respectively. The water velocity is 12m/s at the nozzle exit diameter $D=0.635$ cm. An amplification factor defined by the ratio of intensities

$I_{\text{two-phase flow}} / I_{\text{fluid flow}}$ is measured as a function of the void fraction β of the air bubbles.

I. INTRODUCTION

Using Lighthill's¹ aerodynamic theory as a starting point, Crighton and Ffowcs Williams² showed (under reasonable hypotheses) that the effect of bubbles in a turbulent flow is to increase the acoustic power output of radiated noise by the factor $(c_{\text{fluid}} / c_{\text{mixture}})^4$ where c_{fluid} and c_{mixture} are the low frequency sound speeds in the fluid alone and in the fluid-air bubble mixture, respectively. More recently, Prosperetti³ investigated this amplification mechanism and was able to show that the low frequency ambient noise in the ocean might be explained by the amplification effects of bubble layers in a turbulent ocean - caused by breaking waves.

Measurements of the acoustic intensity are made as a function of void fraction β (the ratio of air volume to total volume) in an effort to verify the theoretical amplification predictions made in Ref 1 and 2. For low frequencies, the sound speed in a mixture can be expressed by $(c_{\text{fluid}} / c_{\text{mixture}})^2 \approx$

$[\beta \epsilon + (1 - \beta)] [\beta \chi + (1 - \beta)] \approx \beta \chi + 1$. Define $\epsilon = \rho_g / \rho_f$ and $\chi = \rho_f c_f^2 / \rho_g c_g^2$, which involve the densities ρ_g and ρ_f and sound speeds c of each phase in the mixture. Here $\beta \ll 1$ and let f and g represent the fluid and gas phases, respectively.

II. EXPERIMENTAL SETUP

The experiment is performed in a 6.5m x 6.5 m x 5m deep section of the U.S. Naval Academy Hydrodynamics Tow Tank. An apparatus is constructed to produce a turbulent shear flow that is generated by a submerged circular jet which is arranged to flow in an upright position. See Fig.1. The submerged water jet apparatus has a plenum section followed by a conical section that is joined to a circular nozzle (which tapers from a 7.62cm diam to a 0.635cm diam at the exit.). The bubbles are generated in the nozzle throat by a fritted ceramic disk (1cm diam, 5µm pore size)

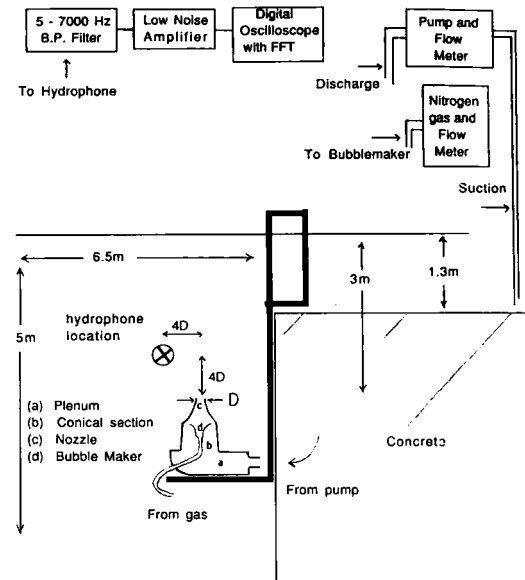


Fig.1. Experimental setup for measuring flow noise from a two-phase turbulent flow containing air bubbles.

that is housed in a glass Buchner funnel. Compressed nitrogen gas is regulated and metered from a copper pipeline above the surface.

Measurements of the near-field acoustic pressure spectrum are made from a hydrophone that is shown in Fig.1. Voltage signals from the hydrophone are band pass filtered between 5Hz and 7000Hz and amplified. A digital oscilloscope, with a Fast Fourier Transform algorithm, computes the average acoustic pressure spectrum of 50 trials.

III. EXPERIMENTAL RESULTS

In Fig.2. the average of 50 trials of the squared rms acoustic pressure spectrum is shown for the following two cases: flow noise generated by (1) turbulence alone and by (2) turbulence with bubbles. (We define a power spectrum to be proportional to the squared rms pressure spectrum.) The volume flow rate of N_2 gas and water are measured to be 19 ± 3 cc/min and 2.5×10^4 cc/min respectively. From these measurements, a void fraction β was estimated to be 7.6×10^{-4} .

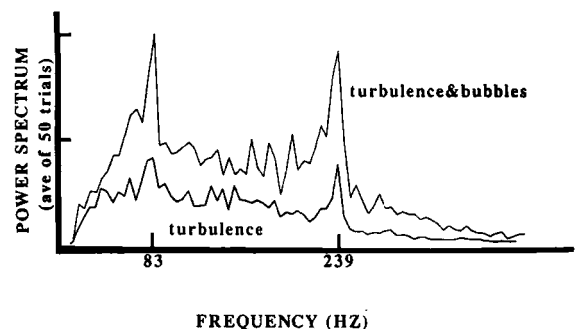


Fig.2. Flow noise power spectrum. Turbulent flow; containing bubbles, without bubbles. (Linear vertical scale is in relative units.)

Since the pressure to voltage sensitivity of the omni-directional hydrophone did not change from case (1) to case (2) an amplification or gain factor G can be computed from the results in Fig.2. Define $G = I_{(2)} / I_{(1)}$ where the intensity $I \propto \int_{f_1}^{f_2} (\text{rms pressure spectrum})^2 df$ corresponds to either case (1) or (2). The amplification factor G was computed to be $G=2.76$ when $f_1=5\text{Hz}$ and $f_2=4000\text{Hz}$.

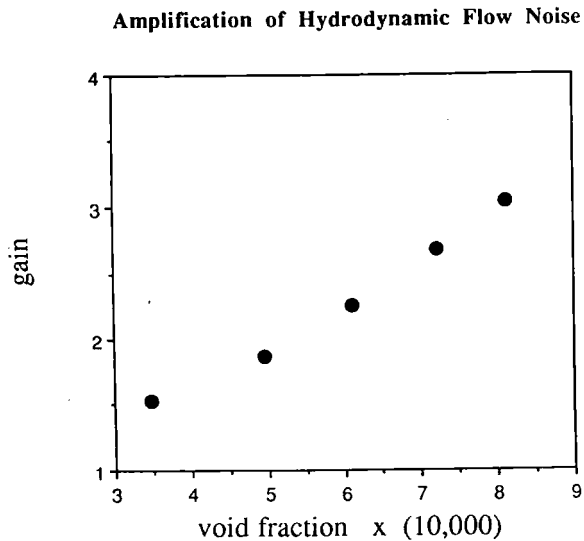


Fig. 3. Intensity gain of turbulent (two-phase) flow noise vs void fraction.

Amplification measurements of the hydrodynamic flow noise are presented in Fig.3. Here, the gain G is measured as a function of void fraction β . The volume flow rate of the water is kept constant for all data runs while the volume flow rate of N_2 gas going to the bubblemaker is varied. The captured pressure signal, shown in Fig.4., is a single transient burst (labeled trial 1). For this case the turbulence is generated with a bubble void fraction of $\beta = 4.9 \times 10^{-4}$.

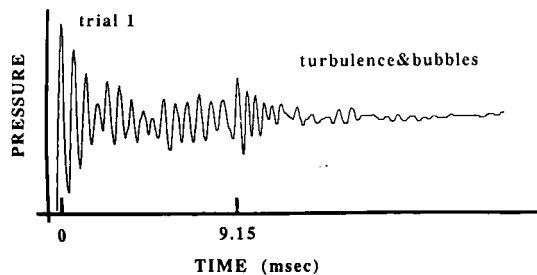


Fig. 4. Transient pressure signal vs time of turbulent two-phase flow noise.

Figure 5. shows the corresponding power spectrum of the burst. The spectral peaks between 1 and 2kHz are significant when compared with the relatively low frequency flow noise spectrum of the turbulent jet (in the absence of bubbles). These peaks rapidly increase in magnitude with increasing β . This effect might be an extremely large amplification of the minute tail end of the flow noise spectrum. More likely it may be due to collective oscillations of the bubble cloud in the jet plume.

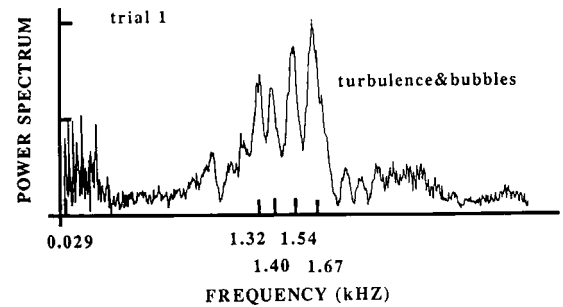


Fig. 5. Power spectrum (for the transient pressure signal in Fig.4.) of the turbulent two-phase flow noise.

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