pressures, but depart from each other after a few microseconds. In the atmospheric spray, the penetration depth versus time has a nearly constant slope at all times but in other cases, the slope of the curve depends on time.

M-2F-2. ON TURBULENCE MODULATION TERM IN A PARTICLE-LADEN TURBULENT CHANNEL FLOW

B. WANG, *Department of Engineering Mechanics, Tsinghua University, Beijing, China,* The closure problem of turbulence modulation terms is one of the key issues both in particle Lagrangian trajectory model and in Eulerian-Eulerian two-fluid model. It's difficult to measure these modulation terms in experiments. Therefore, examinations of closures are mostly based on numerical simulation methods. In this study, one-way coupling large eddy simulation is used to calculate the gas-phase turbulent channel flow, with a friction Reynolds number Re_τ =180. Three different kinds of particles: lycopodium (700 kg/m^3, 30μm), glass (2500 kg/m^3, 57μm) and copper particles (8900 kg/m^3, 80μm), which are heavier than gas-phase, are chosen to release into the fully developed turbulent flow field. All the individual particles are tracked by Lagrangian trajectory method, neglecting SGS turbulence fluctuating velocity on particle motion. The corresponding to statistics results are obtained by averaging data spatially and temporally. Based on the statistics of two-phase velocity fluctuation terms, two closure models proposed by Chen & Wood, Mostafa & Mongia, respecitively, widely applied in RANS, are examined. The streamwise normal-correlation term has the highest level, and the largest value happens at about y^+~15. The normal-correlation term in the wall-normal direction has the lowest level. As particles Stokes number increases, all the correlation terms decreases in the whole channel, because the particle inertia filtering function becomes very strong. Lagrangian integral time scale τ_{Li} is calculated to parameterize particle Stokes number, which is computed in a Lagrangian way assuming an exponential decay of the fluid velocity autocorrelation function. Particle Stokes number based on the Lagrangian integral time scale has largest value near the wall and decreases about one-order magnitude towards the channel central plane. It's shown that for the streamwise two-phase correlation term, both two models predict poorly, but Chen & Wood's model is better than Mostafa & Mongia's model. Both two models predict better in the wall-normal and spanwise direction than in the streamwise direction. In the near-wall region, y^+<10, both two models predict poorly in three directions for three kinds of particles, because the local equilibrium conditions between $<u_{fi}'u_{pj}'>$ and $<u_{fi}'u_{fj}'>$ fail in construction of the models.

M-2F-3. THE EFFECT OF AIR ENTRAINMENT ON THE PRESSURE DAMPING IN PIPELINE TRANSIENT FLOWS

T. S. LEE, *NUS, Singapore*, H. T. LOW, *NUS, Singapore*, D. T. NGUYEN, *NUS, Singapore,* Studies show that even a small amount of air entrainment in the flow can give significant effects to the fluid transient. In general, the first pressure peak with entrained air is found to be higher than that predicted by models with no air. The pressure transient damping with air entrainment is faster than the damping with no air entrainment. The damping of pressure surge is contributed by different sources and processes. From the corresponding numerical experiments it is noted that friction and any devices put into the system have a damping effect on the pressure waves owing to the hysteresis in the energy cycle. However, the damping produced by losses alone is small and is independent of the local surge pressure encountered. The transient shear stress has only a small damping effect on the pressure fluctuations. The thermal exchange between the gaseous phase and the surrounding liquid does not always explain the observed dissipation, and frictional dissipation does not appear to be mainly responsible for the oscillation damping. The remaining prime factor on pressure damping is the effect of air entrainment which is considered in the below investigation. The paper aims to investigate the effect air entrainment on the damping of pressure transients in pipeline flows. A set of experiments were carried out in a single pump pipeline system to test the fluid transient behaviour for the case of pump trip due to power failure. A variable wave speed model is used to simulate this transient flow which includes the effects of free gas in the fluid on the pressure transients in the pipeline. This model is solved numerically by using the method of characteristics. The experimental results were investigated together with numerical results using the variable wave speed model. The results show that the peak pressure varies significantly with increasing initial air void fraction. Moreover, the rate of pressure damping is higher caused by the increased effective bulk viscosity of the fluid as a result of the presence of air entrainment. This is due to the fact that the increase of initial air void fraction leads to the decrease of the wave speed. The reduction of the wave speed of the mixture directly causes changes in the strength of pressure oscillations. In further research, the effect of 2D flow should be taken into account to provide more accurate predictions of pressure transient in pipeline system.

M-2F-4. FLUID-ELASTIC INSTABILITY OF NUCLEAR STEAM GENERATOR U-TUBES IN TWO-PHASE FLOW

I.-C. CHU, H. J. CHUNG, Y. J. YOUN, *Korea Atomic Energy Research Institute, Korea,* In the present study, the critical velocity of fluid-elastic instability, damping ratio, and hydrodynamic mass were experimentally investigated, and the instability constant of Connors' equation was evaluated for a rotated square array U-tube bundle with p/d of 1.633 in air-water two-phase flow. In addition, the effects of primary side flow and anti-vibration bar (AVB) on the vibration displacement of U-tubes were examined. The vibration displacements of the U-tubes showed that the out-of-plane (OP) first mode vibration dominated over the in-plane (IP) mode vibrations. Fluid-elastic instability was clearly observed in the OP first mode vibration. The damping ratio of the present U-tubes was higher than the damping ratio of the cantilever tubes in the literature. The instability constant (K) of the Connors' equation was assessed with a simplified effective gap velocity based on the void fraction measurement and the flow visualization. The K was in the range of 6.5 ~ 10.5. Another set of experiments was carried out to examine the effect of AVBs on the vibration displacement of U-tubes for the void fraction of 70 - 95 %. The vibration displacements in the OP 1st mode were significantly decreased after the AVBs were installed. However, the effect of the AVBs on the IP 1st mode vibration was not that significant and different among the U-tubes. This might due to the difference in the gap and contact force between the U-tubes and AVBs.

14:50 ~ 16:10 (Room107-108)

Computational Fluid Dynamics (II)

Session Chair : Dr. M. Shigeta, Tohoku Univ/Japan

M-2G-1. MATHEMATICAL TREATMENT INVESTIGATION OF AXISYMMETRIC SUPERCAVITATING FLOW PARAMETERS, USING BOUNDARY INTEGRAL METHOD

R. SHAFAGHAT, *IUST, Iran*, S. M. HOSSEINALIPOUR, *IUST, Iran*, A. VAHEDGERMI, *IUST, Iran,* Supercavitation has become a hot topic due to its potential to significantly enhance the speed of undersea weapons, projectiles, and vehicles by enabling them to travel inside a vaporous or gas fed cavity through significant reduction of viscous drag. The boundary integral method (BIM) is formulated numerically for the problem of the unbounded potential flow past a supercavitating body of revolution (flat disk) placed perpendicular to the flow direction. In the analysis of potential flow past a supercavitating flat disk, a cavity closure model must be employed in order to make the mathematical formulation close and the solution unique. In the present study, we employ Riabouchinsky closure model. According to this model, an image body is introduced at a certain distance downstream of the real body to make the cavity closed. It should be noted that this closure model has been chosen as a compromise between simplicity and physical validity. An iterative scheme is employed to locate the cavity surface. Upon convergence, the exact boundary conditions are satisfied on the body-cavity boundary. For this work, a software pack, based on CFD code, is developed. The predictions of the software are compared with those generated by analytical solution and with experimental data. The predictions of software for supercavitating flat disk are seen to be excellent. Using the obtained data from software, we investigate the mathematical treatment of axisymmetric supercavitating flow parameters including drag coefficient of supercavitating flat disks, cavitation number and maximum cavity width for a wide range of disk diameters and cavity lengths. The main objective of this study is to propose appropriate mathematical functions describing the behavior of these parameters.

M-2G-2. LESS DISSIPATIVE CHARACTERISTIC SCHEME IN *X-Y-T* SPACE

R. TRIATMADJA, *Gadjah Mada University, Indonesia,* The Method of Characteristics has been widely used for solving free surface flows in *X-T* and *X-Y-T* spaces. Apart from the advantage of the method, the existing characteristic schemes are dissipative in both *X-T* and *X-Y-T* which sometime make the scheme not suitable for simulating wave propagation in significantly large area. In this paper an additional factor (plane) that reduces the dissipation of the characteristic scheme in *X-Y-T* is developed. The term representing the additional plane is a function of both $L/\Delta s$ and Courant number to keep the scheme stable. Hence, information on the level of discretization ($L/\Delta s$) at grid points is developed. The scheme was