Monday, August 18

Plenary Lectures & Invited Lectures

PL-1. MECHANISMS OF CORE PERTURBATION GROWTH IN VORTEX-TURBULENCE INTERACTION
F. HUSSAIN and D. S. PRADEEP, *Department of Mechanical Engineering, University of Houston, Houston, TX, USA,* We study mechanisms of coherent structure decay via direct numerical simulations (DNS) of a vortex column interacting with external, fine-sale turbulence. Ensemble-averaged statistics show growth of strong core (Kelvin) waves induced by the external turbulence - surprising, given the stabilizing effect of rotation in the vortex core. We explore two potential mechanisms of perturbation growth and core transition: (i) resonant forcing of Kelvin waves by turbulence filaments wrapping the column, and (ii) growth of optimal transient perturbations. We demonstrate the possibility of ring-vortex wave resonance even for relatively weak rings. Resonance in the form of amplifying core dynamics results in sheath-like structures in the core, known to be unstable to a Kelvin-Helmholtz-like instability. However, this process requires sustained organized ring-like structures over several vortex turnover times. Amplification of core perturbations in optimal transient modes also occurs through resonant forcing. Several orders of magnitude growth is possible at even moderate Re ($\sim 10^4$) before the inevitable (linear) decay. We briefly examine the nonlinear evolution of optimal bending modes and show that such growth reproduces features of vortex interaction with turbulence: enhanced core diffusion, core perturbation growth, and circulation overshoot. Results from transient growth analysis suggest the importance of optimal transient modes in governing the decay of turbulent vortices.

PL-2. RECENT EXPERIMENTAL STUDIES ON MICROSCALE CHANNEL FLOWS
Jung Yul YOO, *School of Mechanical and Aerospace Engineering, Seoul National University, Korea*, Young Won KIM, *Institute of Advanced Machinery and Design, Seoul National University, Korea,* In this paper, we review recent studies on single-phase and multiphase flows in microchannels and their applications. First of all, overviews of physical phenomena of fluid flow in microchannels, and measurement techniques mainly in conjunction with the flow visualization, are given. As for the study of single-phase flows, the current state-of-the-art of electrokinetics and optofluidics is outlined. Electrokinetic flow has quite different characteristics from pressure-driven flow because the surface charge plays an important role. Optofluidics is currently a new emerging technology combining optics with microfluidics for creating highly versatile systems. Prominent examples of optofluidic devices are introduced. On the other hand, many microfluidic devices are operated in two-phase flow patterns, such as solid-liquid, liquid-liquid and gas-liquid flows in terms of their appropriate functionalities and applications. Most microfluidic systems often transport particulate samples, such as blood cells, bacteria, DNAs, and spherical particles, which possibly represents solid-liquid two-phase flow. In this situation, the solid particle may not necessarily follow fluid streamlines, and as a result, lateral migration of the particles occurs. However, this study has been poorly reported in microscale. We thus present a systematic evaluation of lateral migration, and propose a novel 3-D focusing method by controlling the lateral migration. It is also noted that the use of liquid-liquid flows on microfluidic device platform has various applications, such as bio/chemical reaction, droplet-based cell assay, and so forth. We review the droplet generation process (generation, merging and breakup) in microchannels. Finally, recent issues on gas-liquid flows are overviewed, particularly, focusing on pressure drop, void fraction, bubble speed and effect of channel size for straight microchannels and/or converging-diverging microchannels.

IL-1. MODELING INDIAN OCEAN CIRCULATION: BAY OF BENGAL FRESH PLUME AND ARABIAN SEA MINI WARM POOL
P. N. VINAYACHANDRAN, J. KURIAN, *Centre for Atmospheric and Oceanic Sciences, Indian Institute of Science, Bangalore, India,* The Indian subcontinent divides the north Indian Ocean into two tropical basins, namely the Arabian Sea and the Bay of Bengal. The Arabian Sea has high salinity whereas the salinity of the Bay of Bengal is much lower due to the contrast in freshwater forcing of the two basins. The freshwater received by the Bay in large amounts during the summer monsoon through river discharge is flushed out annually by ocean circulation. After the withdrawal of the summer monsoon, the Ganga – Brahmaputra river plume flows first along the Indian coast and then around Sri Lanka into the Arabian Sea creating a low salinity pool in the southeastern Arabian Sea (SEAS). In the same region, during the pre-monsoon months of February – April, a warm pool, known as the Arabian Sea Mini Warm Pool (ASMWP), which is distinctly warmer than the rest of the Indian Ocean, takes shape. In fact, this is the warmest region in the world oceans during this period. Simulation of the river plume and its movement as well as its implications to thermodynamics has been a challenging problem for models of Indian Ocean. Here we address these issues using an ocean general circulation model – first we show that the model is capable of reproducing fresh plumes in the Bay of Bengal as well as its movement and then we use the model to determine the processes that lead to formation of the ASMWP. Hydrographic observations from the western Bay of Bengal have shown the presence of a fresh plume along the northern part of the Indian coast during summer monsoon. The Indian Ocean model when forced by realistic winds and climatological river discharge reproduces the fresh plume with reasonable accuracy. The fresh plume does not advect along the Indian coast until the end of summer monsoon. The North Bay Monsoon Current, which flows eastward in the northern Bay, separates the low salinity water from the more saline southern parts of the bay and thus plays an important role in the fresh water budget of the Bay of Bengal. The model also reproduces the surge of the fresh-plume along the Indian coast, into the Arabian Sea during northeast monsoon. Mechanisms that lead to the formation of the Arabian Sea Mini Warm Pool are investigated using several numerical experiments. Contrary to the existing theories, we find that salinity effects are not necessary for the formation of the ASMWP. The orographic effects of the Sahyadris(Western Ghats) and resulting reduction in wind speed leads to the formation of the ASMWP. During November – April, the SEAS behave as a low-wind heat-dominated regime where the evolution of sea surface temperature is solely determined by atmospheric forcing. In such regions the evolution of surface layer temperature is not dependent on the characteristics of the subsurface ocean such as the barrier layer and temperature inversion.

IL-2. THE FOSSILS OF ECTOPLASM IN A NUTSHELL: A BRIEF HISTORY OF THE CHALLENGES INTO THE AIR IN THE ANIMAL KINGDOM
T. SUGIMOTO, *Dept. Info. Systs. Creation, Kanagawa Univ., Japan,* Ectoplasm is a pair of condensation trails originating from the both wing-tips. The aim of this talk is from the mechanical point of view to look back upon the essential events in the origin of flight in the animal kingdom with special emphasis upon respiration and aerial locomotion. Each corresponds respectively to internal- and external-biofluiddynamics. The first flyers come from the insect group in the middle Carboniferous period, 310 million years ago. These are gigantic ancient dragonflies with more than one meter wing span. Insect wings derive from gills and have membrane structures. They breathe with the aid of the trachea system; this is a pneumatic pipe network spanned all over their bodies; delivery of oxygen is totally dependent on diffusion. The gigantism and the trachea system were possible, because dense oxygen existed in the Carboniferous atmosphere: oxygen percentage is estimated even up to 30% of the air, while the percentage of carbon dioxide was almost the same as the present value. The next dominant fliers are pterosaurs. They first appeared in the Triassic sky 220 million year ago. In the Mesozoic era oxygen had been as thin as 12% of the air, while carbon dioxide level had been 8 times higher than the present value. Pterosaurs are thought to have the lung system augmented by air-sacs, which is supported by the fact that fore-limb bones are pneumatic. A pair of air-sacs acts as tandem pumps to the lung in between; air flows in the lung against the direction of blood flow; this counter flow configuration makes the gas exchange more efficient than the parallel flow configuration found in the mammalian lung system. The fore-limbs and the elongated forth digits are the main structures that support pterosaurs' membrane wings. Experiments show that heaving such a wing induces lag in the trailing edge motion and that this passive feathering motion plays an important role in generation of thrust. Pterosaurs' gigantism cannot be accounted for, because the density of the air is lighter than today's value. The first birds *Archaeopteryx* appeared in the Jurassic sky more than 140 million years ago. They are covered with light-weight and flexible feathers suited for flight and warm-bloodedness. Birds have the lung system augmented by air-sacs. They are also adapted to thin oxygen in the Jurassic atmosphere, and hence they can fly over the Himalayas today. Bats appeared as the last active flyers. Their bones are fragile, and hence fossils are not well preserved; the oldest bat record dates back to 55 million years ago; in Tertiary oxygen level has risen up to 20% of the atmosphere. Bats have the typical mammalian lung system; they don't have air-sacs or pneumatic bones. Their feat of acrobatic flight owes largely to the wing structure; four of five digits

span membrane wings; this is not mere fail safe structures. Recent experiments show the doubly folded vortex wake of bats; digits afford complex camber control during flapping.

IL-3. SMALL-SCALE STATISTICS IN HIGH REYNOLDS NUMBER TURBULENCE – A STUDY BY DIRECT NUMERICAL SIMULATION

Y. KANEDA, *Department of Computational Science and Engineering, Nagoya University, Japan,* In 1941, Kolmogorov proposed an idea of universality in turbulence [1]. According to this idea, there is a certain kind of universality in small scale statistics of turbulence far from flow boundaries, provided that the Reynolds number (*Re*) is high enough and the scale is small enough. The universality is insensitive to the details of the large scale flow conditions. This idea has been generally supported by experiments and direct numerical simulations (DNSs), and it is at the heart of modern theories of turbulence. However, little seems known quantitatively about the meaning of "*Re* is high enough and the scale is small enough". What is needed here is the understanding on the dependence of the statistics on the finite *Re* and the scale. The talk presents a review of results of the analysis of high resolution DNS data of incompressible turbulence, with an emphasis on the dependence of the small scale statistics on *Re* and the scale. The DNSs consist of two series of simulations of forced turbulence obeying the Navier-Stokes equation in a periodic box with the number of the grid points up to 4096^3; one is with $k_{max}\,\eta \sim 1$ (Series 1) and the other is with $k_{max.}\,\eta \sim 2$ (Series 2), where $k_{max}$is the highest wavenumber in each simulation, and η is the Kolmogorov length scale [2, 3]. The DNS is based on a spectral method free from alias error. In the 4096^3 DNSs, which were performed on the Earth Simulator, the Taylor-scale Reynolds number R_λ~1130 (675) and the ratio L/η of the integral length scale L to η is approximately 2130 (1040), in Series 1 (Series 2). The data analysis has shown new aspects of the *Re* or scale dependence of the statistics including (i) the energy spectrum in the inertial subrange and the near dissipation range, (ii) the third order velocity structure functions, (iii) the normalized mean energy dissipation rate, (iv) moments of the velocity gradients, (v) intermittency of energy dissipation, and (vi) the energy cascade from large to small scales. The visualization of intense vorticity regions at high *Re* shows a clear difference between the structures of small eddies in the dissipation length scale and those of clusters of eddies in the inertial subrange scale. The talk also presents a review on a study of the anisotropy in small scale statistics in turbulent shear flow, stably stratified turbulence and magneto-hydrodynamic turbulence under a strong uniform magnetic field. A simple analysis suggests that one may regard the effect at small scale of mean shear, buoyancy, and external magnetic field as disturbances applied to the locally homogeneous and isotropic universal equilibrium state determined by the inherent Navier-Stokes dynamics. The theoretical predictions are in good agreement with experiments and DNSs.

IL-4. SUPERSONIC FLOW OVER CAVITIES : A FEW THERMO FLUID DYNAMIC ASPECTS

Job KURIAN, *Indian Institute of Technology, India,* Self sustained oscillations generated by wall mounted cavities were studied earlier as a source of flow noise and undesirable structural loading. In recent times, studies are conducted to investigate their utility to aid applications such as fuel air mixing in high speed streams and in the generation of stable regions of vortex dominated flows for flame holding. The present paper consolidates a part of the work on cavities carried out in the Gas Dynamics Laboratory of Indian Institute of Technology, Madras, India and gives details of the results of studies on the scaling effect of cavities, effect of aft-wall modifications and on the active control of the oscillations generated by the cavity. The experiments are done on the supersonic free jet facility. Rectangular cavities of lengths, L = 50, 70 and 90mm and of L/D = 1.8, 3, and 6 are tested in a confined supersonic flow of Mach number 1.76. Mean static pressure and acoustic pressure measurements are done with in and in the vicinity of the cavities. The results presented demonstrate that the flow and acoustic behavior are considerably affected by changing cavity dimensions for a given L/D ratio. Amplitude of acoustic pressure which is a measure of oscillatory behavior of the flow field is found to increase with cavity size for open shallow cavities. The increased mean static pressure level inside the cavity and more recompression of the flow towards its trailing edge are observed with increase in cavity size. This could give rise to more cavity drag. Aft ramp cavities could be effectively used for suppression of oscillations and for passive entrainment control. The low aspect ratio cavity is more stable for lower ramp angle than that for high aspect ratio. Cavity based injection strategies are suggested for the active control of cavity performance for applications such as in flame holding. The technique is suitable for controlling the entrainment in to the flame holding region. Further, it suppresses the cavity oscillations and improves the cavity residence time.

11:00 ~ 12:20 (Room101)

Acoustics / Waves

Session Chair : Prof. D. J. Lee, KAIST/Korea

M-1A-1. VORTEX SHEDDING FROM A LEADING-EDGE SLAT AND NOISE GENERATION AT LOW REYNOLDS NUMBERS

Sanehiro MAKIYA, Masahito ASAI and Ayumu. INASAWA, *Department of Aerospace Engineering, Tokyo Metropolitan University, Japan,* In order to clarify the mechanism of noise generation around a slat, vortex shedding from the slat trailing edge and the associated noise generation are investigated experimentally at low Reynolds numbers. When the slat operates to suppress the leading-edge stall, periodic vortex shedding occurs due to the global (absolute) instability of slat wake for the slat Reynolds numbers $Re_s < 2.3\times10^4$. For such low Reynolds numbers, acoustic noise is not found in spite of the occurrence of strong vortex shedding. For $Re_s \geq 2.6\times10^4$, on the other hand, discrete spectra appear both in the velocity and sound-pressure fluctuations. The frequencies of the dominant discrete tones which coincide with those of vortex shedding exhibit ladder-type variations with each rung proportional to $U_\infty^{0.85}$. These frequency variations are similar to those observed in the past experiment on the discrete tone generation in a single-element airfoil at small angles of attack, strongly suggesting the onset of feedback mechanism between the boundary-layer instability on the slat surface and the vortex shedding from the trailing edge through radiation of acoustic waves generated by the shedded vortices. That is, instability waves are excited in the slat boundary-layer by acoustic waves generated by the periodic vortex shedding, sufficiently amplified up to the trailing edge under adverse pressure gradient and force the wake instability to be locked on. The resulting wake vortices are so strong in the vicinity of the trailing edge and radiate acoustic waves, which trigger a feedback loop. Indeed, a frequency lock-on phenomenon that the absolute instability mode is suppressed as the discrete tone increases in magnitude is observed in the transient Reynolds numbers $Re_s = 2.3\times10^4$~2.6×10^4. Thus, the transition from the global instability of the absolutely unstable wake to the onset of feedback loop mechanism occurs in the vortex shedding from the slat trailing edge.

M-1A-2. THE FREQENCY SPECTRUM OF SOUND RADIATED FROM ISOTROPIC TURBULENCE

H. D. YAO, *LNM, Institute of Mechanics, Chinese Academy of Sciences, China,* Since Lighthill proposed the acoustic analogy (1952), many works have been carried out to study the frequency spectrum of sound radiated by isotropic turbulence. Proudman derived an $\omega^{*-7/2}$ scaling law by considering decaying isotropic turbulence. Lilley suggested that the spectrum scales as $\omega^{*4}/(1+2\omega^{*2})^{-3}$ (1994). Rubinstein and Zhou (2000) deduced an $\omega^{*-4/3}$ scaling law at high frequencies if the random sweeping hypothesis is used. And it is found that Lilley's model follows the sweeping model. Recently, Yao et al (2008) have extended the sweeping model to pressure without invoking the quasi-normal assumption. Besides, the hybrid method of direct numerical simulation (DNS) and the Lighthill analogy were used to compute the frequency spectrum by Sarkar et al (1993) and Seror et al (1999, 2001). In the hybrid method, the turbulence velocity is computed by DNS to get Lighthill's tensors and, then, the turbulence noise is computed by Lighthill's analogy. In this paper, it is theoretically deduced that the time correlations of Lighthill's tensors are dominated by the sweeping effect in isotropic turbulence without using the quasi-normal assumption. Then, the hybrid approach of DNS and Lighthill's analogy is used to prove the theory. The numerical results from the hybrid method show that Proundman's -7/2 law does not exist in isotropic turbulence. The results obtained support Rubinstein and Zhou's model where the frequency spectra scale as -4/3 in the initial range. The Lilley's model is more appropriate for finite Reynolds numbers. And both of the models are based on the random sweeping model after using the quasi-normal assumption. It suggests that the sound spectra are dominated by the sweeping effect and thus determined by the sweeping hypothesis in isotropic turbulence.

M-1A-3. NUMERICAL SIMULATION OF UNDERWATER LANDSLIDE INDUCED TSUNAMI WITH SPH METHOD