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