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TRANSIENT GUST EFFECTS ON FLOW PAST A BLUFF BODY

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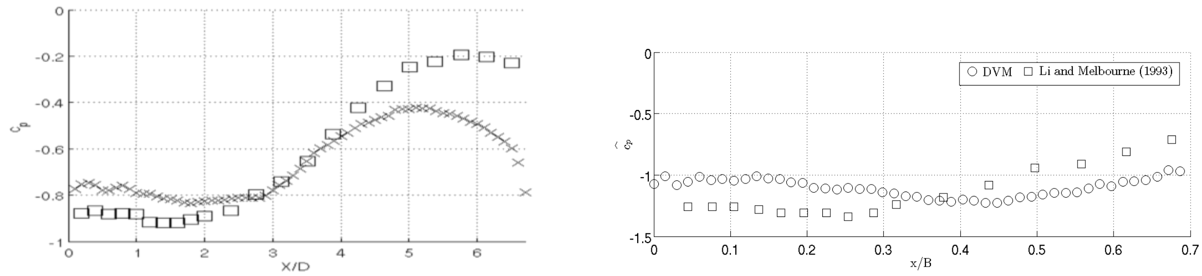
1 INTRODUCTION

The motivation for this work arose from the primary assumption of the current practice of boundary layer wind tunnel testing-that atmospheric velocity variations can be adequately modeled by stationary mean and turbulent flow properties. In the field, extreme wind loads result primarily from weather events where non-stationary gusts, transitional flow structures and rapid wind directionality changes may play a significant role. This work sought to investigate one such phenomena, specifically, the non-stationary gust.

A number of active turbulence generation schemes have been developed to produce very large integral scales. These techniques generally involve a combination of grids, flaps, and airfoils that are forced to oscillate or arrays of individually-controlled fans Ref. [1, 2]. While such devices are useful for generating a large range of turbulence scales and spectra, they have not generally been used to simulate the non-stationary gusts that can occur in thunderstorms or hurricanes. Hurricanes have been observed to produce wind gusts in the range of $10\% \sim 40\%$ of the mean velocity Ref. [3]. The boundary layer wind tunnel at Iowa State University (ISU) has an active bypass duct system that can generate large-scale gust events up to 25% at a rate of $0.4 \sim 10.0\ m/s^2$ Ref. [4].

The focus of this study was essentially on the reaction of the separating and reattaching shear layers to the incident gusts. Some researchers Ref. [5] have observed shear layer behavior under sinusoidal perturbations to order to identify frequency ranges most effective at altering shear layer behavior (such as reattachment length). The current effort sought to complement such studies but with a focus on non-stationary gusts. This meant seeking time scales and structures of gusts that might be most effective at altering shear layer structure and in turn altering surface pressure distributions.

This study investigated the effects of non-stationary gusts on a rectangular cylinder. Both experimental and numerical simulations were conducted. The experimental approach employed the ISU boundary layer wind tunnel. The computational approach employed a discrete vortex simulation developed specifically for this project. Due to the complex nature of this fluid structure interaction, this problem remains computationally taxing. The discrete vortex approach was chosen because it focuses computational resources on the regions of primary interest, that



(a) c_p (□), Experiment; (×), DVM simulation) (b) Peak c_p (□), Experiment; (◯), DVM simulation)

Figure 1: Mean surface pressure coefficient c_p and Peak surface pressure coefficient for a rectangular body ($\Re = 2.1 \times 10^4$)

is the shear layers. The current study seeks to extend the use of these methods to investigations involving transient load conditions. A 2D simulation of smooth flow past a rectangular body was conducted along with smooth flow with gusts of 25% of the mean velocity with different time scales. Wind tunnel experiments using hot wire anemometry and pressure measurements were also conducted for comparison with the computational simulations.

2 COMPUTATIONAL AND EXPERIMENTAL APPROACH

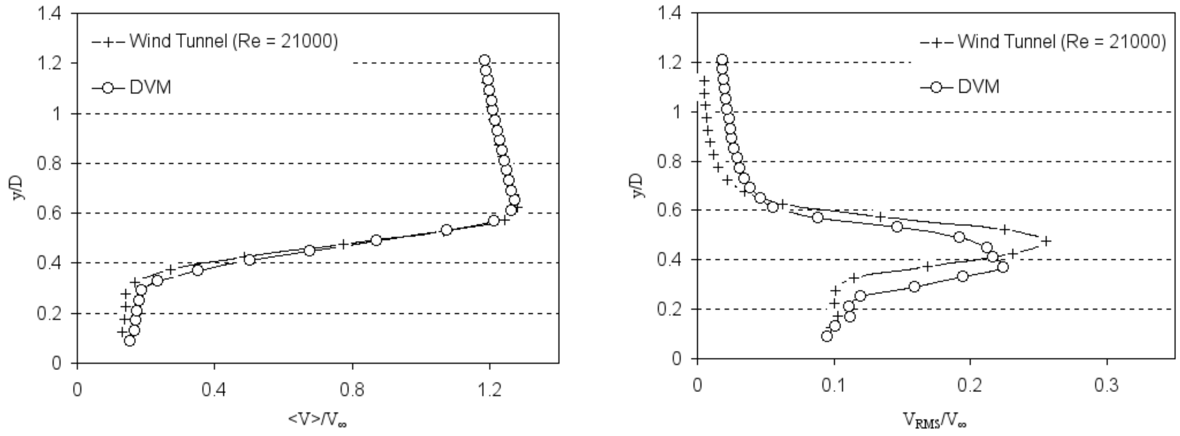
Discrete vortex methods are Lagrangian techniques for simulating viscous fluid flow. In this method, a Lagrangian particle formulation is used to discretize the vorticity field. Grid-free random vortex methods have undergone significant development in recent years and are well suited to the analysis of unsteady, highly separated, incompressible flow fields Ref. [6]. The current formulation employs a linear discretization (rather than point discretization) of surface vorticity primarily because this allows better representation of flow and vorticity transport near the surface. Both computational and experimental simulations were conducted at Reynolds numbers of 21000. The rectangular model had an aspect ratio of 6.67:1.

The time scales at which gusting events must occur are smaller in the wind tunnel than at full scale. For example, if typical geometric scales for low to medium-rise structures, λ_L, from the wind tunnel to full scale range from $1/50 \sim 1/200$ and a typical velocity scale, λ_V, is $1/3 \sim 1/2$, then the time scale range would be calculated as $\lambda_T = \lambda_L/\lambda_V = 0.01 \rightarrow 0.06$ (Ref [4]). This means that full scale events that take minutes must be simulated in the wind tunnel in seconds. In our case we run the simulation with gust event time scales of $0.085, 0.165, 0.33$ seconds, respectively, corresponding to full scale events in the range of $1.5 \sim 33$ seconds.

3 RESULTS

3.1 Steady Flow Validation

The capability of DVM to accurately predict flow features around the model was investigated first. Figure 1a shows the comparison of mean pressure coefficients on the surface of the model with wind tunnel experiments. The mean profile shows a reasonable match between experimental and computational simulations particularly in the shape of the curve and the streamwise position of the pressure recovery. This is evidence that the overall structure of the separation bubble is reasonable. Figure 1b shows that the peak minimum c_p envelope is a good match with experimental results Ref. [7]. Another measure of the accuracy of the computational simulation can be found in the velocity profiles in the separated region. Since a hot wire probe cannot be used to detect flow directionality, hot wire data were compared to total velocity estimates from the DVM simulation. Mean and RMS velocity profiles (normalized with freestream velocity) are plotted in Figure 2. Mean velocities show excellent match between computational predictions and experiments. While RMS velocity magnitudes agree only within 15% or so, the comparisons of vertical positions of the maximum RMS values and the increase in size of the large RMS region with downstream position are further evidence that the overall structure of the shear layer is being captured adequately. It is possible that some mismatch between experiment and DVM simulation is due to the use of a hot wire anemometer in a region of separated flow.



(a) $x = 1.0D$ (b) $x = 1.0D$

Figure 2: Time averaged velocity profiles and RMS velocity profiles at a streamwise position on the body, showing comparisons between Wind Tunnel and DVM results ($\Delta t = 0.005$)

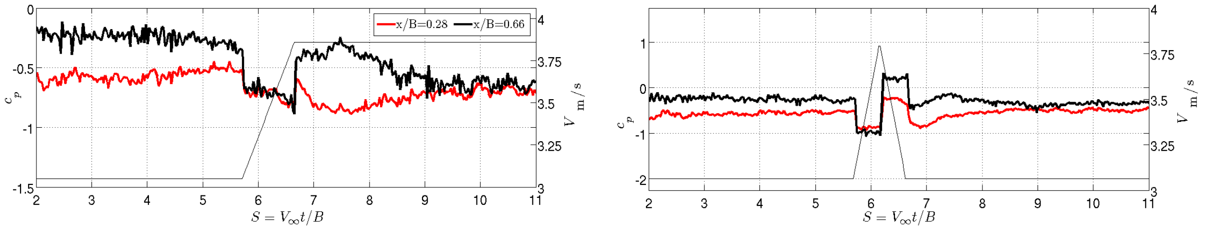
3.2 Transient Flow Results

Preliminary results from DVM gust simulations are shown in Figures 3. The plots trace the c_p time history at two streamwise stations ($x/B = 0.28$ and $x/B = 0.66$). The velocity plot for different gusting time scales is overlayed to give an idea of gusting condition at any particular time. c_p is normalized using this instantaneous velocity. The effect of gusting is clearly evident. It shows that the gusting time scales are inversely proportional to the peak suction pressures. For step-up gusts we see at least 50% increase in net suction. Spiked gusts produce even higer suction pressures. Another significant observation is the development of a second suction event, at positions closer to leading edge, after the gust has returned to a sustained velocity ($S \sim 7$). The pressure difference between the leading and aft positions diverges greatly before returning to an almost constant value. More detailed comparisons between computational and experimental simulations of the gust events will be included in the full paper.

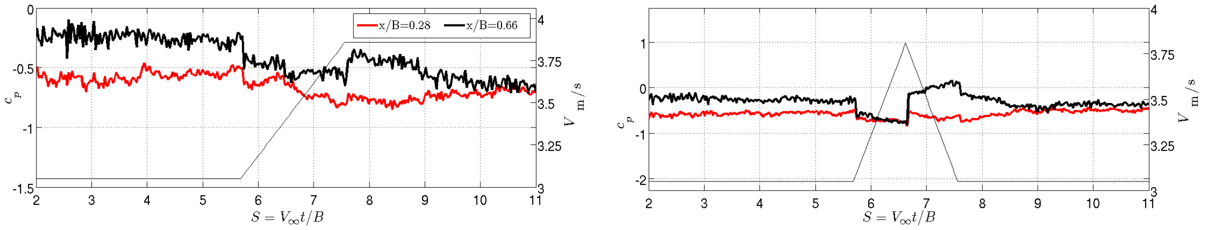
REFERENCES

[1] H. Kikitsu, J. Kanda, and R. Iwasaki, “Flow simulation by wind tunnel with computer-controlled multiple fans,” *Journal of Wind Engineering and Industrial Aerodynamics*, vol. 83, pp. 421–429, 1999.

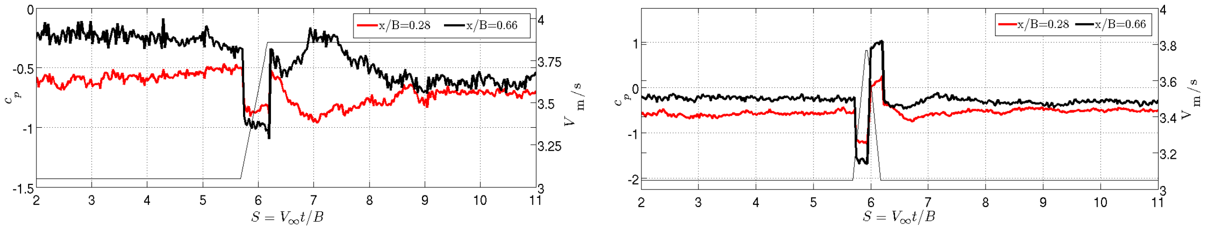
[2] A. Nishi, H. Kikugawa, Y. Matsuda, and D. Tashiro, “Active control of turbulence for an atmospheric boundary layer model in a wind tunnel,” *Journal of Wind Engineering and Industrial Aerodynamics*, vol. 83, pp. 409–419, 1999.



(a) Timescale $\tau = 0.165 sec$ (b) Timescale $\tau = 0.165 sec$



(c) Timescale $\tau = 0.33 sec$ (d) Timescale $\tau = 0.33 sec$



(e) Timescale $\tau = 0.085 sec$ (f) Timescale $\tau = 0.085 sec$

Figure 3: Comparison of c_p history at two stations for step-up and spike gusts with various timescales (c_p normalized using instantaneous velocity)

[3] M. D. Powell and S. Houston, "Surface wind fields of 1995 hurricanes erin, opal, luis, marilyn, and roxanne at landfall," *Monthly Weather Review*, vol. 126, pp. 1259–1273, 1995.

[4] F. L. Haan, P. P. Sarkar, and N. Spencer-Berger, "Development of an active gust generation mechanism on a wind tunnel for wind engineering and industrial aerodynamics applications," *Wind and Structures*, vol. 6, no. 5, pp. 247–269, 2006.

[5] L. Sigurdson, "The structure and control of a turbulent reattaching flow," *Journal of Fluid Mechanics*, vol. 298, pp. 139–165, 1995.

[6] G. Morgenthal, *Aerodynamic Analysis of Structures Using High-resolution Vortex Particle Methods*. PhD thesis, University of Cambridge, Cambridge, U.K., Oct. 2002.

[7] Q. Li and W. Melbourne, "An experimental investigation of the effects of free-stream turbulence on streamwise surface pressures in separated and reattaching flows," *Journal of Wind Engineering and Industrial Aerodynamics*, vol. 54-55, pp. 313–323, 1995.