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CHARACTERISTICS OF SURFACE PRESSURES ON PRISMS IMMERSED IN A TRANSIENT GUST FRONT FLOW FIELD

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Abstract: *Thunderstorm generated gust fronts are responsible for structural damage in many areas of the world. However, the resulting impact of gust front winds is not understood to the level that flow kinematics, dynamics and its impact on structures can be quantified. Gust front winds are highly transient and have a flow profile that differs significantly from a typical boundary layer flow field. This study focuses on investigating the effects of flow profile and its transient nature on the aerodynamics of bluff, prismatic bodies. A gust front flow field is modeled using a multiple fan wind tunnel and the resulting surface pressures are captured on a suite of prismatic models, which vary in size in relationship to the oncoming wind profile. The temporal variations in surface pressures are analyzed using traditional time, frequency and time-frequency domain approaches. Results indicate the changing nature of the surface pressure field in time, highlighting differences between local and area-averaged pressures under a host of flow profiles.*

1 INTRODUCTION

Thunderstorms, downburst outflows and gust fronts constitute various extreme wind events that cause significant damage to life and property, particularly to low or mid-rise buildings, transmission lines, industrial structures and, potentially, long span bridges. Some characteristics of these events are similar, primarily their respective horizontal wind velocity profiles near the ground surface and their short life span. However, the impacts of such events are not as easily quantified as is the impact of typical synoptic boundary layer flow fields.

The simulation of downbursts and gust fronts has been attempted through various physical and numerical techniques including impinging jets, large vortex generators, wall jets, and a flat plate at high incidence, along with numerical models aimed at reproducing storm event time histories (e.g. Letchford 2006). This paper presents another approach to the study gust front wind loads on structures. As opposed to recreating the entire thunderstorm or downburst, a more basic approach was undertaken to uncover the broader impacts of these events that distinguish these events from synoptic flow systems. Based on this, a newly designed wind tunnel was employed to isolate the impact of two distinct features of gust front flows: the profile shape and the transient aspects. These features were captured on square cross-section, prismatic models, to better understand the basic underlying mechanisms in gust front type flows.

2 EXPERIMENTAL SETUP

The multiple-fan wind tunnel constructed at Miyazaki University, shown in Fig. 1a, is comprised of 99 fans, each individually controlled through AC servo-motors. Experiments conducted in this facility were aimed at capturing the surface pressures on various prismatic models as a result of transient changes in the flow field, both in the horizontal velocity profile and the magnitude of the velocity. Previous experiments utilizing this facility have shown its efficacy at capturing the statistical characteristics of atmospheric flows (e.g. Cao et al. 2002). In this study, emphasis was placed on simply generating a transient variation of the mean flow profile. Surface pressures were captured on three models, varying in height with respect to the height of the maximum outflow.

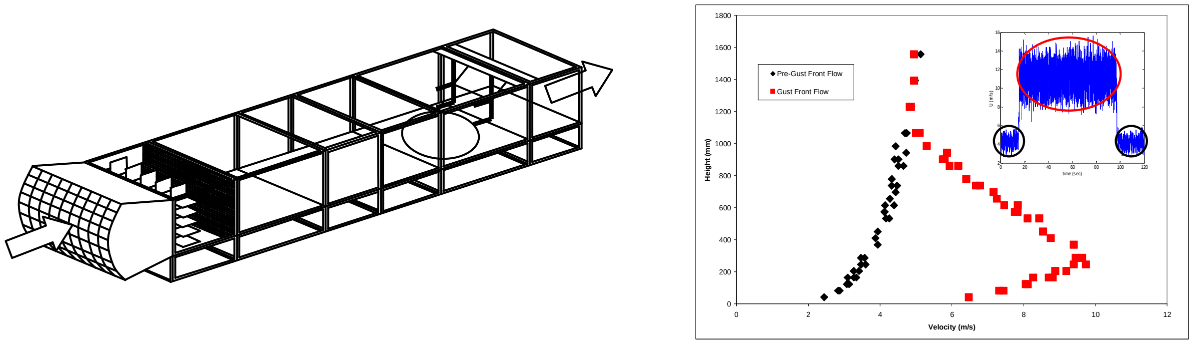

Figure 1: a) Multiple fan wind tunnel setup (Cao et al. 2002) and b) flow profile shape before/after and during the gust front flow, along with a time history at the maximum outflow

3 RESUTLS AND DISCUSSION

Each prismatic model studied was exposed to a gust front like event, where the wind speed was accelerated to induce changes in the flow profile. The acceleration of the wind speed took place over a time span of approximately 1 to 2 seconds. The prismatic models were exposed to the gust front like profile for approximately 80 seconds, before the wind speed was returned to its initial flow condition. Fig. 1b shows the typical flow profile shape and, in the inset, a corresponding plot of the velocity time history at the maximum outflow velocity location in the gust front. Comparisons of the mean behavior of surface pressures within these two profiles showed variation between the flow profiles corresponding to the flow increase impacting the windward surface, as compared to the side and rear faces. The RMS of the surface pressure fluctuations showed decreased variability along the side faces when the building encountered the gust front flow compared to the boundary layer flow. Other stationary measures, such as the power spectral density, showed variation in the frequency content at individual pressure measurement locations as result of the changing flow velocity.
Examination of global forces, such as lift and drag, show more intriguing results. The lift force encountered by the tallest prismatic model, shown in Fig. (2a), reveals no obvious impact in the intensity of lift due to the changing boundary layer. However, the

corresponding wavelet scalogram, Fig. (2b), reveals frequency content changes, primarily as a result of the changing flow speed. What is interesting to note is that the intensity of the spectra decreases with the gust front flow, compared to the slower boundary layer flow at the beginning and end of the experiment.

In order to understand the impact of a non-stationary process, different techniques are required beyond tradition stationary measures. A moving window correlation was performed to uncover the short time behavior of the system. Fig. (3) shows the correlation between two pressure measurement locations on the side face (3a) at mid-level height and (3b) the correlation between the oncoming flow and a pressure measurement on the leeward surface. Higher correlation coefficients occurred during the instances of accelerated/decelerated flow. By comparing global attributes, such as lift, and local features, it is apparent that the gust front flow field induces higher correlation of pressures around the model surfaces during significant flow changes, and that the changed flow field also reduced the global pressure impact.

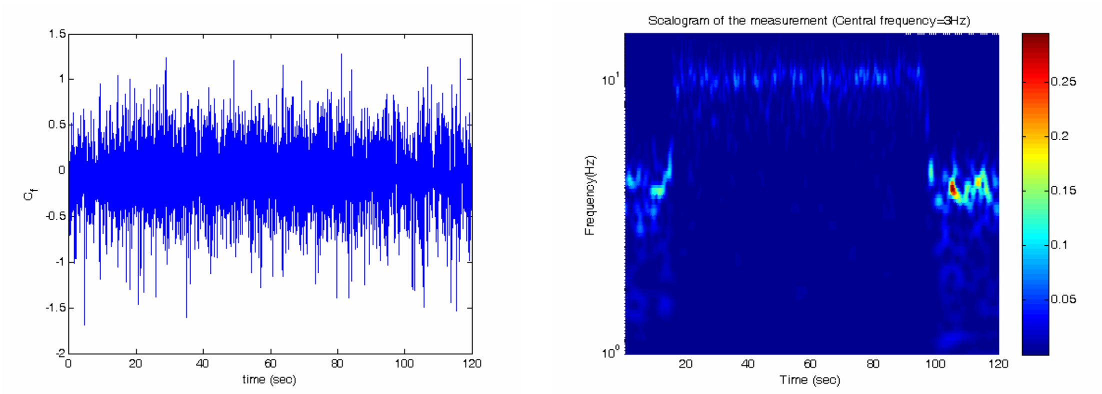

Figure 2: a) Coefficient of lift force time history and b) the corresponding wavelet scalogram.

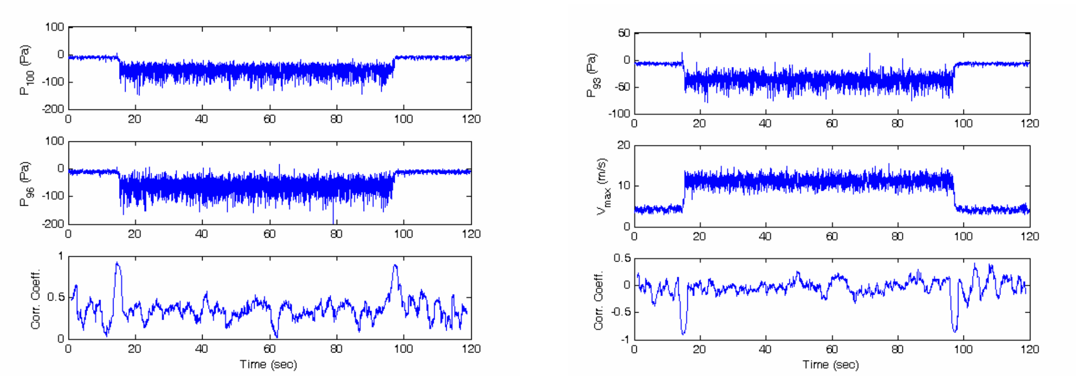

Figure 3: Correlation of a) surface pressures along the side face at mid-level height and b) between the oncoming flow and rear surface pressures.

Wavelets are also used to investigate variations in the dominant frequency content in time. In this analysis, wavelets were used to examine changes in fluctuating surface pressure frequency. Wavelet co-scalograms were used to identify common frequency content between pressure measurement locations as a function of time, and as a function of the pressure measurement location varying in downstream distance along the side face, at various levels. Results showed that as the downstream distance increased, the level of intermittency and intensity of the scalogram, at the dominant frequency level increased.

To assess the nature of the time-frequency variations in surface pressure within a spatial context, scalograms were analyzed at critical points, such as leading and trailing edge corners.

Data was organized using a 3-dimensional representation of the wavelet scalogram, where the scalogram was generated for each surface measurement in the spanwise direction and interpolated connections between corresponding values of intensity were drawn. Fig. (4a) demonstrates the multi-dimensional wavelet along with a caricature of gust front induced flow behavior. This allowed for a spatial view of the scalogram energy, to uncover where and when particular frequency contents appeared or ceased to exist. This representation is aimed at examining the wavelet scalograms to uncover flow structure, as indicated in Fig. (4b), such as zones of flow separation and rotation where the fluctuating pressures exhibit a frequency signature, possibly as a result multiple flow gradients in the oncoming profile.

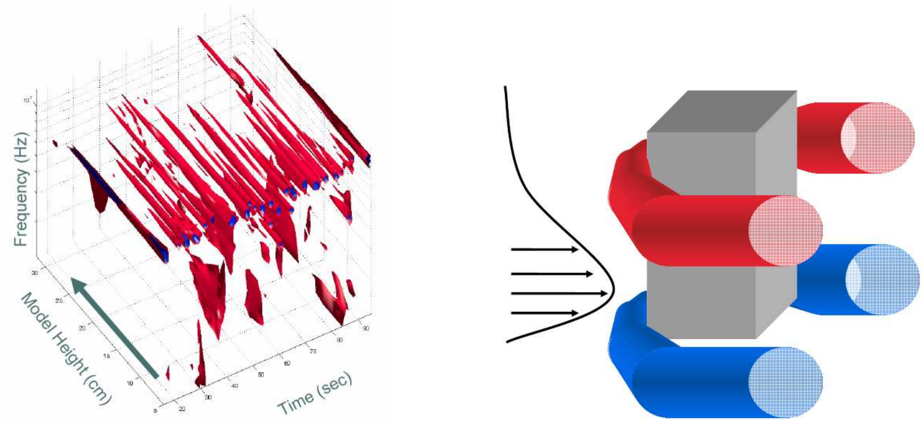

Figure 4: a) 3-dimensional wavelet scalogram generated in the spanwise direction and b) caricature of idealized flow structure resulting from gust front flow

4 CONCLUSIONS

A fundamental study aimed at delineating the kinematic and transient effects of variations within the oncoming flow field on the surface pressures of prismatic models is presented. A multiple fan wind tunnel was employed to simulate a transient gust front flow field with changing flow profile shape. Surface pressures were examined on a suite of prismatic models, capturing transient changes within the flow field. The results of this experiment were examined through traditional statistical methods, and more recent analysis techniques. It was noted that the correlation of surface pressure around the model surfaces was markedly higher during the flow field acceleration, compared to the quiescent flows before and after, while wavelet scalograms showed marked differences between the typical near surface flow field and the gust front profile. Further analysis is aimed at mapping the effects of the gust front flow within a temporal and spatial context.

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