Separated Shear Layers In Non-Stationary Gusts -
Discrete Vortex Simulation and Wind Tunnel
Experiments

Nikhil Murgai\(^a\), Jesse Oltrogge \(^a\), Fred L. Haan Jr. \(^b\)

\(^a\)Research Assistant, Iowa State University, Ames, Iowa, USA
\(^b\)Assistant Professor, Iowa State University, Ames, Iowa, USA

ABSTRACT: Due to their complex nature, shear layers separating from bluff bodies continue to
pose a challenge to researchers investigating wind engineering applications. These separating and
reattaching shear layers produce large pressure fluctuations on the underlying surface. Understanding
the relevant physics is particularly important for designing structures to mitigate extreme loads.
The research described in our paper employs discrete vortex methods to investigate separated shear
layers about bluff bodies in non-stationary, gusting winds. Our study investigated non-stationary
gusting flow for the flow about a rectangular cross section. The results reported employ a 2D dis-
crete vortex model which combines vortex blob and sheet approximations of the shear layers with
panel models on the body. This project involves simulation of the near-surface flow physics and
carefully planned experimental validation of bluff body aerodynamics under gusting conditions.
Results to date show an adequate match between simulation and experiment and moderate effects
of non-stationary gusts on surface pressures.

KEYWORDS: Discrete Vortex Methods, Bluff Body Aerodynamics, Non-Stationary Wind Gusts

1 INTRODUCTION

Shear layers separating from a bluff body produce interesting and important fluid-structure
interaction phenomena. These separating and reattaching shear layers produce large pressure fluc-
tuations on the underlying surface. This work represents the first phase of a larger effort to develop
discrete vortex methods for use in a wide variety of wind engineering applications. While a greater
understanding of bluff body flow physics is the primary goal, one practical objective of the cur-
cent work is to develop useful tools to improve wind resistance of structures using complementary
integration of numerical and experimental simulations of the phenomena.

A discrete vortex element method (DVM) computer code has been developed\(^1\) in order to facili-
tate the study of such shear layers and their effects on surfaces. A number of wind engineering
researchers\(^2\)–\(^4\) have used discrete vortex methods in the past for fluid structure interaction analy-
sis of bridge decks and of low-rise buildings. The current study seeks to extend the use of these
methods to investigations of flow structure in the separated shear layer rather than to predictions
of aerodynamic loading only.

This project involves careful simulation of the near-surface flow physics and carefully planned
experimental validation. The primary focus is on the study of effects of gusting on shear layers.
The results presented here include work done on a body of rectangular cross section. A series of
experiments using hot wire anemometry were done for validation and calibration process.
2 DISCRETE VORTEX METHOD

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. The particles collectively induce a velocity field in which they are free to convect. In the formulation used in our study, viscous diffusion of vorticity is modeled by subjecting these particles to random walks (similar to the well-known work of Chorin\textsuperscript{5}). One of the advantages of this method is that computational effort is focused on the shear layers and other regions of non-zero vorticity, rather than spread out over the entire domain. 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.\textsuperscript{6–8}

3 FORMULATION OF THE PROBLEM

The current formulation employs a linear discretization of surface vorticity. This allows better representation of flow and vorticity transport near the surface.\textsuperscript{7} The linear discretization was implemented within a numerical boundary layer to eliminate the singularities associated with point-to-point interactions. The model for DVM represented a rectangular block with the dimensions 0.1 m x 0.667 m (6.67:1). The Reynolds number was 21000. The experimental approach was designed from the beginning with the specific goal of validating the numerical simulations. The test model for the experiment was a rectangular cylinder with cross section dimensions of 0.0508 m x 0.3397 m (6.67:1). The experimental tests were also conducted at a Reynolds number of 21000.

4 RESULTS

The capability of DVM in predicting separated shear layers and associated structures is currently being investigated. One of the main flow features of interest is the velocity profile in the region of separation and attachment. The total velocity profiles obtained from DVM were compared with the total velocity profiles obtained from hot-wire measurements (figure 2). Because a hot wire probe cannot be used to detect flow directionality, only a total velocity estimate was made. The computational predictions of the mean velocities show a reasonable match, the profiles of the RMS velocity fluctuations show similar trends with some mismatch in magnitudes.

Figure 1 shows the comparison of pressure coefficients on the surface of our model. The comparison of pressures on the surface at $x/D = 0.5$, $x/D = 1.0$, $x/D = 2.0$ for gusting conditions is shown in figure 3. The input velocity conditions are 3.048 m/s input free stream velocity with a 25% increased velocity gust at the 1 second mark. Different gusting time scales $\tau$ are being studied. Results of two such time scales are shown in figure 3. There is some evidence that the gusts produce peak suction pressures lower than the peak suction pressures produced by a constant
Figure 2: Time averaged velocity profiles and RMS velocity profiles at different streamwise positions on the body, showing comparisons between Wind Tunnel and DVM results ($\Delta t = 0.005, M = 154$)
higher velocity. This matches the preliminary results of our experiments and that of Hwang. 

Figure 3: Time history of normalized pressures on selected surface points. Also shown is the comparison between peak pressure coefficients for gusting and non-gusting cases

5 CONCLUSION

Numerical predictions of pressure fluctuations over bluff rectangular bodies in wind gusts using discrete vortex methods have been presented. These computational simulations are being validated using wind tunnel experiments. The boundary and shear layer is of great importance and its structure can indicate if a stable solution is achieved. Mean velocity profiles obtained from DVM compared reasonably well with those from experiments. Considering the unsteadiness of the flow and the complexity of the turbulence structure in the separation and reattachment region, the present predictions are fairly good.

6 REFERENCES