A Resource for the State of Florida

HURRICANE LOSS REDUCTION
FOR
HOUSING IN FLORIDA:

WALL OF WIND RESEARCH

A Research Project Funded by
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PREPARED BY
THE INTERNATIONAL HURRICANE RESEARCH CENTER
FLORIDA INTERNATIONAL UNIVERSITY

The Wall of Wind Project

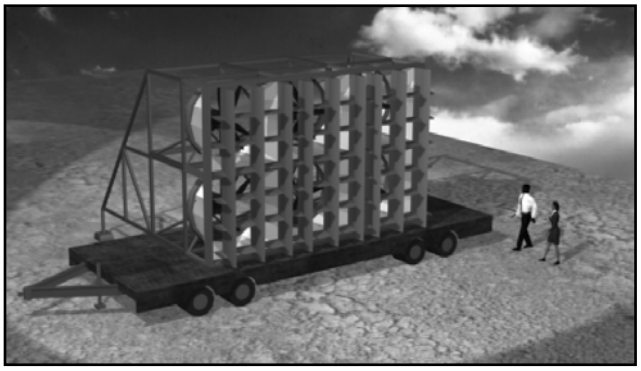
Background

The current trends of reduced vertical wind shear and elevated sea-surface temperatures in Northern Atlantic climatology have created a favorable environment for tropical cyclone formation. Tropical meteorologists anticipate these conditions to last for several decades, spawning a predicted increase in hurricane activity over the next 10-40 years. As a result, structural damage mitigation research is necessary to further enhance the designs, materials, and building codes governing structures built in regions vulnerable to hurricane impact.

The IHRC has undertaken the Wall of Wind project as an innovative solution to overcoming problems and simplifications inherent to conventional methods used in the field of structural damage mitigation research. For example, destructive testing—carried out by means of static and dynamic vacuum chambers, small and large missile air cannons, reaction frames, and other specialty equipment—provides useful data about the strength of the members and the connections being tested, but it may not adequately account for factors such as environmental loadings, aging effects, and system effects that change the load paths actually developed in the test specimen. Wind tunnel modeling—the other commonly used method implemented for this type of research—supplies important information about the pressure field acting around immersed bodies in a turbulent flow field, but the results are limited due to scaling issues. The loads impinging the performance of low-rise structures modeled at ranges between 1:25 and 1:50 are extremely difficult to determine. Additionally, wind tunnel modeling cannot simulate the performance and resistance of full-scale building materials.

The Wall of Wind apparatus is under development to eliminate the aforementioned performance and scaling issues by reproducing the actual dynamic interactions between hurricane-force winds and rain with full-scale low-rise structures. The IHRC has planned three phases of the project. Phase I and II are now under development (Figure 1). The two-fan Phase I unit will be used to conduct limited research experiment and support outreach efforts to local schools. The six-fan Phase II unit will be employed to test building systems for research. Phase III consists of 18 fans working in concert inside of wind tunnel—funding is being sought. This research will build upon studies (Kennedy 1999, National Research Council 1999) that validated the technical feasibility of such a testing apparatus. This report details the work of Phase I, from which the larger Phase II testing will find its basis. This two-fan array is a prototype that is being used to establish and improve the control systems that will eventually operate the larger, more sophisticated Phase II and III Wall of Wind testing apparatus.

a. Phase I



b. Phase II (under construction)

Figure 1. The Wall of Wind

Phase I Progress

Ensuring that the apparatus is designed and functioning properly (i.e., the turbulence coming off the unit accurately simulates actual hurricane-force wind and rain) is vital to the quality of the testing that will result from use of the Wall of Wind. Because of this, a significant amount of time and resources have been emphasized into Phase I. Thus far, important progress has been achieved in the following areas:

- Acquisition and operation of the initial Phase I array
- Development and calibration of the control/acquisition algorithms
- Installation of the water injection system

Acquisition and operation of the initial Phase I array

The Phase I Wall of Wind consists of a two-fan array designed and manufactured by Diamondback Airboats, Inc. Each individual fan unit is comprised of an outer steel frame that houses a Chevrolet ZZ402 big block engine. Mounted to the engine is an Airboat Drive Units, Inc. CH 3 belt-driven reduction assembly that spins two 80+ inch counter-rotating airboat propellers. Three vertical and neutrally shaped rudders are installed beyond the propellers to create the desired turbulence field by manipulating the air coming out of the unit. The entire steel frame assemblies are mounted onto a trailer, which facilitates transportation of the apparatus to different testing sites. The Phase I unit was delivered to FIU in January of 2005. Since its arrival, the machine was assembled and then operated at Miami-Dade County's Tamiami Park during the weeks of June 27-July 1, July 18-22, and July 25-29. During this time, work was performed on the development and calibration of the control and data acquisition algorithms, which will be discussed in further detail below. A mobile laboratory was made available to F.I.U. at no cost to the project to optimize the modularity and mobility of the Wall of Wind. This self-sustaining laboratory houses the computer equipment associated with the project, and it serves as the command center from which the Wall of Wind is monitored and controlled.

Development and calibration of the control/acquisition algorithms

Using the Wall of Wind as a viable alternative to conventional testing techniques is essentially dependent on successfully reproducing and duplicating the correct turbulence characteristics. All of the mechanical controls on the Wall of Wind—the throttle, the Y-rudders, and eventually the X-rudders on the Phase II and Phase III arrays—operate by means of computer-based algorithms developed within the National Instruments Labview software. This software is remotely controlled by a standard laptop, which is connected to a PXI system via a wireless network connection. The PXI system is comprised of a National Instruments PXI-7354 4-Axis High-Performance Stepper/Servo Motion Controller, a National Instruments MID-7654 4-Axis Servo motor drive, and a National Instruments Multifunction DAQ. A single Kobelt Model 6524 Electronic Actuator is responsible for physically moving the throttle and rudder cables that operate each individual fan unit on the Wall of Wind. RM Young UVW gill anemometers measure 3D wind velocity. The Labview software intertwines all of these components together by actively controlling a feedback loop on the PXI system. The feedback loop works by sending output signals to the electronic actuators and receiving input signals from the anemometry. This allows the Wall of Wind to be calibrated by comparing the engine tachometer readings with the anemometry wind speed measurements and the amount of throw made by the actuator. The engine RPMs are then varied to create the necessary longitudinal turbulence, while the rudders are used to manipulate the vertical turbulence (and eventually the lateral turbulence for Phases II and III). When perfected, the program will execute and the Wall of Wind will automatically throttle up and down while the rudders deflect along their respective axes, exactly producing the desired wind spectra. The data used to derive the intended wind turbulence characteristics comes from three-dimensional surface wind observations recorded during actual tropical cyclones by the Florida Coastal Monitoring Program (FCMP).

Installation of the water injection system

In addition to wind loading, the effects of wind-driven rain on building facades, wall assemblies, and subsystems (doors and windows) is a major impetus for the Wall of Wind research. Design work has begun on both freestanding and wall-mounted wind-driven rain gauges that will be implemented to measure both horizontal and vertical rainfall intensities. Field measurements of wind-driven rain intensities will be compared to rain intensities produced by the Wall of Wind to ensure that accurate conditions are achieved.

Installation of the prototype water injection system has occurred on the Phase I Wall of Wind. A steel frame was fabricated at FIU to extend beyond the rudders of each fan unit. Four rows of Tee Jet spray nozzles, joined together with high pressure hosing, were mounted vertically to this frame. The spray nozzles on each line are spaced 18 inches apart. Two different types of spray nozzles are being used in the current system: 8005VX nozzles that release 0.5 gal/min at 40 psi are located on the inner lines, and 8003VX nozzles that release 0.3 gal/min at 40 psi are located on the outer lines. When operated at 40 psi the entire two-fan array will release 14.4 gal/min (864 gal/hr). The system was

designed and assembled using Quick Tee Jet caps so that a variety of spray nozzles with different capacities may be interchanged in the future to produce a multiple number of rainfall intensities. Water for the injection system is stored in a 550-gallon agricultural-grade horizontal leg tank. An electric pump transfers the water from the tank through the hosing and into the spray nozzles. The electric pump will be replaced with a gasoline-powered pump that will more effectively work to overcome the head and preserve the water pressure in the spray injection nozzles located on the upper fan unit.

Supplemental Funding and Advisory

The IHRC is committed to attracting industry and federal funds that serve the interests of the State of Florida and otherwise would not be available to government programs. During the project period, additional Wall of Wind grant received from Renaissance Reinsurance ($379K) and the National Science Foundation Partnership for Advancement of Technology in Housing Program ($300K) to support the overall research effort.

An advisory panel, comprised of industry and government interests was also formed to produce a balanced research agenda. It will consist of the following representatives:

Home Builders	Tom Kenney, P.E., Vice President of Contract Research for the NAHB (National Association of Home Builders) Research Center, Inc.
(Re)Insurance	Dr. Tim Reinhold, P.E., Vice-President for Engineering of the Institute for Business and Home Safety (IBHS)
State Government Mitigation	Charles McCool, Planning Manager for the State of Florida Department of Community Affairs Residential Construction Mitigation Program
Local Government Mitigation	Frank Reddish, Manager of the Bureau of Recovery and Mitigation of the Miami-Dade Office of Emergency Management
Roofing Industry	Chuck Goldsmith, AIA, Roofing Industry Committee on Weather Issues
Material Manufacturing Industry	Do Kim, P.E., Director of Technical Services, Guardian Building Products

Additionally, industry support is being solicited to supply building products for the Wall of Wind project. The W.P. Hickman Company (Scott Hickman, CEO) will provide flashing and roofing material. Hickman will also assist with the development of vortex suppression technologies under development by Jason Lin, founder and co-owner of AeroEdge Wind & Structures Consulting. Guardian Building Products (Do Kim, P.E., Director of Technical Services) will provide soffit and screen enclosures as well as $5K annually through the project duration. Andersen Corporation (J. Guy Reithmeyer, Senior Product Development Engineer) will provide glazing and fenestration. Simpson Strong-Tie (Randy Shackleford, P.E., Florida Area Manager) will provide connectors and

anchors. Stanley Bostitch (Dr. Ed Sutt, Engineering Manager of Fastener Technology) will provide fasteners and specialty tools. Support for equipment has been provided by Renaissance Reinsurance, Ltd., and the State of Florida Department of Community Affairs.

Summary

The IHRC's Wall of Wind project offers a revolutionary new concept in the field of structural damage mitigation research by allowing test specimens to be exposed to actual hurricane-force winds and rains at full-scale. Testing done with the Wall of Wind will not be prone to the errors, difficulties, and assumptions associated with the more commonly used testing methods. Necessary and important steps have been completed in the development aspect of the Wall of Wind project. The use and operation of the Phase I prototype array has allowed for improvements to be made to the hardware and software needed to control the apparatus. Further progress has taken place with the installation of a water injection system that will serve to reproduce the wind-driven rain phenomenon associated with tropical cyclones. Steps have been taken to ensure that the Wall of Wind remains as modular and mobile as possible so that it can be easily transported to various testing sites. The resources emphasized into Phase I of the project will ensure that the desired wind field will be produced. This effort translates into accurate testing that will ultimately serve to improve building techniques, thereby reducing the overall losses sustained by hurricane-prone communities.