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March 27, 2007

Scruggs Law Firm
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Attention: Mr. Richard F. Scruggs

Reference: Katrina Litigation
Mr. and Mrs. Thomas and Pamela McIntosh
2558 South Shore Drive
Biloxi, MS 39532

Expert Witness Report

STRUCTURAL RESPONSE OF THE PROPERTY OF MR. AND MRS. THOMAS McINTOSH DURING HURRICANE KATRINA (8/29/02)

1.0 Introduction

The following summary report is prepared in reference to your request to assess the interaction of the high velocity wind forces from hurricane Katrina with the structure of the residential property owned by Mr. and Mrs. Thomas and Pamela McIntosh, 2558 South Shore Drive, Biloxi, Mississippi. An assessment of the structural damages is also included with recommendations for structural inspection for damages, retrofitting and repair as necessary. This report is for your own use, and you may use it in its entirety as a single piece of evidence as you see fit. I will be glad to answer any questions in the future, or expand on any idea presented, as per your request, and on my own initiative as necessary to satisfy any and all inquiries presented to me.

This report is based upon the evidences made available to me, and on basic well known established wind engineering scientific facts that are related to hurricane Katrina. Only refereed published research material on the subject of hurricane wind loadings and related damages to residential structures is used. No theoretical mathematical modeling or computer simulations based on assumed scenarios are employed in this presentation. All wind engineering data and the structural response presented in this report are based on either documented observations, measurements, or refereed findings from physical situations in the field or full scale laboratory testing on structures.

2.0 Background of Expert Witness

In August, 1969, I lived in Pass Christian, Mississippi when the eye of hurricane Camille hit the Mississippi Gulf Coast. I was working that summer for the General Electric Company at the NASA Test Facilities at Bay Saint Louis, Mississippi, while I was a faculty at Mississippi State University, Department of Civil Engineering. I lost my entire home at the beach property in Pass Christian with "only slab left" including a close friend who died as a result of the hurricane, Mr. Slim Wagner.

On the morning after the hurricane Camille hit the Mississippi Gulf Coast, I was contacted by the Manager of the General Electric Company and I was asked to inspect the damage to the Gulf Coast area including the NASA Test Facilities. I was granted special permission to access the then restricted area and I witnessed first hand and evaluated the destruction and resulting damages from the hurricane.

Ever since that day, I have dedicated part of my professional education and activities to study the interaction between hurricanes' high velocity winds and structures.

For the past sixteen years, I have concentrated my full time research efforts working on simulating in the laboratory hurricane wind forces on structures. This effort was finally successful for the first time ever in 2005, and the on-going research at the present time is dedicated to advance the knowledge and the state-of-the-art on this topic, see Exhibit 1, attached. Several publications on this topic are already available, and the work on this subject is quoted in recent presentations and publications by several wind engineering experts on the national and international scene, see Exhibit 2, references 1,2,3,4.

3.0 Forces from High Velocity Wind and Structures

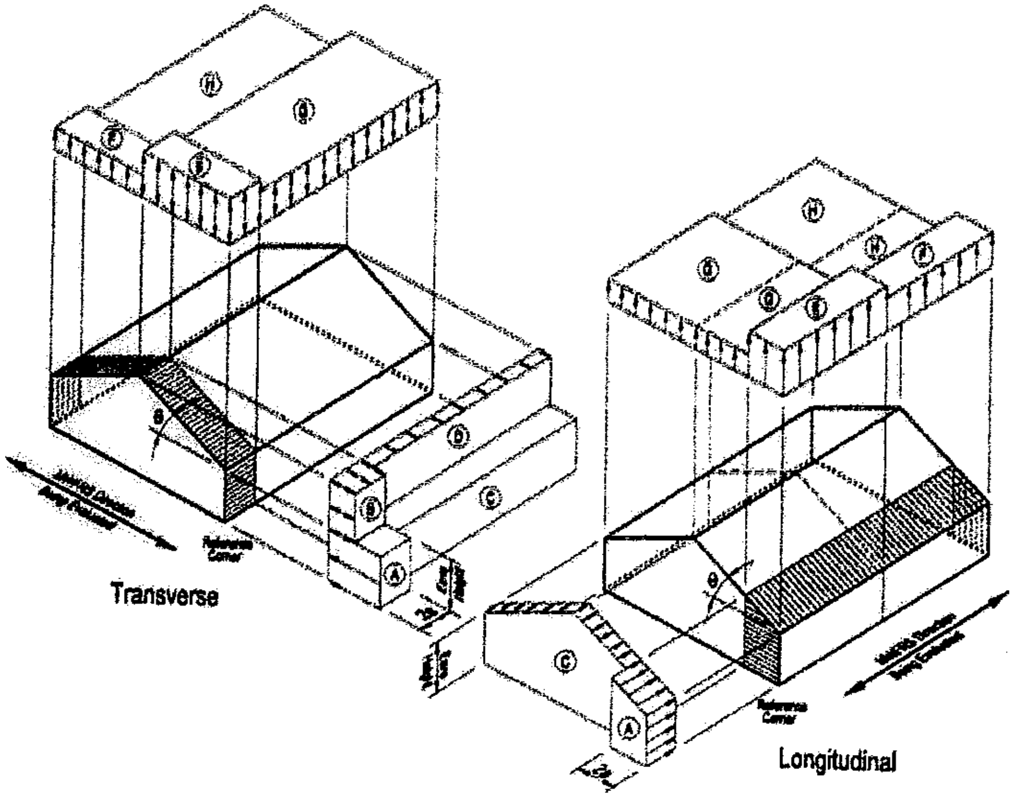
Hurricanes are wind driven events coupled with variations in barometric pressure differentials. As a result of hurricanes, high velocity turbulent air flow is generated. This unsteady flow of air causes severe pressure differentials on structures leading to high loading forces and potentially catastrophic structural failures.

Wind forces are translated to pressures per unit exposed surface areas that have dynamic variable effects on structures. Wind produces direct pressures on structures when these structures block the natural flow of the high velocity air flow. Furthermore, these forces from the wind flow increase significantly if this blockage tends to increase the air flow velocities. Also, this high velocity air flow produces a vacuum between the flow of wind streams and the structure causing severe suction forces, see Figure 1, as presented in ASCE-7 for minimum design loads. [5,6]

Uplift forces on the roof and suction on the sides and leeward walls of the house are by far the most destructive forces because they generally exceed all other forces and cause detachment to components from the structural framing. In our case in question, the McIntosh residence (house), these pressures acted on both the external and internal surfaces of the envelope of the house, as it will be discussed later, see Figure 1.

A house or a building (structure) must be strong enough to insure overall adequacy of the structure as a whole, and the adequacy of individual components that forms the envelope. ASCE-7 covers the loading on structures accordingly and under these two items: 1. Main Wind Force Resisting System (MWFRS), and 2. Components and Cladding forces (C&C).

Main Wind Force Resisting System – Method 1		h ≤ 60 ft.
Figure 6-2	**Design Wind Pressures**	**Walls & Roofs**
Enclosed Buildings		



Notes:

1. Pressures shown are applied to the horizontal and vertical projections, for exposure B, at h=30 ft (9.1m), for I=1.0. Adjust to other exposures and heights with adjustment factor λ.
2. The load patterns shown shall be applied to each corner of the building in turn as the reference corner. (See Figure 6-10)
3. For the design of the longitudinal MWFRS use $\theta = 0°$, and locate the zone E/F, G/H boundary at the mid-length of the building.
4. Load cases 1 and 2 must be checked for $25° < \theta \leq 45°$. Load case 2 at 25° is provided only for interpolation between 25° to 30°.
5. Plus and minus signs signify pressures acting toward and away from the projected surfaces, respectively.

Figure 1. Direct inward, outward suction, and uplift pressures in the direction of high velocity wind on the McIntosh Residence

3.1 Main Wind Force Resisting System (MWFRS):

The main wind force resisting system is the structural system that provides the overall integrity and framing stability of the envelope as a whole when the effects of wind forces are applied to the entire structure. The MWFRS forms the load path that the winds follow to the ground. The MWFRS is expected to withstand all external and internal pressures, applied in one or more combinations that produce the most severe forces in the system's components, see Figure 2. Adequacy of the MWFRS is necessary for the survivability of the structure.

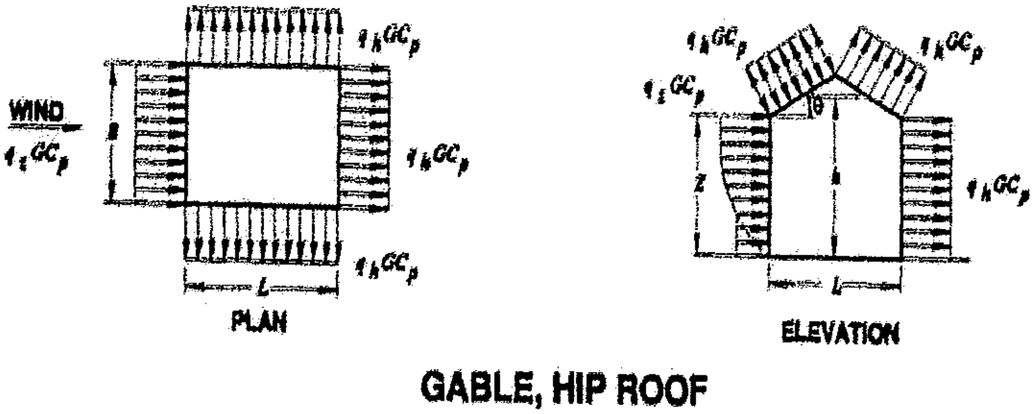


Figure 2. Main wind force resisting system (MWFRS) external and internal pressures as per ASCE-7

Typical MWFRS configurations for horizontal and uplift load transfer can be found in moment resistant structural framing. These frames are commonly used in a multistory or a single structure. Load path is provided by the beam-column rigid connections. The two story, McIntosh house did not have moment-resisting structural framing but it had main simple and free to rotate framing all around. It was well built using classical wooden framing, roof trusses, and plywood roofing with asphaltic shingles. The integrity of the framing and the good workmanship of the structural framing for this house in particular were evident from the field inspection of the house after the hurricane.

In the absence of moment-resisting integrated connections in the frames, then the structure must depend on braced frames such as trusses and shear walls, external and internal partitions as diaphragms, or the roof itself to provide structural stability. In limited special cases, the corner panels in a single story framing of a house, if well designed and anchored, could provide the lateral bracing to secure structural stability. The McIntosh residence did not have x-bracings or shear walls. This approach is seldom used in wood framing to a house, but commonly used in metal framing and in multi-story buildings. However, the McIntosh residence did have external solid columns and internal partitions. The external walls for the McIntosh house are extremely weak structurally by the fact that they are almost transparent with excessive lines of windows. Such glass windows are known to be subject to initial failure by instantaneous high direct pressures and breakage by flying debris. The main columns in the McIntosh house framing are fairly solid and this is good for the structural stability of the house. The internal partitions are definitely not designed as shear wall diaphragms in this house. The only good structural cross-framing left in the McIntosh residence is the roof. This is the easiest part in such a residential house to get uplifted because of the extremely high suction forces created by the vacuum from the high velocity lines of wind flow. As per the ASCE-7 for the design of structures using minimum design loads from high velocity winds, the design is governed by the corners of the roof because they are the most vulnerable zones to uplift wind forces in addition to localized damages due to flying debris and falling trees, as it will be discussed later, see Figure 1.

The structural stability of the framing of the McIntosh house was not lost during hurricane Katrina, but the roof did get uplifted and clearly damaged at several locations and all around the house envelope. This severe shingle damage, uplift, and loss of integrity was clearly evident in the roof of this house and all around the neighborhood, see Figures 3, 4 and 5. Part of the roof plywood sheets were uplifted and blown away to cause severe rain and wind damage to the interior of the house. This roof damage is due to high wind velocity and occurred most definitely early in the timing of the hurricane history and way before any water surge occurred on the ground level.

Figure 3. View of the damages to the roof taken from the front elevation of the McIntosh Residence

Figure 4. View of damages to the roof taken from the back elevation of the McIntosh Residence

Figure 5. View of uplift damages and penetration of debris to the McIntosh roof

3.2 Components and Cladding (C&C) Forces on the Envelope Enclosure:

The components and cladding, as defined by the ASCE-7, are the individual components that collectively enclose the house. They make up the envelope. The C&C components including the roof cover transfer the wind loads from the exposed surfaces of the envelope to the MWFRS.

C&C failure degrade the integrity and serviceability of the house, cause unacceptable damage to the framing interior and to the contents. For example, loss of windows in a house would not necessarily result in the collapse of the structure, but could prevent the house framing from functioning as a stable structure. Failure in the C&C causes severe increase in the wind pressure differentials from the high velocity winds. This is common in wooden residential construction. The presence of excessive openings, windows and doors, in the envelope of the McIntosh house, that are highly susceptible to breakage by flying debris, made it easy to speculate premature failure in C&C. Failure of the C&C is often, but not always, followed by catastrophic structural failure of the MWFRS.[5,6,7,8]

For this reason the C&C, as per ASCE-7 Specifications for Minimum design loads, is subjected to higher pressures than the structure as a whole. But, this was not the case in the McIntosh Residence because the envelope was very fragile to wind loading and considerably weaker than the main framing, as it will be discussed and shown later on in the Report.

4.0 Wind Field from Hurricane Katrina at Biloxi, Mississippi

Katrina was a major hurricane when it made landfall in Biloxi. Because it was also an unusually large hurricane, the Mississippi Gulf Coast was exposed to hurricane-force winds for many hours, including several hours before landfall. Katrina's hurricane-force winds extended 120 miles from the storm center, and tropical storm-force winds 230 miles outwards. Katrina also maintained a large eye, thereby providing a large area coverage of its most fierce winds. Satellite images, National Weather Service radar, airborne radar (from the Hurricane Research Division), dropsonde data, buoy data, and an Ingalls Shipyards' anemometer provide intriguing insight into the three-dimensional structure of the hurricane. But, due to field failures of some critical instrumentations, the entire picture of the wind forces especially the extremely high instantaneous gust of wind loading was not recorded.

An outer-core band of strong thunderstorms from a second eyewall impacted the Biloxi area. The strong winds also created a situation where potent wind gusts could occur in thunderstorms and boundary layer turbulent eddies to create tornado like effects on localized areas. Structural damages to many residential areas in the neighborhood to the McIntosh residence are noted to reflect this localized catastrophic failures known only to occur in severe wind vortices and downbursts. National Weather Service radar data indicates many tornadoes, and satellite shows mesovortices on the inner edge of the eyewall capable of extreme wind damage that were similar to the damage caused by the mesovortices in Hurricane Andrew.

Eyewitness accounts of next door neighbors to the McIntoshes confirm wide spread structural failures before the water surge inundated the land and describe intense winds on the early morning of August 29. The affidavit of Ron and Linda Muchk, neighbors to Mr. McIntosh, are quoted in this regard.

An affidavit from Mr. George Sholl, director, Jackson County Emergency Communications District, tells of his observation of the wind speeds from anemometers mounted on the Emergency Operations Center (EOC) building. Mr. Sholl states that the two anemometers were professional type equipment and accurate to the best of his knowledge. He states that he observed the indicated wind speed from this equipment starting Sunday night, August 28, 2005 at 75 mph up to the early daylight hours of Monday, August 29, 2005 at an indicated wind speed of 137 mph. He states that shortly thereafter sections of the EOC building roof blew off and he evacuated to the nearby courthouse. He further reports that some personnel in the EOC building stayed for a short time after he left and observed the indicated wind speed at 140 mph. He further states that the anemometers' tower blew down approximately 20 minutes after he left and no more wind speed readings were possible. Mr. Sholl then states that the winds continued to increase after the tower blew down and he estimates that the winds must have been over 150 mph. He further states that the highest flood waters came later. The widespread wind damage is likely due to the longevity of hurricane-force wind exposure, fierce wind gusts, tornadoes, and mesovortices.

This affidavit from Mr. George Sholl is confirmed and backed by Mr. Butch Loper, the director of the Civil Defense for Jackson County. Mr. Loper testified that a wind gust speed of 137 mph occurred between 8:00 a.m. and 8:30 a.m.

At the McIntosh residence the sustained wind speed is estimated by the ADCIRC Simulation at 100-110 mph with the 3-second gust wind to reach 120-130 mph.

5.0 Magnitude and Distribution of Wind Pressures:

Factors that determine the magnitude and distribution of high velocity wind forces, with special reference and emphasis on the impact of these factors on the McIntosh residence, are the following:

Location: This is the single-greatest factor in determining wind effects. The McIntosh residence is in the coastal region with water front not too far from the house. The house is almost 4 miles inland from the sea shore but the adjacent Big Lake and the open waterfront most definitely created a situation for wind flow to gain speed and momentum as compared to adjacent neighborhood houses. It is therefore expected to face greater wind damage from hurricane Katrina than houses further inland away from the water and on dry land locations.

Exposure: The McIntosh residence is in open land spaces, adjacent to a large body of water. The effects of high velocity winds are not shielded or partially shielded by adjacent structures and thus no unusual increase in design velocities is to be expected, exposure Category C as per ASCE 7-02 "Specifications for Minimum Design Loads."

Topography: McIntosh residence is on a relatively flat terrain and no special topographical impact on design wind velocity is to be expected.

Orientation to wind: The greatest wind effects and the most vulnerable direction on this house are probably from the south to southeast, that is at the time the eye of hurricane Katrina hit the Gulf Coast. The McIntosh house has southeast-northwest orientation with windows over the entire length of the front and back elevations. These windows created open enclosure of the entire house after failure of the glass due to wind suction forces and direct pressures coupled by the impact of flying debris, see Figures 6, 7, and 8 for before and after the hurricane.

Structure: Wind effects increase with height above ground. The McIntosh residence should feel higher direct and suction wind effects on the roof and the front and back elevation walls. The corners of the roof plan will be subject to extreme uplift forces, with the overhang extension over the open front and back porch areas of the roof experiencing added intensity of the uplift forces.

Shape: Wind exerts inward pressure on the windward face of this house, outward suction on the leeward and side faces of the house and both inward pressure and outward suction on the roof surfaces. The shape of the house dictates the aerodynamics of wind flow and the creation of catastrophic suction forces. The shape of the McIntosh house with extended window openings on the front and back elevations of the house will create an open alley for the high velocity wind to travel through. A tunneling effect is created that ripped through the house from right to left causing internal damages and inviting flying debris into the house. This open space allowed later on to be inundated by floating debris from the water surge.

Natural period: Most wind contains turbulences (*gusts*), which causes periodic fluctuations in the effect that the wind has on the structure. The McIntosh residence, whose natural periods are expected to be near the natural periods of the energy contained in the wind gusts should feel the effects of the wind more than other houses whose natural periods are not near those of the energy contained in the gusts. Buffeting is the effect of gusts on a building, and for the shape of this house it is expected to be severe due to its flexibility.

Building importance: No special importance can be attached to the McIntosh residence as defined in the referenced ASCE-7 standards.

Design criteria: If houses are designed properly, then they are often designed for two risk criteria: 1. risk of failure of the structural framing, and 2. risk of disruption of function due to failure of components, serviceability. Strength design is based on the most severe wind effects that are relatively infrequent. Serviceability design is based on wind effects that occur more often, but which are less severe. The McIntosh residence was most likely designed for strength but not for serviceability.

A review of the post Katrina pictures taken by the home owner show very clearly the sever destruction to the front and back elevations, detachment and displacement of the blown out window, and cracking of the outward walls and separation from the main house elevation due to suction forces. The internal structure of the house was severely damaged by this open harsh wind environment, and the open roof for rainwater to enter the attic and destroy the false ceiling and the interior partitions of the house, see Figures 9 and 10. The damage to vegetation, trees, in the yard of the house as a measure of wind forces can be seen in Figure 11.

Figure 6. Before and after showing the line of windows on back elevation of the McIntosh house.

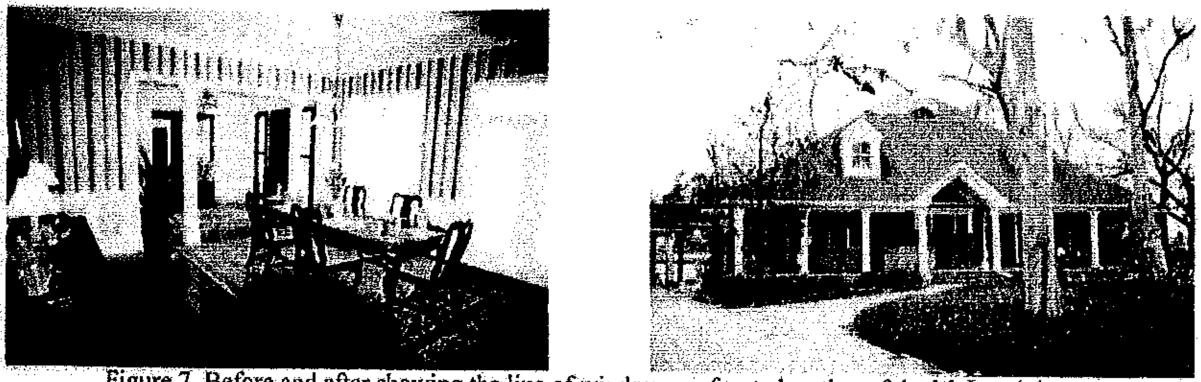


Figure 7. Before and after showing the line of windows on front elevation of the McIntosh house.

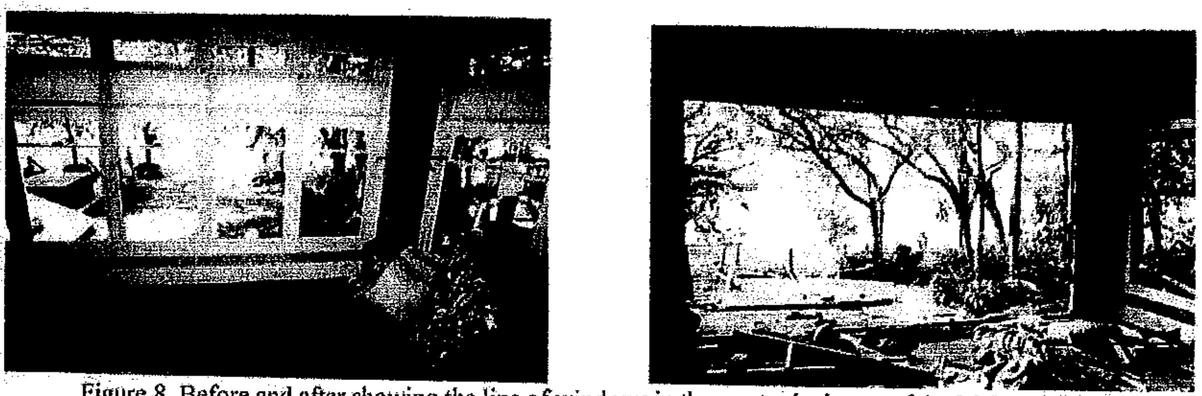


Figure 8. Before and after showing the line of windows in the master bedroom of the McIntosh house.

Figure 9. Damage to the interior false ceiling from rain water due to roof failure caused by wind.

Figure 10. Damage to false ceiling caused by roof failure due to wind.

Figure 11. Trees in the yard stripped and broken due to high wind velocity.

6.0 Hurricane Wind Forces and Structural Response

6.1 General: The fundamental measurement of the effect of hurricane wind forces on structures is wind speed. Wind speed is normally measured using anemometers that record the sustained speed. A typical wind speed plot recorded during a thunderstorm is shown in Figure 12. The wind pressure at an average sustained wind speed at 65 mph for one hour is not a hurricane force, but for a 3 seconds gust, it is equivalent to a force of a hurricane wind speed of 110 mph.

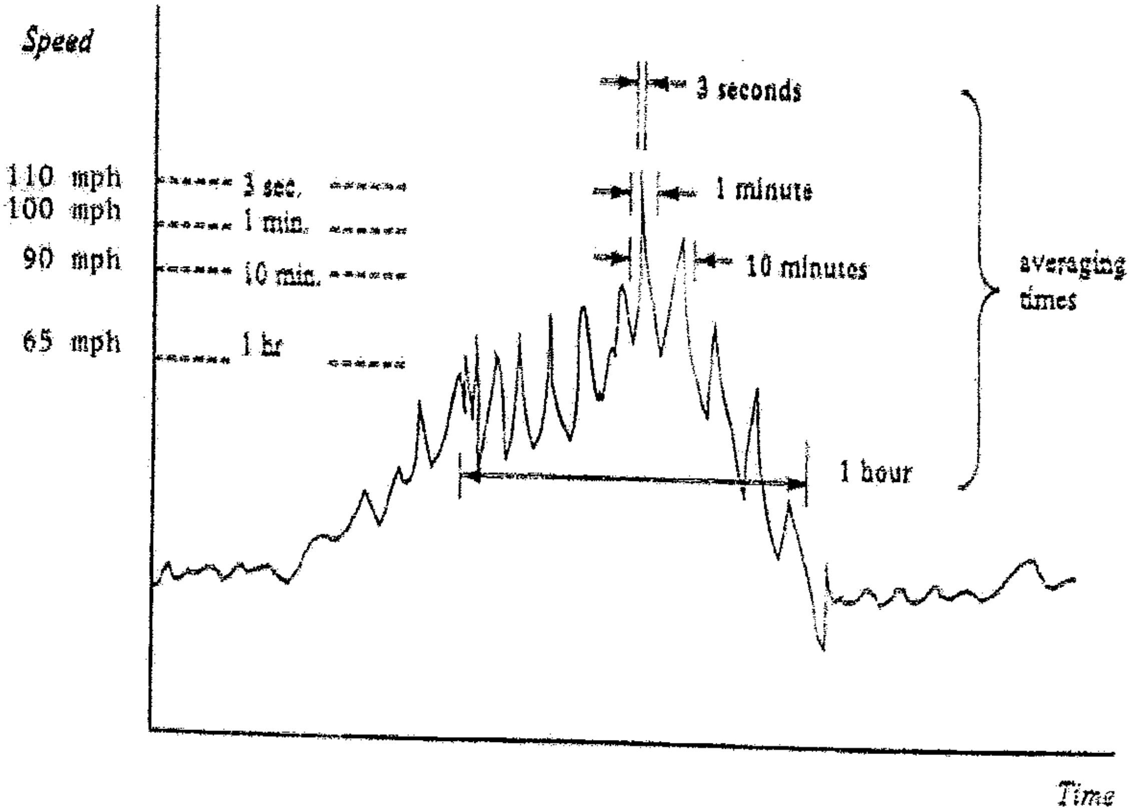


Figure 12. Typical wind speed variation vs. time from Ref. 6, see true measured hurricane wind loading in Figure 13 and in the Appendix.

6.2 Sustained Wind Speed: Only the critical and documented sustained one minute wind speed at the time the hurricane impacted the structural framing of the buildings on the site will be addressed here.

For the design purposes of the structural framing of buildings, the structural designer will be most interested in the 3-second gust wind speed as per the ASCE-7 specifications for the requirements of minimum design wind loads.

However, the assignment here is not the design process, but rather assessment of wind forces, damages, causes, and modes of structural failures. Thus, to address the impact of wind loading on the structures, it is vital and detrimental to use the maximum gust wind speed that these structures will be required to respond to and to sustain. Based on the most recent research conducted at Mississippi State University, at the Kelly Cook Structural Wind Simulation Laboratory, it was established beyond any shadow of a doubt that structures respond fully, 100% of the time, to one second instantaneous gust wind loading. Thus, to properly address the structural behavior of the McIntosh residence, the assessment must address the maximum one second wind gust rather than the 3 second wind pressure.

It is now well understood by all engineers working with wind loading on structures that the real wind pressures that act on building surfaces can vary dramatically from place to place, and from instant to instant. The spatial variation with a single surface on a building, say the roof, is remarkable. For example, the peak suction, uplift, spatially averaged over an area 8 ft X 14 ft can vary by a factor of 4, or more, compared with the worst, peak, local suction acting at a point within the same area at the same time, for critical wind direction. Time variation of significance occurs up to several cycles per second under real life hurricane wind conditions. These conditions are very significant and will be illustrated in more detail later under the discussion of "wind tunnel testing." Video recordings of the response of full scale true roofs to real life instantaneous loading duplicating the footprint of hurricane Andrew (1992) confirmed the significance of instantaneous loading. Those recordings were made recently by the writer at the Kelly Gene Cook Wind Simulation Laboratory at MSU[13].

The most significant change in the design specifications "Minimum Design Loads for Buildings and Other Structures," known as ASCE-7 was made in 1995. They introduced for the first time the 3-second gust wind speed instead of fastest-mile wind speeds. This change necessitated revisions of many factors. Figure 13 shows real life hurricane wind loading that varies in time and space at the rate of several cycles per second, and the variation is extremely unpredictable.

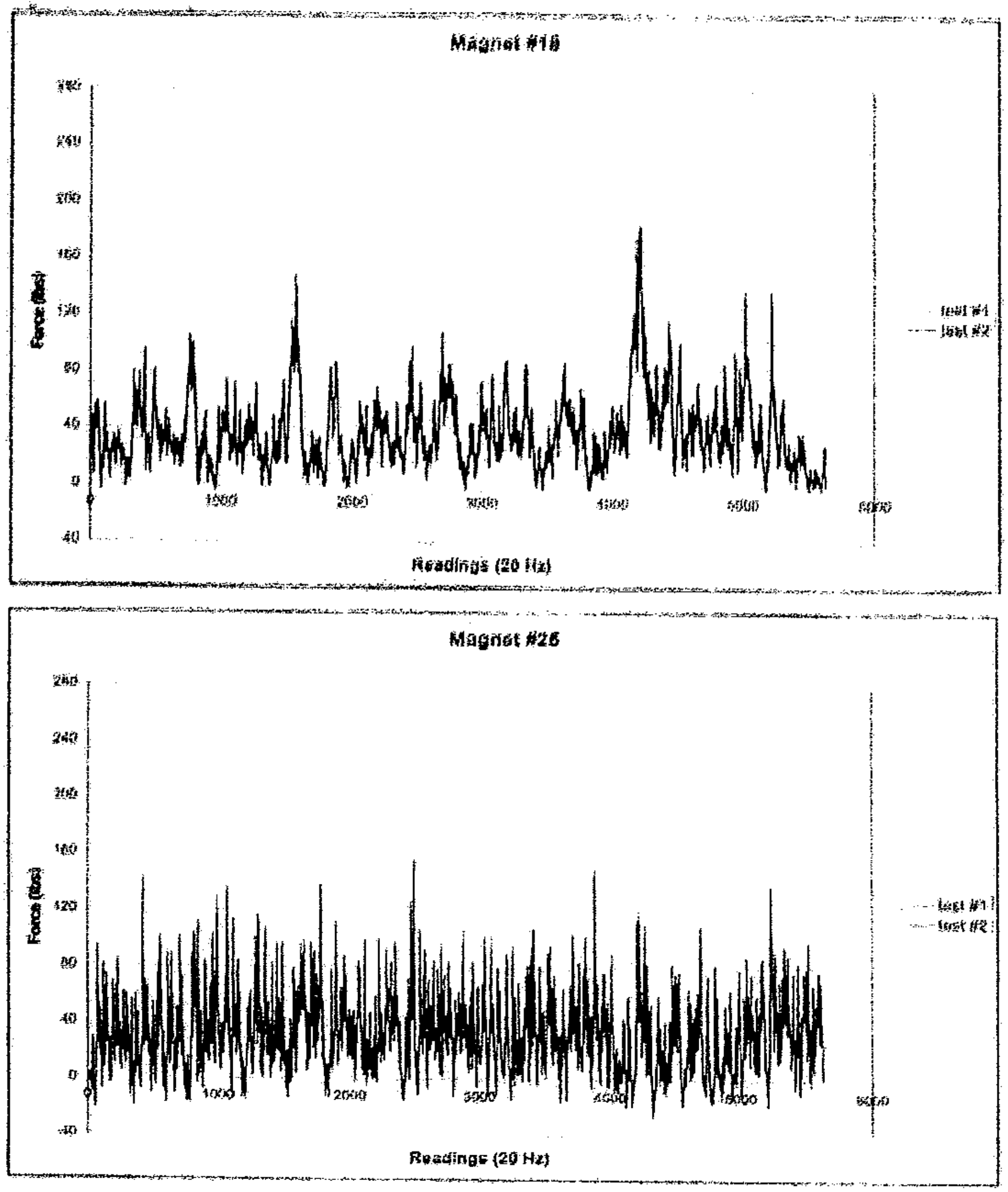


Figure 13. Instantaneous uplift wind pressure vs. time in seconds for Hurricane Andrew (Florida, 1992)
(#18 and #25 are two one square foot areas on a roof 6 feet apart)

The data in Figure 13 was collected and plotted at the rate of 20 (Hz), readings per second, of real life. The instantaneous peak uplift pressure on a flat roof can vary as much as 200 pounds per square foot for a sustained wind speed of 115 mph. It is important to note that the unit dead load weight of a typical wooden roof similar to that built at the McIntosh house is about 13 pounds per square foot. Accordingly; the maximum instantaneous uplift wind loading at the flat corners is about 15 times the weight of the roof.

It is also universally accepted now that the rate of change in time and space of true hurricane wind loading on structures is nonuniform and unsteady; that is, variable and dynamic. Fatigue of anchorage details of the roof to the walls and to the base boards of the house including the framing panels of roof and wall siding panels are severely tested under high velocity winds. This known fact makes it extremely vital and necessary to inspect and retrofit all anchorage points and connections of the structural framing of the McIntosh residence as an integral part of any repair to protect it from future sudden failures under moderate thunderstorms or hurricanes.

For design purposes, and for simplifying the complexity of wind loading in time and space, the ASCE-7, and all other design standards, rely on average wind speed and loading. The average over 3 second wind speed has been selected by the ASCE-7, called 3-second gust, and loading on panel areas in any structure are divided into zones in order to use uniform pressures, see Figures 1 and 2.

6.3 <u>Instantaneous Gust Wind Speed at the McIntosh Site</u>: The gust in hurricane winds are caused by slow overturning of air as it travels at high velocity. The hurricane boundary layers rolls have been documented in every recent hurricane. Truck-based radars that usually follow hurricanes and tornadoes and record the wind speed in the hundreds of a second have provided detailed footprints of loading spectrum including the boundary layer rolls of the wind that cause the wind gusts. These gusts when they collide with structures cause the unsteady nonuniform wind pressures. The loading that needs to be considered in this assessment of damage is the one second gust based on the ability of the structures to respond to the changes in the unsteadiness of the loading. This loading is referred to here as the instantaneous gust wind loading.

The instantaneous wind gusts played an important role at the McIntosh site by the fact that the roof and all the windows and the structural framing got severe wind damage. The entire structure of the house shifted away and deflected from its original location causing separation from encased brick columns and horizontal shear cracking was evident in these columns, see Figure 14 for a typical failure. It is also a well known fact by all wind engineering researchers and related studies as acknowledged by the ASCE-7, that the 3-second gust wind factors are between 20 to 30 percent higher than the one minute sustained wind speed. ASCE-7 uses the three seconds gust. The instantaneous wind speed, one second gust, is another 20 to 30% higher than the three second gust wind speed. These instantaneous wind speeds are the cause of the initial wind failures in the envelope and uplift in roof shingles and cladding. The instantaneous wind speed at the McIntosh house that needs to be used in the assessment of initial structural response based on 110 mph sustained wind speed is then equal to 160 – 180 mph.

Figure 14. Horizontal shear cracking of column encasement and separation from the house envelope.

6.4 **Rain water:** All eyewitnesses and weather reports confirm that heavy squalls of rain accompanied the gusty high velocity winds of hurricane Katrina. If the rain water is assumed to be transported by the wind, then the direct impact of this water against the structures, walls and roofs, will be huge. Furthermore, if the impact of rain water is assumed to be uniform and steady, then the impact forces will be at least 800 times that of the wind assuming that the water is traveling at the same velocity as the wind. The impact forces will be over twice that of the wind if the velocity of the water is only 10 mph. This logic is purely theoretical because it assumes that the rain water is traveling at a uniform mass, steady, and uniformly distributed, a "tsunami" effect. This is obviously wrong and an invalid assumption.

But, if the rain water is considered to be carried by the wind as transported debris to impact structures, then this is a valid assumption and the impact forces are most definitely higher than those produced by the wind alone. The findings from wind tunnel testing and ASCE-7 specifications for minimum design loads are not adjusted accordingly for rain water. Thus, it is only fair to note that by intentionally ignoring the rain water in the instantaneous gust wind loads is a significant underestimate in the true instantaneous direct loading impacting the envelope of the structure of the McIntosh residence.

7.0 TIMING OF HURRICANE WIND AND WATER SURGE VERSUS STRUCTURAL DAMAGES

Tide gauges show tropical-storm force winds from hurricane Katrina arrived about three (3) hours before significant flooding from the water rising or the water surge. Computer models, National Weather Service radar, reconnaissance radar, dropsondes, surface observations at Ingalls Shipyard, buoy data including a nearby Dauphin Island CMAN station, tide gauge data, eyewitness accounts, newspaper reports, and videos show hurricane-force winds, tropical storm-force winds, and strong wind gusts occurred hours before the surge impacted the Beach Boulevard, Highway 90, at Biloxi, MS. The official Hurricane Research Division wind analysis and experienced reputable local meteorology experts concur with this assessment, see Pat Fitzpatrick Report.

Low lying coastal areas are always susceptible to water pressure as a result of rise in water level. This includes the forces resulting from the movement of water onto land while the area becomes inundated by the hurricane wind forces. In the initial stages of a hurricane, land very near the coastline will be subjected to the impact of relatively large surface waves. However, much of this energy is absorbed as the waves break in shallow water approaching land. As time progresses, rising water is pushed toward the shore by the force of the winds. Thus, the rise in the surface water level is again a wind driven event coupled by the reduced barometric pressure within the eye of the hurricane that causes the rise in the water. This is known as the storm surge and mistakenly interpreted by some evaluators as a hydrostatic wall of water. This, in my opinion, is absolutely false, and unrelated to the physical mechanics of all around rising water levels. The structural response to an active turbulent water level with a known directional wind force is minimal. Water from a storm surge rises slowly initially at the rate of 2-3 feet per hour, and then at a higher rate, 1.0 inch per minute, as the wind increases in velocity.

A team of experts quoted and stated in a very recent publication the following:

"Storm surge does <u>not</u> occur as a wall of onrushing water like the Indonesian Tsunami; however, large wind-generated waves moving on top of the surging waters may create the impression of a tsunami-like effect, and the force of those waves may be responsible for great damage."[10] The emphasis by underlining the word "not" is added here. The unfortunate mistake made by most assessments of hurricane damages after a water surge is the isolation of rising water with aggressive wave action, if the surge is in open waters, from the high velocity wind forces that are driving the water surge.

The water rise during hurricane Katrina lasted several hours and affected about 100 miles of coastline. The peak wind speed generally preceded the peak surge, as expected, and for hurricane Katrina, this lag time has been estimated by most meteorological researches and experts to vary between 2-3 hours for the McIntosh site, see Figure 15.

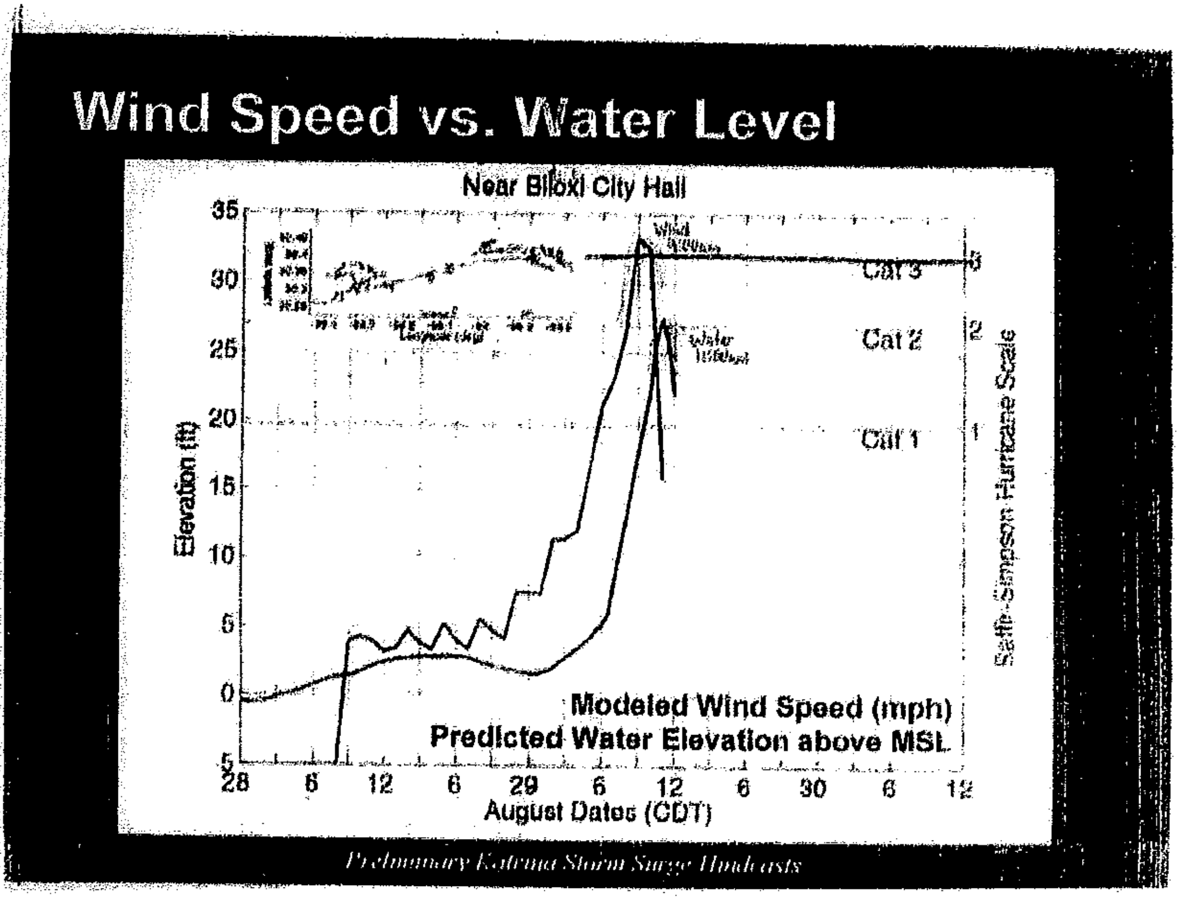


Figure 15. Wind speed and water surge elevation vs. time for Biloxi, MS (Reference 11)

In order to cause structural damage to existing buildings in a storm surge there must be significant differential pressure applied by the water. It is well accepted that water surge is a slow rising water at a maximum rate of less than one inch per minute and causes severe flooding around and inside residential homes. Water surge is a serious threat to the building's curtain walls, interior partitions, and contents of a residential house if the house is severely inundated by the water surge. However, damages from water surge are usually occurring after the peak high pressure differentials from winds have passed through the house. To evaluate the total water surge as a hydrostatic pressure behind a wall barrier is a fatal error by any engineer. For the McIntosh residence the water surge exceeded the ground level around the house. The back porch of the house itself was raised 4 feet above ground, and the water surge at its peak reached 2-3 feet above the ground slab level. The McIntosh residence is 4 miles away from the sea shore, and the Big Lake water front is a confined water with a restrained openings to the Iberville Bay. Thus, there are physical restrictions on water velocity and transportation with no wave action other than localized turbulence from the wind forces that were impacting the McIntosh residence at that same time.

But, in my opinion, since the water surge occurred three hours after the collision of the damaging sustained peak high velocity wind forces with the McIntosh residence, then this leaves no justification whatsoever for the water surge to be blamed to have caused any structural damage to the wall framing and the envelope of the house.

This opinion is also shared by the document "Is it Wind? Or is it Water?" prepared jointly by the Civil Engineering Department of the George Washington University, Washington, D.C.; the National Committee on Property Insurance (NCPI); the National Flood Insurance Program (NFIP); the Property Claims Services (PCS); the Property Loss Research Bureau (PLRB); State Farm Insurance Companies; and the Federal Insurance Administration (FIA) of the Federal Emergency Management Agency (FEMA). The purpose of this working document is that an adjuster can carry it with him or her when visiting the site of a disaster to help him evaluate site damages. This document is also aimed at providing technical information to assist property insurance claim adjusters in making determinations as to whether losses sustained to properties as a result of a hurricane or severe storm were caused by wind or water.

The following section in this report is a direct quote from the above noted insurance endorsed publication. It is presented here because it fits exactly the situation at the McIntosh residence and the resulting structural damages (this document is not copyrighted and permission is given to copy or quote from it):

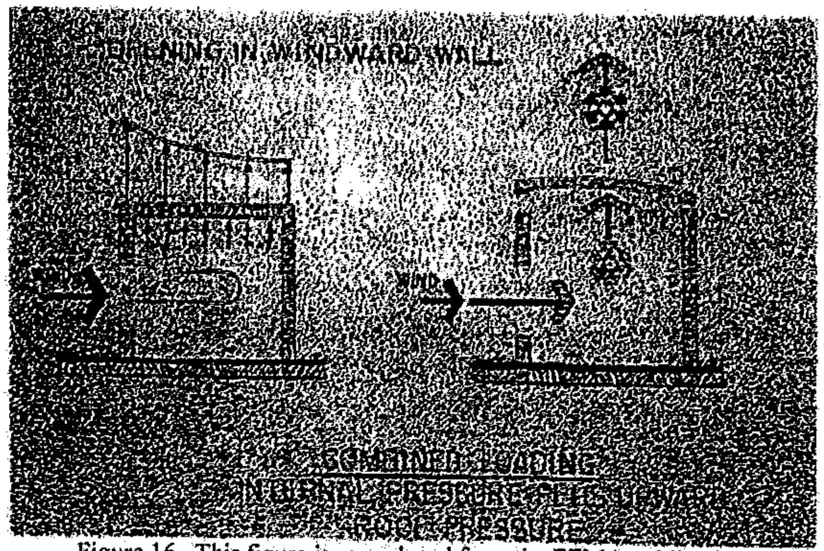


Figure 16. This figure is reproduced from the FEMA publication

- *Knowing the power of wind as compared to the power of water can help one determine what caused the damage.*
- *At 40 miles per hour, wind can exert an effect of about seven (7) pounds of pressure per square foot. At 60 miles per hour, the pressure increases to about 15 pounds per square foot.*
- *A wind of 100 miles per hour can exert an effective pressure of over 40 pounds per square foot on a building. Further, winds passing over and around a building can*

develop negative or "pulling" pressure in addition to the "pushing" pressure. See Figure 4.1(Figure 16 above).

- *The average wooden roof is built to sustain a weight of about 30 pounds per square foot. Thus, if a roof is fairly well constructed, winds of approximately 80 miles per hour would be necessary to cause considerable damage.*
- *If windows on the windward wall were open or broken, the pressure within the building would increase and push even harder from the inside out. See Figure 4.2 (Figure 17 below).*

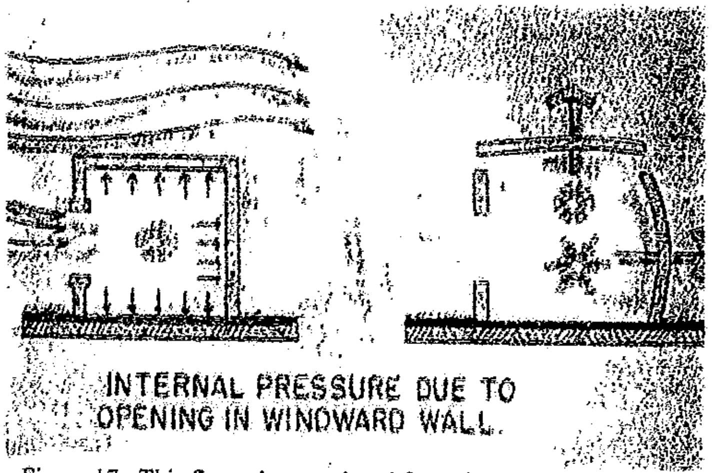


Figure 17. This figure is reproduced from the FEMA publication

Figure 18. This figure is reproduced from the FEMA publication

- *The pressure on the outside of the roof and leeward and side walls is negative, or pulling. This combination can be enough to lift off an entire roof, especially under hurricane wind* *force conditions. See Figure 4.3 (Figure 18 above). Inexpensive, galvanized straps can be used to tie the roof to the wall and thus reduce damage. Proper nailing of walls is required to prevent their removal by suction forces. Refer to the FEMA Coastal Construction Manual for additional construction details.*

- *The power of wind can also be devastating to the landscape. As shown in Figure 4.4 (Figure 19 below), trees snapped off at a high level, bent, or uprooted are indicative of wind damage.*
- *Sometimes a documented canvas in the area and talking to clean-up crews and eyewitnesses will give some special insight about the conditions during and after the storm that would help an adjuster determine the cause of damage.*

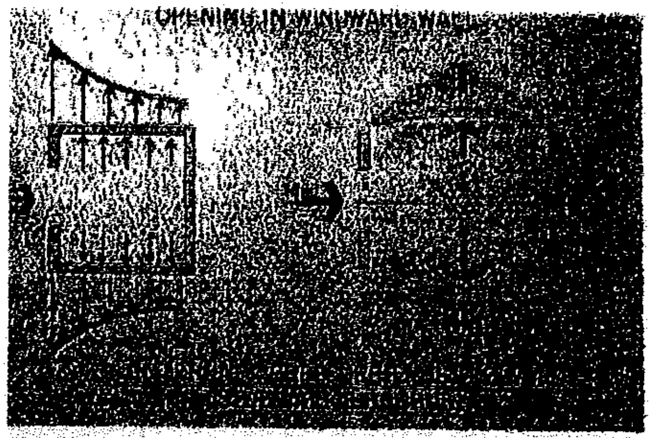


Figure 19. This figure is reproduced from the FEMA publication

Figure 20. This figure is reproduced from the FEMA publication

- *This house suffered extensive roof damage caused by wind. The wind damage left holes in the roof, allowing rain to enter. From this view there is no evidence of damage from water, but read on, (see Figure 20 above).*

Figure 21. This figure is reproduced from the FEMA publication

- *This is an interior look at the house in Figure 7.1,* (see Figure 21). *Notice the ceiling damage caused by water that came through the wind-created holes. This evidence, together with the evidence in Figure 7.1,* (see Figure 21), *clearly established wind damage for both the interior and exterior.*
- *Remember, water coming in through the roof probably caused damage to the plasterboard and ceiling. This would be covered under the wind policy.*

8.0 WIND TUNNEL TESTING

Several attempts in real life have been made to capture the response of low rise buildings to hurricane wind loading. All of these attempts to date have either failed completely or registered only marginal success. The only valid and currently available testing has been the use of boundary layer wind tunnel testing. In such tests, almost all of the major variables that influence the magnitude and distribution of wind pressures are duplicated; namely, location, exposure, topography, and wind orientation. However, only scaled miniature models of the buildings can be used, 1/50 scale. Therefore, the true characteristics of building framing and materials used for construction and the details of the connections are lost in the models.

Data from boundary layer tunnel testing is collected using over a hundred pressure cells spaced at 6 to 12 ins. apart and at a rate of at least 20 (Hz) cycles per second, see Figure 13. All building codes, including ASCE-7, are based in part on the findings from boundary layer wind tunnel testing among other research data. The unsteady nonuniform pressures of real life are simplified in the codes into static uniform loads over designated and well defined zones in any panel, wall or roof. Therefore, the loadings from ASCE-7, or any other building code, are not the true loadings of hurricane wind pressures, but rather simplifications of a very complex problem. This is the only thing that we have available for design at the present time. But, as we experience more hurricanes in time and with the current applications of advanced technologies, these codes or standards will be changing in the future.

It is important to note here that the ASCE-7 specifications have consistently and significantly increased the hurricane wind pressures on structures for the Mississippi Gulf Coast over the past twelve years.

9.0 STRUCTURAL LABORATORY TESTING

Present structural testing in the laboratory for the response to high velocity wind pressure loading can be found for individual components (C&C) of housing construction. Since hurricane loadings are caused by pressure differentials, the present testing in the laboratory uses this same procedure. The most used specifications in this regard are the ASTM – E 1592 "Standard Test Method for Structural Performance of Sheet Metal Roof and Siding Systems by Uniform Static Air Pressure Difference" and ASTM – E 330 "Standard Test Method for Structural Performance of Exterior Windows, Doors, Skylights and Curtain Walls by Uniform Static Air Pressure Difference."[7,8] These are relatively new tests, 10-12 years old, and they have been excessively used only during the past 5-6 years. The air pressure difference procedure can be either direct pressure or suction uplift pressure. Both of these laboratory tests use uniform static load application, contrary to the nonuniform unsteady loading from high velocity winds in real life.

Tests performed using air pressure difference has confirmed that almost all procedures and techniques used in the past for placing roofing and siding materials, fixing windows, doors, curtain walls, etc. have been found to be marginal, if not inadequate[9,10]. Impressive improvements have been made especially after hurricane Andrew and the rigid requirements for testing by the State of Florida. The construction procedure and techniques for building wood houses over the past five years, in this regard, have improved impressively.

The reason this subject matter is discussed here is to show that laboratory testing using pressure differential to simulate wind loading on windows, doors, skylights, and curtain walls has already captured the ASTM requirements for future designs. Failures of these C&C elements due to wind are very common and the McIntosh residence is no exception.

10.0 COST ESTIMATE OF STRUCTURAL REPAIRS

It is difficult to estimate the additional cost for the structural repairs that need to be done following a detailed structural inspection to the McIntosh house. However, it is expected that the existing anchorage mechanisms that were definitely compromised by the dynamic unsteady wind loading will require to be reinstated if not up-graded and retrofitted. The cost of engineering inspection, review, design and supervision of the work that needs to be done at cost-plus basis for this kind of structural work is left to professional appraisals in this field.

11.0 SUMMARY AND CONCLUSIONS

In my opinion, the following summary and conclusions based on the facts presented can be made:

1. The McIntosh residence was subjected to a sustained wind velocity of at least 110-115 mph during hurricane Katrina, and for an extended period of time. This sustained wind velocity with heavy down pouring rain lasted for at least three hours before the land was inundated by the water surge.

2. The 3-second wind gust, as defined by the ASCE-7 to be used for design purposes, reached at least 120-130 mph. This wind speed needs to be addressed when checking the current structural status of the house for repair and retrofitting as needed.

3. The McIntosh residence suffered extensive roof damage caused by the wind to compromise its integrity. The damage left large holes in the roof for an open exposure to the enclosure of the house that caused severe damage to the interior of the house. Glass windows that were present over the full left and right elevations of the house were also compromised. The house interior was severely damaged due to the rain water from the roof and due to the wind.

4. In summary, the structural integrity of the McIntosh house was compromised for both the exterior and interior by the high velocity winds of hurricane Katrina and extensive repair and retrofitting will be needed to retain its original status and structural strength.

Submitted by,

Ralph Sinno

R. Ralph Sinno, Ph.D., P.E., F. ASCE
Professor of Civil & Environmental Engineering

Appendix

TABLES OF TRANSFER OF WIND VELOCITY IN MILES PER HOUR TO UNIFORM PRESSURE IN POUNDS PER SQUARE FOOT (ASCE 7– 02)

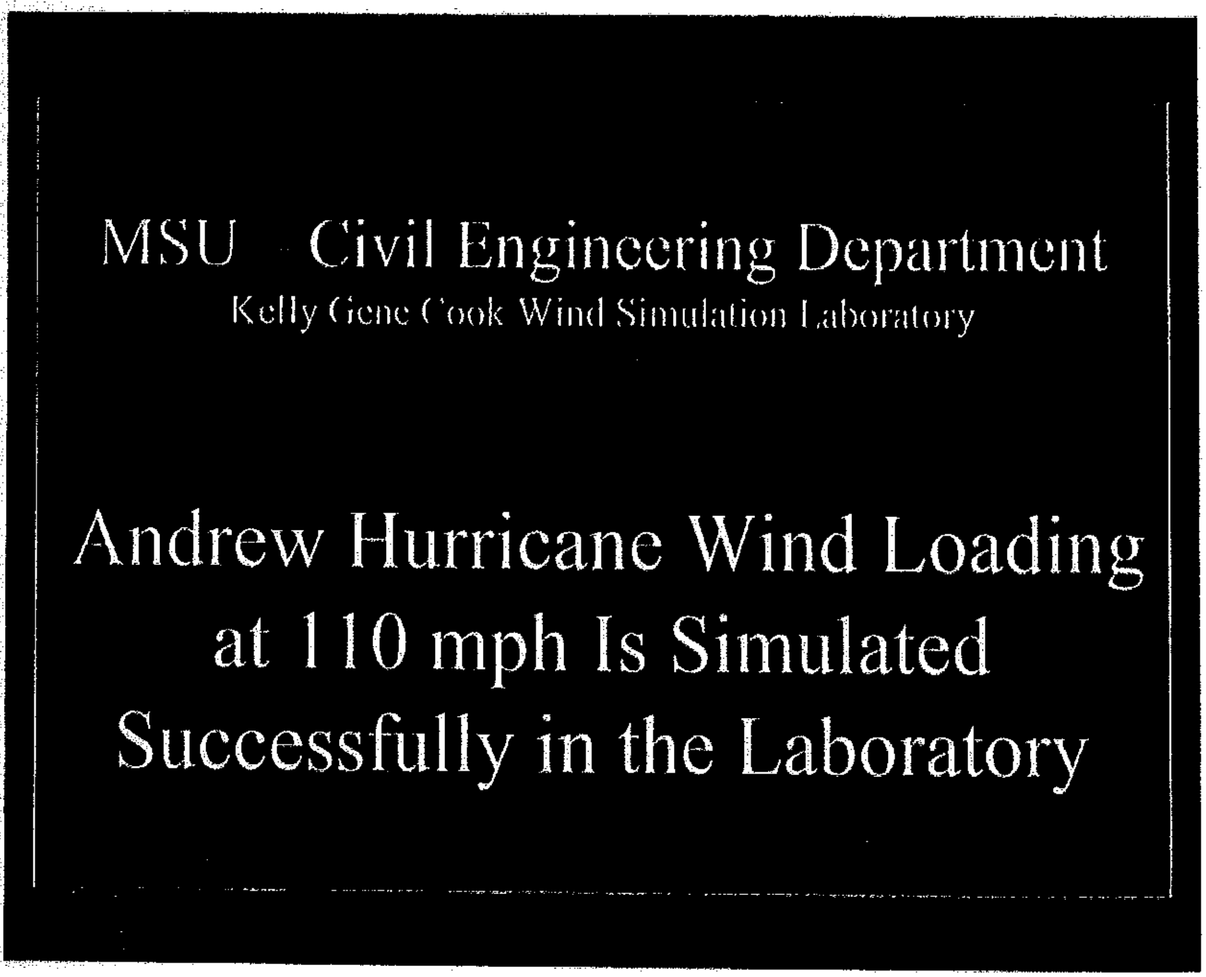
Velocity Pressure, q_z = (0.00256 * K_z * K_{zt} * K_d * V^2 * I)
Roof Uplift Pressure, q = (0.00256 * K_z * K_{zt} * K_d * V^2 * I) * (GCp + GCpi)

EXPOSURE C	**ASCE 7-02**	
Eave Height (ft) = z =	32	
z_g (ft)	900	Table 6-4
α	9.5	Table 6-2
K_z = 2.01 * $(z/z_g)^{2/α}$		Table 6-2
K_z	0.9957	
K_{zt}	1.0	No Topographic Effect
K_d	0.85	Table 6-4, MWFRS
I	1.0	Table 6-1, Building Category II
GC_p(roof center)	-1.0	Figure 6.11B
GC_p(edge)	-1.8	Figure 6.11B
GC_p(corner)	-2.8	Figure 6.11B
GC_{pi}	-0.18	Figure 6.5

[illegible] Fastest mile Wind Speed (V) Mph	Conversion to 3 sec Gust [illegible]	Velocity Pressure [illegible]	Roof Uplift Pressure [illegible] at mid-span (psf)	Roof Uplift Pressure [illegible] at edge (psf)	Roof Uplift Pressure [illegible] at corner (psf)
50	1.23	8.195	-9.670	-16.226	-24.420
55	1.225	9.835	-11.605	-19.474	-29.309
60	1.22	11.609	-13.699	-22.986	-34.596
65	1.21	13.402	-15.815	-26.537	-39.939
70	1.2	15.288	-18.039	-30.270	-45.557
75	1.195	17.404	-20.536	-34.459	-51.863
80	1.19	19.636	-23.171	-38.880	-58.516
85	1.185	21.982	-25.938	-43.523	-65.505
90	1.18	24.436	-28.835	-48.383	-72.820
95	1.175	26.996	-31.856	-53.453	-80.449
100	1.17	29.659	-34.997	-58.725	-88.383
105	1.165	32.420	-38.256	-64.192	-96.612
110	1.16	35.276	-41.626	-69.847	-105.124
115	1.155	38.225	-45.105	-75.685	-113.909
120	1.15	41.261	-48.688	-81.697	-122.958
125	1.145	44.383	-52.372	-87.878	-132.260
130	1.14	47.586	-56.151	-94.220	-141.806
135	1.14	51.317	-60.554	-101.607	-152.924
140	1.14	55.189	-65.122	-109.273	-164.462
145	1.135	58.683	-69.246	-116.192	-174.875
150	1.13	62.248	-73.452	-123.250	-185.498
155	1.125	65.880	-77.738	-130.442	-196.321
160	1.12	69.576	-82.100	-137.760	-207.336

Exhibit 1

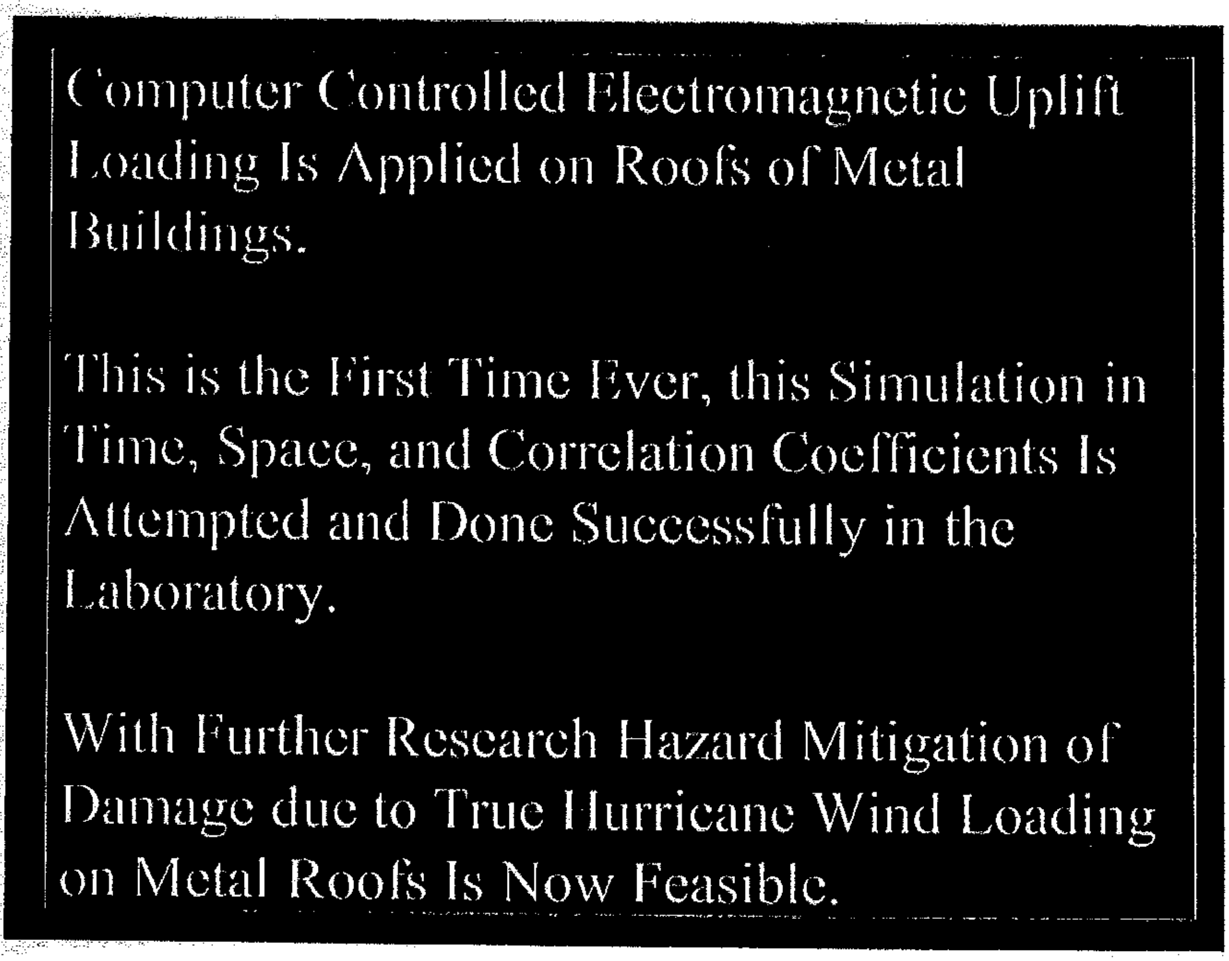
The Department of Civil Engineering at Mississippi State University announced the success of simulating true hurricane uplift wind forces on a metal roof in the laboratory. The footprint of hurricane Andrew (Florida, 1992) from the University of Western Ontario Boundary Layer Wind Tunnel was used in the simulation. The accuracy of the simulation was verified by Dr. Eric Ho from the UWO, Canada. The test set-up and work on the simulation was envisioned and directed by Dr. Ralph Sinno, Professor of Civil Engineering at MSU.



MSU Civil Engineering Department

Kelly Gene Cook Wind Simulation Laboratory

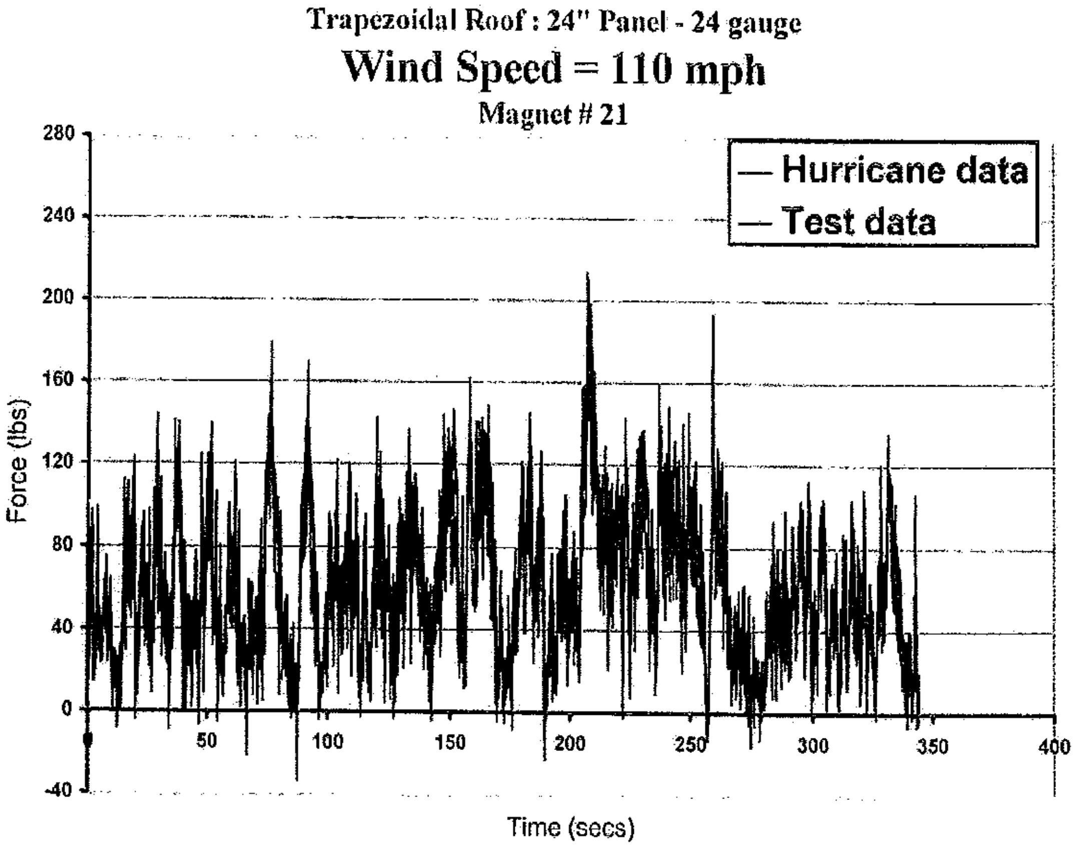
Andrew Hurricane Wind Loading at 110 mph Is Simulated Successfully in the Laboratory



Computer Controlled Electromagnetic Uplift Loading Is Applied on Roofs of Metal Buildings.

This is the First Time Ever, this Simulation in Time, Space, and Correlation Coefficients Is Attempted and Done Successfully in the Laboratory.

With Further Research Hazard Mitigation of Damage due to True Hurricane Wind Loading on Metal Roofs Is Now Feasible.



Trapezoidal Roof : 24" Panel - 24 gauge

Wind Speed = 110 mph

Magnet # 21

Exhibit 2
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