Wind and Structures, Vol. 8, No. 3 (2005) 179-196
DOI: http://dx.doi.org/10.12989/was.2005.8.3.179

Application of a wireless pressure sensing system to coastal wind monitoring

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(Received March 2, 2004, Accepted February 22, 2005)

Abstract. This paper describes the application of a wireless data acquisition system to monitor wind pressures and velocities with absolute pressure sensors and an anemometer. The system was developed for future deployment, as part of a research effort currently underway to instrument coastal homes in Florida to monitor roof wind pressures during hurricanes. The proposed wireless system will replace the current system that involves a large amount of hardwired connections from the sensors to the data processing unit that requires labor intensive wiring and preparation of the home. The paper describes comparison studies and field tests to assess the performance of the system. The new system offers the advantages of light hardware, ease of installation, capacity for 48 hours of continuous data acquisition, good frequency and amplitude responses, and a relatively simple maintenance. However, the tests also show that the shape of the shell that has been previously used to protect the sensors might interfere with the proper measurement of the pressures.

Keywords: wireless sensing; hurricane wind loads; coastal monitoring; pressure transducer.

1. Introduction

An increasing number of people are moving to Florida and other coastal states, and most of these people want to be close to the ocean. Consequently, in recent decades, the US extensive coastline has become more and more urbanized. On the other hand the frequent occurrence of hurricanes are a permanent threat to the man made structures on the coast.

Not only contractors do build structures in hazardous place, but also in many cases these structures are not designed to withstand the corresponding wind and flood forces. When a hurricane strikes the coast, the structures are destroyed with considerable economic loss, and a huge amount of debris is generated that has a negative impact on the coastal environment.

In order to build wind resistant structures that will not be a danger for their occupants and for the surrounding coastal environment, we need to understand the interaction between wind and structures during big storm events like hurricanes. An accurate description of fluctuating wind loads is the key to defining the ability of structural components to resist damage, and thus evaluate retrofits. So far,

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wind tunnel tests have yielded a sizeable amount of data. However, because of the artificial nature of the wind tunnel environment, and equally important because of scale issues, not to mention cost problems, wind tunnel tests can only provide a limited answer to the problem. The real answer lies in full scale testing and monitoring of real structures during actual events (Davenport 1999).

Until recently, this option was not feasible because of problems with instrumentation and data acquisition systems. However, thanks to recent advances in instrumentation and software development, researchers now have hardware and software that can be successfully deployed during a storm to monitor actual wind effects (Levitan, *et al*. 1991, Poterfield and Jones 1999, Schroeder and Smith 1999).

In particular in the past several years a team of researchers from the University of Florida and Clemson University, and more recently Florida Institute of Technology, (UF, CU, and FIT) have collected full-scale wind measurements of the turbulent ground-level wind field and the resultant pressures on low-rise structures. The Florida Department of Community Affairs (FDCA) provided initial major funding for the Florida Coastal Monitoring Program (FCMP), which utilizes mobile-instrumented towers and 30 instrumented buildings to collect time histories of wind velocity near ground level and pressures over the surface of residential structures during hurricane landfall. The Florida Sea Grant Program funded subsequent complementary aspects of this project.

This research provided very valuable data during recent hurricane seasons. To date the effort has provided an extensive cache of datasets from nine storms. For example, during tropical storm Isidore, wind pressures were recorded on the roof of an instrumented house (Dearhart 2003). More recently, the wind field data from the recent hurricane Isabelle (2003 season) was measured by a mobile tower system and relayed live via a radio link to the National Hurricane Center (Masters, *et al*. 2003). However, the pressure sensor system used for instrumenting the houses (Michot 1999) requires a large amount of hardwired connections from the absolute pressure sensors to the data processing unit that involve labor intensive wiring, and preparation of the home. Therefore, a wireless data acquisition system that was developed and tested at the Florida Institute of Technology could be used instead for future deployments. It includes a series of wireless sensors that measure pressure and temperature and an anemometer that measures wind magnitude and direction. The design specifications of the system and its theory of operation are described in a companion paper (Subramanian, *et al*. 2005). This paper investigates the suitability of the system for the proposed use through a series of performance tests, comparison studies, and including some 2004 Florida hurricane measurements. The new system offers the advantages of less and smaller pieces of hardware, ease of installation, capacity for 48 hours of continuous data acquisition, adequate frequency and amplitude responses, and relatively easier maintenance.

2. System description

The new wireless sensing system consists of three main components, the data manager, the base unit and the remote units. A complete system requires only one data manager, one base unit and it can have up to 60 remote units. The data manager is a PC compatible computer running dedicated software for data collection activities. The base unit is a communication device with a half-duplex transceiver that links the data manager with the remote units, and it is connected to the data manager through a serial port. Remote units are monitoring devices with wireless communication ability. The system is designed to impose no restriction on the type of variable to be measured by a remote unit. With the actual hardware, variables can be digitized at any sampling rate from 0.125 Hz to 100 Hz through a 10-bit A/D converter. More details of the system design and operation logic are provided in a companion paper by Subramanian, *et al*. (2005).

The system has a maximum data throughput rate of 700 samples per second, which limits the number of units that can be connected to the system for a given sampling rate. For example, with 60 units in the system a maximum sampling rate of 11 Hz can be used while at the maximum sampling rate of 100 Hz, only 7 units can be working at the same time. The current system has 24 units, so the maximum practical sampling rate that can be achieved is about 29 Hz. Wind engineering applications use typically 3-second average gusts to evaluate forces on structures, and natural frequencies of typical structural components of low-rise residential roof structures are not expected to exceed 10 Hz. Therefore the maximum sampling rate of 29 Hz is considered to be adequate for the purpose of wind effect measurements. It is further noted that at this sampling rate, according to the Nyquist criterion, the effective anti-aliased signal frequency will be below 14.5 Hz. Even then the frequency is not considered as a serious limitation because a preliminary analysis (discussed later) indicated that the higher frequency wind pressure fluctuations are generally below the noise level of the system (0.174 mb).

Two different types of remote units are being used in the system: the pressure sensing unit and the anemometer unit. Both are described in detail in Subramanian, *et al*. (2005). The pressure-sensing unit consists of a circuit board, a pressure sensing port and a battery. The battery has a capacity for about 48 hours of continuous operation. The unit uses a Honeywell 142-PCA absolute pressure transducer (0-1034 mbar) with a response time of 1 ms. Measuring absolute pressure, as opposed to relative pressure, eliminates the need for additional piping installation on the house since there is no need for a common reference pressure for all units. However, the main drawback is that small pressure variations are obscured by the large magnitude of the ambient pressure unless some signal offset is provided. The board also includes an analog signal conditioning circuit to produce an output suitable for covering a dynamic pressure range between 900 and 1050 mbar, expected during hurricane events (Michot 1999). Since there is a tradeoff between range and resolution, range should be kept to the minimum required to maximize resolution. The signal conditioning circuit maps the output from the transducer into a suitable input for the A/D converter. The maximum pressure of 1034 mbar, equivalent to a transducer output of 6 V is mapped as 5 V input to the A/D converter. The minimum expected pressure of 900 mbar, equivalent to a transducer output of 5.35 V is mapped as 0.65 V to the A/D converter. The signal conditioning circuit also provided an analog low-pass filtering of the pressure transducer output with a cut-off above 1 kHz. This cut-off frequency was experimentally selected to eliminate the incoming noise from electronic components. 1 kHz proved to keep signal noise levels below the resolution of the A/D converter. Although this filter does not eliminate high frequencies generated by the physical phenomenon that is being measured, amplitude in wind speed is known to decay rapidly for frequencies above 10 Hz, so at the current system sampling rate aliasing shouldnt present a significant problem.

Each unit also carries a miniature temperature sensor that provides continuous temperature monitoring during the pressure recording in case any temperature correction of the pressure readings is warranted.

The anemometer remote unit consists of a commercial anemometer interfaced to the wireless system. The original electronic hardware of the anemometer was completely removed and only the mechanical parts were used in order to obtain speed and direction measurements at any sampling rate from 0.125 Hz to 100 Hz. Having the anemometer included in the system as another remote unit helps to simplify the correlation between the ambient wind speed and the local pressure measurements since all the recording process is kept synchronized by the data manager.

3. Sensor housing

In a laboratory environment, the pressure tap can be mounted on the surface being monitored with the pressure sensing unit under the surface or panel. However, in the field test on the roof of a residential structure, it is not possible to drill holes in the roof to accommodate pressure taps and connect them to the pressure sensing unit under the roof covering. Therefore, each pressure sensing unit needs to be on the outside of the roof, and must be protected from the weather. For that purpose, each pressure sensing unit is enclosed in an aluminum metallic shell. This hermetically sealed, fry-pan shaped shell is intended to protect the circuitry from water and flying debris, and at the same time to provide means for easy handling and deployment of the unit. The shape and size of the shell are similar to the ones used in the original system (Michot 1999) to ensure geometric compatibility and interchangeability between the new system and the original hardwired system.

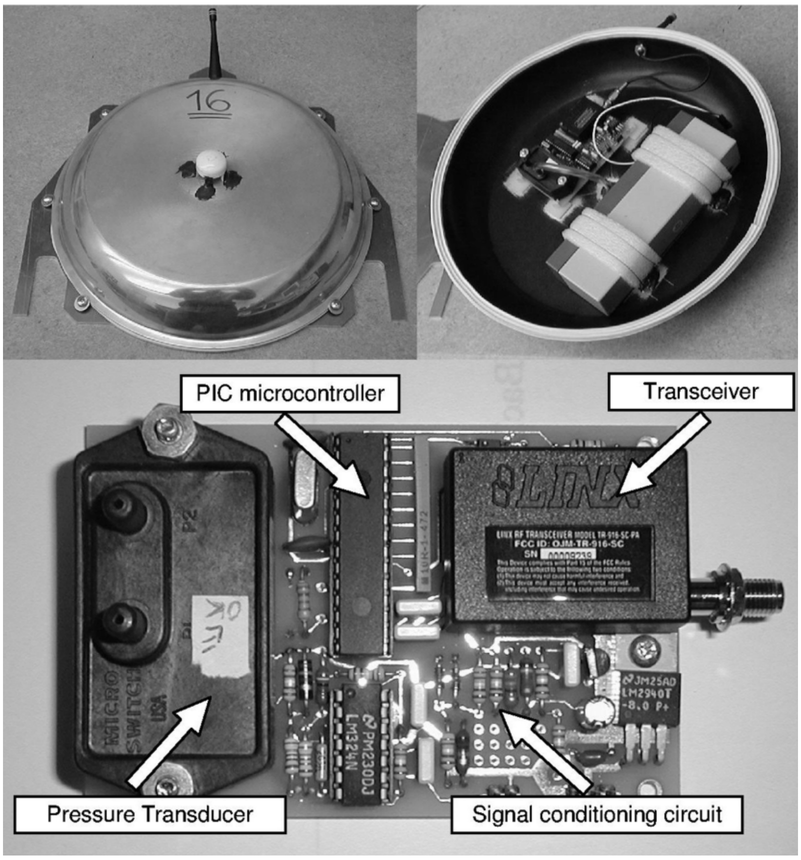

Fig. 1 Pressure sensor remote unit

Fig. 1 shows a finished pressure-sensing unit (top-left), the same unit opened showing all the components (top-right) and a close-view of the main circuitry (bottom). All the components in the unit are attached to the inside top surface of the shell and facing down, as shown in Fig. 1 (top-right), so that the circuit board is protected if the shell hermetic seal leaks during a heavy rain event. The shell is bolted to a flat base plate (Fig. 1 top left), which in turn can be bolted to pre-installed brackets on the shingle roof of selected homes. The diameter of the shell is 0.30 m and its height is 0.05 m.

A sensing port is located in the center of the dish as shown in Fig. 1 (top-left). It protects the pressure transducer from water and allows proper reading of air pressures during heavy rain conditions. The original port design (Michot 1999) required a copper drainage pipe with a corresponding additional hole in the protecting shell which necessitated the sensor to be mounted on a slope for proper drainage. The design was modified as shown in Fig. 2, in such a way that:

- The sensor can work properly on both horizontal and inclined surfaces with the opening oriented in any direction
- Pressure is measured at a single point at the center of the dish. There is no need for a drainhole.
- All parts are made of plastic and high-impact PVC, which simplifies the manufacturing process, avoids corrosion problems, and at the same time lowers the cost
- Risk of leakage is reduced, since only one pipe is passing through the aluminum casing which is tightly sealed

Hurricane winds are associated with heavy rains. The raised inlet port and rubber gasket (Fig. 2) prevent the water from entering into the pressure transducer and affecting the pressure readings. The sealant prevents water from entering the system and damaging the electronics. Since the measured

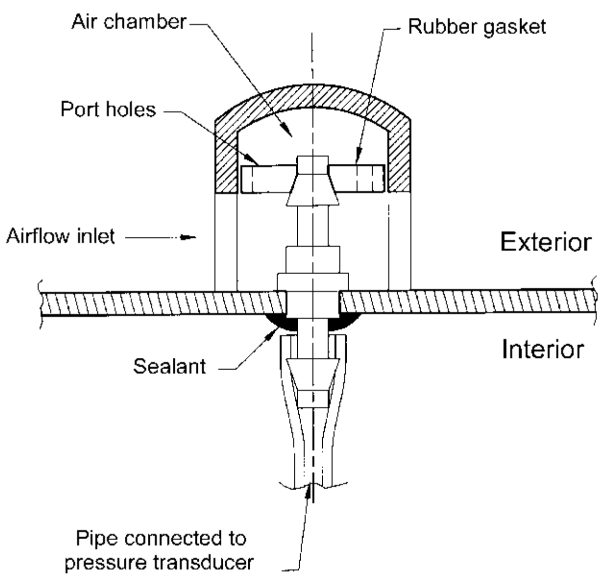

Fig. 2 Redesigned sensing port

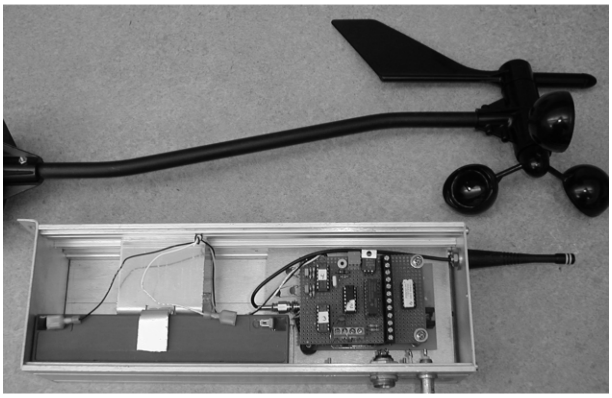

Fig. 3 Anemometer remote unit

pressure is that of the air settled in the hemispherical chamber, reduced effects of inlet turbulence are expected.

The anemometer unit is installed in an aluminum protective case with a battery similar to those used in the pressure-sensing units as shown in Fig. 3.

4. Performance testing of the pressure-sensing remote unit

Several tests were conducted to assess the performance of the sensor system when used for the monitoring of roof wind pressures. The tests had two main purposes: 1) to compare the performance of the new shell and sensing port design versus the original one (tests 1 to 4); and, 2) to assess the influence of the shell protection system on the accuracy of the roof pressure measurements (tests 5 and 6).

In all the tests, one or two sensors shells were mounted on a fiberboard on top of a minivan vehicle, which was driven on an interstate highway, at speeds between 27 m/s and 36 m/s. The moving vehicle provided a high-speed airflow that was not perfectly uniform, a desirable characteristic for comparison with the real-world scenario of a storm acting on a roof. In addition to the pressure measurements from the shell, pressure was also monitored at additional points by attaching pressure taps to the surface of the board and to the sensors shells. The pressure taps consisted of small brass tubes with a length of 120 mm and diameter of 2.5 mm. The small taps have a porthole that can record the static pressure at a point with minimum disturbance to the flow. These taps were piped to additional remote units in the interior of the vehicle by using flexible tygon tubes, about 2 m long, passing through an open window. Inside the van, a laptop computer was connected to the base unit that collected data from all the remote units.

4.1. Test # 1

In the first test (Test #1), two remote units were mounted on the horizontal fiberboard attached to the minivan's rack as shown on Fig. 4. The purpose of this test was to evaluate the difference, if any, between the pressures measured through the new port design and the original port design.

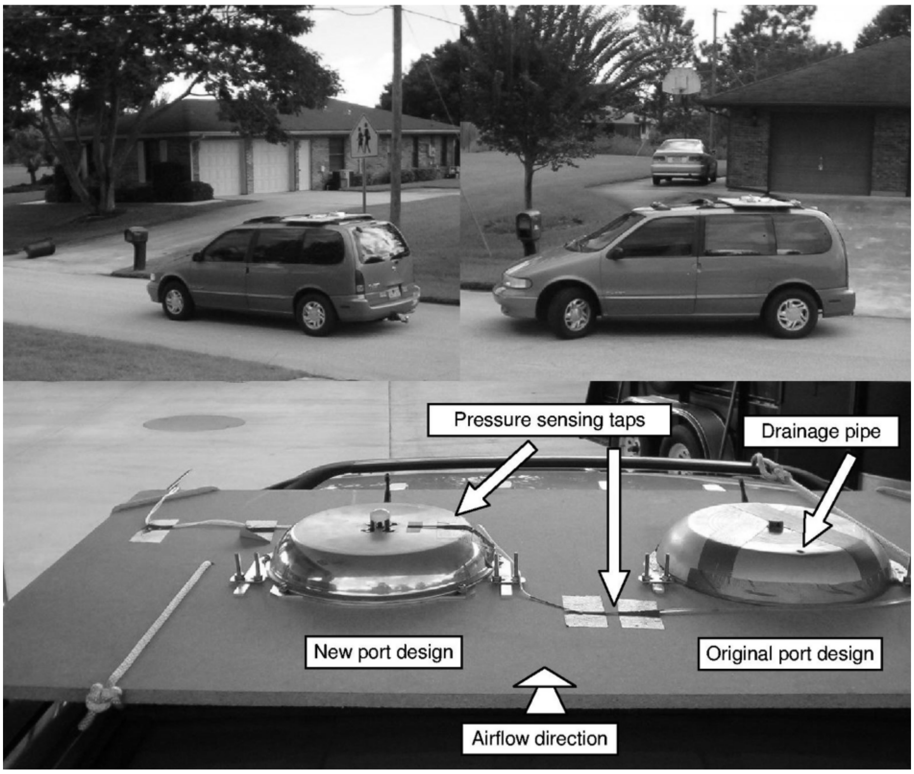

Fig. 4 Test #1 setup, horizontal position

4.2. Test #2

The new sensing port has only four large air openings as opposed to several smaller equally-spaced holes. This was required to minimize the risk of clogging the holes with water or debris at the expense of potentially introducing some directionality effect in the measurements. To check if this effect existed, a second test (Test #2) was conducted with the sensors again in horizontal position. In this case, the new unit was rotated 45^{o} about its center as shown in Fig. 5 to test for directionality, and the drain hole in the original unit was covered with a tape to investigate the effect of the drain hole in the measurements of the original design (Fig. 5). In this test, pressure taps were also installed at the exact same position as Test #1 (Fig. 4).

4.3. Tests #3 and #4

Another series of tests were conducted in the minivan, this time with the sensors on a 15^{o} slope, which is a slope commonly used in the roof of low-rise residential buildings and therefore a situation that compares better with the final application of the system. A new setup was prepared as shown in Fig. 6 (top-left and top-right) with a wooden frame to provide the necessary slope. Fig. 6 also shows the position of the small pressure taps that were attached to the fiberboard and to the shell of both sensors in a manner similar to Test # 1. One test (Test #3) was conducted with the

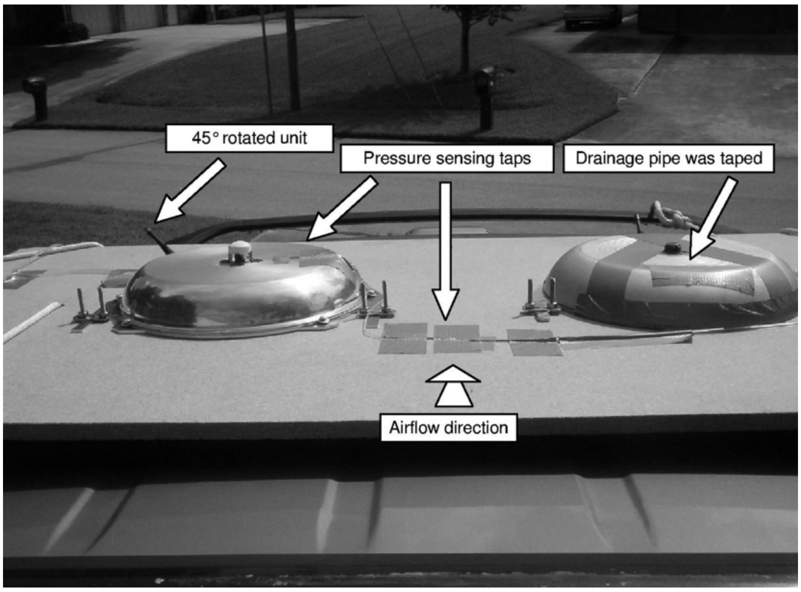

Fig. 5 Test #2 setup, with covered drain hole and unit rotated 45^o

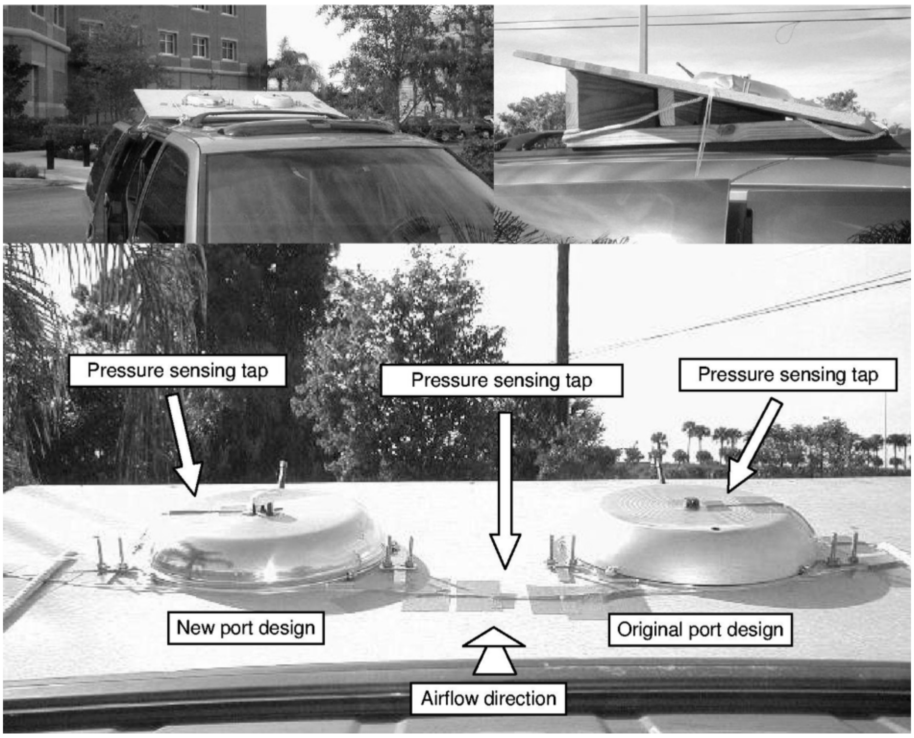

Fig. 6 Test #3 setup, sensors at 15^o slope, windward position

sensors facing the windward side (shown in Fig. 6, top-left), while the next test (Test #4) was done with the sensors on the leeward side by rotating the wooden frame 180^o on the minivan's roof.

In Test #3, with the sensors facing the windward direction, the air flows over the minivan's roof passing over the slope at increased speed (top picture, Fig. 7) with minimum flow separation. The pressure field generated by this flow will typically show lower pressures on the downstream region of the board (at the left of the top picture in Fig. 7) and higher pressures on the upstream region (at the right in Fig. 7) due to flow acceleration effects.

In Test #4, with the sensors facing the leeward direction, the air flows on the minivan's roof, impacts with the solid wooden frame and creates a turbulent separation zone surrounding the sensors (bottom picture, Fig. 7) with a large zone near the board having relatively uniform (but turbulent) low pressures. This pressure will change if the flow reattaches downstream.

The purpose of Tests #3 and #4 was to compare the performance of the new sensor vs. the old sensor on an inclined surface in both a windward and leeward situation.

4.4. Tests #5 and #6

Tests #5 and #6 were aimed at getting an accurate comparison between the pressure measured through the sensing port and the actual pressure acting on the board. The new setup was on a 15^{o} slope, on the windward side for Test #5 and on leeward position for Test #6. Airflow pattern was similar to the one present in Tests #3 and #4 for windward and leeward position respectively (Fig. 7). Only one remote unit with the new sensing port was installed on the board, and a pressure tap was attached exactly at the point where the center of the second unit was in the previous tests (as shown in Fig. 8). Additional taps were also installed on the shell of the remote unit to evaluate in each case the difference between the pressure measured on the top of the shell, and the pressure measured through the sensing port.

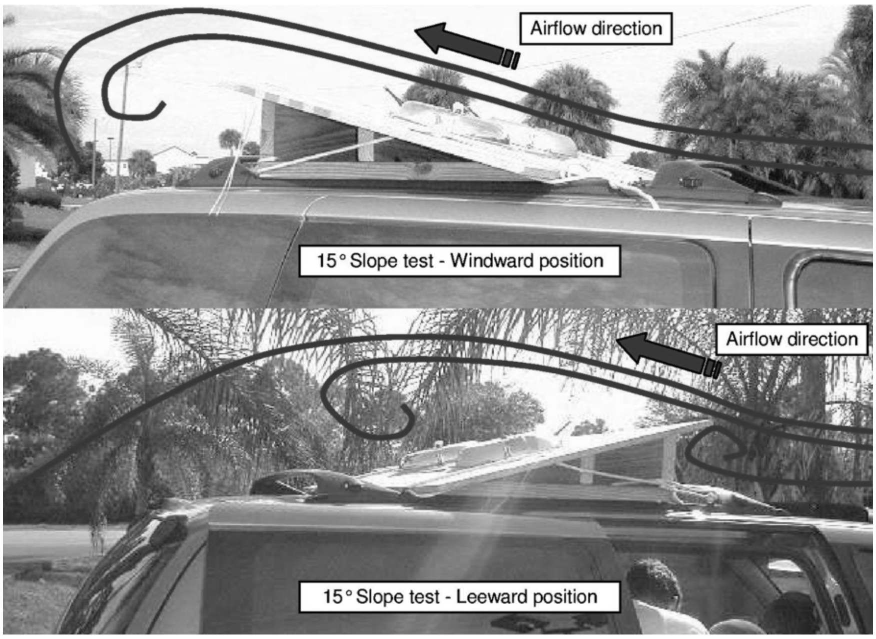

Fig. 7 Airflow scheme for Tests #3 and #5 (top) and Tests #4 and #6 (bottom)

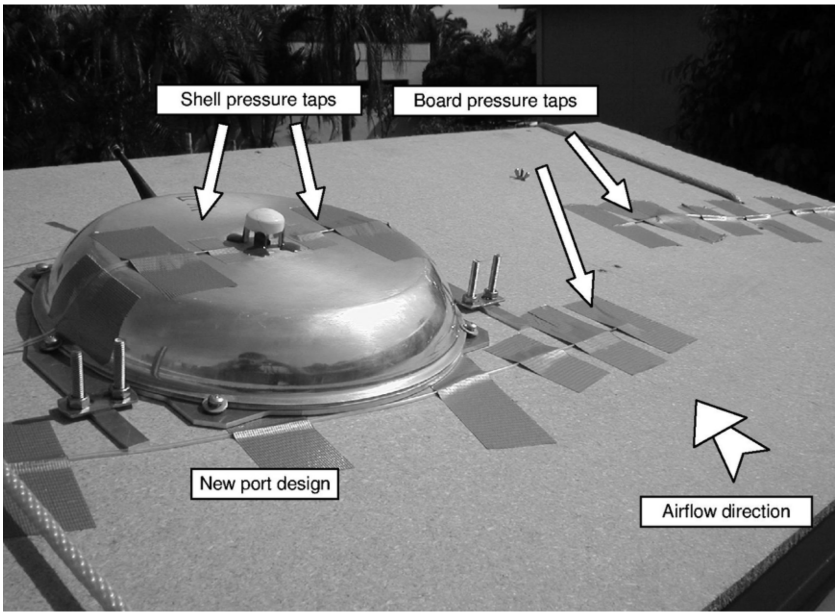

Fig. 8 Tests #5 setup, sensor on 15° slope. Test #6 setup is identical with opposite flow direction

5. Discussion of sensitivity and uncertainty

As mentioned previously, using an absolute pressure transducer eliminates the need for additional tubing on the house thus greatly simplifying the system installation. The drawback is that every unit calibration has to be verified periodically with a reference pressure to get accurate results. Typical zero error for the pressure transducer used in this system is about ±1.6 mbar in the final measurement. Therefore differences in the measurements between sensors should be expected within this range. They can be corrected during the deployment operation by creating a short record of measurements when the units are subjected to a known uniform pressure, like in the interior of the instrumented house. From this short pressure record the initial shift can be determined for every sensor and used for correction in the post-processing stage.

The maximum overall resolution of the pressure-sensing remote unit is ±0.175 mbar. Records of different units during the same event will exhibit differences in this range (±0.175 mbar) after applying a zero-error correction, but without the correction or when comparing values from two different events, uncertainty will be about ±1.8 mbar.

Records from Test #1 are shown in Fig. 9(a). All the pressure records were sampled at 100 Hz using the wireless sensing system. The figure displays the records obtained from both the sensing port in the new design and the sensing port in the original design superimposed on top of each other. The new wireless system is expected to have relatively less electronic noise as compared to the original wired system due to less wiring and digital data transmission. The bottom plot shows the vehicle speed read from the odometer at random time intervals. The speed corresponds to the vehicle speed, not necessarily equal to the airflow speed on the vehicle due to the presence of variable ambient wind. Also, speed is approximated since the accuracy of the vehicle's odometer is unknown. The dotted line joining the points is included for visualization purposes only and it does

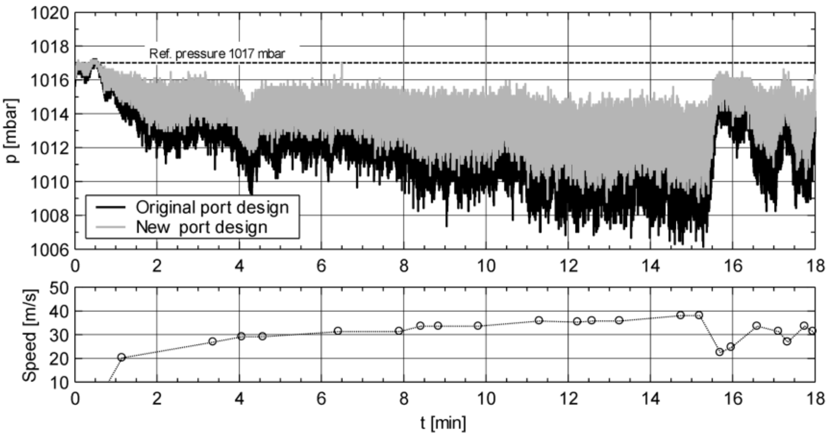

Fig. 9(a) Unprocessed pressure record, Test #1

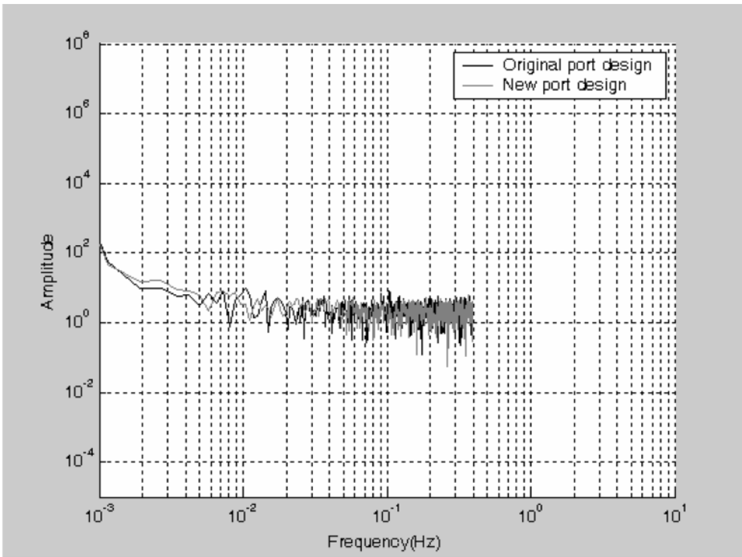

Fig. 9(b) Comparison of power spectrum between new port design vs. original port Test #1, 100 Hz sampling rate

not represent the real speed variation between the points. Fig. 9(a) shows a good general agreement between the speed changes and pressure changes. The frequency spectrum for the old and new sensors is compared in Fig. 9(b). It shows that there is very little difference in the frequency response between the old and new sensors.

Wind gusts produce fluctuations in the value of pressure of about ±2.2 mbar in the sensing ports, which exceeds by one order of magnitude the sensitivity of the measuring device (±0.175 mbar after applying a shift correction). Similar or even larger variations are expected during a real windstorm, therefore the sensitivity of the system is considered appropriate for this application.

For structural engineering analysis typically 3-second gusts averages are used. Therefore over sampling and ulterior filtering can reduce the magnitude of fluctuations in undesirable frequencies. All future presented results is obtained with a low-pass digital filtered data with a cut-off frequency of 2 Hz for easier visualization. In addition, in all the subsequent graphs, the atmospheric pressure when the vehicle is stopped will serve as the reference pressure for each test.

6. Evaluation of the new sensing port design

6.1. New port design vs. original port comparison

Fig. 10 and Fig. 11 show the response of the new sensor port design vs. the original one in each of the first four tests (Test #1 to Test #4). There was a difference between the pressures read through the original port and the pressures read through the new design in Test #1 (Fig. 10 top). This difference disappeared in Test #2 when the drain hole opening in the original design was taped (Fig. 10 bottom). Test #3 (with the drain hole open on a sloped windward surface in Fig. 11 top) shows a smaller difference than in Test #1, while leeward Test #4 (Fig. 11 bottom) shows the best agreement between old and new for the tests with the drain hole open.

The results clearly show that the drain hole in the original design affects the measurements, and that this influence varies with the direction of the airflow and the slope of the surface. Since the new design is in excellent agreement with the original one once the drain hole is taped, the authors are confident that the new design is an improvement over the original one in that it eliminates the source of error due to the drain hole.

6.2. Directionality test of the new port design

The remote unit will operate under severe weather conditions, where water and debris could clog

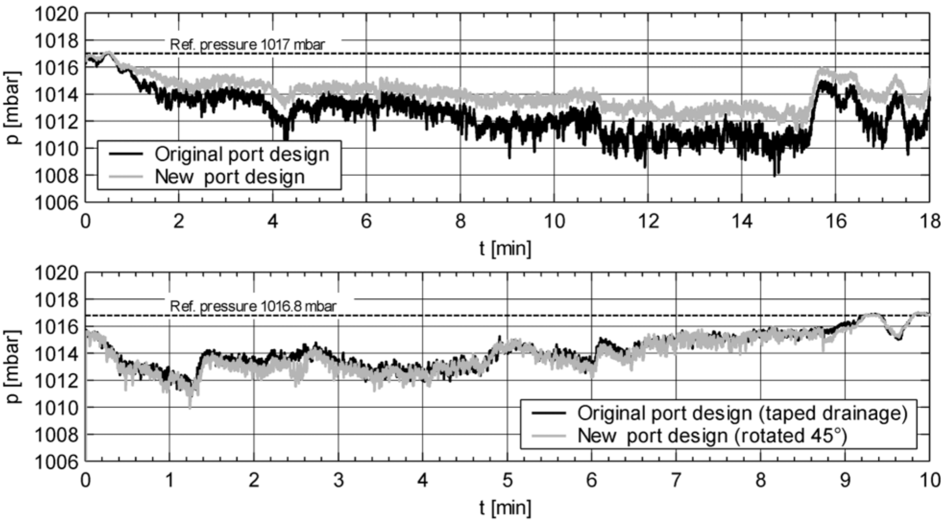

Fig. 10 Comparison between new port design vs. original port in horizontal position Test #1 (top, open drain-hole) and Test #2 (bottom)

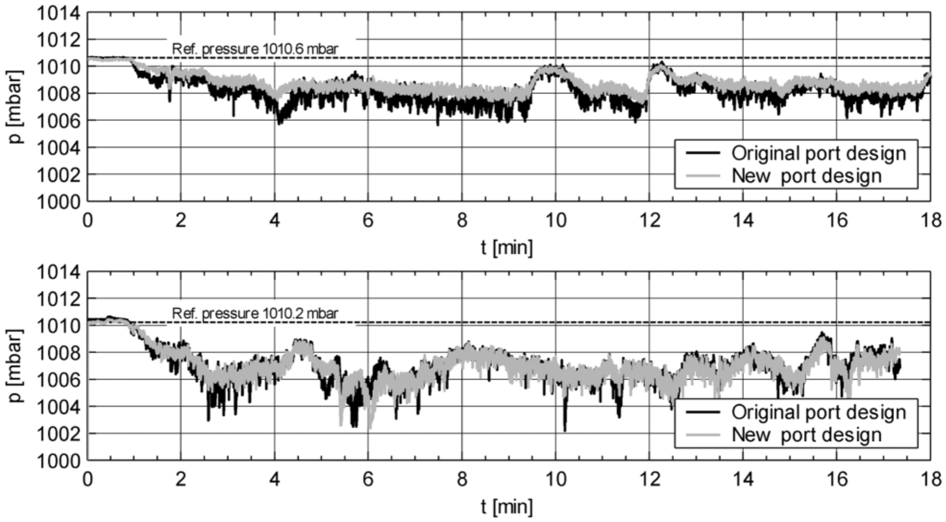

Fig. 11 Comparison between new port design vs. original port in inclined position in Test #3 with drain-hole open (top, windward) and Test #4 (bottom, leeward)

the sensing port, altering the results. Through the use of larger holes, the design should avoid clogging of the sensing port. However, directionality problems may occur, depending on how these holes would be oriented with respect to the airflow. In flat Test #1 the remote unit was located with one opening directly facing the flow (Fig. 4) while in flat Test #2, the sensor was oriented with two holes at a 45^{o} angle with the flow direction (Fig. 5). This way, hypothetically Test #1 offered the position with least resistance to the wind and Test #2 offered the most resistance. Some turbulence inside the sensing port was expected in Test #2 that could alter the measurements.

Although an increase in fluctuations was expected due to the mentioned turbulence, no evidence of such problem was found. The unfiltered records for Test #2 (not shown here) exhibited the same fluctuation magnitudes seen in Test #1. The magnitude of the relative pressure recorded by the sensor during Test #1 at a speed of about 33 m/s was −3.5 mbar (at 9 minutes in top graph, Fig. 10), while the magnitude for Test #2 was about −3.7 mbar for the same speed (from 1 minute 40 seconds to 2 minutes, bottom graph, Fig. 11). This difference is within the uncertainty of the remote unit, and therefore it indicates that directionality effects are not significant enough to affect the pressure measurement. Similar comparisons for other points in the records lead to the same conclusion.

7. Validation of the sensor measurements

Once the new sensing port design had shown to be as good, if not better, than the original design, it was important to investigate what is the influence of the shell and the sensing port on the accuracy of the recorded pressures. Comparing the pressures recorded by the taps attached to the fiberboard with the pressures read by the sensor gives an idea of how representative of the true pressure field are the measurements done with the sensor in the shell. For that purpose, Tests #5 (windward) and #6 (leeward) were specifically prepared with the taps at the same streamwise position as the sensor as explained in the previous section.

Fig. 12 and Fig. 13 show the comparison between the pressure read through the sensing port and the pressure over the board in both tests.

Record from Test #5 (windward facing) consistently exhibited a small difference, showing a higher variation in the sensing port. Difference was between 0.2 and 0.4 mbar throughout the test, which is larger than the instrument error of 0.17 mbar.

Test #6, in a leeward position, showed larger oscillations in the pressure measurements (Fig. 13) that reflect the turbulence due to the separated flow. There is a better agreement in general between the pressure on the board and the pressure measured by the sensing port. The magnitude of the difference in this case is less than the magnitude of the oscillations due to the turbulence.

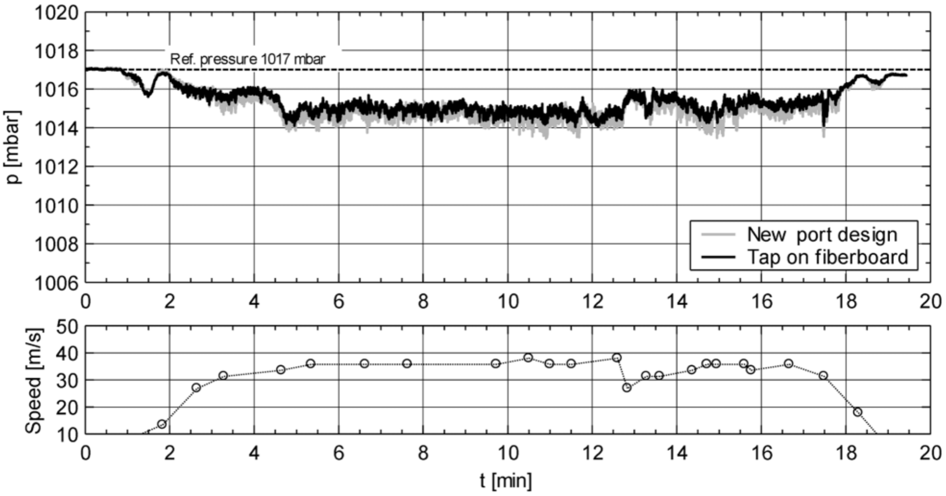

Fig. 12 Test #5, comparison between tap on fiberboard vs. new port design on a 15^o slope, windward position

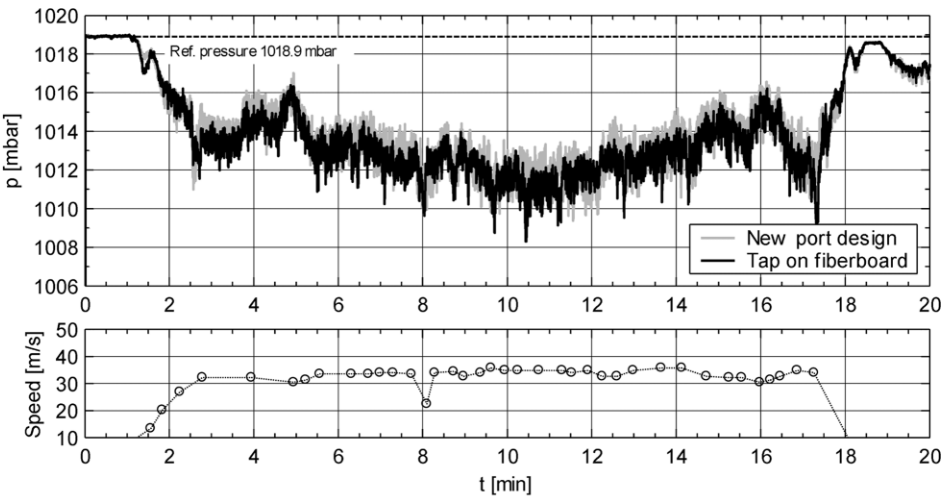

Fig. 13 Test #6, comparison between tap on fiberboard vs. new port design on a 15^o slope, leeward position

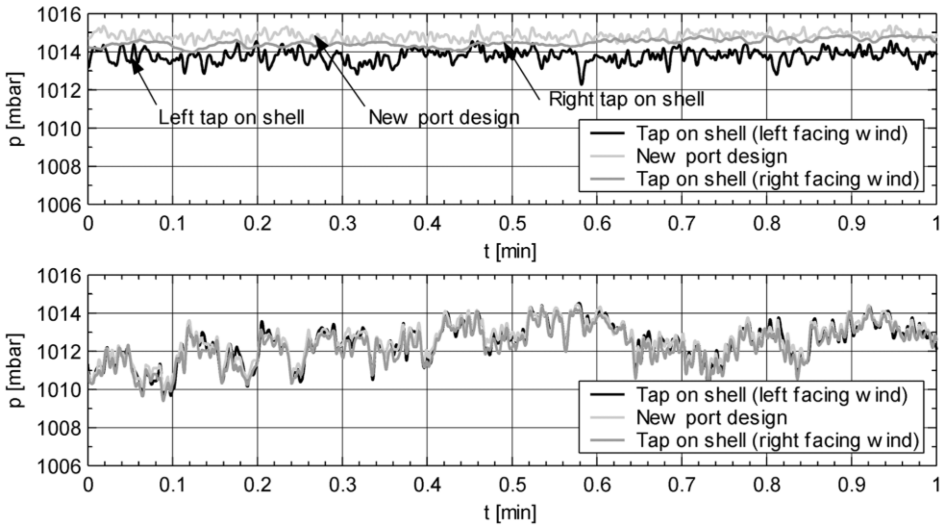

Fig. 14 Comparison between taps on the shell vs. new port design, on a 15^o slope, in windward position (Test #5, top) and leeward position (Test #6, bottom), 1-minute duration record

In a windward position, the shape of the sensor shell can affect the pressure measurements by causing turbulence, and local flow acceleration. The fry-pan shape used for the shell eliminates directionality effects because it has circular symmetry. The rounded edges minimize local turbulence and local separation zones, but flow acceleration will likely occur due to the diameter (0.30 m) and height of the shell (0.05 m). This adds up to the fact that in a windward position, at a height of 0.05 m above the board the flow is expected to have a different speed than at the surface of the board. Therefore, in an effort to identify the causes for the discrepancies between board pressure and shell recorded pressure the authors also recorded the pressure on top of the shell with pressure taps as shown in Fig. 8. Fig. 14 shows that, as expected, there is no difference in the leeward case between the pressures measured through the inlet and through the shell taps. On the contrary, in the windward test, there is a difference of up to 0.6 mbar (27% relative difference) between the pressures measured through the inlet and those measured through any of the two shell taps. However, the sign of the difference depends on the location of the tap. It demonstrates that the mentioned local acceleration effects do exist but, not surprisingly, they are not uniform and will depend on the interaction between shell geometry, roof slope, and wind direction.

7.1. Field tests during 2004 Florida hurricanes

Three 2004 Florida hurricanes (Charley, Frances and Jeanne) out of the four that passed through Central Florida provided an opportunity to test the new sensor system under the real storm situations. A pressure power spectrum result of the sensor number 9 out of 22 deployed roof sensors during hurricane Frances is shown in Fig. 15.

Here the data was sampled at 20 samples per second. For the above spectrum, therefore only up to 10 Hz signal frequency is considered. The spectral distribution clearly suggests that the energy

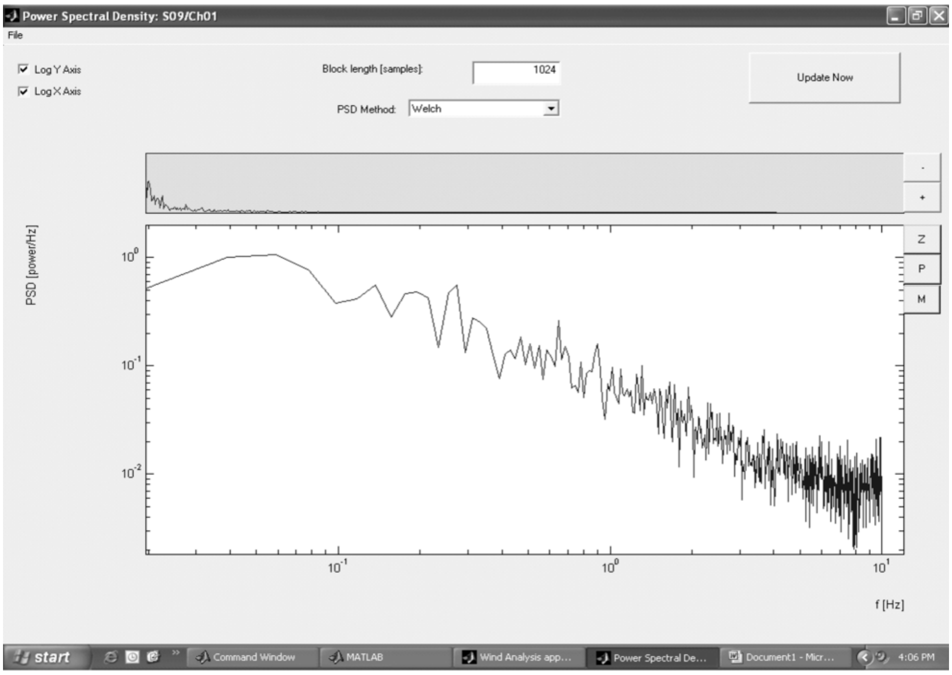

Fig. 15 Power spectral density plot of pressure fluctuations during hurricane Frances (9/3/04)

levels are decreased by more than two orders magnitude for frequencies greater than 6 Hz from the maximum power at a frequency of about 0.3 Hz. The pressure power spectrum on the full-scale Silsoe Structures building obtained by Richardson and Surry (1994) shows a very similar trend with practically no power above 1 Hz. They also used a signal cut-off frequency of 10 Hz and sampling rate of 20 Hz. The observed peak power at 0.3 Hz probably justifies the reason why a 3-sec average peak is the accepted norm for describing the gust characteristics. This also validates the previous statement that the maximum sampling frequency of the new system is adequate to resolve the significant gust effects in natural hurricanes.

8. Conclusions

This paper explores the possibility of using absolute pressure transducers coupled to a wireless remote transmission system to monitor wind roof pressures. The sensitivity of the sensors of ±0.175 mbar is one order of magnitude lower than the fluctuations found due to turbulence of the air during the tests (±2.2 mbar), so the sensors themselves are adequate to record the pressures generated by a turbulent wind. However, the tests need to be unobtrusive and nondestructive to protect the integrity of the homes to be monitored. Therefore, the sensors need to be housed in a protective shell that will interfere with the natural flow of the wind. The tests reported here have shown that the proposed sensor port design presents no significant directionality effects and shows a good sensitivity to air speed changes.

In a real roof, the sensors will be usually located in separation zones, specifically on a leeward gable or near a ridge or eave. The tests have shown that the shell does not have a significant effect on the wind pressure measurements in that case. However, in other cases, like on a windward gable, the unit may receive a direct airflow through the port. In this case, a small difference was observed between measured and actual pressures that, although small, is larger than the sensitivity of the sensors. This error is attributed to the geometry of the shell and inlet. Because the magnitude of the error is dependant on the direction and intensity of the wind and the magnitude of the roof slope, it is not possible to define a correction factor. It might be necessary in that case, barring an alternate shell design, to discard the measurements of the sensors in a non-separation zone. It was noticed in the tests that when the sensors were on the leeward side (a separated flow) they exhibited larger amplitudes in the fluctuations with frequencies below 2Hz than the sensors on the windward side, fact that can be used to determine which sensors to discard. An option to minimize this effect of the shell geometry would be to use a flatter shell, which in fact requires miniaturizing the electronic components and the battery of the unit.

The existence of a zero-error in the absolute value of the measurements (a shift of ±1.6 mbar) makes it difficult to get accurate comparisons between records of different storm events. For each event the zero shift can be corrected, having an uncertainty equal to the resolution of the system (±0.175 mbar) when comparing different units. When comparing between events or with an external source, the uncertainty raises up to ±1.8 mbar, since no zero-shift correction is possible.

To separate the effects of external and internal pressure on the structures requires measuring an external reference pressure not affected by the flow around the house, which goes back into the problem of the comparison with an external source.

Acknowledgements

The work was carried out with the financial support of the Florida Sea Grant Program under the Grant Number NA16RG-2195.

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