Testimony of

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State of Hurricane Research and H.R. 2407 - The National Hurricane Research Initiative Act of 2007

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1. INTRODUCTION

Chairman Baird and Chairman Lampson and Honorable Subcommittee Members, my name is David Prevatt, and I am a professional engineer and Assistant Professor of Civil and Coastal Engineering at the University of Florida. The faculty of the Department of Civil and Coastal Engineering (CCE) is very active in multiple aspects of hurricane hazards research and the design of hazard resistant infrastructure. Our research focuses on understanding the hurricane effects (wind, rain, storm surge) on buildings and infrastructure in hurricane-prone coastal regions in order to increase their resilience. Our combined expertise includes:

- Building and infrastructure design against surge and wind hazards
- In-field measurement and characterization of hurricane winds and wind loads
- Evaluation of structural capacity to resist wind loads and the efficacy of retrofits
- Prediction and modeling of storm surge, wave, and coastal flooding
- Remote sensing of high resolution ground elevation and bathymetry (ocean depth contours)
- Lifeline protection and restoration
- Transportation issues for emergency evacuation
- High performance computing and data warehousing/mining.

It is clear that there are several common areas of interest for H.R. 2407 and the wind and civil engineering research community. I applaud this increased emphasis on understanding and predicting the nature and impact of hurricanes. However, the proposed research efforts, while they address important goals, do not do much to reduce the damage or economic losses from hurricanes. Funding for research to address damage to buildings and civil infrastructure, which by far dominates the economic impact of hurricanes, is underrepresented in the current budget. We believe emphasis of several categories in this bill and the National Science Board (NSB) report of 2007 should be re-prioritized.

1.1 Background

Nearly 40 years ago, the National Bureau of Standards reporting on Hurricane Camille damage noted that the most common failure in homes was to roofs and that proper anchorage was non-existent. These same concerns have repeatedly been voiced by researchers over the ensuing years (Table 1), who also noted recurring widespread structural damage due to loss of roof sheathing, failure of load transfer at joints and connections. Sadly, the situation today is not much different, wherein roof failures and improper anchorage still account for the majority of building damage from hurricanes.

Table 1: Main finding and recommendation of various hurricanes over the years

Hurricane/ Year	Main Finding/ Recommendation	Report
Camille (1969)	• Most common failures were roofs. • "… proper anchorage***……..”***	(Dikkers et al. 1970)
Alicia (1983)	• Most structural damage was due to loss of roof sheathing. • "Total collapse of timber-framed houses was a common scene."	(Kareem 1985)
Gilbert (1988)	• Most of the damage due to anchorage deficiencies • Continuous load path is needed	(Adams 1989; Allen 1989)
Hugo (1989)	• Roof loss with subsequent collapse of walls. • Most damage was roof and wall cladding failures resulting in extensive rain damage.	(Sparks 1990)
Andrew (1992)	• Excessive negative pressure and/or induced internal pressure • Correct methods for load transfer are needed	(FEMA 1992)
Iniki (1992)	• Overload on roof systems due to uplift forces. • Load path must be continuous from the roof to the foundation.	(FEMA 1993)
Georges (1998)	• The shingle damage resulted in extensive water penetration and subsequent damage.	(FEMA 1999)
Charley (2004)	• High internal pressure due to window failure was the major cause of roof loss. • Load path needs to be continuous.	(FEMA 2005a; FEMA 2005c)
Ivan (2004)	• Structural damage was due to sheathing loss. • ….ensure a complete load path for uplift loads.	(FEMA 2005b; FEMA 2005c)
Katrina (2005)	• Structural failures limited to roof sheathing loss & roof-to-wall connection failure. • A continuous load path must be present.	(FEMA 2006)

It is estimated that 50% of the U.S. population now lives in hurricane prone coastal areas (Alvarez 2000). Hundreds of miles of once empty coastlines are now major population centers with trillions of dollars of buildings and infrastructure exposed to the risk of hurricane damage. The vast majority of residential structures (over 80%) in these areas were constructed before recent improvements to building codes that occurred after Hurricane Andrew. Therefore there is an urgent need to harden those homes to reduce annual hurricane losses. It must be recognized that hurricanes are just one of the several sources of damage and loss due to extreme winds and that tornadoes, downbursts and frontal winds also contribute to large annual losses that could be reduced through better connections and development of continuous load paths.

Civil engineers and particularly wind engineers are critically aware of factors contributing to high failure rates of buildings and infrastructure and we have been intimately involved in the effort to improve the knowledge base to reduce hurricane impacts. Indeed many of us have previously testified before Congressional Subcommittees (Bienkiewicz 2004; Levitan 2005; Prevatt 2005; Reinhold 2005) and our members have supported related legislation H.R. 3940, the National Windstorm Impact Reduction Act of 2004.

Hurricanes, tornadoes, thunderstorms, and associated phenomena cause an excessive level of property losses and human suffering in the United States. With the exception of Hurricane Katrina, loss of life has been significantly reduced through warnings about hurricanes and the loss of life in tornadoes and other extreme wind events typically average less than 100 per year. Consequently, the highest national priority should be placed on reducing the damage and minimizing economic loss. With the exception of strengthening building codes in some hurricane prone regions, our success in reducing losses has been poor over the past 40 years. This is due in large part to the limited research and technology transfer support that is focused on strengthening the existing built infrastructure and in the development of cost effective retrofit and mitigation measures.

1.2 Effects of Recent Hurricanes on Buildings and Infrastructure

The 2004 and 2005 hurricane seasons were a real-time laboratory for evaluating the performance of our buildings. Several of our faculty were deployed during the storms and collected perishable damage data immediately after the events. There were several areas of concern regarding performance of buildings and infrastructure:

- Small breaches in the building envelope, especially in the roofing systems, can provide paths for water leakage that result in extensive water damage to the interior walls, ceilings, and to building contents. Minor roofing failures (loss of asphalt shingle and underlayment) to one Pensacola house resulted in water damage to about 80% of all interior finishes on the ceiling and walls. The cost of drying out water-soaked buildings and removal of mold has been a growth industry since these hurricanes. Less durable materials, insulation, gypsum sheathing and acoustic ceiling tiles cannot be dried out and must be removed and replaced. The gutting of houses and businesses contributes tons of debris and toxic substances to our landfills.

- Numerous engineered buildings suffered little damage, and retrofitted non-engineered houses also performed satisfactorily. In Charley, a major success story was the good to excellent performance of newer manufactured homes that were built in accordance with 1994 HUD guidelines. Most of these survived with minimal damage, while adjacent older manufactured homes that did not have wind-resistant construction were destroyed.

- Failure of building envelope systems caused significant disruption to hospitals and critical facilities during these storms. From Mobile, AL to Ft. Myers, FL, more than a dozen hospitals were damaged or were evacuated due to the 2004 hurricanes. Charlotte Regional Hospital in Port Charlotte and the Navy Hospital in Pensacola both sustained damage to their roofing systems, and windows. One hospital damaged in Hurricane Frances in 2004, suffered further damage as Hurricane Jeanne passed through the area just three weeks later.

- Several fire stations and hurricane evacuation shelters were not able to maintain function throughout or after the storms. The Turner-Arcadia Civic Center in Central Florida suffered a masonry wall and roof collapse while sheltering 1,200 persons from Hurricane Charley.

These poor and variable performances are examples of a larger problem related to buildings and infrastructure.

1.3 Research Priorities to Improve the Resilience of Structures

Specifically some of the factors that are important to reducing loss and wind damage to buildings and infrastructure are:

- A need to improve our knowledge of surface level winds and their spatial variability during extreme wind events.
- A need to better understand the potential loadings on structures through a comprehensive program of boundary layer wind tunnel testing and validation using field observations.
- A better understanding of how and at what level of loading existing structures fail and the application of this knowledge to new construction.
- An intense program to study various ways of identifying weaknesses in existing infrastructure and practical retrofit techniques to ameliorate these problems.
- Comprehensive testing of full scale structures to learn how to economically improve wind and hazard resistant construction and associated water penetration and damage.
- A need to improve the techniques to assess the economic impacts of different design decisions for both new and retrofit applications.
- A need to quantitatively understand the surge and wave loading on coastal structures and how the coastal structures respond to loading.
- A need for a new robustness in the supporting academic infrastructure to generate improved basic supporting science and technology, to improve the availability of trained new university faculty/researchers, and trained engineers to implement improved practices and planning.

In this era of limited funds, it is necessary to set realistic expectations and to give priority to initiatives that have the greatest chance of reducing the hurricane impact. Consideration should also be given to increasing support for the most severely under-funded areas, that of civil infrastructure. In their comment on the draft NSB report, the Weather Coalition stated *that "Hurricanes are complex and violent systems. Even the best research initiative will only improve forecasts, not perfect them."* However, the focus should be to improve performance of buildings and infrastructure, and we will see the most immediate and tangible benefits from increased research on infrastructure improvement. Improved forecasts will not have a significant impact on loss reduction.

2. COMMENTS ON NATIONAL SCIENCE BOARD 2007 REPORT

The University of Florida faculty experts in hurricane winds and storm surge recommend changes to the proposed budget distribution, as well as a re-prioritizing of subjects within the three investment categories. Comments and suggestions are delineated below by the following subsections of the NSB document: investment category, recommendations, and appendix.

The purposes of the National Hurricane Research Initiative shall be to set research objectives based upon the findings of the January 12, 2007, National Science Board report entitled 'Hurricane Warning: The Critical Need for the National Hurricane Research Initiative', to make recommendations to the NSB and NOAA science Advisory Board and to assemble expertise and pursue multi-entity research in three areas:

1. improving hurricane and other severe tropical storm forecasting capabilities, including formation, track, and intensity change

2. durable and resilient infrastructure; and

3. mitigating impacts on coastal populations, the coastal built environment, and the natural coastal environment, including but not limited to, coral reefs, wetlands, and other natural systems that mitigate hurricane wind and storm surge impacts.

For the sake of clarity, the comments below follow the structure of the NSB report. General comments are provided on the overall document, followed by comments on specific sections in the report and delineated herein.

2.1 General Comments on the NSB Report

The NSB Report identifies for Investment categories (#1, Understanding and Prediction, #2, Impacts, #3 Preparedness and Response Measures, and #4 Crosscutting Activities), and it provides recommendations for action and budget of approximately $300 million. H.R. 2407 proposes that $285 million be authorized for this effort for each of the fiscal years 2008 through 2018.

> **We recommend that** a working group be assigned with direct links among the four investment categories, so that R&D will not be performed independently, but that resources be assigned to address those issues that can be shown to have the most significant impact.

> **We recommend that** the initiative be developed within a defined interagency group, comprising of NSF, NOAA, FEMA and NIST.

Appendix C: Proposed Strategic Investment in the National Hurricane Research Initiative – pg 29

Problem: Funding to address damage to civil infrastructure, which by far dominates the economic impact of hurricanes, is underrepresented in the current budget. Given the weighting of expertise represented on the NSB panel (only 10 out 55 panel members were civil engineers), this priority received less attention than warranted. Consequently, the proposed NHRI budget is directed to already heavily funded NSF programs, while research areas that represent the highest potential gains in risk reduction are not well funded.

> **We recommend that** funding support the core high-priority research areas that are currently most severely under-funded.

> **We recommend against** redistributing NHRI funding to already heavily funded NSF programs, such as cyber infrastructure ($492M in FY2005), networking and information technology R&D ($811M in FY2005) and climate change ($197M in FY2005). Rather, an increase in the current (and very modest) annual expenditures on engineering and the built environment would provide far greater immediate benefit, given the dominance of infrastructure damage on economic loss. The table below reflects our suggested reprioritizing of strategic investments.

<table>
<tr><th>NHRI Research Program</th><th>NSB Report ($millions per year)</th><th>Modification ($millions per year)</th></tr>
<tr><td>Power, Communications and Remote Access Systems</td><td>$60 →</td><td>$30</td></tr>
<tr><td>Structure and Behavior of Hurricanes</td><td>$40 →</td><td>$60</td></tr>
<tr><td>Engineering and the Built-Environment</td><td>$40 →</td><td>$60</td></tr>
<tr><td>Risk Assessment, Communication and Response</td><td colspan="2">$20</td></tr>
<tr><td>Biological and Ecosystem Dynamics</td><td>$20 →</td><td>$10</td></tr>
<tr><td>Economic and Societal Impacts</td><td colspan="2">$20</td></tr>
</table>

Investment Category #1: Understanding and Prediction, pages 13 - 15

HIGH PRIORITY: Predicting hurricane intensification and size, and reducing the uncertainty associated with where and when hurricanes will make landfall – pg 13

Problem: Existing hurricane models do not have adequate parameterization to represent the dissipation effects of land on hurricanes.

> **We recommend that** an additional HIGH PRIORITY item be established to focus research to understand the effect of land roughness on hurricane intensity decay.

HIGH PRIORITY: predicting storm surge, rainfall and inland flooding from hurricanes and tropical storms – pg 13

Problem: One key to limiting the loss of life in both coastal and inland flooding is having high resolution topographic maps with sufficient spatial resolution to identify where constricted flow is likely to cause flash flooding. The U.S. is well behind when it comes to producing high quality, one foot contour topographic maps. During the past decade many European nations have used airborne laser swath mapping (ALSM, also known as LiDAR) and ground based laser scanning to map their entire nations. In the U.S. only a few states have launched programs to obtain high resolution digital terrain maps and contour maps suitable for comprehensive flood planning, using airborne and ground based laser scanning. The U.S. should have digital elevation models adequate to support one foot contour maps across the nation. The highest priority should be given to areas at risk for flash floods. The combination of airborne and ground based laser scanning is the method of choice for collecting the necessary observations.

> **Suggestion #1**: Emphasize the importance of high resolution topographic maps to predict both coastal and inland flooding and limit loss of life and economic loss.
>
> **Suggestion #2**: Research is needed to fully understand and predict the effect of waves on storm surge, coastal inundation, and loading on coastal infrastructures, including houses, bridges, levees, and power plants. Wave loading is much more destructive for coastal infrastructures than storm surge alone.
>
> **Suggestion #3**: For more accurate and cost effective mitigation and evacuation planning, high resolution street-level forecasts are needed. Current hurricane and storm surge forecasts by the U.S. government have much lower spatial resolution (hundreds of meters) than the LiDAR data. Street-level forecasts are needed to enable more accurate and cost-effective mitigation and evacuation planning. To enable street-level forecasts, it is more prudent to adopt more efficient forecast models than to increase computational capability.
>
> **Suggestion #4**: Research is needed to fully understand the flow-structure interaction during hurricanes. Storm surge and coastal flooding is strongly affected by such manmade or natural structures as levees, wetlands, marshes, coral reefs, and beach dunes.

HIGH PRIORITY: Improved in situ observations – pg 13

Problem: Direct measurement of the hurricane is a necessary underpinning of virtually every other investment category enumerated in this document. Prevention of infrastructure damage to winds must be based upon detailed knowledge of dynamic wind loads, which can only be gathered via direct measurement. A historical dearth of direct observation of ground level wind speeds during landfalling hurricanes is among the biggest obstacles in the design against extreme wind loads. Additionally, all remote sensing is ultimately dependent upon direct measurement for refinement, validation and calibration.

> **Suggestion:** Emphasize the importance of observations of data at surface level winds and its interactions (pressure generation) on structures.

<u>Investment Category #2: Impacts and Interactions, pages 15 - 16</u>

<u>HIGH PRIORITY: Interaction of hurricanes with engineered structures – pg 15</u>

Problem: Current codes (except for perhaps earthquake effects) do not adequately incorporate dynamic loading (e.g., wind, vessel impact, surge, waves) for foundation/soil interaction or foundation/water interaction for cyclic or surge loading. We have the system characterization capabilities, and the mechanics/computational abilities to account for dynamics, but we sorely lack experimental research to calibrate and validate our analysis systems, particularly at full-scale. With the advent of Network for Earthquake Engineering Simulation (NEES) at NSF, we now have the experimental equipment capable of full-scale experiments. We now need the funding to pursue this research.

> **Suggestion #1:** Add an additional HIGH PRIORITY item that addresses the need for full-scale experimentation to capture the effects of dynamic wind / rain / surge loads on the infrastructure, which as of today is poorly incorporated in building codes. Current practice focuses on the performance of individual components in isolation, but the most often observed failures are a result of interaction among multiple components (system response). We sorely lack research to evaluate system performance issues via full-scale experiment.

> **Suggestion #2:** Add an additional HIGH PRIORITY item that addresses retrofitting of existing structures. Retrofitting of critical infrastructure in hurricane prone regions is urgently needed to protect the public and life-line services. 90% of existing residential homes were built before building code improvement modifications that occurred after Hurricane Andrew. As with earthquake prone regions, retrofitting of existing structures will result in lower damage and fewer lives lost. This, combined with a tightening of the existing building codes, should be a substantial emphasis.

Problem: Recent hurricane seasons have clearly demonstrated that highway bridges which are key components of infrastructure lifelines, at risk of failure due to the combined effects of wind, storm surge, and vessel impact loading. During Hurricanes Ivan (2004) and Katrina (2005), major interstate bridges along critical lifelines were destroyed by storm surge loading. Additionally, Hurricane Katrina demonstrated that barges, ships, and floating structures such as drill rigs, can break loose during storms and collide with bridge structures and levee walls, thus generating significant impact loads and damage.

> **Suggestion #3**: As with earthquake prone regions, retrofitting of critical infrastructure in hurricane prone regions is urgently needed to protect the public and lifeline services. This should be addressed in the draft.

> **Suggestion #4**: Development of procedures for evaluating (both pre- and post-event), and improving, the resistance of infrastructure components under the combined effects of wind, storm surge, and vessel impact needs to be a high priority item. The approach taken must account not only for structural aspects of bridge performance under these

conditions, but also the statistical probabilities that such combined multi-hazard loading conditions occur simultaneously.

Investment Category #3: Preparedness and Response Measures, pages 16 - 18

HIGH PRIORITY: assessing and improving the resilience of the built environment – pg 16

Problem: The massive economic impact of hurricanes is in many ways a direct result of engineering designs mandated by building codes. For a large majority of the existing infrastructure, extreme events associated with hurricanes (e.g. wind & wave loading, tidal surges, bridge scour, etc.) are simply a secondary consideration. For example, current bridge design specifications only address wind induced forces, with no recognition of wave loading, even when more than 15 bridges were lost from waves / surge during Katrina. In addition, much of the existing infrastructure involving geotechnical related issues (i.e. levees, dams, bridge foundations, etc.), were designed using the "allowable stress" procedure that incorporates a global factor of safety. However, no consideration for the degree of risk or probability of failure of said systems has ever been undertaken. Moreover, even though some of the newer codes are moving towards incorporating risk assessment, i.e. (Load and Resistance Factor Design (LRFD), with associated load and resistance factors developed through research, the majority of geotechnical infrastructure (dams, levees, building foundations, etc.) load and resistance factors have never been established.

Suggestion: Emphasis needs to be placed on research toward the efficacy of the current design practice in light of recent infrastructure failures. The NSB report calls for the investigation of damage due to non-compliance, but the majority of damage is clearly the result of adequate compliance with inadequate codes.

HIGH PRIORITY: Disaster response and recovery – pg 17

Problem: Getting victims out of and relief services into an affected area is critically dependent on the condition of the roadway network in the area. Aerial based technologies need to be developed and/or evaluated for their ability to provide a survey of critical roadway infrastructure items (e.g., passable roads, navigational signage condition, and status of traffic control devices). This information can be used with Geographic Information Systems to develop usable transportation routes into and out of the area.

Suggestion: A prioritization of critical links in the highway system should be developed, based on anticipated origin-destinations in disaster response conditions (for example, to and from shelters, hospitals, etc.)

Investment Category #4: Cross-Cutting Activities

MEDIUM PRIORITY: Computational Capability – pg 18

Problem: With the well-recognized scarcity of funding, it is not prudent to divert funds to well-funded and generic research that will advance full-force with no funding from a hurricane mitigation-specific program. This is an important but not well-funded item.

We recommend removal of this priority item: Computational capability is an important, but is already well-funded through existing programs.

MEDIUM PRIORITY: Training and education programs related to hurricane impacts – pg 18

Problem: Education and training already receives $844M annually from NSF. This falls under the category of "important but heavily funded elsewhere.

Suggestion: Remove or de-emphasize the funding for this priority.

General Implementing Recommendations, pages 19 – 21

Leadership – pg 20

Problem: Although considerable progress has been made on arriving at improved loading standards and on some methods of improving constructed facilities many of these improvements are based on an existing information base that is over 30 years old. Unfortunately support for these efforts has not continued at a level that encourages basic research. What is needed now is new research capabilities to supplement current efforts and generate fundamental knowledge from which next generation buildings and retrofit techniques can emerge. The emphasis of these activities resides in understanding buildings and infrastructure.

> **Suggestion:** Designate the National Science Foundation as the custodian for all funding. This research belongs in the hands of the Federal agency primarily tasked to supported basic research conducted by our colleges and universities. Operational agencies (meaning those organizations responsible for exploration, prediction, monitoring, response, and recovery) should carry a supporting role, but not share parallel responsibilities.

Maintaining dialog with the broad community – pg 20

Problem: Progress will be made by engaging all stakeholders responsible for construction and retrofit of buildings and infrastructure, including legislative bodies, academic researchers, and building professionals.

> **Suggestion:** Use conferences already in existence. Stage the meetings/presentations from the annual Interdepartmental Hurricane Conference held by the Office of the Federal Coordinator of Meteorology. It is the most reputable and well-attended by government stakeholders.

> **Suggestion:** The panel is recommended to seek input from civil engineers through the existing associations who work to protect buildings and infrastructure from hurricanes. We recommend that the American Association for Wind Engineering and the American Society of Civil Engineers be consulted within the process, since those organizations combined nearly a decade ago to initiate the initial legislation that will expire in November 2008.

3. SUMMARY

The cost of hurricanes is something that we bear as a society. The losses and disruptions have profound and widespread impacts to the social structure of communities and to the ecological systems upon which we depend. While the loss of life in hurricanes has dropped over the past decades due to improved warning and forecasting, the amount of damage and economic loss continues to spiral upward at an exponential rate. This trend is projected to continue upward as more properties and wealth are concentrated in vulnerable coastal areas. It is only through mitigation that we have any hope of reducing the increases much less begin to reduce losses when major events occur.

Investing in the creation of new knowledge and in more effective ways of using existing knowledge is the only way to change the current trends. The research to improve the resilience of civil infrastructure and houses can significantly reduce the enormous economic costs of hurricanes. Many unanswered questions regarding the design and construction of new facilities remain, and the problems of existing construction have hardly been addressed. However, a sustainable, Federally-supported, long-term research program can indeed make the difference.

Biographical Sketch of David O. Prevatt

Born in Nassau, Bahamas and growing up in Trinidad and Tobago, Dr. David O. Prevatt has lived in hurricane-prone regions for most of his life. In 1985, Prevatt graduated from the University of the West Indies (UWI), Trinidad with a BSc (Honours) degree in Civil Engineering. He worked as a structural engineer in Trinidad until 1990 when he joined an IDRC-funded research project on Caribbean Cyclone-Resistant Housing at UWI's Civil Engineering Department. Prevatt came to the United States in 1993 to pursue his Ph.D. at Clemson University, working at the Wind Load Test Facility. His research on evaluating the wind uplift capacity of various mechanically attached commercial roofing systems sought to assess the validity of industry-standard test methods and compare these with roof behavior subject to true spatial and temporally varying wind loads. After earning his Ph.D. in 1998, Dr. Prevatt worked as structural engineer with the Boston-based ENR500 consulting engineering firm, Simpson Gumpertz & Heger Inc., from 1998 through 2004, concentrating in the design, performance and investigation of building enclosure systems. His expertise is in structural engineering, wind engineering and the performance of building envelope systems, and forensic engineering. Dr. Prevatt is a professional engineer registered in the Commonwealth of Massachusetts and in Trinidad and Tobago with over 15 years consulting experience in structural engineering and building investigations.

In May 2007, Dr. Prevatt joined the faculty at the University of Florida as an Assistant Professor in the Department of Civil and Coastal Engineering. Dr. Prevatt's research continues to focus on the mitigation of hurricane damage, particularly to low-rise construction. His current research involves experimental investigation and analytical modeling of the structural load paths in wood-framed structures, and the wind uplift testing of building cladding components. Prior to this appointment, Dr. Prevatt was on the faculty of Clemson University where he was an Assistant Professor and served as Director of the Wind Load Test Facility, conducting wind engineering research using a boundary layer wind tunnel to quantify wind loading on residential structures, to compare and validate field wind pressures collected during the 2004/2005 hurricanes. Dr. Prevatt is a member of the American Society of Civil Engineers, the American Association for Wind Engineering, and the UK Wind Engineering Society. Email: dprev@ce.ufl.edu
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