MsRI-EW: Conference to Identify Research Infrastructure Concepts for a National Full-Scale 200 mph Wind and Wind-Water Testing Facility

August 20-21, 2020 (Virtual)

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Executive Summary

To address windstorm related hazards (e.g., high wind, surge, wave, debris, flood, rain) as one of the grand challenges in U.S. engineering research, a Mid-Scale Research Infrastructure (MsRI) conference was held to (a) identify gaps in existing mid-scale research infrastructure, and (b) assess design options for and the economic and technical feasibility of a "Full-Scale 200 mph Wind and Wind-Water Testing Facility." A multi-disciplinary group of 50+ experts (APPENDIX A) convened virtually for two days to "*dream big*" and consider the potential need for such a national facility. The conference agenda (APPENDIX B) was designed to define the need for the MsRI for full-scale testing of buildings and other structures under the combined effects of hurricane's multi-hazards, including wind, rain, debris, surge, wave, and flooding. The research areas to be enabled by such a unique MsRI facility had to be carefully evaluated, revised (as needed), and augmented to identify current and emerging knowledge gaps. The conference aimed to develop an overview of an MsRI facility that can deliver unparalleled full-scale holistic testing capabilities to realistically investigate real-world systems or sub-systems under a hurricane's multiple component stresses.

The driving force behind this conversation is the recognition of a national, and global, need to reduce to the degree possible, damage from wind and wind-water natural hazard events. Achieving this goal requires objective, credible, and compelling basic and applied science to demonstrate effective loss prevention and reduction tactics to multiple audiences and policy and decision-making levels.

The overarching question posed to the group was whether such a facility is needed, given existing capabilities at laboratories in the U.S. and around the world. Topics explored in pursuit of an answer included: 1) existing societal problems that could be solved and knowledge gaps that could be filled (for buildings, the natural environment, critical infrastructure, risk models and computational simulations, readiness and recovery, mitigation, etc.); 2) optimal application of wind, rain, wave, surge, and bathymetry – in combinations and separately; 3) appropriate experts and allies to assess, strategize, utilize, promote, and activate research techniques and results; 4) big data acquisition, management, and dissemination; 5) integration of computational, small- and mid-size testing into large/full-scale programs; 6) validation of foundational science to support design, retrofit guidance, and standards; 7) integration of social science into necessary education and outreach to consumers, policymakers and industry; 8) research that could be leveraged to effectuate beneficial change (e.g., codes and standards, regulations, mitigation guidance); and 9) design, cost, power, throughput, safety, management and other operational considerations.

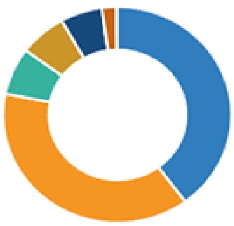
An overall agreement was reached that a need exists to develop (a) procedures so that structures can be designed and/or retrofitted to resist combined effects of wind and water, and (b) a realistic multi-hazard (e.g. wind-water-debris) risk analysis beyond the sum of single-hazard (e.g., wind only) risk examinations. It was agreed that the MsRI facility can foster a systems approach that takes into account nonlinear behaviors of materials together with loading complexities. Computational efforts supported by the experiments in such a facility would result in more reliable models and fragility functions, and a higher potential for integration into community level resilience modeling.

While it was broadly agreed that there is a critical need for such a versatile facility, it was also agreed that the conversation on how to optimize its design and operation should continue, and that an iterative process going forward should be open and seek input from other experts as needed. Participants also discussed whether such a complex facility is feasible even when a multi-million budget is available as well as whether field monitoring and computational tools might answer partially the posed research questions if the cost associated with the facility is enormous.

It was further agreed that additional research is needed to understand what different scales and/or speeds are required for simulating the combined effects of wind and water on civil engineering infrastructure. More specifically, the construction of a smaller facility combined with extensive numerical modeling would provide a valuable input to the optimal design of a larger facility. A smaller facility would also provide insight into fundamental science questions, particularly when full-scale testing under combined extreme conditions is not justified. It was agreed that physical, computational, and hybrid simulations may have to be considered in making that assessment.

1 MsRI Conference Introduction

Recent statistics indicate that extreme wind events such as hurricanes, tornadoes, and downbursts are the most fatal and costly natural hazards impacting the built environment in the United States and worldwide. Figure 1 shows that wind events cause the most losses.



Events including tornadoes (2)	$168.1	39.9%
Hurricanes and tropical storms	161.1	38.2
Other wind/hail/flood	29.7	7.1
Winter storms	28.2	6.7
Terrorism	25.0	5.9
Fires (3)	8.4	2.0
Other (4)	0.8	0.2
Total	**$421.2**	**100.0%**

Figure 1. Inflation-Adjusted U.S. Insured Catastrophe Losses By Cause Of Loss, 1997-2016 (2016 $ billions) - Source: The Property Claim Services® (PCS®) unit of ISO®, a Verisk Analytics® company.

The five U.S. states that have historically (1851-2018) experienced the most Category 3 to Category 5 hurricane landfalls are, in order: Florida, Texas, North Carolina, Louisiana, and South Carolina. Five other states, however, have also seen major (Category 3 or higher) hurricane landfalls, including Alabama, Georgia, Mississippi, and even New York and Massachusetts. Given the often concentrated human, infrastructure, and economic assets at risk in those 10 states alone, the hurricane hazard is effectively a threat to the United States as a nation, not only physically and economically but also to its society's sense of well-being and personal and family security.

Exacerbating future hurricane risk are indications from climate science that more intense hurricanes, as well as more intense downbursts and tornadoes, should be expected. Evidence to that effect, however, is already appearing. Recent major Western Hemisphere hurricanes, including Patricia in 2015, Irma and Maria in 2017, Michael in 2018, and Dorian in 2019 all demonstrated rapid intensification processes where wind gusts, and even sustained speeds, exceeded 200 mph in some cases. The result – from wind, storm surge, wave action, or flooding, and in places from all four – was devastating to the most affected U.S. and Caribbean communities, including of course the U.S. territory of Puerto Rico. The levels of damage, from housing to businesses to infrastructure to critical facilities and lifelines, have often made community recoveries painful, slow, and often incomplete.

Non-synoptic wind events, such as downbursts and tornadoes, have caused fatalities and injuries as well as significant damage to critical infrastructures in the United States and around the world. Moreover, thunderstorms may be accompanied by severe precipitation that in combination cause extensive damage. In fact, an investigation of U.S. weather-related hazard events between 1986 and 2003 indicated that human casualties and injuries caused by non-synoptic winds in the form of downbursts and tornadoes exceeded those from hurricanes [1]. Non-synoptic wind events have been the major contributor to weather-related failures of such energy infrastructure as transmission line systems [2]. A recent DOE [3] report estimated that 679 widespread power outages (i.e., those affecting more than 50,000 customers) accounted for approximately 87% of all outages between 2003 and 2012, and were due to severe weather including downbursts and tornadoes.

The study of extreme wind and/or water events has been accomplished through both field and laboratory efforts in the past. Experts discussed the need for such infrastructure and research findings in conference sessions, workshops, and special collections of published articles [4-21]. The NHERI facilities (e.g., the 12-fan Wall of Wind at FIU, BLWT at UF, and Wave Basin at OSU) and such other facilities as WindEEE at Western University, VorTECH at TTU, and WiST at ISU) can simulate small-scale, large-scale, and limited full-scale experiments on wind effects. For instance, the Wall of Wind NHERI Experimental Facility (https://fiu.designsafe-ci.org/) [22] is powered by a combined 12-fan system capable of repeatable testing in up to 157 mph wind speeds through its flow management system, and is capable of introducing rain into the flow. The University of Florida NHERI Experimental Facility (https://ufl.designsafe-ci.org/) [23] enables investigators to characterize loading on and dynamic response of a wide range of infrastructure in a large, reconfigurable boundary layer wind tunnel (BLWT) and conduct full-scale tests on large building systems with equipment capable of ultimate/collapse loads associated with a Simpson Hurricane Wind Scale Category 5 hurricane or an Enhanced Fujita Scale 5 tornado. The NHERI Experimental Facility at Oregon State University, known as the NHERI Coastal Wave/Surge and Tsunami (https://oregonstate.designsafe-ci.org/) [24] consists of two main resources to support a wide base of users: the Large Wave Flume (LWF) and the Directional Wave Basin (DWB). Both the flume and basin are capable of generating wind waves and tsunamis.

However, at present there are significant gaps in mid-scale research infrastructure (MsRI) capabilities in the U.S. and worldwide to advance knowledge and reduce often enormous losses resulting from extreme wind events. Full-scale or near full-scale testing under simultaneous stressors are needed to study the effects of:

- Wind and surge (water/wave)
- Wind, surge, and wave-borne debris
- Wind and wind-borne debris
- Wind and rain
- Flood and flood-borne debris

These research testing gaps are precluding more realistic estimations of real-life loading on structures and their performances under such combined and complex loadings.

Enhancing community resilience is increasingly important as populations migrate to more vulnerable locations, particularly coastal and near-coastal regions, and the risks are being heightened by climate-driven intensification of storms. In the past, community level modeling proved valuable in avoiding $65M of flood damage in Omaha, which was achieved by the *Mississippi River Basin Model* [25-26] that used 1: 2,000 (horizontal) and 1:100 (vertical) scales. Such community level modeling is lacking for assessing wind-water damage under natural hazards.

To foster national resilience, the United States needs advanced experimental capabilities that can support research to understand and reduce human, infrastructure, and property losses resulting from extreme wind and wind-water events, particularly hurricanes. To mitigate the impact of extreme wind and wind-water events on the built environment, a university-based research and testing facility is needed that can simulate up to 200 mph wind and wind-water events.

The NSF award "*MsRI-EW: Conference to Identify Research Infrastructure Concepts for a National Full-Scale 200 mph Wind and Wind-Water Testing Facility; Virtual*" (Award # 2034656) supported an engineering-social science workshop to identify research infrastructure concepts for a national, full-scale, 200 mph wind and wind-water testing facility capable of supporting research and testing beyond the wind speeds and scales achievable with current testing facilities in the United States. The two-day workshop was led by FIU and held virtually on August 20-21, 2020 due to the ongoing COVID-19 pandemic. It included 50+ participants (Appendix A) from research and engineering applications communities from universities, businesses, professional associations, and government.

The workshop identified conceptual gaps in existing mid-scale research infrastructure (MsRI) and assessed the feasibility and design options for a full-scale wind and wind-water testing facility. The workshop discussions included design and construction conceptualization of a unique MsRI to (a) advance knowledge on the characterization of the transient nature of the combined wind-surge-wave hazards, and (b) enable robust simulations of the behavior of civil infrastructure under the multi-stressor environment of hurricane landfalls. The workshop included a project management expert and a conference facilitator to coordinate with plenary leaders and breakout session chairs.

A compelling need was identified to fully explore designing and building a large-scale university-based wind testing facility that would be well beyond anything currently existing. The facility is envisioned to be large enough to test full-scale low-rise houses (up to two or three stories). In addition, because storm surge and flooding are primary causes of human as well as economic losses in hurricanes (often more than 50% of the losses), the workshop focused on identifying ways to integrate storm surge and wave actions into the facility design to enable simultaneous simulation of wind-surge-wave actions on structures. The long-term goal of the workshop was to advance wind, water, and wave engineering research with new testing capabilities to enhance the hurricane resilience of the built environment. This workshop supported NSF's role in the National Windstorm Impact Reduction Program.

The workshop's organizers hired an architectural team to create a preliminary conceptual design of the envisioned facility in order to engage the audience and to provide a starting point for the two-day virtual discussion (see Figures 2 and 3). This Final Report of the MsRI workshop highlights the research infrastructure gaps/needs. The ultimate objective of the workshop and this report is to position the U.S. engineering research community to respond to future opportunities for mid-scale research infrastructure projects.

The following sections provide summaries of the discussions from each of the main sessions included in the Agenda (see Appendix B), and they provide an overview of the key topics and outcomes as summarized by each session chair and the organizing committee.

This workshop Outcomes Report is disseminated to the natural hazards and engineering research communities via the Natural Hazards Engineering Research Infrastructure (NHERI) Data Depot (https://www.DesignSafe-ci.org).

Figure 2. Visualization of the interior of the “Full-Scale 200 mph Wind and Wind-Water Testing Facility.”

Figure 3. Visualization of the various aspects of the “Full-Scale 200 mph Wind and Wind-Water Testing Facility.”

2 Summaries of the MsRI Workshop Sessions

2.1 Session 1

Session Title

Identify MsRI components/equipment/instrumentation needed to fill research gaps in characterization of the transient loading on the built and natural environments by hurricanes and associated hazards

Session Chair

Forrest Masters, University of Florida

Panelists

- Forrest Masters, University of Florida (lead)
- John Knezevich, Knezevich Consulting
- Daan Liang, University of Alabama
- Frank Lombardo, University of Illinois at Urbana-Champaign
- Kishor Mehta, Texas Tech University
- Murray Morrison, Insurance Institute for Business and Home Safety
- Partha Sarkar, Iowa State University
- Ted Stathopoulos, Concordia University
- Yukio Tamura, Tokyo Tech University (emeritus) (Dr. Tamura couldn't attend but shared materials which the Session Chair shared with the participants)

Major Findings

The charge of this panel was to identify MsRI components, equipment, and instrumentation needed to fill research gaps in characterization of the **transient wind loading and wind-driven rain effects** (e.g., see Figure 4) on the built and natural environment by tropical cyclones and other wind hazards, e.g., non-synoptic winds. Also considered were storm surge and wave effects. For the purposes of facilitating a discussion with a large and diverse group of experts, "transient" was broadly defined to encompass all relevant scales of motion, e.g. local flow accelerations in the roughness sublayer to surface wind field perturbations caused by mesovortices in a hurricane eyewall. Non-neutral flows were also considered, as the physical dynamics of most non-stationary events cause the velocity profile to deviate from the atmospheric boundary layer (ABL) profile represented by the logarithmic law.

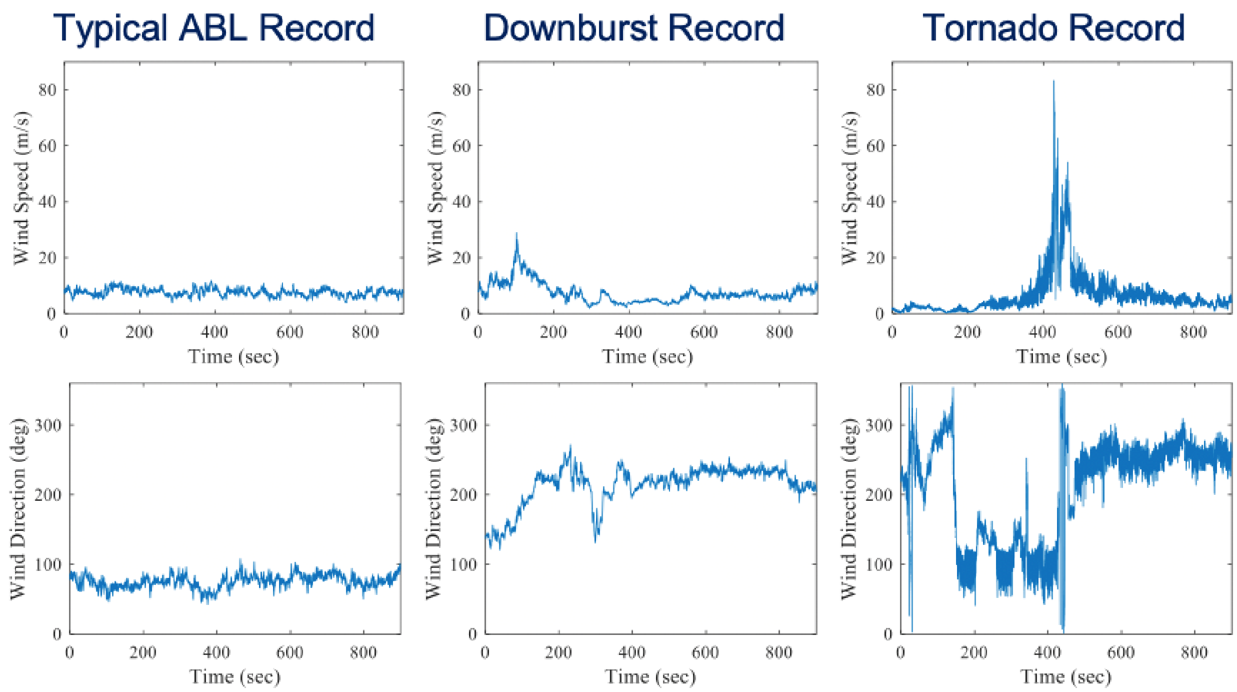


Figure 4. Comparison of velocity time series from a typical boundary layer, downburst, and tornado (Courtesy: Frank Lombardo, University of Illinois at Urbana-Champaign)

The panel unanimously agreed that a strong imperative exists to simulate transient (nonstationary) phenomena that have been implicated in inflicting damage to civil infrastructure/lifelines and natural environment. A full-scale facility of this size would advance the associated body of knowledge (e.g., gust front loading, fluid structure interaction (FSI), Helmholtz modeling for internal pressure) and enable the study of multiple hazard modalities, for example wind-driven rain (WDR), windborne debris (WBD), surge/waves. Simulating WDR was emphasized as a strong need in the panel discussion. Further, operating at full-scale would eliminate known issues with boundary layer wind tunnel modeling (e.g., Reynolds number mismatches) that if left unaddressed would make it more challenging to achieve dynamic similarity for a nonstationary event, for example immersing a low-rise structure in a thunderstorm outflow.

Analysis of peer reviewed literature supports the assessment provided by the panelists. Figure 5 shows publications focused on transient events in two of the most highly cited wind engineering and science journals (shown in reverse chronological order). The number of papers has roughly tripled since more than a decade ago.

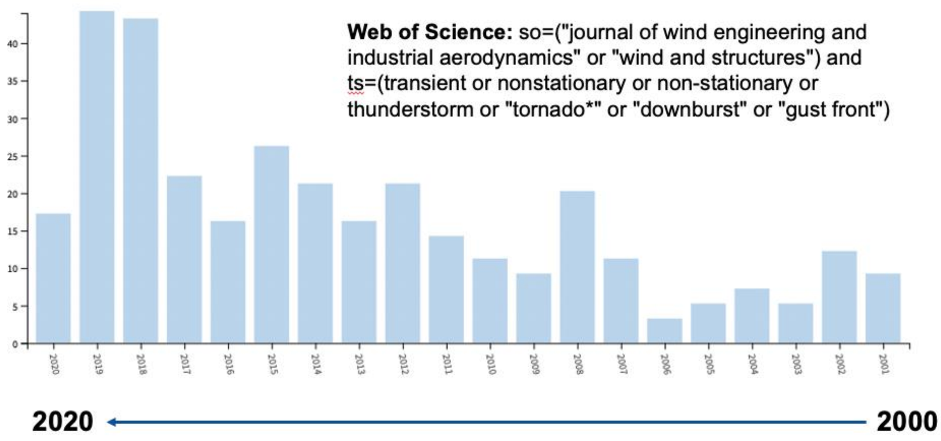


Figure 5. Analysis of Web of Science bibliometric information about recent publications in the *Journal of Wind Engineering and Industrial Aerodynamics* and *Wind and Structures* about transient and nonstationary wind events. The 2020 bar only shows papers published during January to August of that year.

The panel determined that active turbulence simulation (versus using passive devices) was imperative to reproducing transient effects. It was suggested that the design effort would greatly benefit from reviewing prior work on geometrically scaled multi-fan systems, such as those found at the Tongji University, University of Buffalo, University of Florida, and Western University. These systems were designed to simulate nonstationary and even non-neutral profile effects. Significant effort has gone into development of their control and power electronics systems as well as commissioning to achieve realistic approach flows at the turntable.

Further, the design effort would also benefit from advances in field measurement systems (e.g., weather stations deployed in thunderstorm outflows or tropical cyclones) to characterize targets for kinematic similarity (i.e., the turbulent flow properties in the simulated approach flow). These data were not available two decades ago when development of the first full-scale testing facilities began in earnest. These measurements should be leveraged to design “real-world” test cases to ensure the system is capable of recreating highly realistic extreme conditions.

Standards and codes development (e.g., performance-based design, multi-objective design philosophy) would also benefit from a full-scale test facility. The facility would help move the current design paradigm, which is based on similarity assumptions arising from how the lower atmosphere generates turbulence at timescales on the orders of a fraction of a second to atmospheric motions on the order of 30-60 minutes (which are bounded by the so-called van der Hoven spectral gap) to the probabilistic assessment of the role of isolated features within an extreme event episode (less stationary signal processing, more dynamical physics). The anticipated long-term implication would be the widespread adoption of codes and standards in regions prone to extreme wind events that would allow the survivability of the structure and its ability to ensure that occupants can shelter in place. Non–linear behavior and non–stationary wind effects must be well characterized for that to happen. The proposed facility would create an ideal testbed to perform critical validation studies for that purpose, as it would generate a sufficient large wind field to immerse the subject building in both an undamaged and damaged state.

The panelists urged for careful consideration between size and speed as design requirements. Although no particular conclusion was reached, it was evident that both physical and hybrid (virtual) simulations should be considered in making that assessment. Future research designs would more likely be cyber-physical in nature than purely experimental.

While considerable emphasis was placed on the science drivers for such a facility, it was recognized that the technical issues undergirding the design and commission of a system capable of generating transient wind effects at ~100 m/s at full-scale could be more challenging than conducting the wind engineering research itself. Power is a function of velocity cubed at steady state, and the accelerations required to simulate turbulent fluctuations at the proposed speeds are extreme by any conventional engineering lab standard. Thus, the design team should avail themselves of the latest methods (e.g., generative design, digital twin methods) to optimize the system at every design step. Use of recirculating wind tunnel designs could be considered to decrease power consumption. Use of renewable energy sources, specifically photovoltaics, coupled with large-scale battery storage could also significantly reduce operating costs, especially for destructive tests that only require the tunnel to operate a few hours per day.

Session Summary

The example of Western University's WindEEE Dome was offered as a model because it has more than seven operational modes to generate wind (e.g., neutral boundary layer winds, tornado, downburst, sheared flow, reverse flow testing outside the facility for destructive and wind driven rain testing, etc.). The proposed facility could also be conceptualized to test different scenarios in the wind/surge/wave/rain research areas in the same cross-functional context. Evaluation of tree blowdown and aerodynamics can be considered.

Integration of renewable energy resources, battery storage, or other measures to create carbon offsets should be considered. Use of complementary, smaller scale facilities to simulate transient effects could also be considered to save energy with the added benefit of achieving higher fidelity simulations under certain conditions. Discussion was also held regarding the importance of integrating harnessing numerical simulation within the physical experiments (hybrid simulation).

The difficulty of achieving similarity for both conditions was noted, and it was observed that the study of air-sea interaction in the proposed facility would not be a primary science driver for this community. Additionally, there was some concern that the resources for implementing a wave flume would be better put toward achieving a more powerful and accurate simulation. It was also recommended that key advances occurring at other large facilities should be compiled to help the team gain some understanding of where this effort might go in a broader programmatic sense (e.g., study racecar wind tunnels).

Combining wind and water simultaneously was discussed several times (this conversation carried over into the sections that followed), with no clear agreement on the value of studying wave effects during a wind simulation. A theoretical treatment of the water effects was also suggested. Nevertheless, the central argument for building a wind-water facility was that wave/surge effects and wind effects may be treated as additive for design but not necessarily for performance and non–linear behavior. The scientific justification for the MsRI facility is based on the fundamental research questions enabled by the MsRI facility (see Section 6).

2.2 Session 2

Session Title

Identify MsRI components/equipment/instrumentation needed to fill research gaps in modeling the behavior of civil infrastructure systems (buildings and interdependent/interconnected lifeline infrastructure) under hurricane multi-stressors

Session Chairs

Dan Cox and Pedro Lomonaco, Oregon State University

Panelists

- Daniel Cox and Pedro Lomonaco, Oregon State University (leads)
- David Banks, CCP Wind
- Hermann Fritz, Georgia Tech
- Greg Guannel, University of Virgin Islands
- Kurtis R. Gurley, University of Florida
- Andrew Kennedy, University of Notre Dame
- Christopher Letchford, Rensselaer Polytechnic Institute
- Barbara Simpson, Oregon State University
- Benjamin Strom, XFlow Energy Company

Major Findings

The aim of this panel was to identify MsRI components/equipment/instrumentation needed to fill research gaps in modeling the behavior of civil infrastructure systems (buildings and interdependent/interconnected lifeline infrastructure) under hurricane multi-stressors.

The panelist presented and identified a series of desired components to be addressed and/or included in a facility able to properly model the behavior of coastal infrastructures subject to the combined effect of extreme wind and waves.

New data are required to improve understanding of the multi-physics problem and to inform engineering practice and stakeholders. Full-scale data under controlled laboratory conditions are currently not available. Major challenges for a full-scale facility relate to the need to combine wind and water (surge, wave), and to have controlled conditions for both wind and water. Hence, the design of a new facility would need to focus on problems that need to be solved and to prioritize expected achievements. Wave facilities typically specialize in either offshore (deep water) research or coastal (shallow water) research.

Scale effects remain a challenging issue for some research questions, including the mismatch in Reynolds and Froude scaling for conditions different from the prototype geometry and material properties. A full-scale facility for wave, wind, and their interactions with structures may help to address these challenges.

The limitations of physical modeling in a confined space, regardless of scale, presents significant laboratory effects challenges. Laboratory effects for a surge/wave facility include wave reflection and re-reflection from the wavemaker and from sidewalls, unwanted recirculating currents due to sidewalls, and so on. These laboratory effects may be compounded when adding prototype wind (e.g., increased setup at the shoreline due to changes in pressure).

1. **Laboratory Size**. A prototype scale wave facility for coastal research would require water depths ranging from 2-10 m and be able to reproduce wave periods from 10 to 15 s. This would necessitate a facility approximately 300 to 450 m long to properly generate, test and dissipate the waves needed, comparable to existing large flumes worldwide. The use of a flume would limit the capability to study effects of wave direction.
2. **Capabilities**. A wind-wave large-scale facility for extreme conditions needs to incorporate a series of components and equipment to address current research gaps:
    a. Underwater turntable
    b. Building water intrusion equipment
    c. Ability to incorporate sediment transport and morphological changes in the experimentation (unfeasible or incomplete at reduced scale)
    d. Ability to construct full scale specimens (buildings) including a realistic representation of the foundation and soil characteristics/response
    e. Generation of waves, currents, and control of water levels
    f. Ability to simulate natural and nature-based systems to mitigate surge and wave effects
    g. Ability to incorporate 2D-horizontal models (wave basin and the effect of multidirectional waves)
    h. Ability to incorporate geographically distributed and/or (faster than) real-time hybrid simulation equipment
    i. Increased depth to accommodate studies of offshore structures

Session Summary

The discussion included additional questions on the feasibility of a full-scale facility for extreme wind and wave conditions. Concerns were raised on solving the scaling issues, the economic viability, and the possibility of addressing the research gap with advanced techniques, like hybrid simulation and field data.

It was mentioned that wind-structure, wave-structure, and wind-wave interactions have been tested previously at reduced scales. Results indicate a strong dependence for each of these cases. However, the combined effects of waves and wind on structures has been relatively limited to offshore structures such as oil platforms and wind turbines. The construction first of a smaller facility combined with extensive numerical modeling would provide input into the optimal design of a larger facility. Moreover, it was discussed that a smaller facility would also provide insight on some fundamental science questions, when the use of a full-scale testing under combined extreme conditions is not justified.

Some additional discussion required the clarification that waves, surge, and currents need to be generated by specific equipment. In other words, the wave and surge for prototype scale testing cannot be generated by the wind machine because the necessary fetch required for hurricane waves is 1000 km. The interaction of a semi-confined body of water with an open flow of wind at 200 mph is considered one of the major challenges.

Natural and built environment cascading effects were also addressed. These include incorporating morphological changes due to combined wind and wave effects, scour, sediment transport, wind-wave-vegetation interactions, and cascading effects such as wind and water-borne natural (trees) and built (other structures) debris.

2.3 Session 3

Session Title

Identify MsRI components/equipment/instrumentation needed to fill research gaps in achieving storm readiness and speedy post-event recovery of civil infrastructure and communities by vulnerability modeling, shifting vulnerabilities via intervention, and enhancing reliability of systems.

Session Chair

John W. van de Lindt, Colorado State University

Panelists

- Alice Alipour, Iowa State University
- Hannah Blum, University of Wisconsin
- Ashraf El Damatty, Western University
- Carol Friedland, Louisiana State University
- Ahsan Kareem, University of Notre Dame
- Nigel Kaye, Clemson University
- Tracy L. Kijewski-Correa, University of Notre Dame
- Marc L. Levitan, National Institute of Standards and Technology

Major Findings

The ability to simultaneously test strong wind combined with surge and waves was discussed in the context of resilience. It is important to point out that structural performance is not the same as resilience. Resilience is the ability to prepare for and recover from adverse events in an acceptable time. The panel was asked several questions focused on (1) explaining how such a facility could help communities improve their resilience (not just structural performance); and (2) the facility having the capability test simultaneously and/or at full-scale, and why. A number of advantages to full-scale simultaneous testing were identified, as follows.

Testing at full-scale, but more importantly simultaneously, will allow evaluation of the combined component effects of a CAT 4 or CAT 5 hurricane in a facility capable of producing winds between 140 to 200 mph and surge with waves, or events of any lower intensities. This will enable design code changes not only for buildings, but also for other types of infrastructure systems such as berms and levees. The insurance industry struggles with determining the separation between water damage and wind (including rainwater damage), and such a facility will provide key data that do not currently exist to make this important determination. Surge/wave damage is considered flood damage and only covered by flood insurance, whereas wind and wind-related rainwater damage is almost always covered by homeowners' insurance. Moreover, it appears that the wind engineering research community has put more emphasis on the loading component and much less on the resistance part. The concept facility should be able to accommodate a system approach that considers the nonlinear behavior of the material together with the complexity of loading.

From a community or urban resilience perspective, one of the most exciting prospects for such a facility is not only the full-scale testing, but also the ability to test a portion of a community at-scale, e.g., 1:5 or 1:10. This would allow investigation of shielding effects, debris flow and damage, even dependencies within and across networks. One of the hardest questions that arises with community-level modeling is related to the ability (or lack thereof) to validate the models for initial (and subsequent) damage and loss of functionality. Just thinking of the electrical power network, a larger facility with capacity to simulate higher wind speeds provides the opportunity to address the current limitations with small-scale modeling and capacity to simulate effects such as galloping. The larger scales may allow for consideration of the deterioration on infrastructure performance. Wave-wind capacity may allow for also considering the potential of erosion in tower foundations.

Preliminary studies can center on a few communities that will be selected based on their current vulnerability. This will help guide the design and operation towards maximal impact (it also parallels the example of the Mississippi river basin model [25-26]). Coastal regions can be classified based on surge and wave, wind, and soil characteristics. Within each category, it is possible to identify the most vulnerable communities based on socio-economic factors. An adaptable facility can be designed to represent most coastal conditions. The design team should interact with stakeholders in the identified vulnerable communities. The stakeholders (homeowners, contractors, local government officials, etc.) should identify current barriers to implementation of resilient building solutions. Stakeholders should identify the most promising solutions. The MsRI facility should test models representative of current building stocks, identify dominant failure modes in current conditions, and study models representative of proposed improved building stocks. On the other hand, the team should develop minimally intrusive, cloud-based, wireless sensor networks able to monitor wave/wind loads on buildings. Researchers should equip buildings with the sensor networks to record data when a major storm will hit. This could be combined with deployment of sensor systems that can measure local wind and wave conditions; these could be rapidly deployed whenever a storm is predicted to arrive. The data can then be used to investigate the ability of the facility in terms of predicting full-scale loads in the field. If all data in the facility are high-resolution in space and time, with well-characterized conditions, it will also provide a wealth of information to support computational modeling, both physics-based and data-driven.

Establishing partnerships, informing policy, and enabling interdisciplinary research advances are all key features of such a full-scale facility. The importance of diversifying the pathways to translate research to practice through industry and policy-focused partnerships was discussed. These need to be truly national (beyond geography of facility) to be responsive to the different policy contexts and construction practices in coastal communities. Such a facility will have wide implications for policy, and policy in turn, requires the involvement of many disciplines including engineering, social science/planners, policy, business, and information technology, and thus it will be critical to engage all disciplines early in the planning process and through the operations. In the end, for the facility to make contributions beyond damage reduction, and make community planning more effective thereby improve resilience, involvement of many disciplines is needed since many community-level resilience metrics are socio-economic.

Session Summary

This session focused on identifying if (and how) a wind-water test facility of this magnitude would enable research to be performed such that communities can be better prepared for and more rapidly recovery from coastal storms of intense magnitude. Specifically, how can testing wind and water loading simultaneously and at full-scale differ from testing them individually and/or at scale? There were four major impacts and benefits identified, namely: (1) understanding the combined effects from testing in such as facility would have implications for design codes and insurance; (2) studying and improving community-level models; (3) allowing the establishment of key partnerships; and (4) supporting society as more people move closer to coastlines and sea levels continue to rise.

2.4 Session 4

Session Chair

Identify MsRI components/equipment/instrumentation needed to fill research gaps in testing and validating potentially transformative mitigation strategies in achieving resilient coastal communities.

Session Chair

Dorothy Reed, University of Washington

Panelists

- Girma Bitsuamlak, Western University
- Suren Chen, Colorado State University
- Bill Coulbourne, Coulbourne Consulting
- Maryam Refan, Rowan Williams Davies & Irwin Inc.
- Nina Stark, Virginia Tech University
- Wei Zhang, Cleveland State University
- Delong Zuo, Texas Tech University

Major Findings

The session panelists represented a broad perspective of wind and storm surge engineering research in various areas, including bridges, single family homes, tall buildings, and foundations. Similar to the previous sessions, the need for simultaneous wind and wave full-scale testing was discussed at length, although how to accomplish this was not clearly identified. The major findings of the session discussion were as follows:

1. Realistic scaling is critical for soil conditions, wind, wave, marine life (e.g., oyster beds and mussel reefs), and the built environment, especially for existing structures such as housing and bridges.

2. Full-scale measurement challenges exist both to support the facility and as part of the experiments in the facility. In addition, data curation needs must be considered in the design of the proposed facility, especially in examining the fidelity of numerical and small-scale simulations and calibrating such simulations.

3. Testing of bio-inspired structures, single versus multiple structures, and correlations of loadings must be included in the facility.

4. Shelter in place may become the new normal due to pandemic related societal change, so mitigation of the impacts of both wind and wave on structures will become more important.

5. Benchmark real-world scenarios are important to consider.

6. Creative use of green infrastructure and renewable energy coupled with storage capabilities should be encouraged in the facility design. Perhaps the facility could become a research project for energy generation, storage, and delivery.

Session Summary

This session focused on identifying the research gaps in testing and validating potentially transformative mitigation strategies in achieving resilient coastal communities. There were three major outcomes: (1) Realistic scaling is critical for all aspects of the envisioned facility; (2) Full-scale measurement challenges exist both to support the facility and as part of the actual testing that will be carried out in the facility; (3) Testing of bio-inspired structures, single versus multiple structures, and correlations of loadings must be included in the facility.

2.5 Session 5

Session Title

Identify MsRI components/equipment/instrumentation needed to fill research gaps in collecting and sharing big data and information to validate computational modeling, advance risk assessment and loss estimation tools, and leverage emerging trends in artificial intelligence and robotics

Session Chair

Karthik Ramanathan**,** AIR Worldwide

Panelists

- Luca Caracoglia, Northeastern University
- Catherine Gorle, Stanford University
- Victor Maldonado, Texas Tech University
- Stephanie Paal, Texas A&M University
- Jean-Paul Pinelli, Florida Institute of Technology
- Maria Pia Repetto, University of Genoa
- Panneer Selvam, University of Arkansas
- Teng Wu, University at Buffalo - SUNY

Major Findings

Recently there have been significant uses of data, machine learning (ML), and artificial intelligence (AI) to simulate various strong windstorm scenarios. In addition, high fidelity surge simulations are being used to produce numerous scenarios of potential hurricanes that have the possibility of striking at various points along coastlines. Several recent research studies focus on assessing the performance of the built environment, particularly in coastal states, using Computational Fluid Dynamics (CFD) models. These models hold significant promise for other aspects including design, resilience, mitigation, and air quality. In addition, from a risk assessment perspective, there is a need to create a catalogue for possible wind and surge scenarios to assess the possibilities of having the dual impact of the two hazards on the built environment. The major findings of the session discussion are as follows:

1. Assessing the performance of complex structures under the dual effect of wind and wave hazards requires very costly computational analysis. Developing high-fidelity numerical models with inherited assumptions and significant uncertainties emphasizes the pressing need for full-scale experimental data.

2. The proposed facility will enable benefiting from the current advances in hybrid simulation in wind and wave testing facilities to better consider individual building responses while physically simulating a neighborhood.
3. The proposed facility should be designed to foster data measurement, curation, quality control, and dissemination.

Session Summary

The aim of this session was to discuss the need for full-scale experiments to provide wind-water-structure interaction data to validate advanced computational modeling and numerical simulations, which would ultimately reduce reliance on physical testing. The proposed MsRI facility and its components should be designed to fill current research gaps in collecting, sharing, and integrating big experimental-based data (i.e. big data) into high-fidelity computational modeling to advance the science of risk assessment and leverage emerging trends of artificial intelligence or robotics. The panelists of this session came from multiple research disciplines and fields, including computational fluid dynamics, wind engineering, structural engineering, and risk assessment.

2.6 Session 6

Session Title

Identify MsRI components/equipment/instrumentation needed to fill gaps in integrating engineering research, social science, education, and outreach to achieve hurricane resilient and sustainable communities and create a diverse trained workforce.

Session Chair

Lori Peek, University of Colorado Boulder

Panelists

- Jennifer Bridge, University of Florida
- Billy Edge, Texas A&M University
- Yanlin Guo, Colorado State University
- YeongAe Heo, Case Western Reserve University
- Wei Song, University of Alabama
- Elaina J. Sutley, University of Kansas
- Grace Yan, Missouri University of Science and Technology

Major Findings

Session panelists and participants who engaged in conversations regarding education, partnerships, and public awareness offered five key recommendations, as follows:

1. The facility planning should consider social inequality, justice, and equity from the outset. The harm and suffering caused by disasters is not equally distributed across society.

It is therefore critical that the facility engage with questions of inequality to ensure that the knowledge produced helps to reduce, rather than further deepen, already existing inequities and disadvantages.

2. Movement from traditional "top down" approaches to knowledge production, education, and outreach toward more egalitarian and community-driven "bottom up" approaches can help broaden the scope of the facility's impacts. Indeed, bottom up approaches open up opportunities to engage more diverse students and community partners, who will then have real input into the research process, not simply the outputs.

3. New technologies such as hazard simulations and risk visualizations represent an additional option for engaging students, community members, funders, and other potential stakeholders in the work of the proposed facility.

4. It is important that the new facility think broadly and inclusively—using a "whole of community" approach—to developing partnerships and building the coalition of stakeholders involved in this facility. Because people spend so much of their lives in buildings and other engineered structures, it is crucial that a wider group of constituents be engaged in this facility from the outset, including, for example, leaders from the public and private sector, schools and education, healthcare, religious institutions, and other key areas of social life.

5. It is recommended that the facility adopt a convergence research framework to ensure that the facility remains problem-focused, solutions-oriented, and engages diverse disciplinary and professional perspectives from the outset. This will also help ensure that the facility does not develop technical fixes for what are more fundamental and enduring social, political, and economic problems.

Session Summary

The aim of this session was to discuss how the proposed MsRI facility could provide a critical site for fostering novel education and training opportunities for students and early career scholars. Such a facility could also serve as a center of gravity to build partnerships across academia, government, private industry, and beyond to ultimately advance public awareness of and action in response to the knowledge produced.

3 Fundamental Research Questions Enabled by the MsRI Facility (*scientific justification*)

The second workshop day focused on the outcomes of Session 1 and the fundamental research issues to be addressed by the envisioned MsRI facility, as follows:

1. Advance standards and codes, e.g., performance-based design and other approaches based on multi-objective design philosophies

    a. Develop analytical tools to probabilistically assess the role of isolated features aloft (e.g., mesovortices, boundary layer rolls, gust fronts) enhancing surface winds in an extreme event episode, i.e. complement stationary signal processing used in modern rational engineering analysis with dynamical physics;

    b. Eventually ensure that occupants can shelter in place during extreme weather; non–linear behavior and non–stationary event must be better understood. Develop procedures for structures to resist combined effects of wind and surge that are based on system level approaches that address nonlinearity and aeroelastic response, with consideration of scaling requirements;

    c. Produce responsive mitigation solutions, studying/applying best practices from social science, economics, and other research to translate policy to practice;

    d. Expand multi-hazard fragility functions such as [27-28].

2. Develop testing capability to load and break full size as-built in-situ structures in a repeatable environment of dynamic, transient wind and water to investigate resilient infrastructure.

3. Enhance understanding of transient wind effects (e.g., gust front loading, numerical weather prediction combined with large eddy simulation, fluid-structure interaction, internal pressure) by providing validation at full-scale, preferably with coupling to other hazard modalities (e.g., WDR, windborne debris, surge/waves).

4. Elucidate natural and built environment cascading effects, including incorporating morphological changes due to the combined wind and wave effect, scour, sediment transport, wind-wave-vegetation interactions, and cascading effects such as wind and water-borne natural (trees) and built (other structures) debris.

5. Advance hybrid and numerical simulation using physical models for computational model validation and calibration, as well as to assess different scale effects. Implement (real-time) hybrid and geographically distributed simulation for wind-wave-structure interactions.

6. Advance community-scale modeling to inform hazard modeling, urban planning, air quality modeling, wind energy, etc. through testing of geometrically scaled models of entire communities.

7. Create holistic datasets for benchmarking to support future research (data reuse) while implementing reproducibility and enact FAIR (Findable, Accessible, Interoperable, Re-producible) data standards and promoting equitable use of artificial intelligence.

4 Research Topics that can be Improved by Combined Simulations of Wind, Surge, and Waves at Prototype Scales (*identify gaps in MsRI*)

Several topics were discussed among participants during the conference and through email communications about the necessity of simultaneous simulations of wind and water effects. The key points are presented below.

1. Effect of bi-directional correlated loadings of wind and wave on buildings, large scale structures, including offshore wind turbines;
2. Simultaneous loading (wind or wind + wave) + capacity (strength) assessment on the actual building (or components) up to damage;
3. Mitigation for beaches and coastal environments;
4. Debris dynamics for wind and wave conditions;
5. Wind-water-soil interactions and their effects on foundations of structures; and
6. Flutter in loose membrane flood barriers under wind-wave loads.

One of the main issues discussed is that structures that are affected by waves are usually on poor soils (sands and silts), and the waves and currents modify the sediments through momentary liquefaction, localized scour, and widespread erosion. These factors are important because they affect the foundation of the structure. Combined wind-wave effects could be significant, for example, on elevated structures that can be removed from their pilings by the combined loading.

Moreover, study on Tension Leg Platforms showed that results from isolated studies did not match those from studies of the combined action of wind, waves, and currents [29]. A U.K. small-scale wind-wave facility observed the same experimentally for a floating spar type wind turbine. These cases show that such systems are nonlinear, and the dynamics require that studies be performed under the combined action. Also, the hydrodynamic damping could not be estimated under one loading condition. Hence, isolated cases could not be summed so as to arrive at the combined results.

For coastal structures there is non-concurrent arrival of peak wind and wave (something noted by Dr. Ahsan Kareem in analyzing claims for wind and water damage in Katrina). Correlation or phasing can address this issue, and one could add them statistically. However, the nonlinear behavior of the stilts or piles/piers can preclude simple summation of wind and wave/surge effects. Such problems require testing at the proposed wind-surge-wave facility.

Current facilities lack full-scale testing for large objects or very large-scale capabilities. The proposed facility can provide professionals with entirely new capabilities. One example is the experience shared by a Hurricane Mitigation Specialist (John Knezevich) where designing flood protection for large infrastructure projects is absolutely hampered by limited testing facilities. Over the next decade, researchers can anticipate that underground and at-grade facilities along coastal regions will follow the lead of NYC and incorporate large membrane flood barriers. Addressing flutter in a loose membrane structure in a wind field associated with a building or tunnel is not in the research domain today. It will impact billions of dollars in protected infrastructure in the coming years.

There is currently a testing infrastructure gap in the U.S. for extreme weather testing of scale models of floating offshore wind turbines. Likely the most impactful facility design aspect for this use will be the depth of the basin, which should be maximized to properly capture the dynamics of moorings.

The question remains whether there is a need for a combined wind-wave simulation for near-coast structures at full-scale under extreme conditions (e.g., CAT 5 winds with surge and waves). The joint simulation of wind and waves has to be generated using paddles or wave makers. This may be feasible for moderate conditions, but for 200 mph testing, this may not be achievable. Scientists may even not have the characterization of the wind and waves fields at that level to consider modeling. This might be an area to be pursued at a different scale and/or speed.

5 Impacts and Benefits of the Envisioned MsRI Facility (*needs for the facility*)

The second day discussion on the outcomes of Session 3 focused on the impacts and benefits of the envisioned MsRI facility, i.e. the fundamental needs for such an ambitious and challenging testing center. There were three key takeaways.

First was the need for a realistic multi-hazard risk analysis that is not just the sum of single-hazard risk examinations. Simply relying on field investigations to address multi-hazard impact is time and cost consuming as there is high quantity of data from multiple aspects that need to be collected. This task would be more achievable within a controlled environment. Computational models supported by the experiments in such a facility will result in more reliable models, fragility functions, and greater potential for integration into community level resilience modeling.

The second key takeaway was that the wind community has focused mainly on the loading component and much less on the resistance component. On the other hand, seismic research succeeded in developing procedures for designing earthquake-resistant structures through the concept of capacity design relying on ductility. There is a clear need to develop procedures so that structures are able to adapt to the combined effect of wind and surge. A system approach that considers the nonlinear behavior of the material together with the complexity of loading needs to be implemented in research carried out in the MsRI facility. There is an immediate need to think about strength scaling together with loading and aeroelastic scaling.

The last key takeaway was related to the lifecycle concept of directing field observations to rigorous R&D that can inform the scientific community on loss modeling while producing responsive mitigation solutions, both of which need mechanisms to accelerate translation to policy and practice.

Workshop participants provided valuable feedback on the above items, and the discussion generated stimulating comments and questions. For instance, diversifying the pathways to translate research to practice through industry and policy-focused partnerships is of paramount importance. That diversifying needs to be truly national (beyond geography of facility) so as to be responsive to the different policy contexts and construction practices in and around coastal communities. Another issue raised was the case of electric power network infrastructure, for which a larger facility with capacity to simulate higher wind speeds provides the opportunity to address the current limitations with scaling and capacity to simulate effects such as galloping. The larger scales may also allow for consideration of the deterioration on infrastructure performance, and the wave-wind capacity may allow for consideration of the potential of erosion in tower foundations. Finally, given the extremely high cost of such facility, the research community has to make a clear case of when and why combined effects of wind, surge, and waves need to be investigated experimentally and at full-scale.

6 Desired Capabilities (Simulation Parameter Ranges), Required Resources (Equipment, Sensors, Utilities), R&D to Inform Design Process, and Timeframe to Build the MsRI Facility

The second day of the workshop also saw discussion on the desired capabilities (simulation parameter ranges), resources (equipment and sensors), and reasonable timeframe to realize the MsRI facility. The general tenor of the discussion was that realistic combined wind, surge, and wave simulation could be achieved in the new facility. Wind speeds in the range of 20 to 200 mph should be possible, but there should be some consideration of cost constraints, i.e. if a maximum of 180 mph can be accomplished at half the cost of 200 mph, then 180 mph should be the maximum. Similar arguments were made for the hydrodynamics aspects of the facility. For instance, generation of water currents, shallow water conditions indicative of shorelines, wave breaking, and water heights and volume must be simulated adequately. Wave makers and/or paddles will be needed for wave simulations.

Incorporating flood zone characteristics for simulation may be divided into two levels: (1) Low level flooding "inches" with effect on wind boundary layer and wind loading on structures in the flood zone; and (2) High level flooding "feet" with bottom-up wave and current loading in addition to the top-down wind loading. The oscillating water surface will also affect the wind loading in the flood zone.

It was noted that wind and water-borne debris contribute significantly to coastal damage to the built and natural environment. Models of this behavior should be incorporated into the testing, particularly for impacts on structures. Full-scale tree failures should also be considered in developing the facility.

The workshop discussion on equipment needs for this concept facility generated the following items:

1. Sensors to measure at various scales wind and wave direction using Light Detection and Ranging (LiDAR), radar, and large Particle Image Velocimetry (PIV);
2. Large 3D printer to create structural models;
3. Sensors to estimate turbulence intensities in water and wind;
4. Sensors with the ability to simultaneously measure inflow (speed, turbulence, profiles), pressure, and member strains up to damage;
5. Create standard base models that users can implement so as to avoid very high costs every time the facility is used;
6. Wave directionality to incorporate the effect of non-aligned waves and wind;

7. Ultrasonic wave gauges, pressure gauges, acoustic range finders, acoustic doppler velocimeters (ADV), submersible load cells, optical tracking, digital high-speed cameras, digital video, survey instruments (total station, laser scanners), position transducers, and optical back scattering; and

8. Video and audio capabilities for various time scales, which will require adequate lighting.

All these types of equipment should be sturdy and durable enough to survive wind speeds greater than 150 mph as well as extreme wave action. If not, such equipment must be developed.

The discussion of a reasonable time frame started with a consideration of the time frames of smaller scale facilities for wind or water alone, for example the Insurance Institute for Business & Home Safety (IBHS) facility (https://ibhs.org/). It was noted that after a year of design charrettes, IBHS broke ground in 2009, and the facility was completed in 2010. It was noted that the University of Miami has a small-scale combined wind and wave facility, and that they should be consulted about the time frame. Others felt a minimum of six years from concept to completion was appropriate, which would include the steps of conceptualization, feasibility studies, prototype testing, validation, and construction. The Conference Chair (J. Rochman) suggested that the group consider a sort of modular framework for the structure; i.e. start with the simplest possible structure to begin basic testing and then integrate more complex capabilities over time.

7 Involving Emerging Trends in Artificial Intelligence, Machine Learning, Renewables, and Numerical Simulations (FEM, CFD and FSI) Using High Performance Computing

There is an increasing need to develop powerful high-fidelity computational models that are experimentally validated while accounting for the dual impact of wind, surge, and wave. To understand the role that the proposed MsRI facility will play in propelling research in Artificial Intelligence (AI), Machine Learning (ML) as it applies to wind engineering, and numerical simulations using finite element methods (FEM) or computation fluid dynamics (CFD) using high performance computing (HPC), the panelists were posed with two questions:

1. *What are some of the major research gaps related to the role of* ***Big Data*** *analyses or AI to boost traditional wind/wind-water engineering to validate the computational models*? [Note: Recent major advancements and use of big data technologies have helped develop better risk assessment models. For instance, numerous climate scenario simulations are being run on super computers, primarily by training physical and statistical models to incorporate extreme events. Similarly, a wide variety of data, including damage observations and loss or claims, is being used to develop fragility and vulnerability functions [30-31] – all in an effort to help more accurately assess risk at various scales from the individual building level all the way to country and continental scales. Similarly, big data and advances in AI hold extraordinary potential for transforming the wind energy sector.]

2. *What are the essential elements of an MsRI facility that will propel computational modeling, advance risk assessment and loss estimation tools, and make use of emerging areas such as Big Data, AI, ML, Robotics, to mention only a few*?

The following are the major conclusions from the panel discussion:

- Analyzing the loads and response of complex structures such as bridges and coastal structures subjected to hurricane wind, surge, and waves requires performing high fidelity numerical analyses with significant computational costs. Beyond individual structures, more recent numerical simulations have been used to model and study several aspects of large-scale communities and cities including performance of individual buildings to disasters, pollution effects, and sustainability requirements, among others. CFD analysis provides an effective and unique tool to assess these various aspects especially given the advancements in computational capabilities. However, the significant variability and uncertainty in the operating and design conditions together with the lack of validation of these models using experimental data pose a challenge when interpreting results as a basis for design decisions. Furthermore, given that most of these complex neighborhoods are situated along vulnerable U.S. coastlines, the combined effect of wind and water plays a major role, and the need for such data to validate the complex computational models has never been more opportune.

- Assessing the performance of complex systems in a risk assessment framework requires a large number of training samples to accurately capture failure probabilities. As a result, surrogate models are being used for predicting the structural response and the fragilities for these structures while leveraging ML techniques for classification and regression problems. Other applications employing ML techniques for probabilistic hazard modeling, such as surrogate models of hurricane surge and wave, are derived to alleviate the computational cost of high-fidelity hydrodynamic models. Ultimately, a combination of physics-based and data-driven methods for improving the accuracy and efficiency of reliability and risk assessments holds significant promise.

- When considering individual buildings within a neighborhood and community a strong coupling exists between CFD and computational structural dynamics, especially as buildings begin to vibrate. Solving such problems can become extremely costly even with recent advancements in computation power. With a facility like the one proposed, it would be extremely beneficial to have the capabilities of creating a cyber-physical (hybrid) system that would allow a feedback-driven interaction between the experimental set-up and numerical models.
- Other important factors revolve around measurement, curation, quality control, and dissemination of data that will be collected in the proposed facility. When it comes to AI, ML and any other data centric methods, good quality data are quintessential. Collection of high resolution spatial and temporal measurements are essential as researchers aim to validate and scale up numerical models to operate at neighborhood scales. While data collection is important in and of itself, curation, quality control, storage, dissemination, and reproducibility are equally if not more important. These aspects should be in the forefront as the facility is conceptualized and designed.

8 Fostering Education, Training, Partnerships, Industry Involvement, and Public Awareness

This session focused on education, partnerships, and public awareness, and the panel was organized to respond to the following two questions:

(1) What student or early career scholar education and training strategies do you recommend in order to better integrate engineering, social science, and policy in order to ensure a diverse and prepared 21st century workforce?

(2) What outreach and impact strategies do you recommend to advance hazard resilient, equitable, and sustainable communities that prioritize collective well-being?

The panelists and participants offered five key insights and recommendations that are included here for consideration moving forward, synthesized as follows:

First and foremost, decades of social science research have shown that disasters disproportionately impact members of historically marginalized communities, including those from communities of color, persons living in poverty, the elderly, and persons with disabilities [32]. For this reason, and because this facility has such potential to influence the lives of so many people, it is crucial that considerations of social and economic inequality, justice, and equity be integrated into the project from the outset [33-34]. This will not only broaden the scope of the research questions, but also will be key to recruiting diverse students and early career faculty and engaging those living at-risk in the research enterprise.

Second, movement from traditional "top-down" approaches to knowledge production, education, and outreach toward more egalitarian and community-driven "bottom-up" approaches, is crucial (see Figure 6). In the top-down approach, researchers design studies, develop solutions, and then attempt to move them toward adoption. The bottom-up approach treats communities as living laboratories and respects the knowledge and wisdom of the people who are living in increasingly hazard-prone areas. As such, the research process begins through listening and engaging with community members, and then moves toward the identification of research problems, questions, and potential solutions using a participatory action research approach. Not only do such approaches help increase student learning outcomes, they can also lead to greater community buy-in and speed adoption of hazard mitigation alternatives [35].

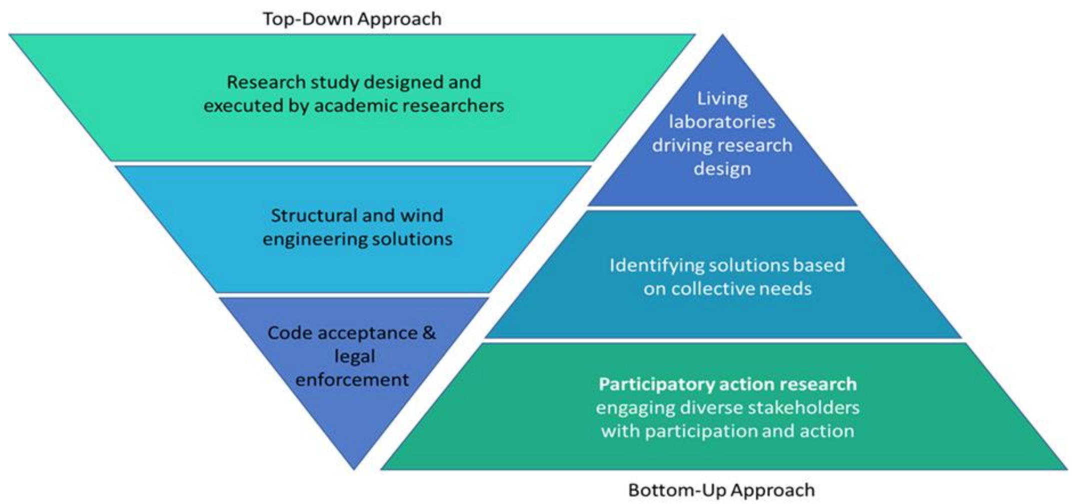


Figure 6. Traditional Top-Down Approach to Research in Comparison to the Bottom-Up Approach

Third, new technologies such as hazard simulations and risk visualizations are an additional option for engaging students, community members, funders, and other potential stakeholders in the work of the proposed facility. In particular, the use of virtual reality and augmented reality experiences can help raise awareness of the potential harm caused by disaster events and can be used to spark community action in response. The key to such simulations is to ensure that any potentially unsettling information is coupled with actions that individuals, families, and communities can take to respond to the risks. This notion of "communicating actionable risk" [36] is exceptionally important as it serves as a reminder to move beyond communicating simply what the risk is, and toward communicating what can be done about it -- particularly by those who may have the least resources with which to respond to the risks. [37].

Fourth, it is important that the facility leadership think broadly and inclusively—using what the Federal Emergency Management Agency refers to as a "whole community" approach—to developing partnerships and building the coalition of stakeholders involved in various research, education, and knowledge dissemination activities. Community resilience goals are more likely to be achieved when diverse segments of the community are involved in the research enterprise as well as solutions-development and implementation. The whole community perspective can help the facility move beyond engineering practice and into thinking about the beneficiaries of advanced engineering design. Because most people spend the majority of their lives inside buildings [38], everyone has a stake in safer single-family homes, rental units, schools, businesses, government offices, healthcare facilities, places of worship, recreational facilities, and myriad other daily life places. This means that engaging new and different leaders in the facility from different segments of society might help accelerate the adoption of the innovations that are generated.

Fifth, the facility should adopt a *convergence research framework* to ensure that the research, education, and outreach goals are achieved. ***Convergence*** is defined here as "an approach to knowledge production and action that involves diverse teams working together in novel ways, transcending disciplinary and organizational boundaries, to address vexing social, economic, environmental, and technical challenges in an effort to reduce disaster losses and promote collective well-being” [39]. This framework, which is both problem-focused and solutions-oriented, can help mobilize researchers, practitioners, and policy makers to respond to the many urgent environmental and social challenges that confront humanity in general but particularly the nation’s and world’s most marginalized people. For convergence to happen, however, interdisciplinary and transdisciplinary teams must be supported to study and respond to society’s grand challenges. These teams should involve from the outset those with social science, engineering, natural science, public policy, and other domain expertise. This facility has the opportunity to help advance the convergence revolution through broadening the horizons of scientific inquiry, building larger coalitions and more robust partnerships, and ultimately responding more effectively to increasingly complex environmental and social challenges. Moreover, engaging such diverse partners from the outset can also help to mitigate some of the unintended consequences of generating technical fixes for what are fundamentally human problems [40].

While it obviously takes time and effort to build interdisciplinary and transdisciplinary teams and to develop diverse coalitions engaged in convergence action, there are major benefits to professions and societies in the long run. Ample guidance is now available in the research literature on how to build diverse teams and develop strong partnerships both within and across academia and beyond. This facility has transformational capabilities if it centers education, partnerships, and public outreach from the beginning while taking questions of diversity, social equity, and inclusion seriously.

9 Implementation Plans and Risk Management

Session Presenter

Michael Browdy, DPR Construction

Contributing Panel Members

- Ryan Bushea, DPR Construction
- Patrick Meagher, Florida International University Facilities & Construction
- Julie Rochman, Retired Insurance Industry Executive

Aim

The aim of this session was to summarize the need, overall concept, and design criteria for a future mid-scale research infrastructure. The discussion was facilitated by a project management expert and covered such MsRI topics as project feasibility, required resources, utilities considerations, regulations, timeline, and the risks with providing the envisioned research infrastructure.

Major Findings

Project feasibility centers around the unique nature of a full-scale 200mph wind and wind-water testing facility, and the design criteria needed for the combined, complex, interdependent effects of wind, surge and waves as they relate to required resources/subject matter experts, site selection, design/program criteria (including utility considerations), and budget considerations. An initial overview was provided to outline the inherent risks in the project delivery of such a facility, recognizing the importance of creating a robust project management plan to manage such risks. Considerable discussion focused on "planning with the end in mind" and how early design decisions will help define the overall goals and effects on total life cycle costs versus initial development budgets. The risk analysis discussion attempted to respond to several questions, including (1) How the science could work in concert (wind, surge, and water); (2) How the facility would change over time; and (3) How many questions/research criteria would be solved with such facility? The top risks that were discussed in more depth included custom solutions, budget, site selection, changes over time, and design/operation considerations.

Testing multiple hazards at full-scale simultaneously poses unique challenges from a custom solutions perspective. The future design would need to consider:

- Target wind speed (e.g. number of fans; fan capabilities – cfm and pressure head; power needed, voltage needed, etc.),
- Rain (e.g. water supply; spraying nozzle arrangement and size, etc.), and
- Surge and Wave (e.g. water and power supply; tank size and maneuverability; wave simulator power and response; scaling issues; wind shear on water surface, etc.).

Special attention would be required in defining the simulation criteria as they pertain to the bathymetry of the wave basin, the throughput of the testing chamber(s), the number of wave pools, scale of specimens, lighting requirements, aging, and research flexibility programmed in the design. An example would include defining the parameters of the conveyance system as it relates to full-scale specimen testing and the capacity, safety, and wear and tear (wind/water) on such system.

In terms of budget risk, it was noted that first cost (including hard/soft costs of development) normally ranges only in the 15%-20% of the total life cycle cost of these types of facilities. Special attention will therefore need to be paid to the following:

- How might the facility change over time?
- What will be the return on investment strategies?
- Are Material/Systems selections going to be made with operations/maintenance/replacement/depreciation costs in mind over the life cycle of the facility?
- What custom versus commercially available solutions are planned/budgeted for?
- How will legacy funds be defined/protected for operations/maintenance?
- What sustainability initiatives can help offset first cost expenses over the lifecycle of the facility?

Additionally, once a clearly defined design criteria/program is established it is important to deliver this project through a collaborative design/build or Construction Manager (CM) at Risk delivery model to have resources to help inform some of the decisions that lead to budget risks. With so much still undetermined (i.e. scale, location, program needs, etc.), a forecasted budget would be better defined during the next steps of development.

Site selection will play a vital role in managing the overall implementation of this facility. The design criteria should be identified from a power, water/sewer, and special systems infrastructure perspective to ensure that appropriate utility considerations inform the location of the facility. Regulatory coordination would also be needed depending on the jurisdiction and/or necessary approvals required well in advance of design development and any local Authorities Having Jurisdiction (AHJ) permitting process. This would include, but may not be limited to local, state and federal compliance/review for environmental concerns, building codes, and site utility coordination. Scientists and planners will need to consider is how this facility might change over time in order to adapt to evolving research criteria. It is also worth noting that instrumentation/infrastructure demands are ever evolving, and the technology would need to adapt and have flexibility within the facility to be modified over time, including data storage and artificial intelligence.

Lastly, design and operational considerations would help inform the overall objectives of the facility while trying to balance its initial/life cycle cost implications. As the program informs the type of spaces/adjacencies for operational efficiencies, many factors would need to be analyzed, including:

- Structural Design for large span clearances & Category 5+ hurricane simulations both inside and out

- Security and controlled access – Site Specific & Testing Protocol
- Managing specimen construction time without interrupting facility use
- Hardware - Instrumentation/Equipment parameters
- Infrastructure - Power/Water Source
    - Energy/Heating Loads (i.e. Cooling System for Fan Drives)
    - Sustainability/Peak Demand
    - Water filtration system or saltwater simulation
- Damage to sensors and equipment over time
- Inlet and outlet of Test Chamber - Safety and protection
- Laser Measurement and Metering Devices - Safety Protocol
- Noise levels and noise suppression
- Debris wall (Height, depth, material type, etc.)
- Weather Related Events Protection/Operations Protocol
    - Lightning protection and surge protection
- Test environment conditions for accurate measurement (e.g. environmental wind interference, electrical noise contamination, acoustic measurement issue, automated roughness control, turntable accuracy, etc.)

It was acknowledged that workshop participants provided valuable insights to help inform the challenges and solutions that this type of facility development will encounter during the planning phase. This facility would help inform future research and would require the involvement of many stakeholders in the delivery of a successful design. It would be crucial to engage all the likely involved disciplines early in the planning process to help inform the project's vision and goals. From a project management perspective, the risk management processes would need to be proactively managed throughout the entire life cycle to avoid surprises that would hinder the ability of the facility to operate for its intended purpose.

Session Summary

During this session, discussion focused on MsRI project feasibility, required resources, utilities considerations, regulations, timeline, and the risks with providing the envisioned research infrastructure. Associated risks included the need to develop custom solutions to generate the target wind, surge, wave, and rain and fields at such a large scale and intensity. In addition, a custom designed flow management system, combining active and passive flow generators, may have to be conceived and built to simulate extreme hurricanes with maximum wind gusts higher than 200 mph. Moreover, the facility would need to use state of the art equipment and instrumentation that might not be currently available in terms of range, capacity, and response requirements. The instrumentation would need to perform in extreme wind and water environments. The knowledge from past lab and field testing would be a valuable guide in evaluating the risk levels associated with instrumentation and equipment. A project execution plan (PEP), required for construction of the facility, would be informed by continued research and development discussions. The strategic goals and objectives for operations and management of the future MsRI were discussed, with a heavy focus on managing total life cycle costs versus initial capital cost expenditures.

10 Conclusions

10.1 Scientific Justification and Needs

A multi-disciplinary group of 50+ experts participated in the MsRI conference to identify research infrastructure concepts for a national, full-scale, 200 mph wind and wind-water testing facility capable of supporting research and testing beyond the wind speeds and scales currently achievable in the U.S. and globally.

The central argument for building such a wind-water facility was that wind and surge/wave effects are not necessarily additive and therefore not adequate to study infrastructure performance and non–linear behavior. Limited past studies showed that results from isolated studies did not match those for the combined action of wind, surge, and waves [41-42]. For coastal structures the peak aerodynamic and hydrodynamic loading can occur at different times. Stochastic analysis is able to address this issue by adding the effects probabilistically, but the nonlinear behavior of structures and phase difference between time-varying loads can preclude simple summation of wind and surge/wave effects. Such cases indicate that realistically capturing system performance requires studies performed under various levels of combined action. *The value of an MsRI facility of this type will be its ability to accommodate a system-level approach that considers nonlinear behavior of the materials together with the complexity of dynamic loading effects*.

The new testing capability would allow loading and breaking full size structures in a repeatable environment of transient wind and water. Moreover, it would yield fundamental knowledge on natural and built environment cascading effects, including incorporating morphological changes due to the combined hurricane-induced stresses, scour, sediment transport, wind-wave-vegetation interactions, and wind and water-borne natural (trees) and built (other structures) debris. In addition, the facility will provide key data that would help inform the insurance industry's determination of the separation between water damage and wind damage (including rainwater damage).

From a community or urban resilience perspective, the facility will not only enable full-scale testing, but also testing of a scaled (e.g. 1:5 or 1:10) portion of a community (similar to the Mississippi river basin model [25-26]). This would allow investigation of shielding effects, debris flow and damage, and even dependencies within and across networks. One of the most challenging questions that arises with community-level modeling is the ability (or lack thereof) to validate the models for initial (and subsequent) damage and loss of functionality. The facility will also help to advance real-time and geographically distributed hybrid simulation for wind-wave-structure interactions to more fully understand individual building responses while physically simulating a neighborhood.

Leveraging Machine Learning (ML) techniques are being used for predicting the response and fragilities for structures. A combination of *physical testing* at the MsRI facility and *data driven modeling* can be significantly cost effective in improving the accuracy and efficiency of reliability and risk assessments for complex systems.

The broader impact of the MsRI facility would be achieved through *"vulnerability reduction"* based on the ability to test full-scale structures (or large-scale community models) under high winds/waves to see which and to what degree different designs and/or retrofits work (or do not). This is crucial for achieving cost-effective mitigation. Mitigation products (e.g., flood barrier fabric structures) can be tested and validated for safe design and deployment to reduce losses. The new facility will be a significant step forward from current prescriptive designs and component-based lab testing (ASTM, TAS, etc.).

Examples of research topics that can be improved by combined simulations of wind, surge, and waves at prototype to large scales are as follows:

- Simultaneous loading (wind or wind + waves) + capacity (strength) assessment on actual buildings (or components) up to damage;
- Effect of bi-directional correlated loadings of wind and waves on buildings, large scale structures, including offshore wind turbines;
- Wind-water-soil interactions and their effects on foundations of civil structures (e.g., potential erosion in tower foundations);
- Flutter in loose membrane flood barriers under wind-wave loads;
- Performance of natural and nature-based systems to mitigate surge and wave effects on beaches and coastal environments;
- Bio-inspired structures and bio-inspired mitigation innovations;
- Debris dynamics for wind and wave conditions;
- Aeolian erosion and sediment transport and effects of morphological changes;
- Deterioration of infrastructure performance under aging and concurrent and sequential loadings effects;
- Functionality of shelter-in-place structures that may become the new normal due to pandemic related societal change;
- Benchmarking to validate computational modeling of multi-phase flow (e.g., wind-wave) effects (and their uncertainties) on the built and natural environments;
- Multi-hazard fragility functions and probabilistic risk modeling of community as system-of-systems under coupled hazard modalities (e.g., wind, rain, debris, surge/waves);
- Advance community-scale modeling to inform hazard modeling, urban planning, air quality modeling, wind energy options, etc. through testing of geometrically scaled models of entire communities;

Create holistic datasets for benchmarking to support future research (data reuse) while implementing reproducibility and enact FAIR (Findable, Accessible, Interoperable, Reproducible) data standards and promoting equitable use of artificial intelligence (AI).

10.2 Design Challenges

While the "bigger is better" viewpoint was discussed, the participants urged for careful consideration between size and speed as design requirements. Full scale data under controlled laboratory conditions are currently not available. Scale effects remain a challenging issue for some research questions. Inadequate scaling of Reynolds and Froude numbers continues to pose challenges for scale model testing. Full-scale or near full-scale testing of structures will help to alleviate those challenges.

Nevertheless, major challenges of a full-scale facility exist related to the need for, and the feasibility of, combined wind and water (surge, wave) effects, especially for extreme wind, surge, and wave conditions. For example, a key question is whether there is a need to combine wind and wave simulations under extreme wind speeds of ~200 mph. Given the expected high cost of such facility, it needs to be ascertained when and why combined effects of wind and surge/waves need to be investigated experimentally and at full-scale. The participants discussed the simulation scales, the economic and technical feasibility, and the possibility of complementing the MsRI with cyber-physical testing and field data. *Hence, the design of a new facility would need to focus on problem that needs to be solved and priority list expected achievements*. *Research needs to be pursued to more fully understand what different scales and/or speeds are required for simulating the combined effects of wind and water on civil engineering infrastructure*. *Also, research needs to performed to determine the range of wind and wave parameters that can achieved based on the economic and technical feasibility.* Physical (scaled model facility), computational, and cyber-physical simulations may have to be considered in making that assessment.

Simulations of both synoptic and non-synoptic (nonstationary) phenomena were emphasized for the MsRI to advance knowledge on hurricane impacts, gust front loading, fluid structure interaction (FSI), Helmholtz modeling for internal pressure, and multiple hazard modalities, e.g., wind-driven rain (WDR), windborne debris (WBD), and surge/waves. The facility should aim to fill current research gaps in collecting, sharing, and integrating big experimental-based data (BIG DATA) into high-fidelity computational modeling. The facility is expected to leverage emerging trends in artificial intelligence, cybersecurity, and robotics.

It was discussed that the construction first of a smaller facility combined with extensive numerical modeling would provide input to the optimal design of a facility for full-scale (and near full-scale) testing. *Such a smaller initial facility would also provide insight on some fundamental science questions regarding scaling requirements for combined simulation under extreme conditions*.

10.3 Convergence, Outreach, and Education

Workshop participants agreed that the facility adopt a convergence research framework to ensure that the facility remains problem-focused, solutions-oriented, and engages diverse disciplinary and professional perspectives from the outset. *Convergence* was defined at the workshop as "an approach to knowledge production and action that involves diverse teams working together in novel ways, transcending disciplinary and organizational boundaries, to address vexing social, economic, environmental, and technical challenges in an effort to reduce disaster losses and promote collective well-being."

It was clear to the participants that research at the MsRI facility would have wide implications for policy and policy change, and will require the involvement of many disciplines, including engineering, the social sciences, planning, policy studies, business, and information technology. In the end, for the facility to make research contributions to improved community policy and planning, active multidisciplinary involvement will be necessary because many community-level resilience metrics are socio-economic.

Another conclusion was that the proposed MsRI facility would achieve transformational impacts if it embraces education, partnerships, and public outreach early-on while fully incorporating diversity, social equity, and inclusion concerns. That is, the MsRI facility should use a "whole community" approach to developing partnerships and building a supportive stakeholder coalition, including leaders from the public and private sectors, education, healthcare, religious institutions, and other key areas of social and economic life.

The whole community perspective will help the facility to move beyond engineering practice and into thinking about the ultimate beneficiaries of advanced engineering design. Because most people's lives are spent inside buildings, everyone has a stake in safer single-family homes, rental units, schools, businesses, government offices, healthcare facilities, places of worship, recreational facilities, and the myriad other "daily life" places. Engaging new and different leaders in the facility's research will help accelerate the adoption of the engineering-based innovations.

It was noted that disaster research has established that losses are not evenly distributed across a society, and that facility planning should consider social equity and justice from the outset to ensure that the knowledge produced helps to reduce, rather than exacerbate, preexisting inequities. A *bottom-up* approach treats communities as <u>living laboratories</u> and respects the knowledge and wisdom of people who are living in increasingly hazard-prone areas. Not only do such approaches help increase student learning outcomes at the university level, they can also lead to greater community buy-in and support for loss reduction measures. Bottom-up approaches facilitate engaging more diverse students and community partners, who would have a say in the research process and the outputs produced. *Such an approach will help produce responsive mitigation solutions by accelerating translation from research knowledge to policy and practice*.

It was noted that the use of new technologies, such as hazard simulations and risk visualizations, offer additional options for engaging students, community members, and other potential stakeholders in the work of the proposed facility. In particular, the use of *virtual reality* and *augmented reality* experiences can help raise awareness of the potential harm caused by disaster events and can be used to spark corresponding community action. The concept of "communicating actionable risk" is exceptionally important as it serves to remind all involved that it is crucial to move beyond communicating <u>what the risks are</u> and toward communicating <u>what can be done about them</u> – particularly to those who often have the least resources to deal with their risks.

Finally, participants agreed that the MsRI facility will provide a critical site for fostering novel education and training opportunities for students and early career scholars, and that it would produce responsive mitigation solutions together with best practices from the social sciences, economics, and other disciplines to more effectively and efficiently translate knowledge into policy and practice.

10.4 Project Management

Determining the feasibility of an MsRI project centered on a full-scale 200 mph wind and wind-water testing facility, and the design criteria for the combined, complex, and interdependent effects of wind, surge, and waves requires a project execution plan (PEP). Needed for the construction of the facility, such a PEP will have to be informed by continued research and development discussions. Workshop participants discussed the strategic goals and objectives for managing and operating the future MsRI and were heavily focused on the facility's total life cycle costs versus its initial capital cost expenditures. Creative use of green infrastructure and renewable energy coupled with storage capabilities should be encouraged in the facility design. It was noted that the PEP has to include subject matter experts and consider resources, site selection, design/program criteria (including utility considerations), and budget.

An initial assessment to outline the inherent risks in delivering such a complex facility recognized the importance of creating a robust project management plan to address such risks. The major risks discussed in more depth included custom solutions for such a unique facility, budget, site selection, use changes over time, and design/operation considerations. More specifically, the design would need to consider:

- Target wind speed (e.g. number of fans; fan capabilities – cfm and pressure head; power needed, voltage needed, etc.),
- Rain (e.g. water supply; spraying nozzle arrangement and size, etc.), and
- Wave (e.g. water and power supply; tank size and maneuverability; wave simulator power and response; scaling issues; wind shear on water surface, etc.).

Workshop participants noted that once a clearly defined design criteria/program is established, the delivery of this project will require a collaborative design/build or Construction Manager at Risk (CMAR) model with resources adequate to inform decisions that lead to budget risks. Regulatory coordination would also be needed depending on the jurisdiction and/or necessary approvals required, for example under the local Authorities Having Jurisdiction (AHJ) permitting process, which would have to be determined well in advance of design development.

It was also noted that the facility would need to use state of the art equipment and instrumentation that might not be currently available in terms of range, capacity, and response requirements. In addition, the instrumentation would need to perform in extreme wind and water environments, and knowledge from past laboratory and field testing would be valuable in evaluating the risk levels associated with instrumentation and equipment. Scientists and planners will need to consider how this facility might change over time in order to adapt to evolving research needs and criteria, in part because instrumentation/infrastructure demands are ever evolving, and the technology would need to adapt and have flexibility over time, including for data storage and increased use of artificial intelligence.

Finally, the workshop participants noted that design and operational considerations would help inform the overall objectives of the facility while trying to balance initial costs with life cycle costs. From a project management perspective, risk management processes will need to be proactively included throughout the entire life cycle to minimize the types of surprises that would hinder the facility's ability to achieve its intended objectives.

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APPENDIX A

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Julie Rochman; Retired property casualty insurance industry executive

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Jean-Paul Pinelli Ph.D., Professor at Florida Institute of Technology

Maryam Refan Ph.D., Technical Director, Americas Wind Tunnel Leader at RWDI

Maria Pia Repetto Ph.D., Professor, DICCA

Partha Sarkar Ph.D., Professor at Iowa State University

R. Panneer Selvam Ph.D., Professor at University of Arkansas

Barbara Simpson Ph.D., Civil & Construction Engineering Assistant Professor, Oregon State University

Wei Song Ph.D., Associate Professor, Civil, Construction and Environmental Engineering, UA Research, The University of Alabama

Nina Stark Ph.D., Assistant Professor AY Civil & Environmental Engineering, Virginia Tech

Theodore Stathopoulos Ph.D., Professor, Building, Civil, and Environmental Engineering, Concordia University Montreal

Benjamin Strom Ph.D., Co-Founder, XFlow Energy

Elaina Sutley Ph.D., Chair’s Council Assistant Professor, Civil, Environmental & Architectural Engineering, The University of Kansas

Yukio Tamura Ph.D., Professor, Director, Wind Engineering Research Center, Tokyo Polytechnic University

Teng Wu Ph.D., Associate Professor, Department of Civil, Structural and Environmental Engineering, School of Engineering and Applied Sciences, University at Buffalo - SUNY

Guirong (Grace) Yan Ph.D., Associate Professor, Structural Engineering, Missouri University of Science and Technology

Wei Zhang Ph.D., Associate Professor, Mechanical Engineering, Cleveland State University

Delong Zuo Ph.D., Associate Professor, Department of Civil, Environmental, & Construction Engineering, Texas Tech University

Project Management Experts

Mike Browdy, DPR Construction

Ryan BuShea, LEED A.P. | DPR Construction

Patrick D. Meagher, P.E., Director, Facilities Construction; FIU Facilities Management Department

Architectural Design Experts

Albert Elias, Information Architect/ Design Technologist/ Entrepreneur

Mark A. Marine, Director, FIU By Design, College of Communication, Architecture + The Arts

Special thanks to the Florida International University team members for their support in organizing this event: Dr. Arindam Gan Chowdhury (PI), Dr. Ioannis Zisis (Co-PI), Dr. Amal Elawady (Co-PI), Dr. Richard Olson, Ms. Carolyn Robertson, Ms. Elizabeth Alvite (Conference Coordinator) and Jocelyn Martinez (FIU AV Chief Engineer).

APPENDIX B

MsRI-EW: Conference to Identify Research Infrastructure Concepts for a National Full-Scale 200 mph Wind and Wind-Water Testing Facility

August 20-21, 2020
Online conference via Zoom:

August 20th	August 21st
https://go.fiu.edu/94486379714 MEETING ID: 944 8637 9714 Passcode: w670169 (additional details below)	https://go.fiu.edu/91545953524 MEETING ID: 915 4595 3524 Passcode: w53842 (additional details below)

Times below are EDT (Miami FL time)

AGENDA

August 20, 2020		
Time	**Item Description**	**Speakers, Chairs, and Panelists**
12:00-12:30	Introduction and Opening Remarks	PI: Arindam Chowdhury, EEI Director: Richard Olson, Conference Chair: Julie Rochman
12:30-12:50	Mid-scale Research Infrastructure (MsRI) Initiatives	NSF Program Director: Joy Pauschke
12:50-1:10	Keynote Talk on 'Need for an MsRI Facility to Lessen Windstorm Impacts' (at the end Dr. Mehta introduces Dr. Masters)	Kishor Mehta
1:10-1:50	Identify MsRI components/equipment/instrumentation needed to fill research gaps in characterization of the transient loading on the built and natural environments by hurricanes and associated hazards. (at the end Dr. Masters introduces Drs. Cox and Lomonaco)	**Session Chair: Forrest Masters** **Panelists:** Partha Sarkar; Murray Morrison; Theodore Stathopoulos; Yukio Tamura; Franklin Lombardo; Kishor Mehta; John W. Knezevich; Daan Liang
1:50-2:30	Identify MsRI components/equipment/instrumentation needed to fill research gaps in modeling the behavior of civil infrastructure systems (buildings and interdependent/interconnected lifeline infrastructure) under hurricane multi-stressors. (at the end Dr. Cox introduces Dr. Van De Lindt)	**Session Co-Chairs: Dan Cox and Pedro Lomonaco** **Panelists:** David Banks; Kurtis R Gurley; Christopher Letchford; Andrew Kennedy; Hermann Fritz; Barbara Simpson; Greg Guannel; Benjamin Strom
2:30-3:10	Identify MsRI components/equipment/instrumentation needed to fill research gaps in achieving storm readiness and speedy post-event recovery of civil infrastructure and communities by vulnerability modeling, shifting vulnerabilities via intervention, and enhancing reliability of systems. (at the end Dr. Van De Lindt introduces Dr.	**Session Chair: John Van De Lindt** **Panelists:** Alice Alipour; Marc L. Levitan; Nigel Kaye; Tracy L. Kijewski-Correa; Carol Friedland; Hannah Blum; Ashraf El Damatty; Ahsan Kareem

	Reed and announces the break)	
3:10-3:25	*BREAK*	
3:25-4:05	Identify MsRI components/equipment/instrumentation needed to fill research gaps in testing and validating potentially transformative mitigation strategies in achieving resilient coastal communities. (at the end Dr. Reed introduces Dr. Ramanathan)	**Session Chair: Dorothy Reed** **Panelists:** Girma Bitsuamlak; Delong Zuo; Bill Coubourne; Wei Zhang; Nina Stark; Suren Chen; Maryam Refan
4:05-4:45	Identify MsRI components/equipment/instrumentation needed to fill research gaps in collecting and sharing big data and information to validate computational modeling, advance risk assessment and loss estimation tools, and leverage emerging trends in artificial intelligence and robotics. (at the end Dr. Ramanathan introduces Dr. Peek)	**Session Chair: Karthik Ramanathan** **Panelists:** Jean-Paul Pinelli; Catherine Gorle; Luca Caracoglia; Victor Maldonado; Teng Wu; R. Panneer Selvam; Maria Pia Repetto; Stephanie G Paal
4:45-5:25	Identify MsRI components/equipment/instrumentation needed to fill gaps in integrating engineering research, social science, education, and outreach to achieve hurricane resilient and sustainable communities and create a diverse trained workforce. (at the end Dr. Peek announces the next session)	**Session Chair: Lori Peek** **Panelists:** Guirong (Grace) Yan; Jennifer Bridge; Yanlin Guo; YeongAe Heo; Elaina Sutley; Wei Song; Billy Edge
5:30-6:00	Discussion session	Conference Chair, Session Chairs, and MsRI PIs
6:00-7:00	Happy hour and discussion session	All participants
August 21, 2020		
Time	**Item Description**	
12:00-1:00	Presentations of Findings from Sessions and Q&A: • Each Session Chair will present THREE most important findings based on his/her session. The Session Chair will also discuss THREE most important Q&A items from his/her session. (7 min.) • Each Session Chair will facilitate participants' discussion. (3 min.)	Session Chairs and Participants
1:00-2:00	Discussion on the Mid-Scale Infrastructure to Address Grand-Challenge-Level Questions: • Fundamental research questions enabled by the MsRI facility (***scientific justification***) – Dr. Masters (10 minutes of discussion/engagement session) • Research topics that can be improved by combined simulations of wind and waves at prototype scales (***identify gaps in MsRI***) – Dr. Cox (10 minutes of discussion/engagement session) • Impacts and benefits of the envisioned MsRI facility (***needs for the facility***) – Dr. Van De Lindt (10 minutes of discussion/engagement session)	Session Chairs, Conference Chair, and Participants

	• Evolve emerging trends in Artificial Intelligence, Machine Learning, Renewables, and numerical simulations (FEM, CFD, FSI) using High Performance Computing – Dr. Ramanathan (10 minutes of discussion/engagement session) • Desired capabilities (simulation parameter ranges), required resources (equipment, sensors, utilities), and reasonable timeframe to realize the MsRI facility – Dr. Reed (10 minutes of discussion/engagement session) • Fostering education, training, partnerships, industry involvement, and public awareness – Dr. Peek (10 minutes of discussion/engagement session)	
2:00-2:20	Panel Discussion on the Strategies for Creation of an Education and Outreach Forum	EEI Director, Session Chairs and Participants
2:20-2:30	*BREAK*	
2:30-3:00	Discussion on the Implementation of the Plans/Construction for the Envisioned MsRI & Summarizing the Need, Overall Concept, and Design Criteria for a Future Mid-Scale Research Infrastructure	Project Management Expert
3:00-3:15	Flowchart discussion for a wind and water MsRI facility (based on deliberations in 1999 NRC Study)	Dr. Ahsan Kareem
3:15-3:45	Q & A	
3:45-4:15	Future Tasks and Concluding Remarks: • Action Items • Outcomes Report and Timeline • Closing remarks by Conference Chair, NSF Program Director, MsRI PIs	MsRI Conference PIs, Conference Chair, NSF Program Director
4:15-5:00	Happy hour and discussions session	All participants

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