Report on Discussions

Workshop: New Trends in Real-Time Hybrid Simulations to Advance Fluid-Structure Interaction Research

Workshop held February 8-9, 2023
at the Florida International University Wall of Wind, Miami, USA

Jointly sponsored by the NHERI-WOW, NHERI-RTMD and MECHS

Executive Summary

Recently increasing attention is needed to the complex interactions between wind/fluids and our structures. Windstorms and hurricanes seem to be occurring with greater frequency and at greater intensities. The research community needs a variety of methods to study these behaviors, for verification, modeling, mitigation and even understanding. Real time hybrid simulation (RTHS) combines computational models with physical testing to design an experiment that can exploit the information we know, to study what we do not know. The development of RTHS for Fluid-Structure Interaction (FSI) applications has been steadily making progress over the past several years. FSI research areas include, among several others, wind-structure interaction (e.g. aero-dynamic behavior), wind-induced vibrations (e.g. aero-elastic behavior) of slender structures, active wave absorption, advanced control for marine renewable energy (energy harvesting), behavior of marine structures (e.g. floating wind turbines, etc), and tsunami loading on structures. In 2020 MECHS formed a subcommittee on RTHS for FSI applications and they prepared a report summarizing the state of the research at that point in time. The 8th Workshop co-hosted by MECHS "***New Trends in Real-Time Hybrid Simulations to Advance Fluid-Structure Interaction Research***" was held on February 8-9, 2023 in Miami, Florida in partnership with the FIU Wall of Wind and the Lehigh RTMS facilities. A group of 45 researchers participated, including multi-hazard engineering researchers, graduate students, international partners and interdisciplinary collaborators. This report provides a summary of those discussions.

The workshop is jointly sponsored by the NSF-NHERI Wall of Wind EF, the NSF-NHERI Real-Time Multi-Directional EF and MECHS.

See the MECHS page for more activities and resources: http://mechs.designsafe-ci.org

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Introduction

An explosion in the use of hybrid simulation methods is now taking place. The use of this class of methods is becoming an essential tool to study the performance of infrastructure systems toward resisting the demands imposed by wind, tsunami, or storm surge. Researchers are also using it to explore thermo-mechanical, earthquake-induced fire, fluid-structure interaction, aerospace, and even biomedical engineering implementations of hybrid simulation are all being explored, significantly expanding the scope of this technology. Cutting-edge research is being performed in industrial settings as well, in particular to demonstrate and validate novel designs that are subjected to wave loading.

The Multi-Hazard Engineering Collaboratory on Hybrid Simulation (MECHS) – RTHS in Fluid-Structure Interaction (FSI) Applications committee, together with the NHERI Facilities at Florida International University (FIU) and Lehigh University hosted an in-person two-day workshop at FIU, Miami, Florida. The purpose of this workshop is to discuss the state of the art, and work that has been accomplished towards these goals. Breakout sessions considered the need for and challenges in performing RTHS. Various expertise from the FSI and RTHS fields used this opportunity to discuss strategies to expand HS/RTHS capabilities to the application of FSI engineering fields. During the workshop there was also an opportunity to learn about recent aero-elastic RTHS capabilities developed by Lehigh and FIU. A live demonstration was provided of a RTHS test, with wind loading occurring during the demo, and building actuation/feedback being controlled in real time from Lehigh University.

The discussion topics included:

- Cyber-physical testing approaches towards optimal wind/wave-resilient structures.
- Implementation and applications of RTHS aeroelastic and aerodynamic wind testing.
- Coupled Aerodynamic and Hydrodynamic Hybrid Simulation.
- Hybrid Simulation -FSI testing of wind turbines, tall buildings, bridges, etc.
- Hybrid Simulation-FSI testing to assess damping systems in structural systems.

This report is intended to document those discussions, and is being incorporated into the next generation of Research Agenda on Hybrid Simulation. This report and that research agenda are being posted on the MECHS site for the community: http://mechs.designsafe-ci.org. With these exciting directions, the various classes of hybrid simulation methods are making advances that allow a new set of problems to be tackled. However, many challenges remain, and over the next several years we will continue to overcome those challenges and advance the science and theory or hybrid simulation for future generations to use and explore as they tackle challenges in multi- hazard engineering.

Figure: Photographs from the Workshop Activities and the Live Demo.

Discussion Group Day 1 — MECHS Initiatives and New Trends in RTHS for Fluid-Structure Interaction: Lessons Learned and Future Action Plans

Discussion Leader: Shirley J. Dyke (*Purdue University)*

Participants/Affiliations:

Kamal Ahmed (*University of Washington*)
Kehinde Alawode (*Florida International University*)
Alia Amer (*Lehigh University*)
Tarak Aziz (*Texas Tech University*)
Hanna Blum (*University of Wisconsin-Madison*)
Liang Cao (*Lehigh University*)
Xinlong Du (*University of California, Berkely*)
Junyi Duan (*Purdue University*)
Amal Elawady (*Florida International University*)
Jeong Eun Ahn (*Rowan University*)
Navid Goudarzi (*Cleveland State University*)
Asma Harun (*Texas Tech University*)
Ali Irmak Ozdagli (*Florida Gulf Coast University*)
Dimitrios Kalliontzis (*University of Huston*)
Soolmaz Khoshkalam (*University of Massachusetts Dartmouth*)
Vasileios Kotzamanis (*University of Huston*)
Oh-Sung Kwon (*University of Toronto*)
Frank Lombardo (*University of Illinois at Urbana-Champaign*)
Pedro Lomonaco (*Oregon State University*)
Saidul Majumder (*Texas Tech University*)
Islam Mantawy (*Rowan University*)
Omar Metwally (*Florida International University*)
Edwin Patino (*Purdue University*)
Brian Phillips (*University of Florida*)
Shayan Razi (*University of Massachusetts Dartmouth*)
James Ricles (*Lehigh University*)
Santiago Ruiz (*University of Alabama*)
Shaikh Sadiqur Rahman (*Texas Tech University*)
Akiri Seki (*Stanford University*)
Tanima Sharker (*Texas Tech University*)
Wei Song (*University of Alabama*)
Arthriya Subgranon (*University of Florida*)
Haifeng Wang (*Washington State University*)
Ioannis Zisis (*Florida International University*)
Houssam Al Sayegh (*Florida International University*)
Ziad Azzi (*Florida International University*)

Main Points of Discussion

The conversation focused on the advantages and challenges of hybrid simulation in engineering. The main aspects of the discussion were related to hybrid simulation technology, including:

- Benefits of real-time hybrid simulation (RTHS) for validating structural designs and exploring advanced concepts.
- Need to involve more practicing engineers in these workshops in the future for technology transfer
- Importance of benchmark problems for evaluating the efficacy of hybrid simulation and identifying their limitations and requirements.
- Development of a curriculum that is helpful to individuals with and without a structural engineering background.

Participants zeroed in on the importance of including industry professionals, sharing knowledge and datasets in public forums, and expanding the scope of testing beyond the traditional laboratory settings. The need for continued research and development toward hybrid simulation testing was emphasized, as well as the collaboration with industry professionals to promote its potential benefits.

Exploring the Benefits and Challenges of Hybrid Simulation in Structural Engineering

During this conversation, the participants shared various ways to promote learning about RTHS (Real-Time Hybrid Simulation) and the progress made in developing an online curriculum on the MECHS website for new researchers. They suggested that webinars and workshops could be useful in helping people learn and improve their skills, particularly for those who cannot afford tuition fees. They also noted that offering options for faster-paced learning for those who already have some background knowledge could be beneficial. The ultimate goal is to make the curriculum accessible and inclusive while providing practical knowledge for real-world engineering challenges.

The participants listed helpful tools for students and informative for the industry to get involved into RTHS, some of these were workshops and webinars on topics of control, signal processing, and multi-hazard related areas, along with hands-on training. However, attracting industry professionals to these webinars is challenging, and the participants suggested involving industry representatives to generate interest. They also believe that developing methodologies for hybrid simulations, such as hybrid fire or hybrid wind engineering, can improve testing methods, gain more knowledge, and attract other engineering sectors.

The discussion also addressed the challenges of developing benchmark problems which are essential for improving simulation technologies and understanding their limitations and requirements. Although funding and incentives for benchmark problems are limited, the participants suggested seeking funding opportunities, collaborating with the industry and researchers in other fields in engineering, and demonstrating the potential benefits of benchmark problems to gain support for these projects.

The Benefits and Possibilities of Hybrid Simulation in Engineering

Some of the benefits of using RTHS that were listed by the participants included improvements in design codes and the resilience of structures under earthquake loads. RTHS allows engineers to design with greater precision and accuracy by better capturing the behavior of a structure under realistic loadings. Thus, helping to reduce the need for conservative assumptions and oversimplifications in their designs. This not only leads to cost savings but also improves overall performance. Compared to other testing methods, RTHS offers a more realistic picture of a structure's performance, making it a valuable tool for the codification process. In addition, RTHS testing is free from equipment failure risk, making it easier to modify and test different buildings without complications.

How can we bring more people into this field, especially those who are interested but not experts?

To further promote the use of real-time hybrid simulation, the group proposed organizing a workshop to build partnerships and showcase the technology to targeted industries such as structural engineering, steel, and concrete. Benchmark tests were also identified as important to establish the realism of real-time results in comparison to other tests and ensure the reliability of the simulations. Sharing knowledge and data is essential to gain a better understanding of real-world behavior, thus, collaboration with other universities and companies to share data and compare results was proposed to help with data analysis and improve the testing process.

The discussion moved towards the challenges and opportunities presented by hybrid simulation testing in the field of fluid-structure interaction. One of the main challenges highlighted was distributed loads and how they could be applied in a test, which can be addressed by exploring new actuator designs and determining the best testing scheme. Another important concern was the feasibility of hybrid simulation testing setups for experiments on wind turbines and ocean wave generators, which may require expensive equipment such as shake tables, large facilities, and specialized actuators. The group discussed the need to explore cost-effective alternatives using actuators rather than relying on expensive equipment. Additionally, the increasing complexity of structural models was highlighted as an issue that may exceed the capabilities of current computer systems. The group discussed the possibility of employing surrogate models or prediction using machine learning algorithms to manage computational complexity.

In general, the participants emphasize the importance of hybrid simulation in improving testing methods and gaining more knowledge about real-world behavior. More laboratories would like to have the ability to perform such tests, and those individuals want to learn how to get started. They suggested involving the industry into webinars, sharing knowledge and data, and expanding the scope of testing beyond traditional laboratory settings, which RTHS allows to do. The group emphasized the need for continued research and development in hybrid simulation testing, as well as collaboration with industry professionals to promote its potential benefits.

Action Items and Future Research Needs

- Organize workshops and learning activities on control, data and signal processing, computer vision, and multi-hazard related topics, along with hands-on training.
- Involve industry representatives to generate interest in hybrid simulation.
- Develop methodologies for other types of hybrid simulations that can be attractive to other fields such as fire, blast, or wind engineering.
- Use RTHS to improve design codes and the resilience of structures under earthquake loads.
- Develop benchmark problems or blind tests to support the community in building capacity
- Build partnerships and showcase current research technologies to targeted industries such as structural engineering, steel, and concrete.
- Share knowledge and data with other universities and companies to gain a collective understanding of real-world behavior.
- Explore new actuator designs, cost-effective alternatives, surrogate models, and prediction using machine learning algorithms to manage computational complexity.

Discussion Group Day 2 – Building Capacity in RTHS and FSI: Needs, Challenges, and Collaborative Solutions for the Next Generation of Wind Engineering Researchers.

Discussion Leader: Frank Lombardo (*University of Illinois at Urbana-Champaign*)

Participants/Affiliations:

Kamal Ahmed (*University of Washington*)
Kehinde Alawode (*Florida International University*)
Alia Amer (*Lehigh University*)
Tarak Aziz (*Texas Tech University*)
Hanna Blum (*University of Wisconsin-Madison*)
Liang Cao (*Lehigh University*)
Xinlong Du (*University of California, Berkely*)
Junyi Duan (*Purdue University*)
Shirley J. Dyke (*Purdue University)*
Amal Elawady (*Florida International University*)
Jeong Eun Ahn (*Rowan University*)
Navid Goudarzi (*Cleveland State University*)
Asma Harun (*Texas Tech University*)
Ali Irmak Ozdagli (*Florida Gulf Coast University*)
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Soolmaz Khoshkalam (*University of Massachusetts Dartmouth*)
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Arthriya Subgranon (*University of Florida*)
Haifeng Wang (*Washington State University*)
Ioannis Zisis (*Florida International University*)
Houssam Al Sayegh (*Florida International University*)

Main Points of Discussion

The main points of discussion were the potential of real-time hybrid simulation in wind and coastal engineering and identifies two main themes: a lack of awareness of this type of simulation and the difficulty of achieving realism due to a lack of benchmarks and real-world data. The discussion also addressed the challenges in validating real-time hybrid simulation in civil engineering, including the need for accessible and standardized data, as well as challenges related to small-scale laboratory wind tunnels. To address these challenges, collaborative approaches were suggested such as targeted field measurements, increasing awareness of the research being done, and collaboration between various stakeholders such as researchers, students, landowners, the government, and industry.

Challenges in Validating Real-Time Hybrid Simulation in Civil Engineering and the Need for Accessible and Standardized Data.

There are well-defined numerical problems in many other fields in literature outside of the civil engineering area that can be used for benchmarking. However, there is a lack of awareness of these problems among most people, therefore researchers need to look outside their typical domain knowledge to make progress in the RTHS field. There is also a need for more full-scale data to validate real-time hybrid simulation. For example, in tornadoes and thunderstorms, there is no benchmark, so testing those things in a wind tunnel provides no idea if it is realistic or not. Therefore, there is a need for more full-scale data to validate real-time hybrid simulation or other forms of simulation.

The challenges of accessing and using data for hybrid simulations in engineering were key discussion points as well as the importance of having easy access to validation data sources that are user-friendly. The participants that there are many data sets on DesignSafe, though it can be difficult to assess them because there are different formats and not everyone knows what is truly available. Furthermore, there is a significant barrier to standardizing the data format without proper funding.

The challenges of small-scale laboratory wind tunnels were also discussed and the need for researchers to have access to data servers with subfolders. Having a unified format for data would be beneficial, but it would require effort from all principal investigators. However, they acknowledge that even if data is standardized, reproducing the same experiments in wind engineering can still be challenging. It was suggested that documentation, including video recordings, could be useful in providing context and classifying the data.

Collaborative Approaches to Address Data Challenges in Structural Simulations.

The discussion moved to the challenges faced in acquiring data for structural simulations and how to work around them. The participants acknowledged that field measurements and structural reconnaissance are necessary for validating models but pose difficulties in acquiring the necessary data from landowners or the government due to various reasons such as confidentiality or legal issues. The participants also noted that industries, specifically those in wind engineering, possess a wealth of data that could be useful in validating these simulations but are unlikely to share them due to the same legal liabilities and confidentiality motives.

To work around these challenges, it was suggested that targeted field measurements could be implemented that focus on specific areas of the building or structure, such as the roof or basement, rather than a full-scale field experimentation. This approach may make it easier for industries to share data since it reduces liability concerns. Additionally, the group proposed that students who end up in industry could help spread awareness of the research being done and the benefits that they could gained from it.

In summary, the discussion highlights the need for collaboration between different stakeholders, such as researchers, students, landowners, the government, and industry, to address the challenges faced in acquiring data for structural simulations. While legal and confidentiality concerns remain, targeted field measurements and expanding awareness of the research being done could help overcome these challenges and benefit all parties involved.

Action Items and Future Research Needs

- Obtain more full-scale data to validate real-time hybrid simulations or other forms of simulation.
- Properly document, store and describe datasets to facilitate data sharing. Use documentation and video recordings to provide context and classify data.
- Implement targeted field measurements that focus on specific areas of the building or structure to facilitate negotiations on obtaining data or permissions from the industry or government.
- Increase the awareness of the industry and other research fields about the research being done in RTHS.
- Collaborate between researchers, students, landowners, the government, and industry by trying to overcome legal and confidentiality concerns to benefit all parties involved.

APPENDIX A: Agenda for the Workshop

NEW TRENDS IN REAL-TIME HYBRID SIMULATIONS TO ADVANCE FLUID-STRUCTURE INTERACTION RESEARCH

February 8-9, 2023

Times below are Eastern Time (ET)

AGENDA

February 8, 2023	
Time	**Item Description**
09:00-09:10	Welcome, introductions and Day 1 schedule – NHERI EFs and MECHS PIs
09:10-09:30	Overview of the NHERI Wall of Wind (WOW) Experimental Facility (EF) – Dr. Ioannis Zisis-*Florida International University*
9:30-9:50	Overview of the NHERI Lehigh Real-Time Multi-Directional Testing (RTMD) EF – Dr. James Ricles (*Lehigh University*)
9:50-10:20	FIU-Lehigh Collaboration to advance RTAHS in wind tunnel testing: Concept, Background and Implementation, Validation, and Prospects – Dr. Amal Elawady (*Florida International University*)-Dr. James Ricles (*Lehigh University*)
10:20-10:40	Advanced Applications: RTAHS testing with performance enhancing devices and Nonlinear Aeroelastic Wind Tunnel Testing using RTAHS technologies-Dr. Liang Cao (*Lehigh University*); Mr. Haitham Ibrahim (*Florida International University*)
10:40-10:50	**Short Break**
10:50-11:40	Tour of the NHERI WOW Experimental Facility – Dr. Steve Diaz-*Florida International University*
11:50-12:50	Networking Lunch
12:50-2:50	**Ongoing applications of RTHS in WE**
12:50-1:40	Keynote lecture: Real-Time Aeroelastic Hybrid Simulation Method for A Base-Pivoting Building Model and A Bridge Deck Section Model—Dr. Oh-Sung Kwon- *University of Toronto*
1:40-1:55	Research Presentation # 4: Development of Aerodynamic and Hydrodynamic Real-Time Hybrid Simulation for Floating Offshore Wind Turbines---Dr. Pedro Lomonaco- *Oregon State University*
1:55-2:10	Real-time hybrid simulation frameworks for offshore wind turbines—Dr. Wei Song- *The University of Alabama*
2:10-2:25	RTHS of Offshore Wind Turbine Structures with Hyrdodynamic-Aeroelastic-Soil-Structure Interaction Effects -- Dr. James Ricles (*Lehigh University*)
2:25-2:40	RTHS Opportunities at the NHERI University of Florida Experimental Facility—Dr. Brian Phillips- *University of Florida*
2:40-2:50	**Short Break**
2:50-3:10	MECHS initiatives: Discussions of future needs and action plans- Dr. Shirley Dyke- *Purdue University*
3:10-3:40	**Working Group Discussion**: Lesson Learned and current needs
3:40-4:00	Group Discussion with Facilities PIs/ office hours (3 groups: Lehigh-FIU-Purdue)
4:00-4:10	Concluding Remarks--- NHERI EFs and MECHS PIs
4:30-6:30	**One-on-one meetings**
7:00-9:00	**Dinner**
February 9, 2023	
Time	**Item Description**

09:00-09:10	Welcome and Day 2 schedule – NHERI EFs and MECHS PIs
09:10-10:00	Keynote lecture: Real-Time Aerodynamics Hybrid Simulation for Assessment of Bridge Post-Flutter Performance: Challenges and Prospects—Dr. Teng Wu
10:00-10:20	Recent Advances and Challenges in Wind Tunnel Testing- Dr. Ioannis Zisis (*Florida International University*)
10:20-10:30	**Short Break**
10:30-11:30	**Working Group Discussion**
10:30 – 11:00	**Discussion 1 (30 min):** Building Capacity in FSI and RTHS: Needs and Challenges. How the WOW, RTMD, MECHS can help in that?
10:30 – 11:00	**Discussion 2 (30 min):** Vision for Next Generation of Wind Engineering Researchers to further make progress in RTHS.
11:00-11:30	**Working Group Report and Actions Items (Day 1 and 2)**
11:30-12:00	Roadmap of Support Provided to NHERI EF Users – Dr. Steve Diaz-*Florida International University*; Dr. Liang Cao (*Lehigh University*)
12:00-12:30	Group Discussion with Facilities PIs/ office hours (3 groups: Lehigh-FIU-Purdue)
12:30-12:40	Closing remarks – NHERI EFs and MECHS PIs
12:40-1:30	**Snacks before leaving**

APPENDIX B: Photographs of the Event.

Figure B.1: Presentations of the available resources and services at NSF-NHERI Wall of Wind (WOW) and aero-elastic RTHS capabilities from Lehigh and FIU.

Figure B.2: NSF-NHERI WOW Facility Tour and RTHS Live Demo

Figure B.3: Discussions on building capacity, lessons learned, and futures steps.