Report on Discussions during the

5th MECHS Workshop:

Exploring Multi-hazard and Multi-physics Hybrid Simulation

held August 8-10, 2023
at Purdue University, Indiana, USA

Summary

When structural systems are too large or complex to test in the laboratory or the conditions cannot be replicated properly, the cyber-physical testing method known as hybrid simulation (HS) provides an important tool for their examination. HS has great potential to increase our expectations regarding standard engineering practices, but engineers and researchers should be able to run HS without needing the advanced skills of developers. Furthermore, synergetic efforts are needed to develop a new generation of HS platforms with which multi-hazard scenarios can be investigated as we aim to provide rigorous solutions to future infrastructure challenges.

The objectives of this workshop were to exchange ideas and share experiences on the use of hybrid simulation in both laboratory and industrial settings. The workshop gave participants a place to share the most recent advances in hybrid simulation approaches for structural testing, engage in research discussions, and consider potential partnerships with the industry sector. Researchers, students, and practitioners were all invited to participate in this workshop. The workshop was organized as a series of presentations mixed with discussions about the scientific challenges and opportunities that will motivate transformative advances in this versatile class of methods. A hands-on activity was organized based on a benchmark problem and attendees were able to design controllers and tried them out on a real RTHS experiment. Attendees learned also about leading-edge developments of the method, aiming at building capacity at more laboratories around the world. Another significant goal was to bring together a diverse group of international researchers to spark new collaborative opportunities.

The 5th MECHS Workshop "Exploring Multi-hazard and Multi-physics Hybrid Simulation" was held on August 8-10, 2023 in West Lafayette, IN. A group of 70 researchers participated, including multi-hazard engineering researchers, industry collaborators, graduate students, international partners and interdisciplinary collaborators. This report provides a summary of those joint discussions.

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

The Research Coordination Network in Hybrid Simulation for Multi-hazard Engineering is supported by a grant from the National Science Foundation (CMMI#1661621).

Introduction

Since the 1st MECHS Workshop "Breaking Barriers and Building Capacity" was held on December 12-13, 2017 at the University of California, San Diego the emerging class of testing methods known as hybrid simulation have been evolving and gaining traction in the multi-hazard community. Since that time, there has been an explosion of new applications for this powerful class of testing methods. Several workshops, including several targeted virtual workshops, have been held through MECHS to discuss technical challenges, as well as best practices and standardization of hybrid testing methods for various applications. MECHS aims to bring people together to participate in discussions and networking activities revolving around the common goals we share to reduce the consequences of the multiple hazards that affect our infrastructure systems.

Researchers, students, and practitioners were invited to participate in this 5th MECHS Workshop to exchange ideas and experiences on the use of hybrid simulation in both laboratory and industrial settings. The objectives of this workshop were to give participants a place to share the most recent advances in hybrid simulation approaches for structural testing, engage in research discussions, and consider potential partnerships with the industry sector.

It is clear that an explosion in the use of hybrid simulation methods is now taking place. The performance of infrastructure systems toward resisting the demands imposed by wind, tsunami, or storm surge is advancing rapidly. And well beyond that, researchers are also exploring 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.

This event attracted 70+ researchers to attend and join in the technical discussions and breakout sessions designed to evolve the research agenda for hybrid simulation forward while also engaging industry. Many more early career faculty joined than had ever joined in the past, and a large number of graduate students also participated. Industry professionals from various structural engineering companies grounded the discussions. Most of the travel for the academic participants was supported with the RCN participant funds. We also invited a speaker from NSF to attend and present about opportunities for writing proposals. Hands-on activities were part of the workshop, including a guided tour of Bowen Laboratory. Through these prepared group activities to design an RTHS test, all participants gained firsthand exposure to hybrid simulation. Although the hands-on activity was optional, over 40 participants joined for this session.

Topics of the Workshop:

- Overview of the latest developments in hybrid simulation and state-of-the-art methods.
- Challenges and opportunities in implementing hybrid simulation methods.
- Emerging trends and future directions in hybrid simulation for industrial applications.
- Hands-on activities and case studies of successful hybrid simulation projects in diverse areas.

Activities:

- **Technical sessions:** researchers and practitioners will deliver talks about their experiences using hybrid simulation in a variety of applications.
- **Keynote presentations:** invited experts will give an overview of developments in hybrid simulation techniques and their industrial applications.
- **Hands-on activities:** these activities will be conducted one day prior to the workshop to provide participants with an opportunity to familiarize themselves with hybrid simulation and work with common problems and receive feedback.
- **Networking:** various opportunities will be available for researchers and industry professionals to engage in casual discussions and break-out sessions, facilitating potential partnerships and collaborations in research.

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.

The momentum in hybrid simulation methods continues to increase, and the various classes of hybrid simulation methods are breaking through barriers that have traditionally limited these methods. Although many challenges remain, there is still work to do to advance the science and theory or hybrid simulation for future generations to use and explore as they tackle challenges in multi-hazard engineering.

Scientific Committee:

Hannah Blum	University of Wisconsin
Liang Cao	Lehigh University
Brian Phillips	University of Florida
Wei Song	University of Alabama
Mariantonieta Gutierrez Soto	The Penn State University
Frank Lombardo	University of Illinois
Pedro Lomanaco	Oregon State University
Tracy Becker	University of California, Berkeley
Jian Li	University of Kansas

Workshop Chair:

Shirley J. Dyke	Purdue University

Discussion Group A — Standards & Validation

Co-Chairs: Hannah Blum (*University of Wisconsin-Madison*)
Erik Johnson (*University of Southern California*)
Recorder: Hyeyoung Koh (*University of Wisconsin-Madison*)

Objective

This group discussed how to develop standards and validate RTHS results. The biggest challenges include (1) design code compliance, (2) validation, and (3) uncertainty quantification in structural systems, control systems, actuators, and more.

Main Points of Discussion

Industrial participants raised questions that revolved around how to demonstrate structural performance using RTHS. For example, an organization in the steel industry, the American Iron and Steel (AISI), has individual provisions regarding testing by analysis in AISI-S100, which allow the use of numerical analysis for design. Moreover, Florida International University has developed its own guidelines, and ASCE 7-22 permits computational fluid dynamics for assessing pressures. However, there are no overall codes that cover multiple construction materials, necessitating an umbrella code. This umbrella code would address general desired outcomes from RTHS and outline how to ensure reliability and repeatability.

Hybrid simulation is a field that is closely related to performance-based design, and a main question here is how to achieve validation of the results. Hybrid simulations combine physical testing with numerical simulations. We wonder how we can determine if the numerical side of the analysis is accurate. Since there are many good examples of physical testing, they can be used to validate numerical analysis. Data would be needed to support those activities.

Uncertainties in material and geometric properties should also be considered in RTHS. While validation for individual structural components seems feasible, it is more challenging for entire structural systems. We can focus on substructural testing for validation.

Standards for hybrid simulation are needed and this work should start by providing pre-standards. Different pre-standards for people engaged in various tasks such as numerical analysis, actuator setting, and controller setting should be developed. It should be noted that these guidelines can sometimes be subjective, depending on the providers.

Action Items and Future Research Needs

- Standards for hybrid simulation are needed
- Uncertainties in material and geometric properties should also be considered in RTHS
- Data is needed to enable validation work to be done

Discussion Group B — Capabilities & Facilities

Co-Chairs: Chao Sun (Louisiana State University)
Mariantonieta Gutierrez Soto (The Pennsylvania State University)

Recorder: Alejandro Palacio-Betancur (The Pennsylvania State University)

Objective

The purpose of this working group was to discuss the possibility of new capabilities and facilities needed for Real-Time Hybrid Simulation. More explicitly, we aimed to consider if there are new capabilities or funding opportunities what is needed to address specific research problems.

Main Points of Discussion

Presently, researchers are working to understand environmental patterns in a city and impacts of natural hazards within a community. While these studies predominantly rely on numerical studies, the implementation of hybrid simulation could improve the understanding of these phenomena on a regional scale. This approach would likely involve deploying sensors throughout a specific region and use of data driven modeling.

Another key discussion point included the use of hybrid simulation for a wide range of research topics beyond earthquakes. This includes strong winds, tornadoes, downbursts, current, tsunamis, soil-structure interactions, and effects of corrosion on new and old infrastructure such as buildings, bridges, dams, and transmission lines. However, there is a significant shortage of field measurements for many of these areas of study. Therefore, there is a need for large-scale field data in a reproducible manner that becomes essential to validate and calibrate new facilities that study these hazards, and to establish key benchmark problems. These benchmark problems can promote the use of RTHS in the research community and improve its acceptability in the industry sector.

During the discussion of lack of field data, it was also highlighted that this data can be used to calibrate and promote studies with multi-physics. For example, it can be used to calibrate NICHE research infrastructure or to advocate the use of geographically distributed RTHS to combine facilities that study different hazards. It was noted that there was previous research with this RTHS approach but the main issue that remains today is the time delay of communication between facilities.

Towards the technical aspect of using RTHS, it was noted that most implementations are in-house developments and there is not that much readily available hardware and software for entry level users of this method. There is specific software for simulations and control separately but there should be a development of an interface program that combines existing software to implement RTHS. This emphasizes a need for cost-effective solutions, particularly when large-scale applications are required. Moreover, it was suggested that a well-defined framework or a set of guidelines is essential to determine when RTHS should be utilized over other experimental techniques.

Action Items and Future Research Needs

- Data is needed for validation of models and methods
- Cost effective testing methods and entry level
- Benchmark problems that demonstrate repeatability and reproducibility
- Approaches for dealing with uncertainty
- Interfaces that help the user design controllers
- Guidelines to help determine when hybrid simulation is appropriate

Discussion Group C — Standards

Co-Chairs: Alia Amer (Lehigh University)
Arun Prakash (Purdue University)
Recorder: Lissette Iturburu (Purdue University)

Objectives

In this session, the attendees established a pathway to incorporate RTHS into existing standards such as IBC, ASCE, AISC and AISI. The following were identified as the critical issues: .

Main Points of Discussion

How to develop standards and guidelines for laboratories? Each laboratory has specific equipment and methods to solve a problem. Therefore, the RTHS community needs to establish guidelines instead of standards. In these guidelines the goal is obtaining accurate and repeatable results that can be compared to established acceptance criteria. The guidelines would not include the use of a specific controller for example, but rather would just focus on the result. For instance, Taylor Devices developed a set of guidelines with acceptance criteria to use their devices within a very limited scope. These criteria have been accepted by the International Code Council (ICC). Another problem that arises with laboratories is how do you trust the results. And here the attendees recommend the use of peer review such as done for ASCE-7 for new load patterns.

Should RTHS be applied for product development or for design? While the whole point of the testing is doing something innovative, to include RTHS in standards, first it needs to be accepted by the engineering body. Therefore, the RTHS guidelines needs to be implemented as a specification. Examples of what could be done that would not be a big leap from what is already well known, is to investigate torsional behavior or interactions of three-story steel frames benchmark problems.

Is the goal, simulation instead of testing? Some standardization bodies are starting to accept simulation instead of testing. Recently, FEM has started to be applied within the code umbrella of allowed methods. But RTHS should not replace testing, but rather be applied to reduce the number of tests. For example, if there is a new connection that needs to be tested, there would be a few tests and the rest would be hybrid simulation.

On the standardization bodies. The attendees see a way to include RTHS in codes through the analysis simulation task group in AISI's Committee on Specifications. This committee manages the cold-formed steel design specification. Therefore, the benchmark problem could be of cold formed steel. The first step is that a subset of attendees will join the task group to be member of the committee. And the goal will be for RTHS to be included in Chapter K of AISI-S100. This specification includes a minimum number of test samples, coefficient of variations, and other specific requirements on how to use your test data.

Action Items and Future Research Needs

- Standards and guidelines should be established that would focus on the purpose of the test
- A path for establishing these is started here, but more work is needed
- Acceptance criteria could be one step along that path forward
- Benchmark problems will help in meeting these objectives

Discussion Group D — Computational Challenges

Co-Chairs: Johnny Condori (Purdue University)
Christopher Gill (Washington University in St. Louis)
Recorder: Manuel Salmeron (Purdue University)

Objectives

The objective of this discussion was to identify and address computational challenges in RTHS, and to explore the potential of novel technologies in providing innovative solutions.

Main Points of Discussion

There is a perpetual **shortage of computational power**, particularly when it comes to matrix multiplications, which are computationally intensive. **Digitization** of models presents another challenge, complicating the simulation process. Estimating errors for model updates is complex, especially when dealing with serial or compound models. To mitigate this, efforts are made to stay in the analog domain for as long as possible, utilizing emergent technologies and sensors designed for specific components like isolators. However, there's a need for interdisciplinary collaboration to advance prototype designs.

The **timing of digitization** remains a critical question, especially for fluid-structure interactions that require small time steps. There is also speculation about using **multi-resolution models** that might incorporate a second layer of information with limited degrees of freedom (DOFs). Calibration of these models will necessitate extensive data collection.

The feasibility of **scheduling** was discussed concerning available resources and the demands of RTHS. There's a need to reconcile the fundamental relationship between control/physics and scheduling to ensure timely and accurate results.

What type of problems require computational power (that we may not have currently)?

Three main issues were discussed: **fluid-structure interactions**, **high-frequency systems**, and **computational paradigms**. Modeling fluid-structure interactions and soil in a computationally and temporally efficient way is essential, especially when systems can have higher frequencies, up to 20,000 Hz. These high frequencies create additional complications, making it crucial to stay in the analog domain as long as possible to avoid lag during digitization.

Energy-collecting systems were cited as an example of high-frequency systems that might have more degrees of freedom, making them an interesting problem for future research. Concerns also extended to the local effects, such as distributed masses at piles and pressure distribution.

Is there currently hardware to allow us to conduct these computationally demanding real-time experiments with high fidelity and accuracy?

Emergent technologies like **quantum computing** and **data-flow computing** were discussed as potential solutions for these computational challenges. However, the application-specific nature of existing hardware ("Hardware In the Loop") limits their generalizability. The topic of converting this into a more programmable format brought up funding and time constraints

There was also a discussion on the utility of **Field-Programmable Gate Arrays** (FPGAs) and potentially using matrix algebra libraries. Although these tools are useful for specific applications like simple nonlinear elastic problems, they may not be easily accessible for Civil Engineering students. C++ was mentioned as a more accessible tool.

Lastly, the conversation shifted toward applying **Neural Networks (NN) and Machine Learning (ML)** as possible substitutes for complex numerical substructures. While NNs hold promise, they come with limitations, mainly when the range of training data is restricted or if the assumptions under which they are trained are violated. This could have significant implications, especially in tests involving different environmental loads like wind and earthquakes. Moreover, the notion of "what does it take to make it wrong?" was brought up, suggesting that real-time hybrid simulations could benefit from training in **adversarial environments** to identify vulnerabilities.

Action Items and Future Research Needs

- Evaluate and review the current state-of-the-art in computational power for RTHS applications.
- Investigate ways to generalize application-specific hardware to make it more broadly-applicable.
- Develop accessible tools and educational modules for students interested in RTHS to understand and use computational science tools.
- Create extensive data repositories for the calibration, validation, and training of machine learning models and neural networks.
- Explore the potential of emergent technologies, like quantum computing or data-flow computing, to address computational challenges.

Discussion Group E — Dealing with Uncertainties

Co-Chairs: Cheng Chen (San Francisco State University)
Srishti Banerji (Utah State University)
Recorder: Kamal Ahmed (University of Washington)

Objectives

The objective of this discussion was to identify challenges involving uncertainties in RTHS, discuss uncertainties in hybrid simulation in the fields of wind and fire engineering, and discuss potential solutions to address these challenges.

Main Points of Discussion

There are different types of uncertainties, some are known uncertainties that need to be minimized while there are some unknown uncertainties which intend to include to study their influence on the RTHS results. It's essential to recognize categories of uncertainties for example, wind, fire, assembly, … etc. Uncertainties in the numerical and physical parts of a test assembly are different. Usually, data/simulation results indicate that for the numerical analysis, it can be done with less uncertainty while the physical test has more uncertainties. Some uncertainties affect nonlinear behavior of RTHS results.

It is important to remember that some uncertainties are inevitable, but they need to be within acceptable limits. For example, concrete strength among samples of the same batch could be quite different, however, it is usually within the reasonable range, and it is acceptable to take the average magnitude of all the specimens tested. We have previous studies on this topic and there are codes of practice that we can use such as ASTM. Such experiences show that quantifying the known uncertainties is important and in order to do that, we'll need benchmark problems to make such quantifications. The uncertainties in servohydraulic dynamics shall be minimized by the controller design.Some steps that help us with the uncertainties are regular calibration of instrumentation and test samples, regular checking/inspection of the devices

To achieve that, we need to divide uncertainties into categories such as concrete, steel, type of test, etc. We want to be able to define limits and thresholds. We need a minimum (should be specified) number of tests prior to RTHS rather than applying the results of one specimen. For example, it's better to test more than on one damper.

Similar to RTHS, hybrid simulation in wind and fire engineering might involve uncertainties and the courses of these uncertainties need to be identified.

Action Items and Future Research Needs

- Establish an acceptable approach to identify the uncertainties in servo-hydraulic system;
- Explore further more effective and efficient ways to account for uncertainties in substructures through a limited number of RTHS tests;
- Incorporate the experimental design into the benchmark problem so that researchers can propose and evaluate their methods through computational simulation;
- Identify sources of uncertainties involving wind and fire engineering tests

Discussion Group F — Building Capacity

Co-Chairs: Xiaoyun Shao (Western Michigan University, USA)
Zhaoshuo Jiang (San Francisco State University.
Recorder: Vasileios Kotzamanis (University of Houston)

The objectives were to discuss how to engage more individuals in this growing research field and expand the community.

Main Points of Discussion

The participants that joined in the hands-on activity in the first day of the workshop expressed how this activity was helpful to get them in RTHS. We talked about how to expand on these activities. Not all students are from the same background and the material needed to be more general and correspond to different levels of expertise. Also, different people have different learning styles. The material in the primer was too general and participants expressed desire for more details. There was interest in participating in RTHS HACKathons where the newcomers would form teams in the competitions (each participant would be from a different field to bridge the language barrier and the knowledge gap).

It would be beneficial to have open access problems available to the public so the control engineers would be motivated to collaborate and see a role for them.

The curriculum could be curated for different levels of expertise and learning style and the user would be able to choose which ones suits them best. Lastly, the benchmark problems should also include simple and relatable problems that newcomers have already seen and they could focus on the experimental side of RTHS and the numerical/experimental interface. Finally, for newcomers who don't know how to code yet, a simple Graphic User Interface (GUI) could be developed.

Action Items and Future Research Needs

- Develop more benchmark open access problems
- Consider ways to include control engineers so they would be challenged too
- Improve the curriculum to include various levels and types of students
- Consider a HACKathon with teams in a competition

Discussion Group G — Machine Learning

Co-Chairs: Mohsen Zaker Esteghamati (*Utah State University*)
Haifeng Wang (*University*)
Recorder: Santiago Ruiz Zorrilla (*University of Alabama)*

Objective

In this session the key challenges and considerations of using machine learning (ML) in real-time hybrid simulation (RTHS) were discussed.

Main Points of Discussion

While ML has demonstrated its potential across various engineering applications, its integration into RTHS remains a challenging task. The participants highlighted several key aspects, including the verification and validation of ML models, compilation of training databases, and the incorporation of physics-based insights into the methods. The discussion underscored that a deeper understanding of these elements is vital for an effective implementation of ML techniques within RTHS frameworks.

Establishing ML models into RTHS is a multifaceted challenge. Participants made emphasis on the challenge of defining appropriate training databases and ensuring access to sufficient data. Several participants made a note that benchmark experiments with consistent boundary conditions should be performed and compiled as open training databases to accelerate development of ML models in this domain. Also, it was discussed that the integration of physics-informed insights into the learning process can be a powerful strategy to enhance predictive accuracy and mitigate errors and uncertainty. However, the participants acknowledged that ML approaches face the challenging task of incorporating suitable boundary conditions to allow for extrapolation scenarios based on the specific type of RTHS. Additionally, a trade-off between model complexity and computational efficiency surfaced as a key consideration to meet RTHS requirements and computational limitations. Participants highlighted the necessity of rigorous validation of ML approaches, and the need for diverse benchmarking that considers distinct problem domains.

<u>Participant's commentary and identified challenges</u>

Key challenges

- Establish the training sets: Do we have enough data to compile training databases that allow reproducible models?
    - Simulation fidelity: How does the fidelity of numerical simulation affect the training of these ML models?

- Verification and validation: How to measure the success of ML models in lieu of significant hurdles to create physical “points-of-comparison”.
    - Physics-informed models.
    - Validation would require performing benchmark experiments.
    - Real time data might defer from ML models during validation. Where can you find data? How to define error metrics?
    - How can we account for different boundary conditions across different experiment in ML model development?
    - Rectifiers can bound the outputs.
- Generalizability of ML models in RTHS: Is it possible or even necessary to extrapolate?
    - Need to define the extent of desirable extrapolation as an objective of ML models.
    - Embed physics-based insights into ML models
    - What are the achievable computing limits? How much hardware is necessary?
- Deep neural networks
    - Performance assessment should not be only based on a loss functions
    - Subjected to noise and uncertainties.
    - Black-box approaches to deep learning RTHS: Physics based vs Data driven.
- Environmental domain: Is there a mapping from one domain to another?
- Hybrid-ML models where numerical models can be embedded with ML.
- Numerical integration
    - Need to have performance metrics
- Discretization is key. Spatial domain take time
- Incorporate noise and outliers.
- Predictability is achievable in linear problems.

Benchmark machine learning models to assess RTHS.
- To validate the implementation but complicated to validate solution.
- Difficult to replicate.

Reinforcement learning. Large search space.
- Going from simulation to real application is challenging.
- The risk of fail would implicate costs. Are we able to afford ML to explore the physical space accounting for the possible costs of such simulations?

Applications of neural networks on RTHS:
- Additional information on what ML is predicting.

Trade-off between model complexity and efficiency of models.
- Sparsity
- Understanding the machine learning models” Not treating them as black box.
- Build up cases with evidence of implementation.

Data sharing
- There is a need for a platform to access consistent and transparent data

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Action Items and Future Research Needs

Potential actions stemming from the discussion included, addressing verification and validation challenges, assessing machine learning's feasibility for initial estimates, validating models through experimentation, and establishing reasonable extrapolation boundaries and confidence intervals. Moreover, embedding physics-based information, benchmarking models for real-time simulations, and facilitating collaboration and knowledge exchange were suggested measures for advancement.

MECHS Workshop:
Exploring Multi-hazard and Multi-physics Hybrid Simulation
August 9-10, 2023

AGENDA

Location: Wilmeth Active Learning Center (WALC)

August 9th, 2023

Time	Location	Activity	Speaker/Leader
8:00 AM 8:30 AM	WALC 2124	Breakfast and Registration	
8:30 AM - 8:45 AM	WALC 1132	Opening Remarks	Dr. Shirley Dyke *Purdue University*
Session 1: Keynotes and Applications			
8:45 AM - 9:30 AM	WALC 1132	**Keynote:** Real-time Hybrid Simulation: Development and Applications Towards Creating Infrastructure Resiliency to Multi-Natural Hazards	Dr. James Ricles *Lehigh University*
9:30 AM - 10:15 AM		**Keynote:** 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*
10:15 AM - 10:30 AM		**Application:** *Challenges on applications of real-time hybrid simulation to wave-structure interaction*	*Dr. Barbara Simpson Stanford University*
10:30 AM - 10:45 AM		**Application:** Developing Thermo-mechanical Cyber-physical Testing Methods	Herta Montoya *Purdue University*
10:45 AM - 11:00 AM		**Application:** E-Defense & RTHS Tests of a Base Isolated Building Frame with an MR Damper in the Isolation Layer	*Dr. Erik Johnson University of Southern California*
11:00 AM - 11:30 AM	WALC 2124	Break	
11:30 AM - 12:30 PM	WALC 1132	**Group Discussion A:** See Topic List after Agenda	
12:30 PM - 1:15 PM	WALC 1132	Networking Lunch & Group Discussion Summaries	
Session 2: Industry-University Collaborations			
1:15 PM - 1:45 PM	WALC 1132	Funding and partnership opportunities at NSF/TIP for research and education in urban infrastructure simulation	*Dr. Yueyue Fan NSF, TIPS Directorate*

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1:45 PM - 2:30 PM		**Panel Discussion:** Industry-Research Collaboration	*Tom Sputo* *Hannah Blum* *Mike Wesson* *Raj Eshwar*
2:30 PM - 3:00 PM	WALC 2124	Break	
3:00 PM - 3:15 PM		**Application:** *Comparative study of computational methods using the virtual RTHS benchmark problem*	*Dr. Mariant Gutierrez Soto* *Penn State*
3:15 PM - 3:30 PM		**Application:** *Assessment of Wind Hazard Mitigation on a Tall Building equipped with Performance Control Devices using 3D Real-Time Aeroelastic Hybrid Simulation*	*Dr. Liang Cao* *Lehigh University*
3:30 PM - 3:45 PM		**Application:** *RTHS Frameworks for Offshore Wind Turbines*	*Dr. Wei Song* *University of Alabama*
3:45 PM - 4:00 PM	WALC 1132	**Application:** *Cyber-physical wind tunnel testing*	*Dr. Brian Phillips* *University of Florida*
4:00 PM - 5:00 PM		**Group Discussion B:** Real-time creation of groups based on participant interests.	
5:00 PM - 5:20 PM		Concluding Remarks for Day 1 Sessions	
5:20 PM - 5:30 PM	WALC 1132	Adjourn and Next Day Schedule *Dinner on your own*	

Group Discussions A: Applications

- Computational Challenges
- Standards & Validation
- Capabilities & Facilities Needed

Group Discussions B:

- Groups to be created spontaneously based on expressed interests.

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August 10th, 2023

Time	Location	Activity
8:30 AM 9:00 AM	WALC ATRIUM	Breakfast and Review of Day 1
Session 3: Hybrid Simulation Research Agenda		
9:00 AM - 10:15 AM	WALC 1132	**Challenges Talks:** A series of short talks will be presented by workshop participants. *Liang Cao, Brian Phillips, Cheng Chen, Wei Song, Mariant Gutierrez Soto, Mohsen Zaker, Arun Prakash, Chris Gill, Bin Xu, Etc.*
10:15 AM - 10:35 AM	WALC ATRIUM	Break
10:35 AM - 11:45 AM	WALC 1132	**Group Discussion C:** See Topic List after Agenda
11:45 AM - 1:00 PM	WALC 1132	Lunch & Summary presentations from Group Discussion C *Followed by* *Concluding Remarks*

Group Discussions C: Research Needs

- Dealing with Uncertainty: Test Design and Data Interpretation
- Enabling Techniques: Machine Learning and Transfer System Control
- Standards: Meeting and Developing
- Education and Awareness

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6	David	Caballero Russi	The Pennsylvania State University
7	Liang	Cao	Lehigh University
8	Cheng	Chen	San Francisco State University
9	Guangzhao	Chen	UIUC
10	Johnny	Condori Uribe	Purdue University
11	Ana Beatriz	De Gois Fernandes Weiss	Pennsylvania State University
12	Sandeep	Degala	ClarkDietrich Building Systems
13	Thays	Duarte	University of Florida
14	Shirley	Dyke	Purdue University
15	Seyyed Amin	Enderami	University of Kansas
16	Raj	Eshwar	ClarkDietrich
17	Chao	Fan	Clemson University
18	Sameer	Fares	New Millenium, Steel Dynamics company
19	OSCAR	FORERO	Purdue University
20	Elnaz	Ghasemi	Pennsylvania State University
21	Christopher	Gill	Washington University in St. Louis
22	Mariantonieta	Gutierrez Soto	Pennsylvania State University
23	Haitham A.	Ibrahim	Florida International University
24	Zhaoshuo	Jiang	San Francisco State University
25	Erik	Johnson	University of Southern California
26	Soolmaz	Khoshkalam	University of Massachusetts Darthmouth
27	Hyeyoung	Koh	University of Wisconsin-Madison
28	Vasileios	Kotzamanis	University of Houston
29	Yun	Li	Stanford University
30	Faisal Nissar	Malik	Lehigh University
31	Xiangyu	Meng	Louisiana State University
32	Juan	Meriles	UC Berkeley
33	Wesam	Mohamed	University of Illinois Urbana-Champaign
34	Alejandro	Palacio-Betancur	Penn State University
35	Dhanushka	Palipana	The University of Kansas
36	Edwin	Patino	Purdue University
37	Brian	Phillips	University of Florida
38	JOSEPH	POTE	New Millennium
39	James	Ricles	Lehigh University
40	Sumant Dilip	Rokade	The Pennsylvania State University
41	Seth	Roth	Penn State
42	Santiago	Ruiz	University of Alabama
43	Manuel	Salmeron	Purdue University
44	Claudio	Sepulveda	UC San Diego
45	Xiaoyun	Shao	Western Michigan University

46	Barbara	Simpson	Stanford University
47	Wei	Song	The University of Alabama
48	Thomas	Sputo	Steel Deck Institute
49	Marion	Sudvarg	Washington University in St. Louis
50	Chao	Sun	Louisiana State University
51	Zhuoqi	Tao	University of Illinois at Urbana-Champaign
52	Esteban	Villalobos Vega	University of Oklahoma
53	Juan	Villamizar	Purdue University
54	Haifeng	Wang	Washington State University
55	Mike	Wesson	Simpson Strong-Tie
56	Shenghua	Wu	University of South Alabama
57	Bin	Xu	Huaqiao University
58	Liuyun	Xu	University of Michigan
59	Mohsen	Zaker Esteghamati	Utah State University
60	Tao	Zhang	Purdue University
61	Tianjie	Zhang	Boise State University
62	Sung Min	Moon	University of Illinois at Urbana-Champaign
63	Shitao	Shi	University of Illinois
64	Rayyan	Alwaneen	Pennsylvania State University
65	Daivik	Manickmalar	Pennsylvania State University