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A multiply-partitioned methodology for fully-coupled computational wind-structure interaction simulation considering the inclusion of arbitrary added mass dampers

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ABSTRACT

Recent advances of the numerical wind tunnel result in a flexible methodological framework, which enables the fully-coupled simulation of wind-structure interactions considering the arbitrary and modular inclusion of additional devices into the system – such as added mass dampers – for the mitigation of vibrations caused by the wind flow. This feature could be seen as an add-on to what can be done with experimental methods and enables further possibilities when the predictive character of such simulations is used for structural design or even for the development and optimization of the additional devices themselves. The procedure promotes an approach fully-solved in time domain using a multiply-partitioned concept to be able to deal with the respective components in an efficient way. It is crucial to adopt a coupled approach and analysis in time as the involved systems can heavily influence each other. The systematic preparation of each module accompanied by coupled simulations is presented, which aims to ensure and enhance the quality of the overall solution strategy. The effectiveness and industrial relevance of the concept is presented on a tall building undergoing dynamic excitation due to vortex shedding with an integrated vibration mitigation device.

1. Introduction

Many recent developments have lead to numerical methods being available for both research as well as industry on an everyday basis. On the one hand, the unquestionable improvement in hardware and lowering of computational costs has permitted the presence of powerful computers. On the other hand, the discrete mathematical and algorithmic part permits the modeling of individual physical phenomena. The respective numerical implementations can be found in commercial and research codes, the latter being frequently open-source.

It can be noted, that the simulation approaches for single field problems, like structural mechanics or fluid dynamics, have reached a significant level of maturity and recent research efforts concentrate on the numerical treatment of coupled multi-field scenarios. These should provide more detailed insight into existing – typically coupled – natural phenomena by removing the need of simplifying assumptions of the considered investigated systems. For each part involved, the most adequate model ought to be selected, whilst the multiply-coupled framework should permit the proper co-functioning of these. Hence, the advances in both hardware as well as simulation techniques permit the investigation of complex physical problems. The present contribution discusses computational wind-structure interaction (WSI) with the possible modular inclusion of various further devices in order to mitigate wind-induced structural response.

In general, for the wind engineer, the number of features provided by various numerical frameworks has been growing, sometimes overwhelmingly. The result is, that more and more advanced numerical techniques, realized as modules/parts, permit additional detailing combined with improved modeling and insights into wind-induced effects. These improvements range from the more accurate modeling of wind (for e.g. using specific inlet generator accompanied with suitable numerical modeling of the flow field) to allowing a more realistic quantification of the coupled fluid-structure interaction (FSI) phenomena (permitting the usage of structural models of various complexity and also the inclusion of additional added mass devices to serve as a kind of controller). Numerical coupling is mostly addressed in a partitioned manner, which allows the individual implementation and availability of proper numerical models (wind flow, structure, added device – here added mass damper AMD) and

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an adequate interaction between these.

The current work discusses a systematic approach for the simulation of multiply-coupled (and possibly multi-physical) problems in case of computational wind engineering (CWE). Whereas most are familiar with how the individual components should be modeled separately, one needs special attention in order to obtain a co-functioning, which is both efficient as well as physically accurate. A conscious choice and proper setup of the individual components needs to be undertaken, which implies comparisons with various other physical and numerical experiments, as well with analytic results, where possible. This investigation needs to be extended to the communication or coupling between the modules, that in turn needs to be done in a smart and efficient way, so that it is fast, reliable, and last but not least, scalable. The latter aspect should not be neglected, as detailed numerical simulations are still relatively computationally expensive and lengthy. For practical purposes, an adequate choice of models and selection of proper software-hardware is a must, otherwise the common usage of such simulations remains utopic.

A systematic approach is proposed, which ensures quality showcased with the example of a simplified generic highrise building geometry in constant wind inflow undergoing excitation due to vortex shedding. The resonant amplification is mitigated using an AMD (here various devices being investigated, such as a classical tuned mass damper TMD and a semi-active variation SATMD). The ideas and framework can be extended to other structures, such as bridges, towers and so on, permitting the usage of other control devices and algorithms as well.

The present contribution begins with the presentation of the WSI as part of coupled physical problems in a numerical context. Modules are identified, notions and specifics of the co-simulation are presented. Winterstein et al. (2016) discuss the control of FSI in a computational context with a strong emphasis on various control algorithms and respective methodology, as well as its application to a well known benchmark problem. Péntek et al. (2017) layout the formalized premise for control by AMDs in a partitioned manner for usage in CWE, accompanied by initial studies. These previous contributions serve as a base for the current discussion. Consequently, the numerical models of various AMDs are introduced in the existing scheme. This is followed by the description of the individual components. Various comparative studies of these separate modules intend to ensure the appropriateness and quality, these being backed up by selected results. A chosen example shows how this methodology is relevant and usable for wind engineering (WE) purposes, namely in case of a skyscraper undergoing heavy oscillations due to vortex shedding. The numerical wind tunnel thus aims to contribute to the knowledge provided by the more established physical one, striving to provide additional insight and options where possible. The challenges and potentials of the numerical approach are thoroughly outlined and discussed in recent contributions by Kareem (2017) and Bletzinger et al. (2016).

Current progress builds upon and ought to be related to previous works which address various aspects of high-rise buildings excited by wind forces. Our chosen example focuses on across-wind excitation. For such cases, structural response on various buildings has been predicted from early on using various mathematical models, such as forcing functions suggested by Kareem (1983). Liang et al. (2002) further contribute to this line of thought with an application on rectangular buildings. Structures of such shape and slenderness generally are expected to exhibit dangerous behavior in low approaching turbulence, so more and more accurate methods should be developed. Yang et al. (2004) propose a benchmark problem for the control of wind-excited tall buildings. Their work includes wind tunnel measurements for the retrieval of loading time history on rigid models. These represent the forces applied onto a simplified structural model. As such, an interaction between the flow field and the building deformation is neglected. This early work elaborates on the usage of control devices and respective algorithms for mitigation purposes. The authors in Yang et al. (2004) humbly note that the interaction between structure and controller is also not considered, which might not be suitable for certain use cases. We currently aim to address and remedy some of these aforementioned shortcomings – for e.g. such as neglecting the interaction between various components – whilst contributing to and exploiting the potentials of recent developments in numerical tools and methods.

2. The modular extension of the numerical wind tunnel

A conceptual discussion aims to present the current state as well as potential enhancements of the numerical wind tunnel achieved through the extension of the staus quo. Focus lies on outlining the various existing components of the numerical wind tunnel with an outlook to possible enrichment. A brief part already discusses partitioned approaches available for WSI simulation.

2.1. Components

A numerical wind tunnel is sketched in Fig. 1 depicting the main building blocks. The fluid solver uses methods from computational fluid dynamics (CFD) to simulate the airflow around the structure. The availability of an inlet boundary condition (BC) or wind inlet generator permits a more realistic inflow. The usage of simplified structural models for fluid-structure interaction (FSI) assessment is proposed to reduce modeling effort and computational necessities leading to the improvement of the overall efficiency. The established parts can be extended with other modules, in the current work we specifically refer to the inclusion of various AMD models for vibration mitigation.

The involved modules need to be properly chosen and correctly setup in order to function as intended. Also, an adequate interaction between these components has to be ensured. These steps are detailed in the upcoming sections.

2.2. Partitioned wind-structure interaction simulation

The assessment of wind effects using wind tunnels already represents a certain level of abstraction. For experimental ones, this implies scaling effects, for the numerical setting, going from the continuous ("real") physical world to the discrete one. Nonetheless, a flow domain is defined,

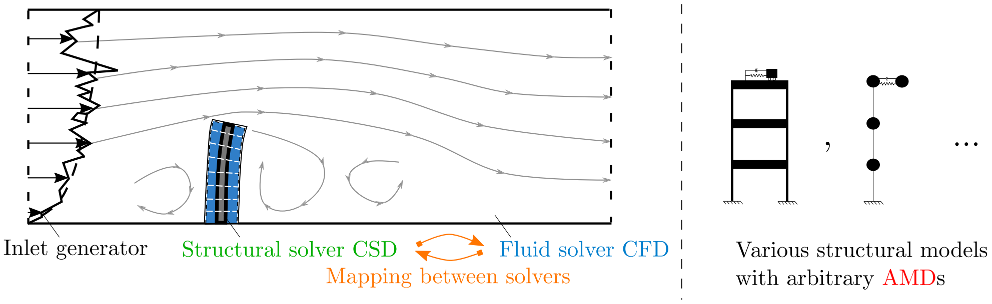

Fig. 1. Key components and the possible extension of the numerical wind tunnel.