Summary

Modern flexible multibody simulation is subject to ever-increasing complexity, employing highly detailed multibody models. The significant attention to detail and accuracy regarding the multibody simulation highlights unavoidable deviations between the actual system's mass, stiffness, and damping distribution and the assumptions made in the modeling process, particularly for complex systems where precise modeling is often very costly or even unfeasible due to limited information. Consequently, experimental identification of the system's dynamics on a prototype of the mechanical system becomes necessary to identify and adjust simulation uncertainties. However, combining flexible multibody models and experimentally obtained data is not straightforward due to the usually strong non-linearity of the multibody's motion.

This thesis presents and investigates a novel approach for building elastic multibody models from experimentally derived data that mitigates some of the drawbacks encountered in previous studies. The novel approach is motivated through a detailed review of the methodologically closely related standard modeling approach based on linear finite element matrices and floating frame of reference formulation. A brief overview of the finite element method establishes the linear finite element system matrices, which form the input of the conventional approach to build upflexible multibody bodies. Subsequently, a thorough investigation of the conventional modeling approach with the floating frame of reference formulation at its core is performed. Particular attention is dedicated to forming identities between the finite element method and reference frame kinematics. These identities enable the straightforward calculation of the flexible multibody system matrices utilizing linear finite element matrices. Introducing these identities early in the investigation streamlines the otherwise tedious derivation of the theoretical framework and provides a concise notation necessary to motivate and refine experimental-based multibody modeling. The review of the standard approach concludes with a condensed summary of all essential calculation steps in the conventional modeling approach.

The formulation of the experimental modeling approach starts with an overview of the necessary assumptions and prerequisites regarding the experimental input data. Most notably, the approach requires a modal model derived from the unconstrained structure, its rigid body inertia properties, and an initial assumption regarding its mass distribution. At the core of experimental-based multibody modeling stands the idea of resorting to modal reduction and using an experimentally determined modal model instead of a numerically derived one. This step allows us to fully model the multibody system matrices relating to the body's deformation and was adopted in virtually every previous study regarding experimental multibody modeling. However, this approach eventually leads to errors in the remaining multibody system matrices, particularly in coupling matrices between deformation and rigid body motion. To mitigate this drawback, the present work extends the experimental modeling approach by additional steps. The first step defines a Buckens-type frame as the body's reference frame, causing most of the error-prone system matrices coupling deformation and rigid body motion to vanish. The second step extends the experimental database to include the body's rigid body inertia properties. The additional data is utilized in a model update step to update the assumption regarding the body's mass distribution, thus reducing conflicts between approximation and the actual physical structure. All steps of the novel modeling approach

are summarized in a condensed overview in direct comparison to the conventional modeling approach. The development of the experimental modeling approach concludes with a brief overview of potential measurement techniques to derive the required input data. Particular attention is paid to the requirements imposed by the experimental modeling approach on the measurement setup.

The experimental modeling approach is investigated thoroughly in three testing scenarios with increasing complexity: a simple numerical study and two experimental cases, one on a simple flat steel and the other on a complex small-scale wind turbine blade. Each test case compares the results obtained through experimental modeling with results from conventional modeling, assuming both approaches utilize the same number of modes.

The strictly numerical investigation of a simple lumped mass system demonstrates the equivalence between the experimental and the conventional modeling approach in the absence of potential experimental error sources and uncertainties in the conventional modeling approach. A controlled error implementation on the initial mass assumptions further reveals that the experimental modeling approach preserves the general matrix structure of the remaining coupling terms and bounds individual errors within reasonable levels, even for severe errors in the initial mass assumptions.

The analysis of the experimental test scenarios reveals the experimental approaches' ability to precisely replicate the experimentally derived inertia, stiffness, and damping properties of the actual structures in the corresponding multibody system matrices. Furthermore, most of the coupling terms show that the experimental approach effectively enforces the decoupling condition between deformation and rigid body motion even when potential measurement errors, such as mass loading effects, distort the mode shapes of the actual physical structure. The most significant discrepancies are observed in the remaining coupling terms that require the updated mass matrix and deformation modes for calculation. As the complexity of the modeling task increases, so are these differences. Likewise, the effort required to create the input data for the two modeling concepts also increases, namely the measurement effort for the experimental approach and the finite element modeling effort for the conventional approach. For the rotor blade, strictly numerical modeling through finite elements is even infeasible without performing measurements on the actual structure. Still, the conventional multibody model of the turbine blade cannot reproduce the actual blades' stiffness and damping properties, further underlining the necessity for experimental multibody modeling for complex mechanical structures. All in all, this thesis establishes an improved experimental-based modeling approach for flexible multibody modeling that is a compelling alternative to the conventional modeling approach, especially for complex modeling tasks where an underlying numerical model is prone to significant errors concerning mass, stiffness, and damping distribution. The investigations of the thesis show that even with rather crude measurement techniques, multibody models were derived that reflect the actual mechanical properties far more precisely than models derived through conventional modeling. However, the direct incorporation of measured data implies that every error made during measurement is directly transferred to the multibody model. This puts rigorous requirements concerning the accuracy of the measurement hardware and execution to result in a multibody model of desired quality. Nevertheless, in light of modern design complexity and measurement equipment becoming increasingly powerful while simultaneously becoming more affordable and accessible, experimental-based modeling may render itself an important simulation tool to tackle complex modern simulation tasks.