The next generation of wind turbine digital technologies requires versatile aero-servo-hydro-elastic models, of various levels of fidelity, and suitable for a wide range of applications. Currently, the available models are implemented for a specific purpose, usually based on an heuristic structure. Small implementation changes often require an extensive redevelopment, and the range of applications of the tool remains limited.

[Suggest to remove:  
, and only keep a loose connection to the underlying physics. Small changes often require an extensive redevelopment and the comparability between different versions or related models is not really viable (Simani, 2015).]

To address this issue, we propose a framework for the automatic derivation, processing and parametrization of models with a varying degree of detail. Our approach is based on Kane’s method (Kane and Wang, 1965) and a nonlinear modal representation of flexible bodies that are described using a standard input format (Wallrapp, 1994), (Schwertassek and Wallrapp, 1999). The method yields compact symbolic equations of motion with implicit account of the constraints.

[Remove?:   
Parameter values can be calculated from readily available physical properties without the need for identification from time-series data (La Cavae et al., 2016), (Loew and Obradovic, 2018). ]  
  
In this work, we use well-establish techniques and leverage the current capabilities of symbolic calculation packages to allow users to easily generate models suitable for their applications, such as:

[Remove:?   
This approach is not new per se but the accessibility of such tools and the special requirements for aero-elastic models justifies a fresh consideration. ]

* Linearization, for controller design and tuning, or, for frequency domain analysis
* Derivation of exact gradients for optimization procedures
* Automatic generation of dedicated code, for applications such as: Simulink models, standalone simulators, state observers, or digital twins
* Further processing by specialized tools, e.g. for the generation of high performance NMPC code such as acados (Verschueren et al., 2018)

Contrary to the approach of Merz (2018), our framework processes all equations on a symbolic level and thus, the model can be used in its nonlinear or linearized form. Our approach is severalfold faster than multiple OpenFAST linearizations because it gives results for all operating points at once.

Most importantly, the different applications listed above are obtained from the same standardized and intuitive model description. The user only needs to describe the individual bodies of the system, their connections, the forces acting on them, and chose a set of generalized coordinates to describe the motion.

[ Remove:  
description is composed of the pose (position and orientation) and properties of the bodies and the active forces acting on them. By writing the pose in terms of so-called generalized coordinates, the desired degrees of freedom (DOF) are introduced (Branlard, 2019).]

This makes it very easy to quickly vary the level of detail, e.g. choosing stiff or flexible blades, or the number of flap and edge modes.

[Remove:  
or the same coordinate to all three blades and thereby yield a model with collective-only blade motion. Composing a model from its bodies and their DOFs makes it possible to tailor the level of detail in a modular fashion (Shabana, 2013).  
]

In the presentation, we will describe the method used in our framework, and illustrate how the equations of motion are generated. We will compare our results with OpenFAST simulations for different models, we will present how we currently use this framework, and how it can be applied to various research projects.

Figure 1 shows a graphical representation of the defining components of an example model and the equations of motion generated therefrom.

Figure 2 shows a comparison between the example model and OpenFAST (ElastoDyn) with all features enabled, both using 5MW NREL onshore turbine parameters and the standard NREL controller DLL. The generated model features a novel rotor effective aerodynamics model with damping.