6 Numerical Foundations of System Simulation
6.1 Introduction to Numerics

Simulation technology has been applied for years now in computer-based system design in various application fields, from ship building to space technology. It also covers the full scope of problems to be analyzed, ranging from the design of a system component for specific stationary load cases up to overall system simulations for analyses of dynamic system operation.

Diverse commercial or user developed simulation program suites are applied to these tasks in industry. For students who want to familiarize themselves with these techniques it is often not easy to understand the modeling technologies and numeric approaches behind such tools. Despite the fact that for specific simulation application fields, detailed technical literature is available, it is difficult to find an overview on the problem specific appropriate tools and numeric methods. The generation of such a technical and methodical overview is the goal of this chapter, without confusing the reader by diving too deep into specific subtopics, (such as numerical solvers). Further reading is cited wherever the central theme prevents tackling details.

For further elaboration, first the following notation convention shall be defined. Where possible explicit technical variables with standardized variable names are cited, like \( p \) for pressure and \( T \) for temperature or \( H \) for enthalpy, the variables of a simulated component are defined as follows:

\[
\begin{align*}
  &u &\text{Input parameter of a component of the simulated system,} \\
  &w &\text{output parameter of a component,} \\
  &y &\text{state variable of a component.}
\end{align*}
\]

In contrast to other diverse literature and to keep consistent over all technical disciplines covered in this book, (like AOCS, thermal, power, OBSW), the variable “\( z \)” is reserved as a geometric parameter. Taking the example of a pipe, a state variable like temperature or molar fraction of a fluid component can be variable over the length “\( z \)” of the pipe.

The variable “\( x \)” is only applied for description of generic causalities, such as in example code for a numeric integrator which integrates \( y = f(x) \). For the integrator it is of no interest whether the independent variable “\( x \)” represents location “\( z \)” or time “\( t \)”.

All following sections cover the numeric foundations of system simulation in state space notation which sums up all input parameters of the component in one vector, all inner state variables in another vector and finally all output parameters too. Thus for more complex components the variables \( u, v, y \), in above figure in reality become vectors. Frequency domain modeling of systems, which is often applied in control engineering for analysis of dynamic responses and control design is only cited at a