Reiner Anderl
Peter Binde

Simulations with NX / Simcenter 3D

Kinematics, FEA, CFD, EM and Data Management

2nd Edition

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Preface

Virtual product development has gained significant importance in particular through the integration of 3D solid based modeling, analysis, and simulation. Supported by the rapid enhancement of modern information and communication technology application, integrated virtual product development has become an essential contribution in higher engineering education, continuing education as well as in industrial advanced and on-the-job training. Furthermore, the very important and new approaches from the Industry 4.0 initiative lead to a new level of added value and affect all areas of the product lifecycle. In this context, the creation and use of so-called digital twins plays a groundbreaking role. Digital twins are digital representations of individual, real components and products. They form the basis for a wide range of analysis and simulation and, in particular, allow the examination of real components and products, independently of their location. Preventive maintenance, servicing and pre-testable repairs are thus preparing innovative approaches for new business models.

Since 2003, Technische Universität Darmstadt has been selected and approved as PACE university and has become part of the international PACE network. PACE stands for *Partners for the Advancement of Collaborative Engineering Education* and is a sponsoring program initiated by General Motors. PACE is driven by General Motors, Autodesk, HP (Hewlett Packard), Siemens, Oracle, and further well acknowledged companies of the virtual product development branch (*www.pacepartners.org*). Donations and sponsoring through the PACE partner companies has facilitated the preparation and the publishing of this book.

This publication has been developed based on cooperation between Dr. Binde Ingenieure – Design & Engineering GmbH (*www.drbinde.de*) and the division of Computer Integrated Design within the department of Mechanical Engineering of Technische Universität Darmstadt (*www.dik.maschinenbau.tu-darmstadt.de*).

We would like to thank the employees of Dr. Binde Ingenieure and those from the division of Computer Integrated Design of Technische Universität Darmstadt for their active participation in the development of this new edition.

Furthermore, we are grateful for the support of Carl Hanser Verlag, mainly Mrs. Julia Stepp. A very special thank you is dedicated to Prof. Dr. Jan Helge Bøhn who supported us through his excellent cross-reading. Last but not least, we thank all readers who encouraged us to prepare this book in English.

We wish all readers and users a successful application of the selected examples and hopefully a beneficial knowledge acquisition usable for their successful graduation or the successful knowledge application during the industrial career.

June 2018

Prof. Dr.-Ing. Reiner Anderl

Dr.-Ing. Peter Binde

Preamble

Analysis and simulation are essential prerequisites for the digitalization of products and processes. The complete digitalization of value streams in all industries drives the acceleration of processes and enables new business models. Digitalization starts with the idea of a new product and accompanies the product along its entire lifecycle. Digital data and digital data models are essential to the creation of digital twins. This data management concept encompasses all physical and virtual data of a product throughout its lifecycle.

The digital twin enables analyses and simulations of physically existing products as well as products only existing in the digital world. Analysis and simulation supply digital models that reflect functionality and behavior of the physical product. Furthermore, digital models can be "interrogated" to gain information and knowledge about the physical product even before it exists. Once the product is produced, physical tests will follow to perform the same interrogation for gaining information and knowledge now in the physical world. Comparing both approaches – the one from the digital model and the one from the physical product – enables to elaborate quality indicators for the digital model used. Digital twins are becoming more and more advanced to reliably analyze and simulate reality and – even more important – to predict its future behavior.

Siemens PLM Software's clear objective is to support all customers in the digitalization of their value streams in order to strengthen their competitiveness. To do this even better, Siemens PLM Software expands its portfolio continuously. This is accomplished by in-house development projects or through acquisitions of technologies or entire companies.

In this context, the Siemens family was expanded by LMS in 2012 and CD-adapco in 2016. To better represent the expanded range of offerings, Siemens created Simcenter™, an umbrella brand that represents an unmatched portfolio of simulation and test solutions. Simcenter includes geometry-based simulation, system simulation, physical testing, and the accompanying engineering services.

The geometry-based simulation solution – formerly known as NX CAE – is now called **Simcenter 3D**. Simcenter 3D incorporates NX CAE and NX Nastran as well as new capabilities from LMS Virtual.Lab and LMS Samtech. This book focuses on Simcenter 3D, which is available both as a standalone CAE solution as well as a solution completely integrated with NX.

Starting with NX10, some new functionalities like the environment for the LMS Samcef solver were made available. In summer 2016, more functionalities were added to NX11 and Simcenter 3D 11: acoustics, motion, and multi-body simulation and the dynamic simulation of flexible hoses and pipes. In October 2017, even more functionalities from LMS Virtual.Lab and LMS Samcef were added to NX12 and Simcenter 3D 12. And Siemens PLM Software is committed to further enhancing this multi-discipline simulation platform.

What does that mean for you as a user of NX CAE?

You will keep your user interface as well as your NX data model and the optional Teamcenter integration. As an NX CAE user, you will see that Simcenter 3D looks exactly the same and is operated as before. Simcenter 3D is based on the NX platform and adds additional functionalities from LMS Virtual.Lab and LMS Samtech to the overall offering.

To reflect this, the book has been titled *Simulations with NX/Simcenter 3D*.

In their successfully proven and well tested manner, Prof. Dr.-Ing. Reiner Anderl und Dr.-Ing. Peter Binde provide vivid and easy to follow examples of simulation use cases.

To the authors: Thank you very much indeed for this comprehensive masterpiece of education, tutorials and reference.

To all readers and friends of NX CAE: I wish you a lot of success and fun using Simcenter 3D.

Eckardt Niederauer

Portfolio Manager Simcenter 3D

Siemens PLM Software

www.siemens.com/plm/simcenter

1 Introduction

Engineering science has been faced with significant changes during the past two decades. These changes have been driven by a powerful development of information and communication technologies and their introduction into both the product development process and the products themselves. In essence, it has enabled computer integrated virtual product development, based on integrated 3D modeling, analysis, simulation, and optimization.

The primary goal of virtual product development is the efficient development of innovative product solutions that satisfy customer needs. Consequently, the integration of computer-based methods into the digital workflow of the product development process has become critical to the success of virtual product development.

Engineering, designing, and detailing are essential tasks for the development of innovative product solutions, as well as the ability to accurately predict the product's behavior subject to the multitude of potential use cases and operating conditions. Fortunately, with the continuous improvement of information and communication technologies, and with the subsequent improvements in integration of computer aided design, analysis, simulation, and optimization, it has become increasingly easier to successfully perform these essential product development tasks.

Impact of information and communication technologies on product development

Information and communication technologies (ICT) are increasingly influencing the product development process, in particular as the product development process becomes increasingly virtualized. This influence results from:

- rapid information acquisition from sources worldwide
- the availability of new computer-based methods for product development and design – such as for product modeling, e. g., parametric, feature based, and knowledge-driven CAD; analysis, simulation and optimization, e. g., finite element analysis (FEA), multibody simulation (MBS), and computational fluid dynamics (CFD); rapid validation and verification, e. g., digital mock-up (DMU); virtual and physical prototyping, e. g., virtually by using virtual and augmented reality, or physically by using generative manufacturing machines; and processing product data in successive process chains (so-called CAX processes, e. g. for advanced manufacturing including additive manufacturing)
- mapping of the organizational and workflow structures into product data management (PDM) systems, with the aim to provide easy, intuitive, and immediate access to development status, progress, and results

The concept of virtual product development has clearly been shaped by the deep penetration of ICT into the product development process, to provide seamless flows of product data. Virtual product development can be systematically achieved over an escalating set of levels (see Figure 1.1). These levels consist of

- 3D CAD;
- digital mock-ups;
- virtual prototyping;
- virtual product analysis and simulation; and
- virtual factory.

In addition, analysis and simulation are becoming increasingly important due to Industry 4.0. The Industry 4.0 initiative stands for the 4th industrial revolution and moves organization and control of the entire added value chain to the next efficiency level across all phases of the product lifecycle. The focus lies on increasing the flexibility of production and on satisfying individual customer demands. A prerequisite is the availability of information in real time in order to optimally control the added-value flow. This requires interconnected and communication-capable cyber-physical systems. This approach also requires so-called digital twins, which are a digital representation of physically existing components and products. Thus, digital twins offer fundamental approaches for performing realistic analysis and simulations.

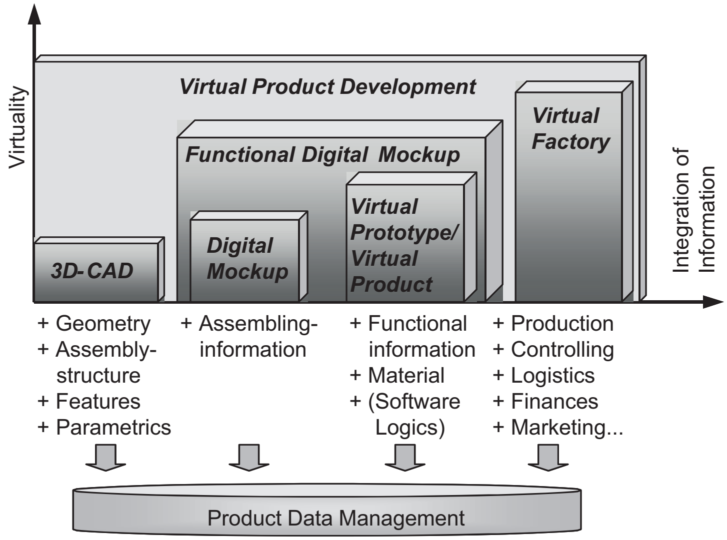


Figure 1.1 Levels of virtual product development

3D CAD is the fundamental basis.

3D CAD is the fundamental basis for describing product geometry, geometrically represented as solid geometry. This digital product representation involves single-part modeling as well as assembly modeling, and typically describes a product structure. This modeling approach is mainly based on features and parametric modelling.

Digital mock-ups (DMU) provide a digital representation of the product structure as well as part and assembly geometry. The geometry representation is typically approximated using tessellation and triangulation approaches. As the part and assembly models are represented as solid geometry and complemented by material data, product properties, such as mass and center of gravity, can be derived. Digital mock-ups enable virtual prototyping for simulating assembly and disassembly processes and for investigating collision detection.

DMU

Virtual prototypes – often referred to as digital prototypes – include material and physical properties in addition to part geometries and product structures. Therefore, these prototypes therefore can be used to simulate the functional and physical behavior of a product and to visualize its behavior. The functional and physical modeling within a virtual prototype tends to be application specific and discipline specific. Typical applications include stress analysis using finite element analysis (FEA) based on the finite element method (FEM), multi-body simulation/dynamics (MBS/MBD), or fluid dynamic simulation using computational fluid dynamics (CFD). Simulations may also integrate thermal analysis, electromagnetic analysis (EM), or kinematic analysis, or their combinations, typically based on FEA, to more fully investigate and understand the product behavior.

The most important simulation methods are FEA, MBS and CFD.

The term "virtual product" refers to the aggregation of a product's physical properties together with its logical dependencies to produce a comprehensive, interoperable product model.

The term "virtual factory" refers to the digital representation of a factory, including its physical properties and manufacturing processes. The objective is to facilitate analysis, simulation, and optimization of factory operations, including material flows, logistics, and order processing.

While the terms "digital prototype" and "virtual product" refer to digital representations of non-existent products and to the development of optimized product solutions, the term "digital twin" refers to digital representations of physically existing, manufactured products with their current physical dimensions and properties.

Product data resulting from the application of the various modeling, analysis, simulation, and optimization software systems is stored as files in the product data management (PDM) system, enriched by meta-data representing organizational and workflow information such as release status, effectivity, identification, classification, and version numbers.

The PDM system manages all product data generated through virtual product development.

The increasing use of 3D CAD in industry leads to an increasing need to integrate numerical analysis, simulation, and optimization methods and tools. With this integration, product data, once described or generated, can then be used and reused in successive processes to avoid manual redescription and errors, as well as to identify errors early. This practice enhances product quality and increases the efficiency of virtual product development process and successive physical product realization.

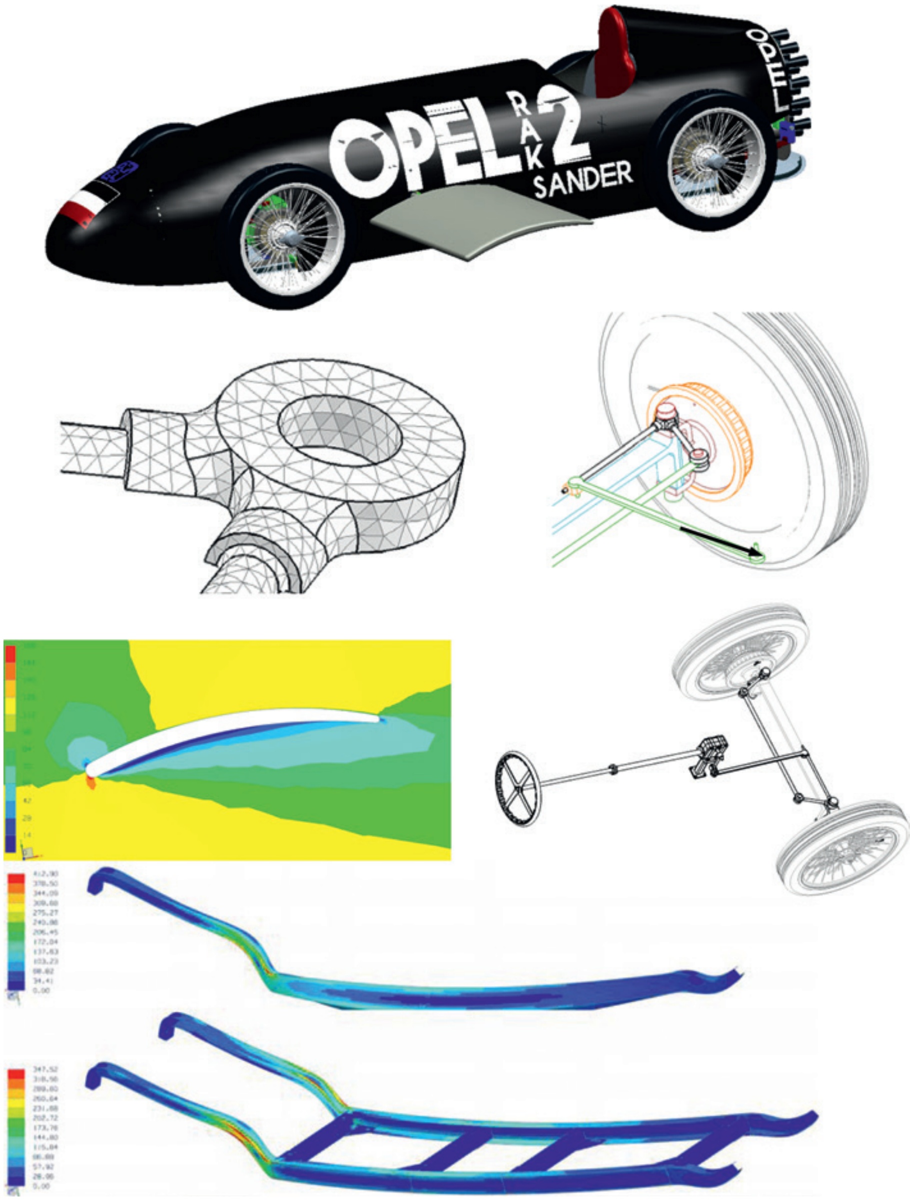
1.1 Learning Tasks, Learning Objectives, and Important Prerequisites for Working with the Book

The training content is taught by using methodic examples.

Based on the objective to use 3D CAD data for analysis, simulation and optimization, the question of how 3D CAD data is to be used further, follows. For this purpose, representative use case scenarios for the procedures of finite element analysis, multi-body simulation, fluid dynamics and electromagnetic simulation have been developed in this book, by which the integration of modeling, analysis, and simulation will be presented. The outlined use case scenarios are based on Simcenter 3D 12 and the 3D CAD system NX with its integral analysis and simulation modules.

To facilitate the understanding of the methodology and to increase the training efficiency, a single contiguous assembly was chosen for most learning tasks of this book. It is the 3D CAD model of the legendary Opel RAK2 (Figure 1.2) which was created in student projects as a 3D CAD solid model at the division Computer Integrated Design (DiK) at TU Darmstadt.

In 1928, Fritz von Opel, grandson of Adam Opel, built the rocket driven cars RAK1 and RAK2 for testing purposes. With RAK2 he reached a speed record of 238 km/h on Berlin high speed track AVUS on 23rd of May in 1928. The RAK2 was powered by 24 solid-fuel rockets, which were filled with 120 kg of fuel. This attempt to establish the rocket engine was followed by further attempts by road, rail and air.



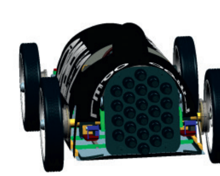


Figure 1.2 The 3D-CAD model of the Opel RAK2 has been selected for deriving the learning tasks: The figure shows some exemplary images. A colored version of this figure is available at *www.drbinde.de/index.php/en/204*.

Prerequisites for working with the book

All 3D-CAD and analysis data used or created in the learning tasks are stored in an archive file for download (see following web link) and should be used to reproduce the examples.

> The archive file can be downloaded at *www.drbinde.de/index.php/en/204*. This file contains all 3D-CAD models, analysis and result files. Furthermore, the installation files for the electromagnetic solver are included in this file.

The training content is taught by using practical examples. Functions of the Simcenter 3D system are therefore not explained stand-alone, but always in the context of an example. Since its similarity to learning from physical-world projects, this method is efficient, memorable and adheres to modern didactic.

The structure of the chapters is based on the didactic concept of continuous learning progress, but it is also built on the fundamentals of working with 3D CAD, in particular the Simcenter 3D system. Therefore, knowledge about the description of 3D parametric models for single parts and assemblies is required.

Objective is to build a fundamental knowledge about engineering, design, analysis and simulation.

The learning objective is to convey knowledge to designers or analysis engineers that she or he needs to solve appropriate tasks using finite element analysis, multibody simulation, and flow simulation supported by Simcenter 3D, and to develop an understanding of these technologies. However, solving complex practical problems needs more engineering experience and knowledge and probably exceeds the examples presented in this book. A novice, however, is able to develop into an expert by working through theory and as many practical tasks as possible. He thereby collects valuable experience and understands the engineering background. The gained experience thus results from successfully developed projects. This book, with its learning examples, provides important basic experiences and thus forms the basis for a systematic expandable knowledge enriched by experience.

1.2 Work Environments

Engineering simulation problems can be subdivided into four classes: rigid bodies, elastic bodies, fluids, and electrical/magnetic bodies (Figure 1.3). Rigid body systems are simulated using Multibody Dynamics programs (MBD); elastic and also electric/magnetic bodies are simulated using the Finite Element Method (FEM); and flow tasks are simulated using Computational Fluid Dynamics (CFD).

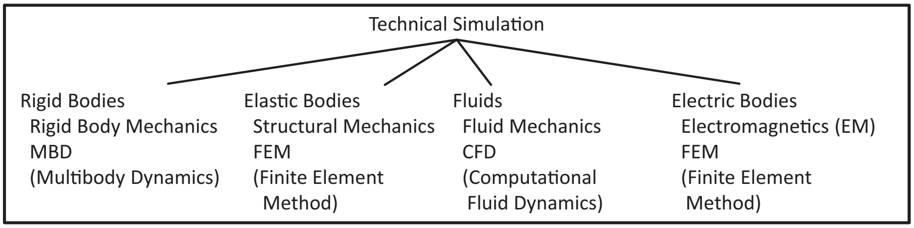


Figure 1.3 Technical simulation can be roughly divided into four parts.

The Simcenter 3D system provides many modules for technical simulation.

Within the Simcenter 3D system, there are several modules for engineering simulation. The three most important ones used in this book are (in addition to some others not covered here):

- *Motion Simulation* for kinematic and dynamic motion simulations with MBD
- *Design-Simulation FEM* for simple structural, thermal, and eigenfrequency analysis
- *Simcenter Pre/Post* for complex simulation tasks: This module is intended for engineers that focus on analysis. Additional simulation capabilities include modeling and simulation of complex assembly structures and the choice of various solvers for addressing particular physical phenomena. The problem domains that can be addressed include structural mechanics, thermodynamics, fluid mechanics, and electromagnetism (EM).

The working environments for these modules have a common interface, and default to only include those features that are useful in the selected context.

This book reflects in detail these working environments. Possibilities and limitations will be illustrated by examples.

1.3 Working with the Book

Structure of the book

The book contains chapters on the following topics:

- Motion Simulation (MBD)
- Design Simulation (FEM)
- Structural (FEM)
- Thermal/Flow (CFD)
- Electromagnetics (EM)
- Management of analysis and simulation data (Teamcenter for Simulation)
- Manual analysis of an FEM example

The joint forces are calculated in Motion Simulation.

First, we will explore motion simulation (Chapter 2) because this class of analysis is common in engineering design and is usually carried out first. The joint forces that are determined here are often used in subsequent strength analysis using FEM.

The chapters can be largely worked through independently. That means, those who do not care for motion simulation, can skip this chapter. One exception: Those interested in FEM and “Structural (FEM)” (Chapter 4) should first read the chapter on “Design Simulation FEM (Nastran)” (Chapter 3) to attain the necessary prerequisites.

-The hurried reader can directly start with the examples.

At the beginning of each chapter an introduction to the principles of each topic is given. For the analysis newcomer these statements might sound very theoretical and difficult. But this should not discourage to begin with the learning tasks on this subject, which are in focus. Explanations in the learning tasks typically build on the principles of the introductions. They are a clarification and expansion of them. A hurried reader can therefore skip the introductions, and might go straight to the learning tasks.

The download files belonging to this book *(www.drbinde.de/index.php/en/204)* contain the *RAK2* folder. This folder includes all outlined learning tasks for the areas motion, structural, thermal, and flow simulation. A second folder named *EM* contains installation files and examples for electromagnetics. The download file also contains solution files so that any result can be looked up in it. For working through the book this entire file should be unpacked and copied to a directory on the hard disk of the computer.

In each case, the first example is of fundamental nature.

The learning tasks of a chapter can best be worked through in the order given, because all learning content builds on each other. In Motion and Design Simulation, as well as EM, the first learning task is a basic example. All important principles and foundations are taught here, which are necessary to understand and build the following learning tasks.

Pin icons indicate steps to be performed.

When describing the learning tasks, there is a distinction between background explanations and steps to be carried out (mouse clicks in NX/Simcenter 3D). Steps to be carried out are always marked with the pin icon:

- Here a step is described that needs to be carried out.

Very hurried readers can therefore skip the background explanations (hopefully, they understand intuitively quite a bit) and jump straight from one pin icon to the next.

NX/Simcenter 3D installation and computer performance

To work through the learning tasks, a computer with NX or Simcenter 3D installation must be available. The examples were calculated by NX/Simcenter 3D 12, but should also work in other versions. With a normal installation of NX/Simcenter 3D 12, all required modules for simulation, especially the NX Nastran solver, are automatically installed. It is, other than with previous NX/Simcenter 3D versions, no longer required to define specific environment variables for the simulation manually.

Only for electromagnetic simulation (Chapter 6), the installation of some additional files is required. This is explained at the beginning of the chapter.

In addition, the computer hardware should preferably be well equipped. We would like to give the following recommendations:

- Processor: The highest possible clock frequency is essential for all simulation problems.
- Multi-Processor: For FEM analysis and some thermal analysis, the use of multiple processors is supported.

- Memory: FEA, thermal and fluid flow analysis need quite some memory. There is a simple rule: the more, the better. To work through the examples in this book, we recommend at least 8 GB of main memory.
- Hard drive: Again, there should be enough free disk space available. For the examples in this book we recommend at least 4 GB.
- 32-/64-bit operating system: For medium to large analysis models 64-bit architecture must be selected, since much more memory can be addressed here. Nowadays the Simcenter 3D installation will only run on 64-bit systems.

For more information on these topics, we recommend reading the documents for parallel-processing [nxn_paral] and for efficient memory usage with NX Nastran [nxn_num].

Presetting the motion solver

For motion analysis, there are three solvers available: Adams, RecurDyn and Simcenter Motion. The learning tasks in this book were carried out with Simcenter Motion solver, but also run with Adams or RecurDyn.

Well, our introduction is now complete. We wish you fun and learning success!

Bibliography

[nxn_num] NX Nastran Numerical Methods User's Guide. Online documentation to NX Nastran

[nxn_paral] NX Nastran Parallel Processing User's Guide. Online documentation to NX Nastran

2 Motion (Multibody Dynamics)

In Section 2.1, first the theory, limitations, special effects and rules of this discipline are represented. This is followed by kinematic learning tasks, which start with a basic example (Section 2.2.1). In the second learning task, principle sketches and kinematics are used to support the early design phase (Section 2.2.2). In the third task, collisions and assembling of various subkinematics are treated (Section 2.2.3). The fourth example deals with dynamic problems and the simulation of contact (Section 2.3.1) and the final task deals with the coupling of Simcenter Motion with MATLAB® Simulink® for the so-called co-simulation (Section 2.4.1).

Content of the chapter

2.1 Introduction and Theory

Simcenter Motion offers the ability to control the movements of a design which is otherwise a statically developed machine. This allows a better understanding of the mechanism and it can be checked if the movement of the components leads to any collisions. It also can be checked if the machine can carry out the desired movement, or even reach certain positions. Often, one of the tasks of the simulation is to adjust the geometrical dimensions in a suitable way. The use of parametric CAD models is an important way to create variations.

Use cases and benefits of Simcenter motion in practice

But also and especially in the early stage of the design process when only rough draft designs are available, the use of kinematic analysis is very useful. Using the Simcenter motion application, principle sketches or simple curves can be moved and their dimensions can be optimized. Thus, the sketches of the early design phase become movement-based control sketches. In the further design process, the kinematic models can be used repeatedly to check the latest state of the mechanism.

As soon as mass properties are assigned to the CAD geometry, motion analysis can be extended to dynamic analysis. In this case bearing and contact forces, velocities and accelerations can be determined. Therefore, motion analyses are often the basis for subsequent FEM analyses because FEM uses bearing forces as boundary conditions. Based on

Mass properties of the components expand the area into the dynamics.

the results (forces and displacements) it is possible to choose springs, dampers, additional masses, vibration absorbers, bearings (load capacity) etc. from supplier catalogs.

Users of Simcenter motion should have experience in modeling components and assemblies with NX. This is necessary because some examples in this chapter are not only based on finished assemblies, but also partially intervene in the design methodology. However, no further previous experience is required.

Subdivision of technical simulation into four fields

Simcenter motion covers the part of the mechanics that deals only with rigid bodies. Usually there is a plurality of rigid bodies that are connected to each other by joints. Such problems appear, for example, in chassis of motor vehicles. The software for the analysis of such tasks is described by the term *MBD* program (*Multibody Dynamics*) (Figure 2.1).

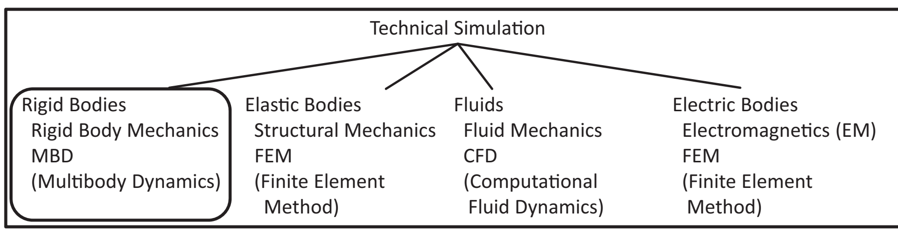


Figure 2.1 The four common fields of technical simulation

Within the CAD model, the user defines moving rigid bodies (links), joints, drivers, and possibly external forces or constraints. Even springs and dampers may be involved (Figure 2.2).

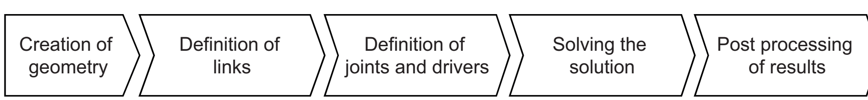


Figure 2.2 Steps to process a MBD analysis

Links are usually defined using CAD geometry (components and assemblies). In addition, the CAD system, with its powerful capabilities, can also be used to define, for example, cams or other control elements.

2.1.1 Simulation Methods

Additional literature

It is difficult to generalize how MBD methods work because the different solvers, including RecurDyn and ADAMS, work quite differently. For a detailed description on ADAMS, see [adams1]. For a detailed description on RecurDyn, see [RecurDyn1]. The current solver which is used by default and supports the new functionality is NX Motion/Simcenter Motion. This solver is documented in the NX Online Help. For the examples in this chapter, we use the NX Motion Solver and for the Co-Simulation example RecurDyn is used.

Internally, the moving bodies, joints and drivers are converted into a mathematical system of differential equations, which is solved to determine the desired quantities (Figure 2.3). This includes the displacements, velocities, and accelerations of the moving bodies and joints, as well as the reaction forces at the joints.

Each component or geometry that should be used as moving body has to be cut free. Six dynamic equations (describing the relation between forces and accelerations) and six kinematic equations (describing the relation between positions and velocities) in the translational and rotational directions are set up. All of these equations together form a system of equations describing the mechanism and its motion.

The number of unknowns in the system of equations can be reduced by adding constraints. Each joint that restricts the possibility of movement of one or between two bodies could be expressed in the form of additional equations in the system of equations. For example, a revolute joint between two moving bodies leads to a reduction of five unknowns in the system of equations because only one rotational degree of freedom remains where once there were six.

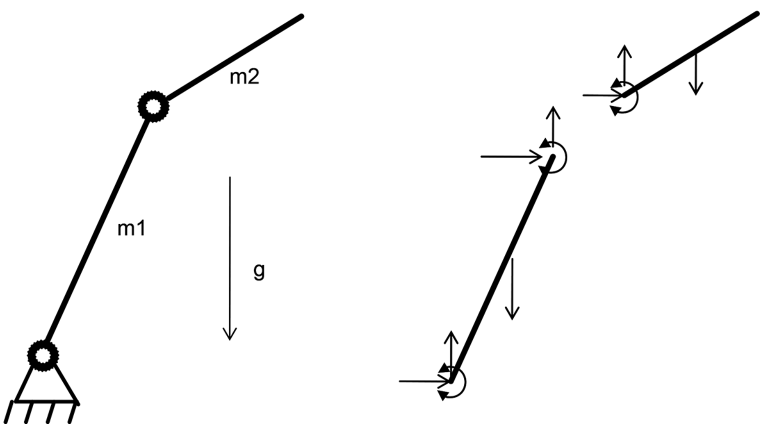


Figure 2.3 A differential system of equations is set up.

Drivers and constraints reduce the number of unknowns.

Motion drivers, which define displacement, velocity or acceleration, also reduce the degrees of freedom (DOF). A rotational driver, for example, with an enforced speed of 360 deg/sec, reduces the number of DOF by one. On the other hand, forces and torques, appearing on the motion model, neither bring additional unknowns into the system nor reduce the count of DOF.

That way, the count of DOF is reduced either to zero (in which case the system of equations can be solved directly) or to a number greater than zero. In the second case, the system can be solved by adding initial conditions and integrating the equations over the time. In the case of zero degrees of freedom, we have a kinematic system; otherwise, we have a dynamic system to be solved.

Some kinds of joints cause non-linearity in the system of equations.

It also should be noted that the resulting system of equations is either linear or non-linear, depending on the correlations that the various types of joints introduce in the system. While simple types of joints such as revolute, slider or spherical joints behave linearly, complex joints such as the *point on curve* connections require non-linear equations. Linear equation solvers – as they are usually used for FEM – are therefore not used for solving MBD systems. For MBD systems, solvers are used with the ability to reduce the order.

After solving the system of equations, the following variables are available for post-processing:

- translational velocity
- rotational velocity
- coordinates of center of gravity
- orientation angles and coordinates of position
- applied, external forces
- forces in joints and constraints

2.1.2 Restrictions

Restrictions of MBD systems and demarcation to FEM

A very basic property and restriction of MBD is given by the rigidity of the considered bodies. A moving body (rigid link) can be moved in space, but cannot be deformed. For MBD, real bodies are reduced to their mass and inertia properties and their geometrical dimensions, while their deformation properties are neglected. This is the basic difference to structural mechanics, which uses FEM to consider flexible bodies, including their stiffness and so their deformations and stresses. The disadvantage of linear FEM compared to MBD is that no movements and only small deformations can be simulated. Therefore, the assumption of rigidity in the motion links in MBD has the advantage of simplifying the analysis and reducing the computational effort, thus enabling even complex motions of large assemblies to be analyzed.

Clearances, tolerances and flexible bodies can be modeled in MBD only with greater effort.

In reality, however, there are some effects that are difficult to model using MBD. These include clearance, tolerance, and flexibility. Because such effects are often not taken into account in the MBD model, in some cases it may appear, for instance, that a clamping situation has occurred, when in reality there is a slight clearance in the joints or there is some flexibility in the body to ensure motion without any problems.

Clearances can be considered in MBD as well, but then the corresponding parts must be considered dynamically and the contacts with restoring forces must be modeled. If so, the system will have unconstrained degrees of freedom, which will make the problem significantly more difficult to define and solve.

2.1.3 Classifications of MBD

Classification of dynamics

For a classification of motion simulation we refer to the classification of mechanics as, for example, it is described in [HaugerSchnellGross]. Accordingly, the mechanics may be divided into *kinematics* and *dynamics*.

Kinematics is the science of the temporal and spatial movement, without regarding forces as a cause or effect of the movement. The *dynamics*, however, deals with the interaction of forces and movements. It is divided into the *statics* and *kinetics*. The statics deals with the forces at stationary bodies e.g., a truss in equilibrium), while the kinetics examines actual movements under the effect of forces (Figure 2.4).

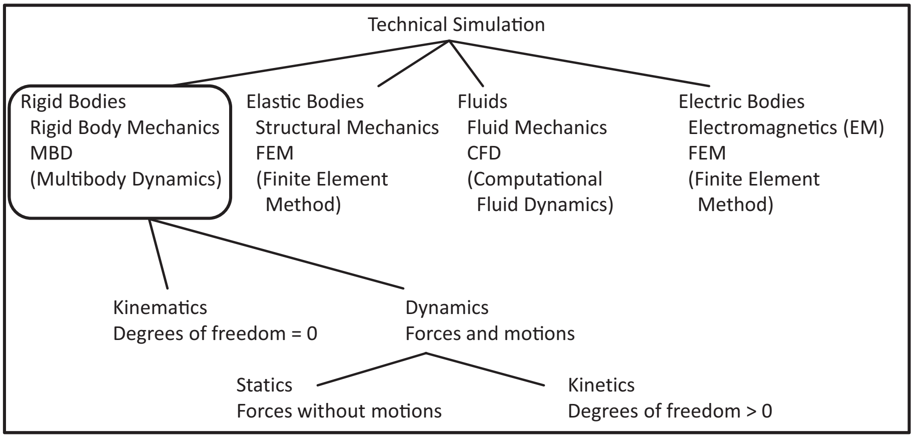


Figure 2.4 Classification of MBD Simulations

Flexible bodies are a special case.

All these phenomena can be analyzed with NX/Simcenter Motion, with the general restriction of rigid bodies in MBD systems. However, starting with version NX 7.5, it also is possible to take into account single flexible bodies in the MBD system. These bodies must be prepared in advance using FEM, which means that the stiffness matrix must be determined (in reduced form) and included as *Flexible Body*  in the MBD system.

Determined and undetermined degrees of freedom

Kinematic systems are characterized by the fact that all degrees of freedom (DOF) of a moving body are determined. This determination may be made either by joints or by driver rules. Such systems are predictable to a certain extent, and can also be referred to as motion-driven systems (tied movement).

Kinetic (Dynamic) systems are available if one or more degrees of freedom are undetermined. In this case, the motion results from external forces (untied movement). For example, the force of gravity can lead to a swinging movement of a lever with rotational DOF. Kinetic systems are therefore also known as power-driven systems.

2.2 Learning Tasks for Kinematics

2.2.1 Steering Gear

This basic example will explain the most important technical matters that are necessary for a simple motion analysis using Simcenter Motion (Figure 2.5). The example will take the user through the process of generating links (the motion bodies in Simcenter 3D) and basic joints and uses the *Articulation* function as the driver since it is well suited for purely kinematic motion simulations. In addition, the function for dynamic analysis will be used as a method for detecting unconstraint degrees of freedom.

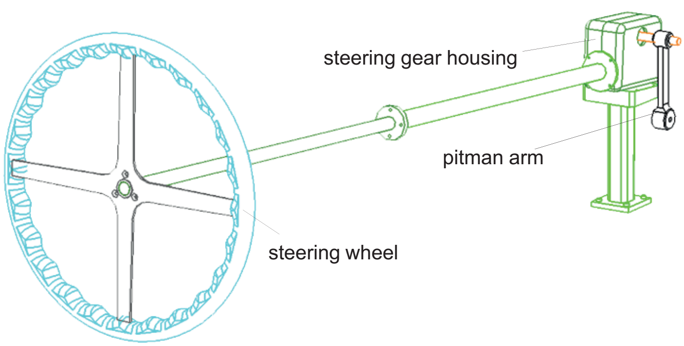


Figure 2.5 CAD model of the first example of motion simulation

This kinematic model based on a subassembly first is defined as a stand-alone mechanism. In a later example, this mechanism will be modularly assembled with other mechanisms in a higher level assembly to form a larger motion model.

> This basic example should be performed by everyone who wants to work with Simcenter Motion.

2.2.1.1 Task

The goal is to control the design.

A designer has redesigned the levers for the steering gear. Now the designer has to check if collisions occur in the mechanism. Therefore, a kinematic model must be created that allows the rotational movement of the steering wheel, and (associated with it) of the stalk on the steering column.

In this task, the steering gear of the RAK2 and its steering wheel and the control stalk are used. The steering gear is accommodated in a housing and connects the steering wheel with the control stalk.

For this task, the simulation should only be used for visual control. However, the examination of minimum distances to other components, the study of the resulting reaction forces in the joints and collision checks would be possible in further analyses.

In the following section, at first some principles are explained. Thereafter, the necessary solution steps for this example are presented. Very hurried readers can skip the next section and move straight to the creation of the model (see Section 2.2.1.4).

2.2.1.2 Overview of the Functions

In the *NX/Simcenter Motion* application the kinematic or kinetic model is set up and the simulation is performed and evaluated. Figure 2.6 shows the *Motion* toolbar that appears after changing to the Motion application. The *Home* toolbar and the *Analysis* toolbar contains all the main features of the *Motion* module that are needed to set up, solve and post process motion analyses.

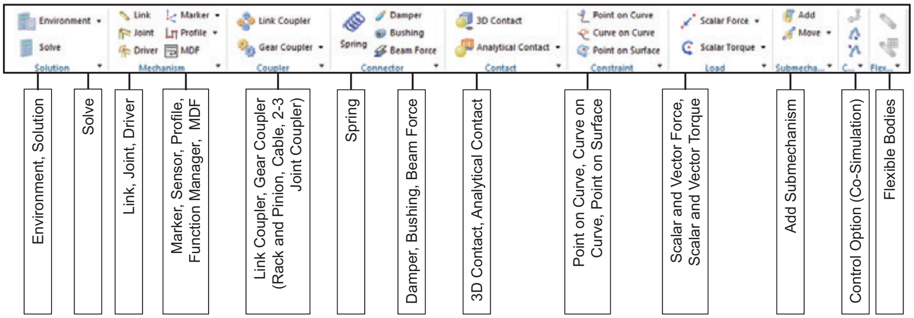


Figure 2.6 Overview and brief explanation of the *Home* tab functions of *Motion*

In the subsequent section we give an overview of the main functions in the *Motion* module with a reference to later use. Very hurried readers can skip this section and immediately move on to the creation of the model (Section 2.2.1.4).

Defining and solving a motion solution

-  The function *Environment* allows to define the basic setting of the system for kinematic or kinetic properties (herein called dynamics). For our task, we will use the "dynamics", although it is actually a kinematic model. The reason for this approach is, that the user has more possibilities, which contribute to a better understanding and error identification. In addition, in the *Environment* dialog advanced solution options can be selected for the RecurDyn solver. The option *Component-based Simulation* is suited for assemblies, because it activates the selection filter for assembly components for the generation of *Links*.
-  The *Solution* function must be activated by the user to specify the type of solution that is desired. The options include the *Normal Run*, the *Articulation*, and others. In addition, the gravity and the solver parameters are defined here.

For running the analysis, first a solution has to be created. An existing solution could be calculated with the following function:

-  *Solve*