



Introduction to Simulation- Based Design

An Online Continuing Education Course for Engineers

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Introduction

Simulation-based design (SBD) is a methodology used in engineering and design to create virtual models of a system or product and test its behavior under different conditions. SBD reduces the need for physical prototypes, shortens development time, and improves overall product performance by allowing engineers and designers to analyze and optimize products and systems in a virtual environment (Fishwick, 1995). The growing availability of advanced computational resources, user-friendly software tools, and interdisciplinary collaboration has further facilitated the adoption of SBD across industries.

1. History of Simulation-Based Design

The roots of SBD can be traced back to the early days of computing in the mid-20th century. The advent of digital computers enabled researchers to model and simulate complex systems, which previously had been the domain of analytical or experimental methods. Some early simulation applications include weather forecasting, nuclear weapons design, and spacecraft trajectory planning (Fishwick, 1995).

As computing power increased over time, so did the complexity and accuracy of simulations. The development of specialized simulation software in the 1970s and 1980s made SBD more accessible, leading to widespread adoption across various industries (Otto & Wood, 2001). Today, SBD plays a crucial role in developing products and systems, from automobiles and airplanes to consumer electronics and medical devices.

The history of SBD has been marked by continuous innovation and advancements in computing and modeling techniques. As engineers continue to leverage these tools and methods to tackle increasingly complex design challenges, SBD will remain an indispensable component of modern engineering practice.

1.1. Evolution of Modeling Techniques and Simulation Tools

The evolution of modeling techniques and simulation tools has considerably contributed to the growth of SBD. Early simulation models relied on simple mathematical equations and numerical methods, which limited their applicability to relatively simple systems (Naylor & Finger, 1967). However, as computational capabilities advanced and new modeling techniques emerged, the scope of SBD expanded to cover increasingly complex systems and design scenarios.

One of the key developments in the history of SBD was the introduction of computer-aided design (CAD) software in the 1960s, enabling engineers to create and manipulate geometric models of their designs digitally (Sutherland, 1963). Integrating CAD with simulation tools allowed for an accurate representation of physical systems and aided the seamless exchange of data between the design and analysis stages of the product development process (Rohe & Westermann, 2003). 1959 General Motors

and IBM initiated a joint project to develop a cohesive CAD environment. Initially named “Digital Design,” the project was later renamed DAC, standing for Design Augmented by Computer. As shown in Figure 1, the formal unveiling of this system took place at the 1964 Fall Joint Computer Conference, where it was referred to as DAC-1 (Carlson, 2017).

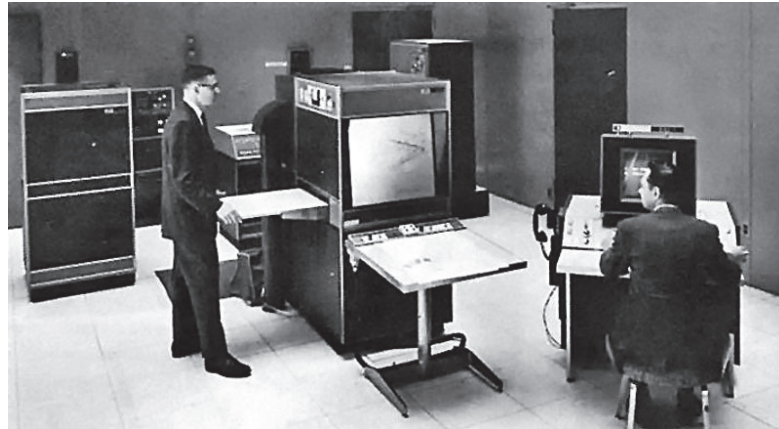


Figure 1. A user working with the DAC-1 program (Carlson, 2017).

Another major milestone in the evolution of SBD was the development of finite element analysis (FEA) in the 1960s and 1970s. FEA enabled engineers to discretize complex geometries and physical phenomena into a system of simple elements, making it possible to simulate and analyze various engineering problems, including structural, thermal, and fluid dynamics (Zienkiewicz & Taylor, 2000).

The rise of the internet and advances in computer hardware and software have further accelerated the growth of SBD by facilitating real-time collaboration, remote access to high-performance computing (HPC) resources, and the development of more sophisticated simulation algorithms (Hosnedl et al., 2017). These advancements have laid the foundation for emerging trends in SBD, such as real-time simulation, digital twins, and the integration of machine learning and artificial intelligence into simulation workflows.

1.2. Basics of Modeling and Simulation

Modeling and simulation have become essential tools in various industries for designing, analyzing, and optimizing systems and products. They enable studying complex systems, testing new concepts, and assessing performance so businesses can make informed decisions, reduce development time, and minimize costs. This section discusses creating virtual models and different simulation types and software.

1.3. Creating Virtual Models of Systems or Products

Virtual models are digital representations of real-world systems or products that facilitate analysis, design, and testing through computational simulations. These models can encompass anything from simple mathematical equations to detailed three-dimensional structures. The process of creating a virtual model involves several steps.

First, engineers and designers must define the problem by identifying the objectives and scope of the simulation, such as understanding a process, improving a design, or optimizing performance. Next, they must formulate the model by translating the real-world system or product into a virtual representation, capturing relevant elements, relationships, and interactions. This may involve selecting appropriate modeling techniques, such as mathematical equations, algorithms, or graphical representations.

The third step is model verification, ensuring the virtual model accurately represents the real-world system or product. This is achieved by comparing model outputs to known behavior, identifying discrepancies, and making necessary refinements. Lastly, model validation involves confirming the model's suitability for its intended purpose by comparing simulation results with actual data or established benchmarks (Sargent, 2013).

1.4. Simulation Software and Tools

Various software and tools have been developed to support SBD across different disciplines and industries. These tools allow engineers to create virtual models, run simulations, and analyze results within a digital environment. Among the popular simulation software are FEA tools, which include programs like Abaqus, COMSOL Multiphysics, and ANSYS, as shown in Figure 2. FEA software analyzes products' and systems' structural, thermal, and fluid properties to predict stress, strain, deformation, and other physical properties under various loading conditions (Sobieszczanski-Sobieski & Haftka, 1997).

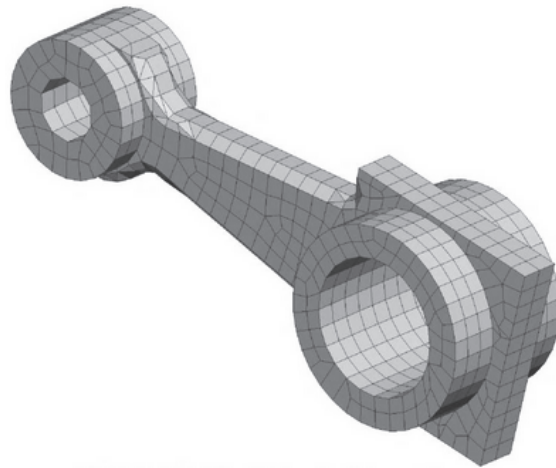


Figure 2. The discretization of a structural CAD model part via the finite element method in ANSYS Workbench (Dadkhah & Zecher, 2009).

Another category of simulation tools is computational fluid dynamics (CFD) software, such as Fluent, CFX, and OpenFOAM. These tools simulate fluid flow and heat transfer processes, permitting the analysis of aerodynamics, internal fluid flow, and thermal performance in various applications (Anderson, 1995). Multibody dynamics (MBD) tools, like MSC Adams and Simpack, are also commonly used in SBD. MBD software focuses on simulating the dynamic behavior of mechanical systems with multiple interconnected components. These tools assist engineers in optimizing system performance, evaluating design alternatives, and identifying potential issues before building physical prototypes (Otto & Wood, 2001). System-level simulation tools, such as MATLAB and Simulink, play a critical role in SBD.

These software programs enable engineers to model and analyze the dynamic behavior of complex systems, including control systems, communication networks, and multi-domain physical systems (MathWorks, 2021).

1.5. Selecting Simulation Software

When selecting simulation software, it is essential to consider several factors to ensure it meets the specific needs of the modeling and simulation task. First, consider the purpose and domain, choosing a tool that aligns with domain-specific features, model fidelity, or analysis capabilities. Next, evaluate the ease of use and learning curve by assessing the user interface, documentation, and training resources to ensure the software is accessible and easy to learn for the intended users.

Scalability and performance should also be considered, as the software must be able to handle large-scale models, complex simulations, or HPC resources if required for the given application. Customizability and extensibility are equally important, so select a tool that allows users to modify or extend its functionality through scripting, plug-ins, or APIs to accommodate specific modeling and simulation needs. Lastly, consider the software's cost and licensing, considering the organization's budget and long-term requirements. Assess the software's price, licensing model, and support options to make an informed decision.

1.6. Working with Simulation Software

Various simulation software tools are available to support the development, execution, and analysis of virtual models. They vary in terms of complexity, scalability, and domain-specific capabilities. Key aspects of working with simulation software include model building, model execution, analysis and optimization, visualization and reporting, and interoperability and integration.

Most software tools provide graphical user interfaces (GUIs), drag-and-drop components, or scripting languages for constructing virtual models, as shown in Figure 3. Users can define system elements, relationships, and interactions (Law, 2007). Additionally, users can run simulations with different input parameters, scenarios, or experimental designs, generating output data that can be analyzed, visualized, or compared with actual results.

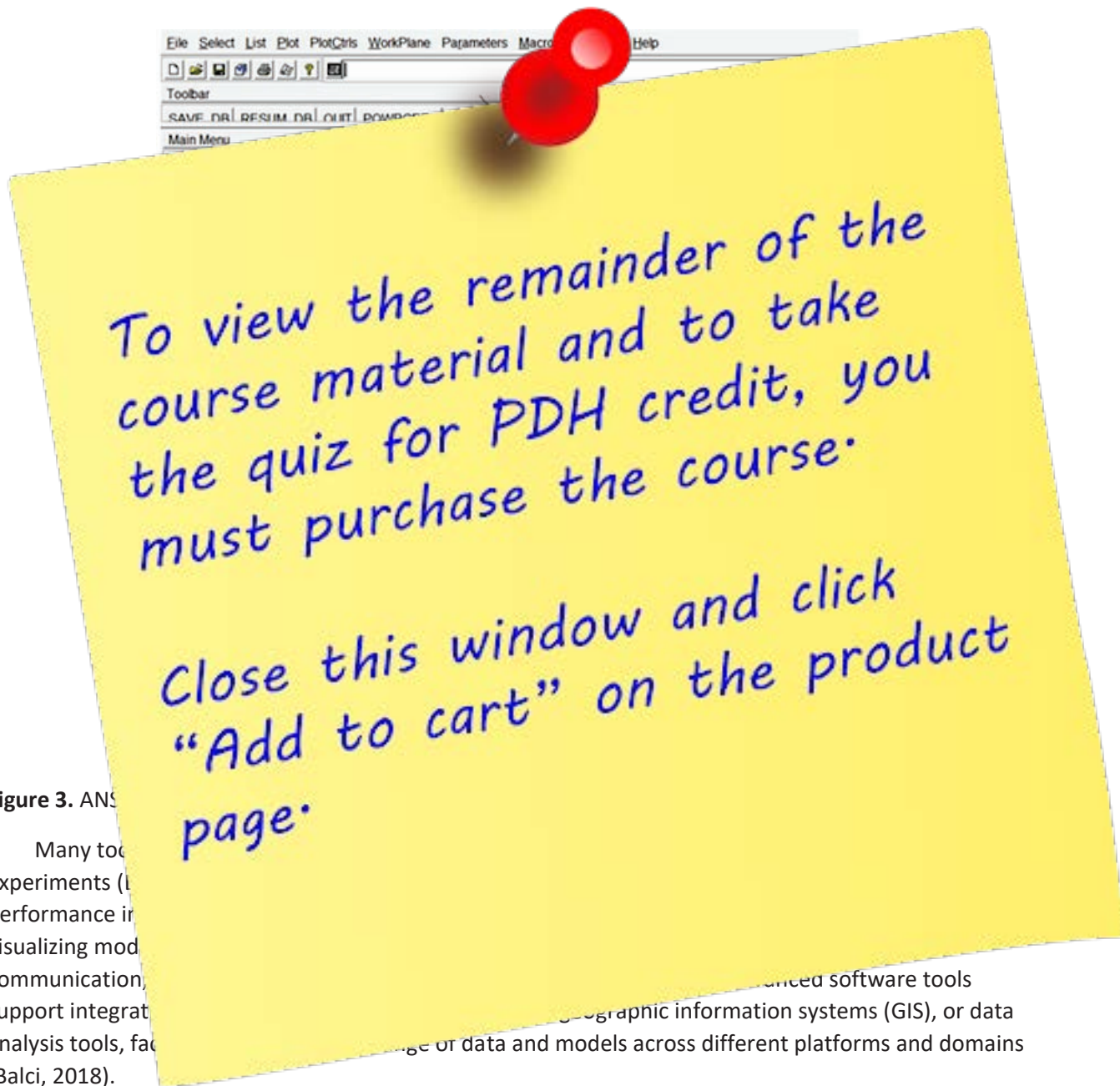


Figure 3. ANS

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Advanced software tools
geographic information systems (GIS), or data
analysis tools, fac

1.7. Evaluating Simulation Models

Evaluating the performance and accuracy of simulation models is a pivotal aspect of the modeling and simulation process. Model evaluation primarily focuses on the model's validity, computational efficiency, and practical usability.

Model validation is the process of assessing how well the model replicates real-world outcomes. It involves comparing the outputs of the simulation model with experimental data or analytical solutions to establish the model's accuracy in portraying the system under study (Oberkampff et al., 2004). However, obtaining high-quality experimental data for validation can be challenging, often requiring careful planning and resource allocation.