Simulation of Internal Combustion Engines

In engineering, simulating has come to mean the development and usage of appropriate formulations that permit critical processes, which take place inside the object of interest, to be analyzed.

Since the early developments of the internal combustion engine in the 19th century, e.g., the simulation of the operating cycle has remarkably contributed to increase the engine performance by estimating potentialities, limitations and practicability of different concepts [5-9].

Nicolaus A. Otto (1832-1891) as well, used the simulation to calculate the expected indicated work of different operating-cycle concepts before prototyping them [7]. These simulations based on gas-law equations permitted to identify a great advantage of combustion in a compressed fuel-air mixture, instead of atmospheric pressure. This was the key idea for an essential evolution of internal combustion engines.

![Figure 2.1: Ideal p-V diagram of the engine operating-cycle proposed by Nicolaus Otto.](image1)

![Figure 2.2: Nicolaus Otto’s first experimental indicating diagram (18th May 1876).](image2)
In order to realize this solution Nicolaus A. Otto, in 1867, was the first to propose and then patent an engine cycle with a four-stroke cycle: intake, compression, expansion and exhaust (Otto’s cycle – see Figure 2.1). Experimental pressure data of the gas in the cylinder over the operating cycle of Otto’s engine prototype confirmed the expectation from the simulation results (see Figure 2.2). In comparison to the first generation of marketable internal combustion engines with combustion at atmospheric pressure (efficiency at best about 5 percent) Otto’s engine permitted to achieve both a thermal efficiency up to 11 percent and an enormous reduction in engine weight and volume [5]. This was the ancestor of contemporary automotive engines.

2.1 Simulation towards Virtual Engine Development

During the years engine simulation has continuously gained in reliance but it was mainly in the last two decades that the rapid increase of computer performance has faced the rising complexity of the engine design process by providing solutions supported by sophisticated simulation programs. At the present time the application of simulation programs that provide a reliable “virtual engine development” represents one of the greatest challenges in the development of future internal combustion engines [10,11].

The role of the simulation in the development process of internal combustion engines and the definition of virtual engine development are still not well defined. Thus engine manufacturers have quite different expectations regarding the considered aspect. For developers the emphasis is most certainly towards the gain of knowledge. Designers aim to exploit the possibilities by means of calculations, but also the limits of their design ideas even during the phase of concept finding. Test engineers desire to find explanations for measured phenomena and to be inspired to seek improvements. The management, on the other hand, appreciates rather the reduction of the technical risk involved with a new development, a possible reduction of development time and investment (“engine test stands are more costly than workstations”) and last but not least reductions in both the development budget, as well as subsequently the manufacturing costs during production.

2.1.1 One Tool for the Simulation of the Entire Engine?

Internal combustion engines are extremely complex machines where detailed and accurate analyses of both the thermodynamic processes occurring in the fluids (charge, cooling, lubrication, etc.) and the stresses, strains and thermal loads of each mechanical part are