

THE PROCESS OF CREATING A MODEL OF A SINGLE-CYLINDER ENGINE USING 1D PROCESS SIMULATION SOFTWARE

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Abstract: The modern development of engines requires advanced methods of analysis and optimization, with 1D modeling becoming a key tool for simulating engine performance characteristics. This paper explores the application of 1D modeling in engine analysis, with a particular focus on its educational benefits. By utilizing computational tools, engineers can efficiently test engine configurations, while students gain practical skills in understanding complex processes. Through the example of modeling a single-cylinder diesel engine, the procedure for model creation and simulation is presented. The paper emphasizes the importance of these tools in both industry and education, as well as their contribution to the development of engineering competencies.

Key words: Internal combustion engine, one-dimensional modeling, simulation, parameters, virtual experiment, engineering education

1. INTRODUCTION

The modern development of engines, whether in the automotive, marine, aviation industries, or in the field of energy efficiency, requires increasingly sophisticated methods of analysis and optimization. Engine modeling using computational tools has become a key element in this process, as it enables precise simulation and prediction of engine performance characteristics without the need for expensive experimental testing [1]. In this context, one-dimensional (1D) modeling software plays a significant role in the analysis and simulation of dynamic processes within engines, such as fluid flow, combustion, and thermal changes, allowing engineers to quickly test different configurations and optimize performance.

Although 1D engine modeling is simplified compared to more complex multidimensional simulations, it offers significant advantages in terms of analysis speed and computational efficiency [2]. Software tools that facilitate such modeling allow users to analyze key engine operating aspects, such as air, fuel, and exhaust gas flow, with minimal computational complexity. For this reason, these tools are widely used in industrial applications, as well as in research laboratories and educational institutions. In addition to industrial applications, the use of 1D modeling in educational processes is becoming increasingly important, as it allows engineering students to gain a practical understanding of complex engine processes in a simple and effective manner. Through working with 1D modeling software, students can simulate real processes, interpret simulation results, and develop skills that will be valuable in future engineering projects [3]. Educational processes integrating such tools allow students to connect with modern technologies and methods in the field of engine systems, making them more competitive in the job market.

The aim of this paper is to explore the application of 1D modeling in engine analysis and to examine the educational benefits arising from the use of such tools in academic settings. We will analyze the key advantages and challenges in applying these software tools, both in industrial research and in the educational process, with a particular focus on the development of student skills and competencies. The complete procedure for creating a model in one-dimensional engine simulation software, using the example of a single-cylinder internal combustion engine, will be presented in the paper. The modeling will be based on data from a Volkswagen diesel engine with a 1.9-liter displacement, adapted to the single-cylinder engine example [4].

2. DESCRIPTION OF THE MODELING PROCEDURE

Before proceeding with the creation of the model, it is necessary to configure the general parameters and working medium parameters. General parameters refer to simulation settings, such as the units to be used for defining the simulation duration, the simulation time span itself, and the choice

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of automatic convergence for the simulation. Regarding the working medium parameters, the type of fuel (in this case, diesel fuel) is selected, along with the properties of air, particularly its compressibility. For this specific simulation, it is assumed that air behaves as an ideal gas.

It is important to note that all parameters can be entered either as specific values or as variables whose values can be adjusted to make the model and simulation more flexible. These variables are referred to as user-defined parameters and are stored in a table called the „Constants Table“. This allows for greater adaptability in modifying the model during simulations and facilitates easier experimentation with different conditions or configurations.

2.1. Creation of the Single-Cylinder Engine Model in the workspace

Due to space limitations, only the modeling of the single-cylinder engine will be described here, within which all necessary dimensions, injection laws, combustion parameters, and others will be determined. The first step is the graphical modeling of the engine, which involves selecting the appropriate elements to be connected in a proper manner. The elements are chosen from an element tree, which contains several subfolders, including:

- Flow Elements (such as pipes, valves, injectors, etc.)
- Control Elements (such as sensors, actuators, etc.)
- Mechanical Elements (such as the turbocharger shaft)
- Predefined Components (pre-built components ready for integration).

All the required elements are transferred from the tree to the software interface's workspace, where they are then easily connected into a coherent model. In Figure 1, the visual appearance of the connected elements is shown. By convention, the elements are connected from left to right. This process allows for the intuitive assembly of the engine model, ensuring all relevant components are integrated in the correct flow path, simulating the dynamic processes within the engine.

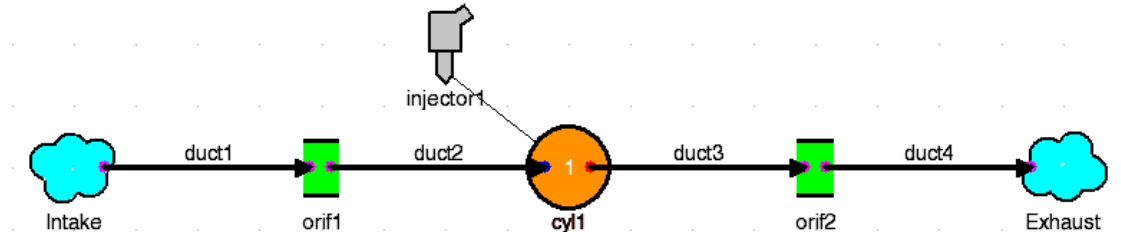


Figure 1 –Visual representation of the single-cylinder engine model on the workspace

The elements "Intake" and "Exhaust" belong to the "Ambient" element type, which represents an "infinite reservoir" at a defined pressure, temperature, and composition. By convention, Ambient elements are always placed on the far left for the intake manifold and on the far right for the exhaust manifold, as the entire process is also conventionally carried out from left to right. The element "cyl1" is of type Engine Cylinder, while the elements "orif1" and "orif2" are of type Orifices, which serve to connect two pipe elements of the same or different diameters. The elements named duct, which appear after the connections are made, actually represent pipes. The element Injector1 is of type Injectors.

2.2. Setting the Parameters

Once the elements are connected, the next step is to define their parameters. By double-clicking on any of the elements, the corresponding window opens, allowing the user to adjust the parameters of that element.

For the "Intake" and "Exhaust" elements, the ambient pressure and temperature are set to 1 bar and 300 K, respectively. After defining the ambient parameters, the next step is to define the parameters for the ducts. The duct parameters are adjusted in the appropriate window, where the duct dimensions, friction coefficient of the duct walls, heat transfer coefficient, and discretization length are

entered. The discretization length of the duct determines whether the simulation will be more precise (but slower) or less precise.

Table 1 will display the dimensions and adopted parameters for all four modeled ducts.

Table 1 –Dimensions and parameter values for the four ducts in the model

	Left diameter [mm]	Right diameter [mm]	Discretiz. length [mm]	Overall length [mm]	Wall friction	Wall heat transfer	Pressure [bar]	Temperature [K]	Wall temperature [K]
Duct 1	40	35	35	150	1	1	1	320	340
Duct 2	35	35	35	50	1	1	1	340	370
Duct 3	28	36	40	50	1	1	1.05	470	470
Duct 4	36	36	40	140	1	1	1.05	900	850

After defining the ducts parameters, the cylinder parameters need to be defined.

However, before that, the parameters of the engine itself must be set, such as the definition of the combustion process model and heat transfer model. For the combustion model, the Diesel Wiebe model was chosen in this case, as it is widely used because it accurately describes combustion in most diesel engines [5],[6]. For the heat transfer model, the Woschni correlation model for convective heat transfer was selected [7], as it assumes simple heat transfer from a limited volume, surrounded by the cylinder head, cylinder wall, and piston crown. Next, the number of cylinders (1), the number of strokes (4) in the working cycle, and the type of engine (diesel) are entered. Additionally, data on the engine speed, reference pressure, temperature, and the start of combustion are entered. These parameters are best formulated as four user-defined variables, as this will allow their variation during virtual experiments.

Once the engine parameters are defined, it is necessary to define the cylinder parameters. This is done in the appropriate window, where the basic parameters, such as piston diameter, piston stroke, and the clearance between the piston and the cylinder head, are entered. Additionally, the connecting rod length, compression ratio, and Wrist Pin Offset must also be entered. Following this, the initial conditions must be specified, including the temperatures of various parts of the piston mechanism, such as the top surface of the piston, the cylinder, the head, the intake valve, and the exhaust valve.

Regarding the valves, the valve type is first defined as a “Lift Valve”, and then in the “Lift Valve Editor” window, the parameters of the selected valve are defined, such as the number of valves, valve diameter, and valve lift profile. The valve lift profile is defined in relation to the crankshaft rotation angle, as shown in Figure 2.

Next, the flow restrictions for different valve positions can be described. Once the intake valves are completed, a similar procedure is repeated for the exhaust valves.

Finally, the injector must be defined. After selecting the injector type “Mg per injection,” based on the available data on the injected fuel mass per cycle at different loads and engine speeds, and connecting the injector directly to the cylinder, the injector parameters are defined. First, the mass of injected fuel per cycle (in milligrams) and the injection start moment (expressed in crankshaft degrees before TDC) are entered as two user-defined parameters. Then, other parameters are defined, such as the mixture temperature, nozzle diameter, and the “spray spread angle.” Additionally, the injection duration and injection pressure are also entered.

Once the injector parameters are defined, the creation of the single-cylinder engine model is complete. The visual appearance of the aforementioned model on the software workspace was shown earlier in Figure 1.

As previously mentioned, all user-defined variables are stored in a constants table. This table, with the specific varying values of all parameters for 9 different engine speeds in 9 virtual experiments, is shown in Figure 3.

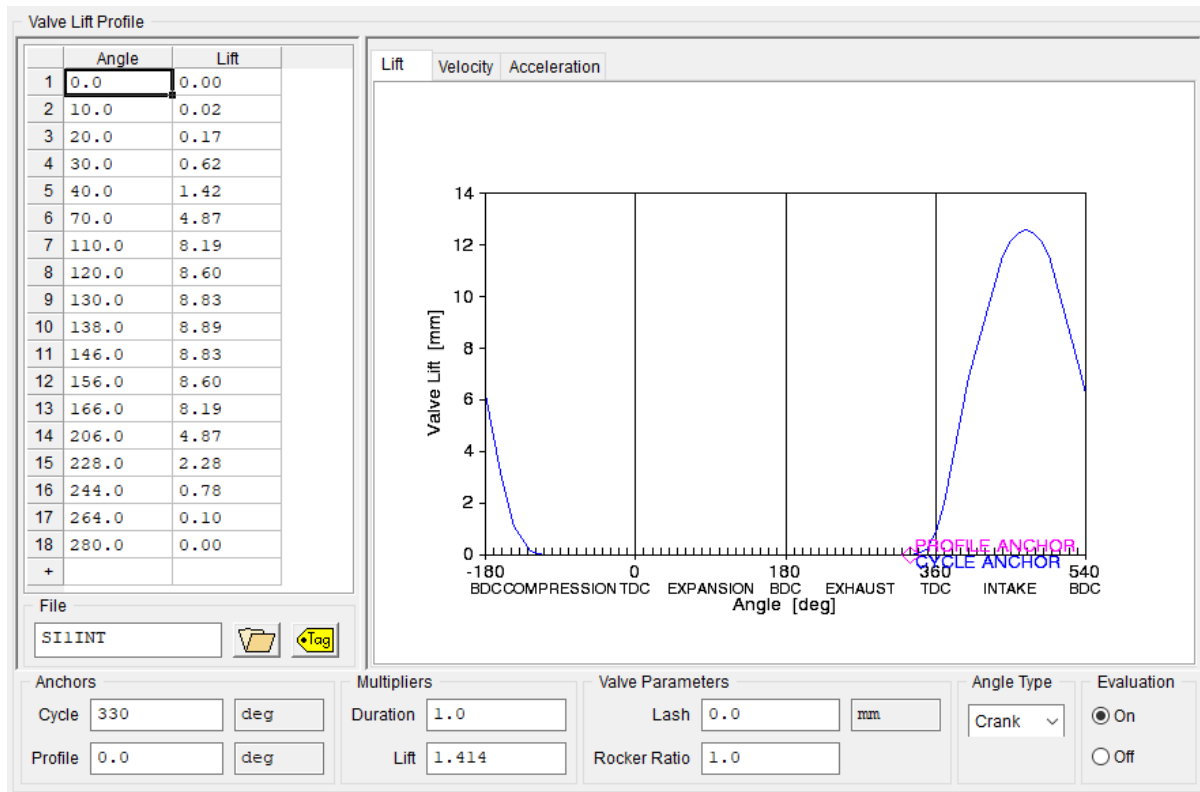


Figure 2 – Defining the valve lift profile

Constants Table											
Sweep Constants		Dependent Constants		External Constants							
Name	Units	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9	
Status		Run	Run	Run	Run	Run	Run	Run	Run	Run	
Title		Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9	
1 speed	rpm	1000	1500	2000	2500	3000	3500	4000	4500	5000	
2 CR		19	19	19	19	19	19	19	19	19	
3 injdur	deg	18	21	24	26	28	31	31	30	23	
4 injmass	mg	57	54	52	50	48.5	47	45.5	44	43	
5 NCYC	cycle	3	3	3	3	3	3	3	3	3	
6 pamb	bar	1.013	1.013	1.013	1.013	1.013	1.013	1.013	1.013	1.013	
7 SOC	deg	{soinj+2.4}	{soinj+3.6}	{soinj+4.8}	{soinj+6}	{soinj+7.2}	{soinj+8.4}	{soinj+9.6}	{soinj+10.8}	{soinj+12}	
8 soinj	deg	-15	-13	-12	-16	-20	-24	-27	-28	-28	
9 tamb	K	298	298	298	298	298	298	298	298	298	
10 tcyl	K	540	560	570	575	580	590	595	600	600	
11 thead	K	550	570	580	585	595	610	620	625	625	
12 tpis	K	500	520	530	540	550	570	580	585	585	
+											

Figure 3 – Constants table with entered values for 9 cases

2.3. Simulation of the Model

Before launching the simulation itself, the user is given the option to request a diagram of a specific parameter that they need. These diagrams are referred to as Time Plots within the program and represent the results obtained during one working cycle. In the case of multi-cycle simulations, as is the case here, the last cycle of each individual case will be relevant. In this particular case, the required diagram is the pressure inside the cylinder as a function of the crankshaft angle. This diagram can be requested by right-clicking on the cylinder, which will open a window displaying a list of parameters whose diagrams can be shown. In this case, the Pressure parameter is found and selected from the list.

Once the model simulation is completed, the results are automatically saved as a text document, and the data can be exported to Excel or another format if further processing is required for other purposes. An example of the diagram showing the pressure variation in the working cylinder, obtained from the simulation in one virtual experiment, is shown in Figure 4.

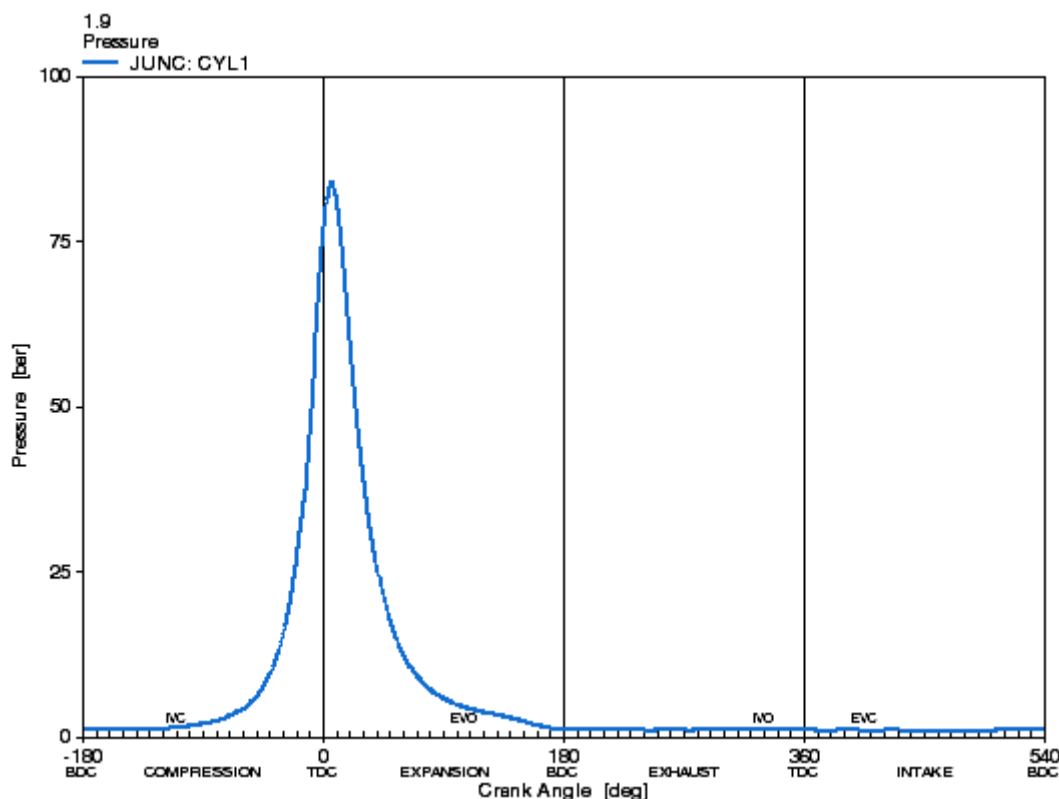


Figure 4 – Pressure variation diagram in the cylinder during the working cycle

By varying different parameters, which are defined as user-defined variables, a large number of such diagrams can be obtained in order to examine the impact of a specific parameter on the pressure variation within the cylinder. In addition to the pressure variation diagram, it is possible to generate numerous other types of diagrams, allowing for the analysis of the effects of various parameters on different phenomena and variables related to the modeled internal combustion engine. For this reason, such software tools are highly suitable for application in the automotive industry, as well as for educational purposes, since students can learn a great deal about the highly complex processes in an engine through concrete examples.

3. CONCLUSION

1D modeling provides efficient engine analysis in the industry, reducing the need for experimental testing and improving energy performance. In education, it allows students to acquire practical skills and an understanding of complex engine processes. While less precise than multidimensional simulations, 1D modeling is an invaluable tool for design optimization and the development of engineering competencies, making students more competitive in the job market.

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4. REFERENCES

- [1] Reif, K.: *Diesel Engine Management: Systems and Components*; Springer Fachmedien Wiesbaden, Wiesbaden, 2014.
- [2] Onorati, A.; Montenegro, G.: *1D and Multi-D Modeling Techniques for IC Engine Simulation*; 1st ed.; SAE International, Warrendale, 2020.
- [3] García- Oliver J.M., García A., De La Morena J., Monsalve- Serrano J.: Application of a One- dimensional Spray Model to Teach Diffusion Flame Fundamentals for Engineering Students. *Comp Applic In Engineering*, 27, 1202–1216, 2019, doi:10.1002/cae.22146.
- [4] Volkswagen of America, Inc. Service Training : 1.9 – liter TDI Engine with Pump Injection Design and Function, 2003.
- [5] Bartlett, M.: *Adlard Coles Book of Diesel Engines*; Adlard Coles Book Of Ser; 5th ed.; Bloomsbury Publishing Plc, London, 2018.
- [6] Heywood, J.B. *Internal Combustion Engine Fundamentals*; Second edition.; McGraw-Hill Education, New York, 2018.
- [7] Chen S. K., Flynn, P. F.: Development of a single cylinder compression ignition research engine. *SAE Technical Paper*, 1965.