Software for engine simulation and optimization

www.diesel-rk.bmstu.ru

The full cycle thermodynamic engine simulation software DIESEL-RK is designed for simulating and optimizing working processes of two- and four-stroke internal combustion engines with all types of boosting. The program can be used for modeling the following types of engines:

- DI Diesel engines (with PCCI).
- SI petrol engines.
- SI gas engines including prechamber systems.

For two-stroke engines the DIESEL-RK supports the following scavenging schemes:

- Uniflow scavenging.
- Loop and cross scavenging.
- Junkers (OP) & OPOC schemes.
- Crankcase scavenging.
- Z-engine concept

Typical applications include:

- Torque curve and other engine performances predictions.
- Fuel consumption prediction and optimization.
- Combustion and emission analysis and optimization.
- Knock prediction.
- Valve timing optimization.
- EGR analysis and optimization.
- Turbocharger and bypasses matching and optimization.
- Conversion of diesel engines into gas engines.

The program DIESEL-RK makes it possible to simulate the working process of any type of internal combustion engines with high accuracy of predictions with the use of minimum empirical coefficients. The values of these coefficients are constant for any configuration and operating modes of engines and over the whole operating range including part load and idling.

The DIESEL-RK is a best tool for a new engine concept analysis because one allows creation of a new project very easily and fast. Philosophy of work of pre- and post-processors is focused on help to engineer.

The modern models of combustion and emissions formations together with built-in optimization procedures allow optimal emission control corresponding with actual emission regulations. These functions were fully tested in industry.

A model of the gas exchange takes into account the non-steady gas flow in ports, specifics of the port’s design, the influence of the neighboring cylinders and the design features of the pulse converter. The two-stroke engine scavenging model is based on the perfect gas mixing law and the perfect displacement and short circuit hypotheses. Such the model allows engineers to numerically optimize the valve timing and also the design configuration of intake and exhaust ports of two-stroke engines.

DIESEL-RK supports modeling and analysis of engines with two-stage turbocharging, Hyperbar concept, etc., and can be used for matching characteristics of piston engines with turbine and compressor maps.

The DIESEL-RK solver may be run under the control of an external code. In that case the interface of the program includes input & output text files. Templates of these files are generated automatically.
DIESEL-RK has the following novel advanced features:

1. Multi-zone spatial diesel spray combustion model (RK-model) takes into account:
   - piston bowl shape: any geometrical shapes can be modeled and saved into the piston bowl data base which already includes the most common geometries;
   - dynamics and profile of swirl;
   - sprayer location: central, non-central, side injection;
   - number, diameter and directions of nozzle holes;
   - shape of injection profile including multiple injection;
   - drop sizes and dynamics of fuel sprays evolution due to swirl & walls;
   - interaction of the sprays with walls and with other sprays: spatial and near walls.

   Publications:
   SAE Paper No 2005-01-2119, 2005
   SAE Paper No 2006-01-1385, 2006
   SAE Paper No 2009-01-1956, 2009
   SAE Paper No 2010-01-1960, 2010
   SAE Paper No 2013-01-0882, 2013
   ASME ICEF2014 – 5700, 2014
   SAE Paper No 2015-01-1791, 2015
   SAE Paper No 2015-01-1859, 2015

   The RK-model has a capability to optimize the piston bowl shape and fuel injection system parameters (nozzles holes directions, diameter and number of holes) as well as to develop multiple injection strategy and the Common Rail controlling algorithm together with EGR strategy over the whole operating range.

2. Fuel Spray Visualization code.

   This code allows engineers to present results of modeling of interaction of the fuel spray with combustion chamber walls, air swirl and neighboring sprays in the animation picture format. The code assists in choosing the best shape of the piston bowl and select the diameter, the number and the directions of nozzle holes for a given injection duration and swirl intensity.

3. Detailed Kinetic Mechanism for the NOx prediction (199 reactions, 33 species).

   User can select the NOx formation model:
   - Zeldovich's mechanism for conventional diesels (the mechanism accounts 18 species).
   - Detailed Kinetic Mechanism for the correct prediction of NOx emissions in the engine with a massive EGR, multiple injection and PCCI/HCCI (the mechanism accounts 199 reactions, 33 species).

4. DIESEL-RK preprocessor is user-friendly and very easy in use.

   The DIESEL-RK, which is an industrial standard level professional tool, can also be quickly learned and successfully used by beginner-level users. To radically simplify creation of a new study case and corresponding data input process, the special Wizard of New Project Creation has been developed. This tool creates input data file by using generic information about the engine and default data on the most commonly used technical solutions accepted in the subject field. Thus, both the process of data input and the calibration of the engine model become significantly easier.
5. Optimization of multiple injection strategy.

The program allows engineers:
- to carry out automatic optimization of multiple injection strategy taking into account the influence of EGR.
- to optimize the fuel fractions $X_1$, $X_3$, $X_5$ and separations $X_2$, $X_4$ for each injected fuel portion; as well as $X_n$=EGR for every operating mode.
Target function may be $SFC = f(X_1, X_2, \ldots X_n)$ or complex

$$SE = \max \left( 1, \frac{NOX}{NOX_{\text{sp}}} \right) + \max \left( 1, \frac{PM}{PM_{\text{sp}}} \right) + \frac{SFC}{SFC_{\text{sp}}}.$$

where: $NOX = f(X_1, X_2, \ldots X_n)$, $PM=f(X_1, X_2, \ldots X_n)$, etc.

6. Premixed Charge Compression Ignition (PCCI) analysis and HCCI analysis.

All calibration coefficients used for PCCI/HCCI and for conventional engines are identical.

Ignition delay is calculated using Detail Chemistry and accounts EGR. The Lawrence Livermore National Laboratory mechanism which considers 1540 reactions between 160 species is implemented.

The advanced combustion model is combined with Detailed Kinetic Mechanism of NOx formation which allows engineers to optimize the PCCI strategy. Low Temperature Combustion (LTC) is accounted.

(The diagram shows the spray evolution process. Each picture is for the instance of the time corresponding to the end of injection of each fuel portion.)

7. Simulation and analysis of Bio-fueled diesel engines and Gas engines.

The DIESEL-RK supports the library of different fuels including different blends of biofuels with diesel oil for diesel combustion and arbitrary mixtures of gases for gas engine. User-Defined Fuels properties are saved in internal data base of the project. Different types of fuels can be specified for a certain mode of engine’s operation.

Physical properties of biofuel blends are used in the spray evolution simulations and in modeling the evaporation and combustion processes. Properties of gas mixture of gas fueled engine are calculated automatically depending on gas composition. Fuel gas may include arbitrary mixture of: $\text{H}_2$, $\text{O}_2$, $\text{N}_2$, $\text{H}_2\text{O}$, $\text{CO}_2$, $\text{CH}_4$, $\text{C}_2\text{H}_6$, $\text{C}_3\text{H}_8$, $\text{C}_4\text{H}_{10}$, $\text{CH}_3\text{OH}$, $\text{CH}_3\text{O}-\text{CH}_3$, $\text{C}_2\text{H}_5\text{OH}$, $\text{CO}$. This list may be extended easily.
8. Multiparametric optimization, 1D and 2D parametrical research procedures.

To perform optimization calculations the DIESEL-RK is equipped with a built-in procedure of multiparametric optimization which includes 14 methods of nonlinear optimization search. There is also a possibility to perform 1D and 2D parametrical search investigations.

Optimization tools allow considerably increase the efficiency of computational researches focused on improvement the engine performances.

When dealing with problems related to a search for optimal combinations of various engine parameters such as compression ratio, injection timing, diameter, number and direction of nozzle holes, combustion chamber shape, valve timing, turbocharging parameters etc., it is often difficult to plan and run a new experiment and process experimental results because of a large number of variable factors. Very effective way to overcome such the problem is using a multiparametric optimization technique. The optimizing procedure uses the engine's mathematical model together with a specified goal function and restrictions to find a set of optimal design parameters. Due to the high computational speed of DIESEL-RK, the optimization procedure is carried out very rapidly without use of significant resources. The target function including list of engine parameters may be calculated in DIESEL-RK or by User Model DLL being linked to DIESEL-RK kernel.

9. Simulation of combustion in engine with few fuel systems

Combustion model allows specification of few independently working fuel injection systems named as A, B, C, D, E in one cylinder. Each system may include few injectors and may supply own fuel with independent control. The injectors may have nozzles with arbitrary orientation and having different diameters.

3D mesh is used for piston bowl and sprays zones interpretation.

It is non-CFD simulation: balance equations are resolved for clusters of cells. Computational time is 1 ... 2 min on conventional PC.

3D visualization of sprays behavior allows analysis of sprays spatial & near wall intersection.
Evolution of sprays from 2 injectors in cylinder of 2 stroke large marine engine with side injection system. (One inner spray is marked by green bullets to separate inner and outer sprays. Light Green is Near Wall Flow (NWF) on piston; Blue is NWF on cylinder wall. Dark Blue is NWF intersections.)

Yellow bullets on figure indicate zones of sprays spatial intersections. The intersections lead to local decrease of HRR.

10. Dual Fuel engine simulation.

One fuel system may supply for example Methanol and another - Diesel oil. Interaction of sprays of different fuel systems is accounted. Self-ignition of each fuel is calculated using detail chemistry simulation. [ASME ICEF2014 – 5700]

11. Variable Valve Actuation analysis.

Valve Lift Diagram with variable valve actuation can be setup and optimized individually for every operating mode.

The Valve Dwell optimization takes also into account the duration and valve lift of the dwell.

Miller cycle parameters may be optimized for every operating mode easily and fast.

Diesel-RK has built-in data bases of:
- Typical pistons, liners and cylinder heads being used in different engines.
- Properties of materials being used for pistons (skirts and heads), cylinder heads, cylinder liners, gaskets, piston rings, etc.
- Boundary conditions for contacts of different parts, cooling in crank case, cooling in galleries, distributions of heat transfer along surfaces, etc.

User can select any parts (they fit each other automatically) and test any concept / combination of piston-cylinder design for analysis a temperature state of engine.

Finite element mesh is making automatically with account the actual piston bowl shape. Heat transfer between piston and liner is simulating with account the motion, lubricating oil properties and the piston skirt profile. Results temperature fields are used at heat exchange simulating, at simulation of fuel droplets evaporation near the walls where spray impinges the wall. The obtained temperatures in critical places (first piston ring, maximum temperature of piston crown surface) are used as limitation at engine optimization. The data base of engine parts may be expanded if customer requires.

Computational time is survived short, so optimization of engine stills in acceptable time period.

Result temperature field of the engine parts.