

The application of a diagnostic simulator in maritime engineering education

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ABSTRACT: The subject of this article is a diagnostic simulator that is based on a mathematical model of a high-power, medium-speed, four-stroke diesel engine. The program simulates an engine operation under various conditions and introduces various defects. The package is particularly suited to diagnostic engineering education, providing teachers with a powerful teaching tool. It also gives students an increased understanding of the relationship between an engine's technical state and its operating parameters. In the article, the author details the design and application of the diesel simulator application, and lists the diagnostic principles, maintenance strategy and assessment, and the design and implementation of the course material. Inspecting engine parameters and changing the engine set-up in the simulation program are also discussed.

INTRODUCTION

The idea for the role that could be played by a diagnostic simulator came to the author during the course of his work lecturing in the subject of marine diesel engine operation, maintenance and diagnostics. Originally, the requirement was for a teaching aid to support the lectures. In a lecture hall, it is very difficult to convincingly illustrate certain aspects of a diesel engine operation; it is not possible to have a real engine on which to demonstrate, and even if a real engine is used separately to the lecture, it takes a great deal of time to set up and then monitor the faults.

The author generated a program to act as a teaching aid as described above [1]. The response from students after using the program made the author decide to extend the software so that students could also use it as a personal teaching aid in their own time. As students used the software more and more, it became clear that there was a great deal of training potential for this kind of simulator.

DESIGN

The most popular version of the PC-based diesel engine simulator, called *Turbo Diesel 2* (see Figure 1), was developed in 2000, but the history of this simulator began in 1994 [2][3]. The *heart* of the program is a diesel engine mathematical model that is based on the physical structure of the modelled object. The model has been developed using actual factory test bed results and classic thermodynamic equations. The package allows an engine operation under selected initial conditions (eg torque, RPM, ambient air pressure) and variable technical state (eg a dirty air blower, broken piston rings, a worn fuel pump and so on). The simulated engine reacts naturally under almost any combination of factors, although some combinations make operation impossible (as they would in real life).

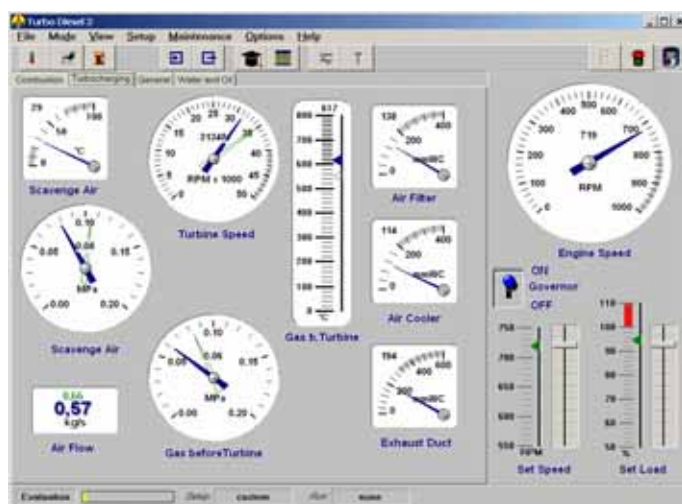


Figure 1: Main simulator window.

In order to validate the software, it was necessary to model an actual engine so that the calculated values produced by the software could be compared to the values measured on a real engine [4].

APPLICATION

The general approach to the diesel simulator application in the diagnostic teaching was based on the author's long-time academic experience in giving courses on diesel engines diagnostics and on some available publications [5][6].

The diagnostic simulator is designed to teach the principles of the generic diesel engine operation. However, it is not designed to teach an operation of any specific engine or type of engine. The main teaching tasks implemented in the simulator are listed below.

Diagnostic Principles

The first requirement was for the software to teach the relation between the diesel engine technical state and its operating parameters. This is performed when the program is in *Evaluation Mode* wherein a student can freely change engine load and operating conditions, can select different engine faults, mix them and see the effects of these changes by inspecting the engine parameters.

Thus, the student learns to understand the relationship between an engine state and the engine parameters. This is particularly important for students early on in their training. It also makes clear the importance of the proper diagnostic method application, since only the correct diagnostic methodology can enable the identification of an engine's faults.

Maintenance Strategy and Assessment

The second requirement was for a more pressurised mode where the student would be obliged to put his/her knowledge into practice, ie run the simulated engine and take responsibility for its condition and maintenance. In the program's *Live Run* mode, the student becomes, in effect, a qualified user. The student needs to monitor closely the engine operating parameters and carry out repairs when necessary. Apart from reacting to student actions, the software also generates random wear and tear factors, which means that no *Live Run* is ever exactly the same as another. Each student's performance is logged and scored for assessment and debriefing.

Design and Implementation of Course Material

The third requirement was for a lesson-mode, both for instructors to be able to create their own specific course material, and for students who could be given set material to work through. The program has a separate lesson-writing program, where instructors can create course material. These courses can then be loaded into the main program for students to complete as required.

OPERATING IN EVALUATION MODE

In program's *Evaluation Mode*, the student can work in the instructor's absence while trying to learn the relationship between the technical state of the engine or the operating conditions on the one hand, and the operation parameters on the other.

The following list gives the recommended training plan for students:

1. The student has to start the engine and observe the operational parameters.
2. Later, the student can increase and decrease the engine load and observe the parameters.
3. The trainee should find his/her way around the engine by changing some of the parameters and observing the effect on the gauges. The program tutorial shows how to do this and how to start making diagnoses by observing the gauges.
4. The current simulation set-up and the engine parameters can be saved in the set-up file.
5. The trainee can also load the previously saved simulation set-up from a file, which is much faster than making a new calculation).

The current simulation set-up and the engine parameters can be printed directly from the program menu. The following is a complete list of the possible simulations:

- Air filter: increase in air path resistance;
- Air blower: decrease in air flow efficiency;
- Gas turbine: increase in gas path resistance;
- Air cooler: decrease in air resistance;
- Gas leak through the piston rings or valves (or both);
- Fuel effective quantity decrease;
- Injection advance angle change;
- Decrease in cooling efficiency;
- Increase in the friction coefficient;
- Engine speed;
- Engine load;
- Ambient air (pressure and temperature);
- Air cooling water flow;
- Cylinder cooling water temperature;
- Lubricating oil temperature;
- Lubricating oil pressure drop at the oil filter air filter: increase in air path resistance.

OPERATING IN *LIVE RUN* MODE

The *Live Run* mode is rather like other computer simulations (a flight simulator for example); the operator has to act as a qualified user, working against the computer, which simulates dangerous situations, faults and so on. Although the scenario is written by an author, additional random factors are also introduced by the computer.

Each *Live Run* starts with the engine in a particular technical state (set by the instructor or loaded from a previously created and saved set-up). As time proceeds, any faults that are present at the outset become aggravated and affect the parameters. The student monitors the engine state and can carry out repairs or maintenance at any time; correct actions lead to more efficient and economical running while negligence, incorrect or unnecessary actions lead to a loss of economical efficiency.

A complete list of the maintenance tasks available in *Turbo Diesel 2* are as follows:

- Cooling pump repair;
- Water temperature controller adjustment;
- Cooling system washing;
- Lubricating pump repair;
- Oil filter cleaning;
- Oil temperature controller adjustment;
- Engine bearing repair;
- Turbocharger general repair;
- Air side washing;
- Gas side washing;
- Air filter cleaning;
- Air cooler cleaning;
- Exhaust system cleaning;
- Cylinder general repair (piston rings and cylinder head);
- Fuel pump general repair;
- Fuel pump adjustment.

Time is measured in steps (the user can speed these up or slow them down at will). At the end of each time step (which can be considered as one day's operation), the computer recalculates

the state of the engine and gives the student his/her current score in dollars; the higher the score, the more efficient the student has been.

The following points are worth noting:

- The student is free to inspect all the available engine parameters, perform maintenance and repairs and change the load, but cannot change the engine set-up directly.
- In certain circumstances, constant engine deterioration can cause an emergency stop. This means an additional penalty on top of the repairs needed to restart the engine.
- The accumulating score is permanently shown in the special *Live Run Info* dialogue box; it will be saved together with the engine set-up while saving a *Live Run*.
- The *Live Run* can be ended at any time. The current result and the cost factors will be saved automatically in the Results file, which lists all the last 50 *Live Run* scores, and the student can save the current status in a special file.

Generally speaking, *the student should repair only what is necessary, when it is necessary.*

INSPECTING ENGINE PARAMETERS

There are many different diesel engine and ambient parameters that can be continuously monitored while running the *Turbo Diesel 2* model engine. Gauges show more than one value (Figure 2). For single gauges, the two readings are the current and reference value. On multiple gauges, the actual value for each cylinder and the reference value common to all three can be observed. The bigger the difference between the actual and reference values, the worse the technical state is.

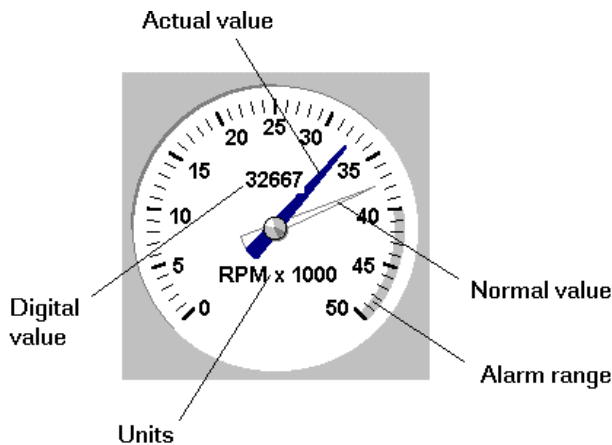


Figure 2: Different parameter values of a single gauge.

The principle that the deviations should be used, rather than the actual parameter values, is very important, especially for students without experience in simulated engine types (see Figure 3). The student can hardly estimate if the observed parameter value is correct, so the parameter deviation is of great help in analysis.

The list of engine parameters that can be inspected in *Turbo Diesel 2* are as follows:

- Set engine revolution speed;
- Set engine load;
- Actual engine revolution speed;

Name	Value	Units	Status	Dev.	-Dev.	+Dev.
Specific Fuel Consumption	239	g/kWh	No alarm	+5%		
Engine Mean Effective Pressure	1.47	MPa	Normal	0%		
Mean Indicated Pressure at Cyl.1	1.77	MPa	No alarm	-3%		
Mean Indicated Pressure at Cyl.2	1.84	MPa	Normal	+1%		
Mean Indicated Pressure at Cyl.3	1.87	MPa	No alarm	+2%		
Lubricating Oil Pressure Before Engine	0.35	MPa	Normal	+1%		
Lubricating Oil Temperature after Engine	79	°C	Normal	+1%		
Cooling Water Temperature before Engine	60	°C	Normal	0%		
Cooling Water Pressure before Engine	0.25	MPa	Normal	0%		
Cooling Water Temperature after Engine	79	°C	Normal	0%		
Air Pressure Drop at Air Filter	366	mmWC	HIGH alarm	+144%		
Air Pressure Drop at Air Cooler	200	mmWC	HIGH alarm	+57%		
Scavenge Air Temperature before Engine	30	°C	Normal	0%		
Scavenge Air Pressure before Engine	0.08	MPa	No alarm	-30%		
Air Flow	0.58	kg/s	No alarm	-16%		
Exhaust Gas Temperature after Cyl.1	533	°C	HIGH alarm	+21%		
Exhaust Gas Temperature after Cyl.2	512	°C	HIGH alarm	+16%		
Exhaust Gas Temperature after Cyl.3	514	°C	HIGH alarm	+16%		

Figure 3: The parameter deviations shown in the Output Data window.

- Engine torque;
- Engine power;
- Engine specific fuel consumption;
- Engine mean effective pressure;
- Cylinder combustion pressure curves (for each cylinder separately);
- Cylinder maximum pressure (for each cylinder separately);
- Cylinder exhaust gas temperature (for each cylinder separately);
- Cylinder mean indication pressure (for each cylinder separately);
- Lubricating oil inlet pressure;
- Lubricating oil inlet temperature;
- Lubricating oil outlet temperature;
- Cooling water inlet pressure;
- Cooling water inlet temperature;
- Cooling water outlet temperature;
- Ambient air pressure;
- Ambient air temperature;
- Turbocharger revolution speed;
- Scavenge air pressure;
- Scavenge air temperature;
- Air flow;
- Exhaust gas pressure before turbine;
- Air pressure drop at the air filter;
- Air pressure drop at the air cooler;
- Air temperature after the air cooler;
- Exhaust gas temperature before turbine;
- Exhaust gas pressure after turbine.

CHANGING THE ENGINE SET-UP

The technical state of the engine elements, as well as the engine load and operating conditions, can be changed with the program set-up. The engine fault simulations are connected with a turbocharging system, combustion chamber, fuel system, cooling system and a lubricating system.

The simulations can be mixed freely (Figure 4), although some combinations make operation impossible (as they would in real life).

Every change in the technical state or in the operation conditions starts the calculation process. The calculation loop

has to be repeated many types until the balance conditions listed below are fulfilled:

- The power required by the air compressor has to be balanced with the power produced by the gas turbine within the given range;
- The air mass flow delivered by the air compressor has to be balanced with the gas flow consumed by the gas turbine within the given range;
- The pressure drop on all passive flow resistors has to be balanced with compression ration produced by the air compressor.

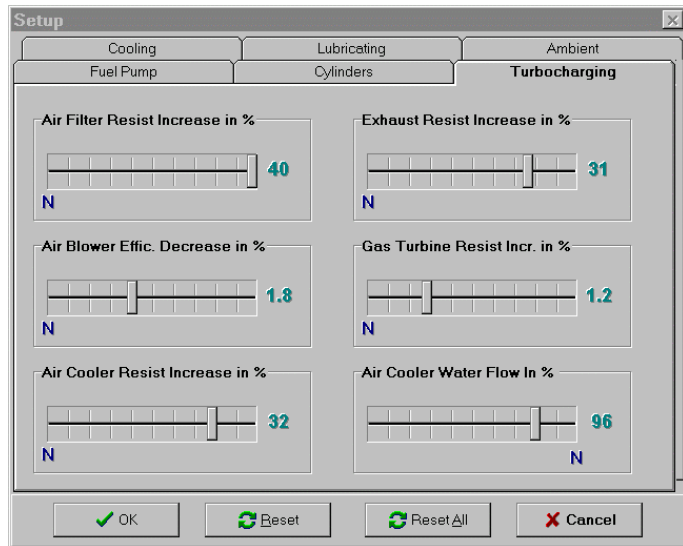


Figure 4: Simulation mixing window.

It takes up to a few seconds until the engine parameters are stable, depending on the actual fault set-up (Figure 5).

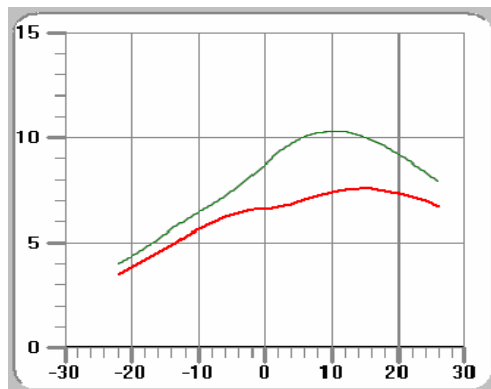


Figure 5: Simulation example – a change in the combustion curve caused by late fuel injection.

A special tool called *Set-up Expert* has also been integrated into the simulator. This explains the relation between the change in the engine set-up and the change in operation parameters, as this is very important when learning about engine diagnostics.

The program enables a student to carry out maintenance and repair in the *Live Run* mode. The student is told when a particular activity was last carried out, as well as its price.

The maintenance and repair tasks possible are as follows:

- Cooling pump repair;
- Water cooler cleaning;
- Cooling system washing;
- Oil filter and cooler cleaning;
- Turbocharger air side washing;
- Turbocharger gas side washing;
- Air filter cleaning;
- Air cooler cleaning;
- Exhaust system cleaning;
- Fuel pump adjustment.

The global cost of the selected repairs is added to any previous repair and maintenance costs. This is a very important measure of competence and can be used for assessment. The engine user who has spent less money for simulated engine operation costs (maintenance, repairs and fuel) will usually be wanted more by a company than another user who produces higher operational costs. The author's experience has shown that, for example, trainees with significant practice as an engineer officer at sea require less money on simulated engine running than the younger, more inexperienced cadets.

CONCLUSION

More than 20 years of the author's experience of different types diagnostic simulators have proved that this kind of a simulator can be successfully utilised for maritime engineering education. The power of personal computers combined with multimedia features, like sound and animation, make the simulation reasonably fast and realistic. Even if this kind of a simulator cannot replace a laboratory with the actual engines, it can surely extend their capabilities.

A very important feature of the simulator presented here is its low cost and the possibility for it to be used also for stand-alone education. A teaching programme based on educational skills and a set of pre-prepared lessons is also necessary for successful simulator implementation.

REFERENCES

1. Kluj, S., The marine diesel engine diagnostic computer simulator ARGUS. *Tagungsmaterial der 18 Internationale Tagung der Ingeieur Hochschule fuer Seefahrt*, Warnemünde, Germany (1988).
2. Kluj, S., the role and mission of a pc-based engine room simulator. *Proc. ICERS 2*, Rimouski, Canada (1995).
3. Kluj, S., The role and mission of the engine room simulator. *Proc. 3rd East-West Congress on Engng. Educ.*, Gdynia, Poland, 162-165 (1996).
4. Kluj, S., The relation between learning objectives and the appropriate simulator type. *Proc. 5th Inter. Conf. on Engine Room Simulators*, Singapore (2001).
5. Percier, M., Caillou, M., Wagemann, L., Adapting simulators for training and the evaluation of operator performance. *Proc. ICERS 2*, Rimouski, Canada (1995).
1. Bichat-Gobard, D., Ongoing research into the use of simulators as an assessment tool to check an applicant's competency as an engineer. *Proc. ICERS 2*, Rimouski, Canada (1995).