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SIMULATION vs. REALITY IN ENGINE DIAGNOSTICS: OPTIMIZING MARINE ENGINEERING EDUCATION

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Abstract. The first lesson a ship's engineer must learn is to constantly monitor all running machinery while standing watch in the engine room. The main propulsion engine is an important piece of equipment which requires monitoring for possible failures. Exhaust gas temperatures, cooling water and lubricating oils are parameters for the operation of the engine that are frequently monitored in order to track the condition of the main engine. A change in exhaust temperature is an indication that something is wrong with the engine and that certain actions need to be taken to determine the cause of such deviation. The next logical step is to obtain more information about the operation of the engine. Teaching this process on the ship engine room simulator is simple: the student must record a pressure-volume diagram by performing in-cylinder pressure measurement, and then determine if the data obtained is sufficient for the final conclusion or if the conclusion is not possible, additional information is needed. The procedure for teaching this process in the real-world engine room is the same, except that in this case a special skill is required when recording the diagram. After such training, marine engineering students should be able to record a diagram in practice, analyze data and recognize possible causes for the engine failure. This article describes how the results of teaching can be optimized when students are taught using a combination of both methods.

Keywords: Engine Room Simulator; Pressure-Volume Diagram; Engine Diagnostics; Engine Room Watch.

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1. INTRODUCTION

Teaching at maritime schools and academies must include practical training in addition to the theoretical part. During practical training, future seafarers must develop the ability to apply the knowledge they have acquired, i.e. to put theory into practice. The theoretical part of the training takes place in classrooms, while the practical part can be carried out on real equipment (high costs of conducting actual training) or using modern teaching methods such as simulation training with high-fidelity simulators (Nyström and Ahn, 2024). When training students on ER Simulator (Engine Room Simulator), the question arises as to how successful these simulators are as a substitute for training on real equipment. A similar question has been asked in many other fields, and there are many studies analyzing the effectiveness of simulator training, many of them in medicine, where simulator training is commonly used (Salimova et al., 2023; Ayaz and Ismail, 2022; Bienstock and Heuer, 2022). Another area in which simulator training is also frequently used and analyzed is the aviation industry (Auer et al., 2021; Somerville et al., 2025). All studies and analyzes emphasize the benefits of using simulators as a substitute for real-world training, as they enable the imitation of reality while eliminating the risks that exist in reality. Similar to the studies mentioned above, there is also significant research on the use of Engine Room (ER) simulators in the maritime industry (Stazić et al., 2022a; Cong et al., 2023). Teaching in marine engineering, as in other fields, is a complex and demanding process. In addition to the theoretical approach, this process requires long-term practical training to educate future marine engineers. The training (or rather the teaching) of future marine engineers starts with a theoretical training in which they should acquire the knowledge they will need in practice, such as the types of equipment, the principle of their operation, the types of malfunctions of this equipment, how to diagnose malfunctions, what to do after diagnosing a malfunction, etc. After completing this part, future engineers should put what they have learned into practice. This part can be completed in an ER simulator or in a real environment, in the engine room of a ship. This article presents the training of future marine engineers as carried out by the authors of this article, their view of the problem and their conclusions as to what should be improved in the training itself to make it even more successful. All readers must therefore bear in mind that this article is only a subjective view of a problem that many of us experience.

2. FIRST STEPS IN TRAINING

Once the trainees have successfully completed the theoretical part of their training and have learned how various machines and devices work, they have to put what they have learned into practice, i.e. operate the machines and equipment. They begin this part of their training on simulators, on which they gradually learn how to operate them in port before completing this part of their training in navigation. The trainees are trained on several different simulators and engine room types in parallel. The training

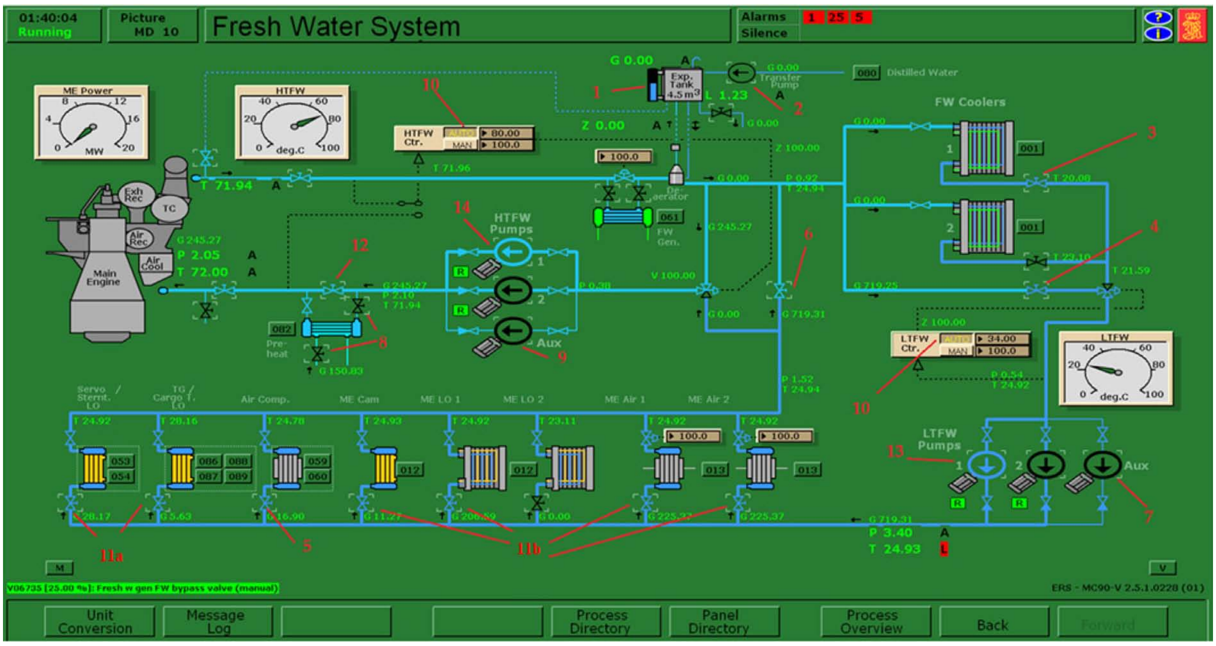

Figure 1. Fresh water system on the Kongsberg Neptune ERS MAN B&W 5L90MC-L11 simulator (Kongsberg Maritime, 2025)

on the Kongsberg Neptune ERS MAN B&W 5L90MC-L11 simulator (Kongsberg Maritime, 2025) is presented in this article. Figure 1 shows one of the systems (fresh water cooling system – FWC system) that the trainees have to prepare when learning how to operate the equipment in port and subsequently in navigation.

In this example, the trainees must fill the fresh water expansion tank (1) using a make-up pump (2) for operation in port. After filling the tank, they must open the circuit through the FW cooler (3) and through the cooler bypass valve (4) as well as open the circuit through some consumers (5). The last step in preparing the low-temperature (LT) circuit in the port is to open the recirculation bypass valve (6) and start the FW auxiliary pump (7). Preparation of the high-temperature (HT) circuit begins with opening the FW and steam valve to the preheater (8) and starting the HTFW auxiliary pump (9). To complete the preparation of this system for port operation, the FW temperature control valves must be set to Auto (11a).

Additional effort is required to prepare the system for departure as the cooling must be set for all required systems operating in navigation. The process begins by opening the valves for all additional consumers (11b). The bypass valve for the FW preheater is then opened (12) and the valve for FW and steam to the preheater is closed (8). The main LTFW pump (13) can then be started and the Auxiliary FW pump (7) stopped. The same applies to the HTFW system, whereby the main pump (14) should be started and the auxiliary pump (9) stopped.

Once the trainees have successfully mastered the system startup (as shown in the example above) and operation of the system, they move on to the next part of the training, which deals with failures during machinery operation.

3. FAILURE DETECTION EXERCISE

The exercise to identify failures and analyze the trainees' reactions begins with two trainees standing watch in the engine room. One trainee is designated as the Engineering Officer on Watch (EOW), who is responsible for the operation of the machinery during his watch, and the other trainee is an oiler, whose role is to assist the EOW in monitoring the machinery (Figure 2) and perform less demanding tasks.

On a real ship, the EOW monitors the condition of the engine by monitoring operating parameters such as temperatures of cooling water, lubricating oil and exhaust gases on the main propulsion system. At the beginning of the simulation exercise, everything is normal (as shown in Figure 2) and the trainees sit in the engine control room and talk. Occasionally, they check FW, lubricating oil (LO), air and exhaust temperatures on main propulsion and generator engines, as well as other machinery parameters.

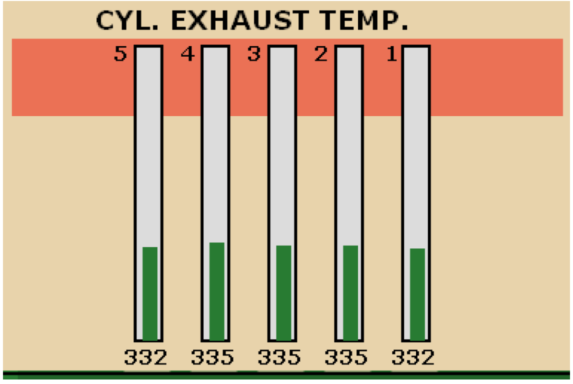

Figure 2. Exhaust gas temperatures in normal condition (Kongsberg Maritime, 2025)

Over time, a pre-programmed fault is activated (engine failure occurs). In this case, it is a failure of the fuel injector No. 2. The trainees should detect this failure by checking the exhaust gas temperatures of the engine (Figure 3).

If they do not notice this change in the machine monitoring, an alarm is triggered for the deviation of the cylinder exhaust gas temperatures. The instructor stops the flow of time on the simulator at this point so that he can talk to the trainees without worrying about what is happening to the simulator. This is where the crux of the whole exercise begins. When asked by the instructor what is happening to the engine and why, the trainees always respond with a wide range of possible causes and they are pretty sure of what they know. The instructor's job is to point out to them that, unlike all the trainees, he as an experienced marine engineer only knows one thing, namely that the temperature on cylinder 2 has

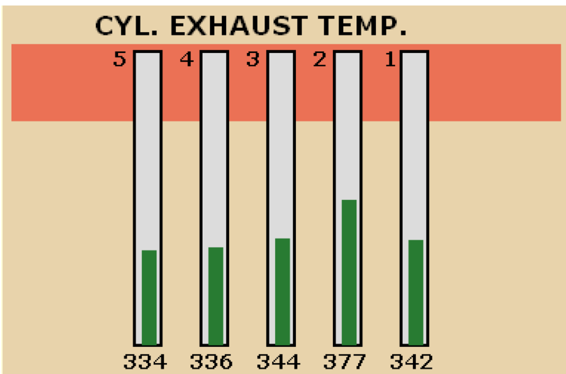

Figure 3. Exhaust gas temperatures in abnormal condition (Kongsberg Maritime, 2025)

risen. As for the cause, he concludes that he does not have enough data to determine the cause of such a reading, nor does he have a crystal ball for divination.

After this critique, the trainees take a step back and conclude that they really need more data and that they should measure the engine pressures on at least two cylinders, the one with the elevated temperature and another for comparison (Figure 4).

Figure 4 shows the *p-α* diagram of two cylinders in different colors (the *p-α* diagram is a diagram that shows the pressure changes in relation to the shaft angle). The pink color shows the cylinder with normal exhaust temperature and the blue color shows the cylinder with high temperature. From the diagram itself, it can be seen that the compression in both cylinders is the same, i.e. both lines are completely identical. Ftom this fact it can be concluded that the condition of the piston rings and exhaust valve is OK (Adomeit, 2002).

The point at which fuel injection begins is also identical, which suggests that everything is in order with the timing. From this point the lines diverge (blue lie is lower than the pink one), it is obvious that the pressure in the cylinder with the higher temperature rises more slowly and less strongly than in the other. At this point the trainees should conclude that it has now been clearly established that there is poor and protracted combustion in the cylinder, caused by poor mixing of fuel and air (McAulay et al., 1966).

The only possible cause of such signs is a failure of the fuel injector in cylinder no. 2. This conclusion is the last part of this exercise on the simulator.

4. SIMULATOR TRAINING RESULTS

In this exercise, the participants learned that decisions should not be made on the basis of insufficient information and that each sign must be carefully examined to determine the cause of the failure. This lesson is very important because in real life, on a ship, they have to make thoughtful decisions based on a detailed analysis of the available data. Simulator training, i.e. this part of the training, has a problem according to ER simulator instructors: the whole atmosphere resembles a common video game, and participants simply play it, often without having any idea of what it looks like in reality.

In order to recheck their doubts and the effectiveness of the training on the ER simulator, a short survey was conducted among the participants in which they were asked to name the main shortcomings of the training offered. The survey was conducted on a sample of 16 students, which is not large enough to consider the results as facts, but it can be considered a good indication of problems. Survey results are:

1. 100% of students indicated that the simulator training was beneficial to their understanding of ER work.
2. 75% stated that ER simulator training helped them better understand the principles of operating ER machines.
3. 93.75% of students felt that it would be good to continue this type of training with practice on a real vessel.
4. Only 12.5% of the students thought that this was enough and that they did not need any further training.

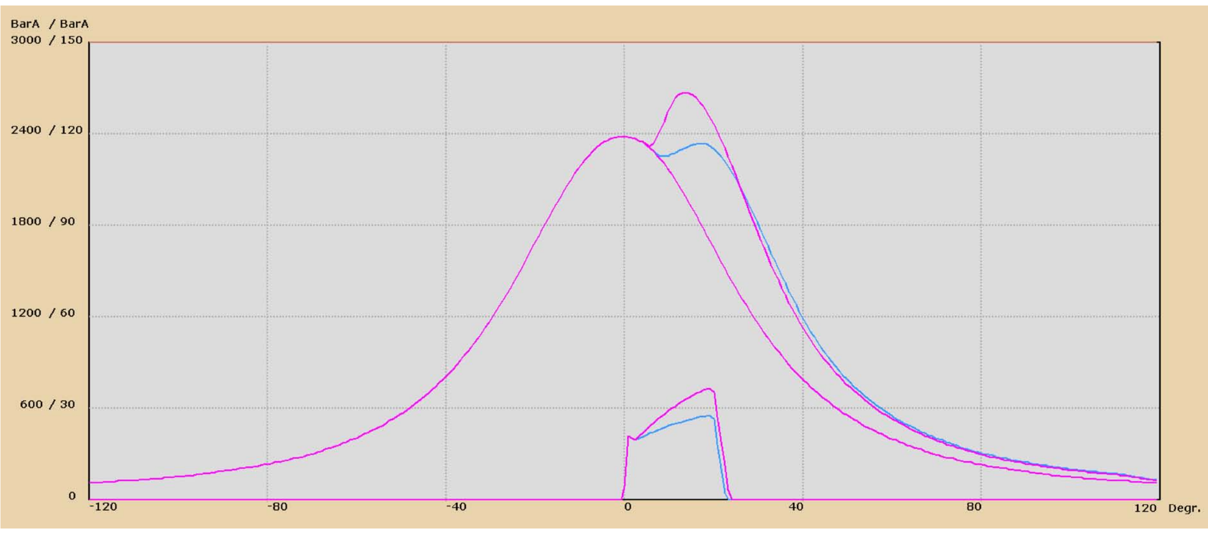

Figure 4. p-α diagrams of two cylinders (Kongsberg Maritime, 2025)

Figure 5. Virtual reality in Simulator training (Wartsila, 2025)

5. 75% of students stated that they do not know what the equipment in question looks like.
6. 100% of students think that this type of simulator training is not entirely realistic, i.e. it does not offer the same stimuli as in reality.
7. 68.75% of students stated that they could not imagine the equipment in question.

In order to reduce the problems listed under points 5, 6 and 7, training on a 3D simulator (Figure 5), i.e. an engine room simulator that mimics virtual reality, was introduced (Stazić et al. 2022b). The introduction of 3D simulator training improved the statistics somewhat, but did not solve the problem completely.

For this reason, an attempt was made to introduce an additional part of the training to be carried out in practice, i.e. on board.

Figure 6. Engine fitted with analogue exh. temp. measuring devices (pyrometers)

5. TRAINING IN PRACTICE

The nature of teaching in practice differs considerably from the simulator (Neumann et al., 2018). It is clear to everyone that the scenario described above cannot be imitated in practice, but it is possible to supplement the trainee's knowledge with the appearance and use of the device in practice. At the beginning of the practical training, the students were taken to the engine room, where they were able to see the structure of the engine room and the diesel engine (Figure 6).

Here they learned that the monitoring of exhaust gas temperatures and cooling water temperatures works somewhat differently than on the simulator (Figure 7).

Figure 7. Indicator cock, pyrometer and cooling water thermometer

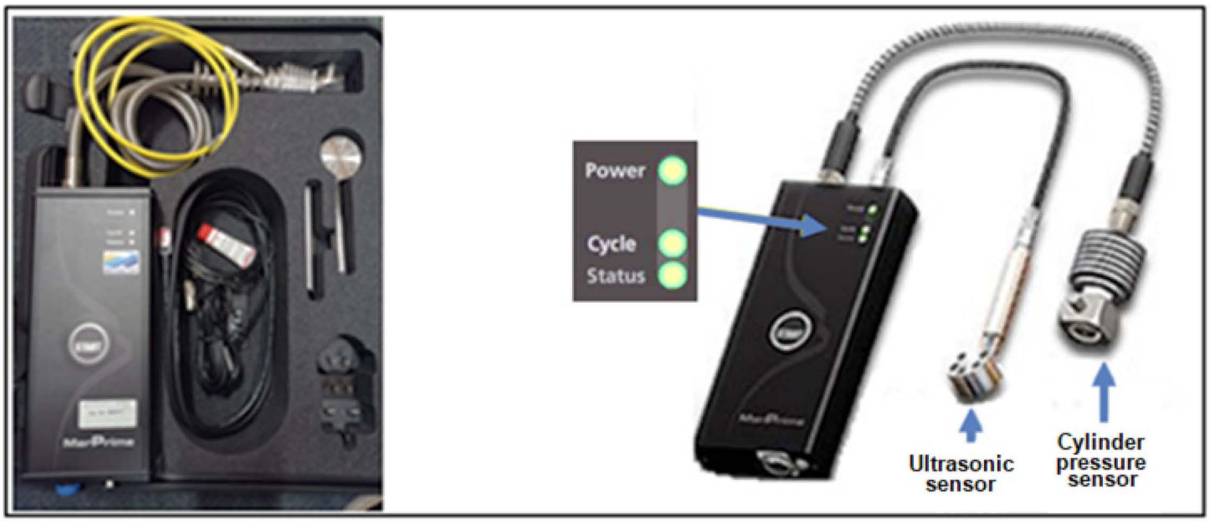

Figure 8. Cylinder pressure indicator MarPrime Ultra (MARIDIS, 2025)

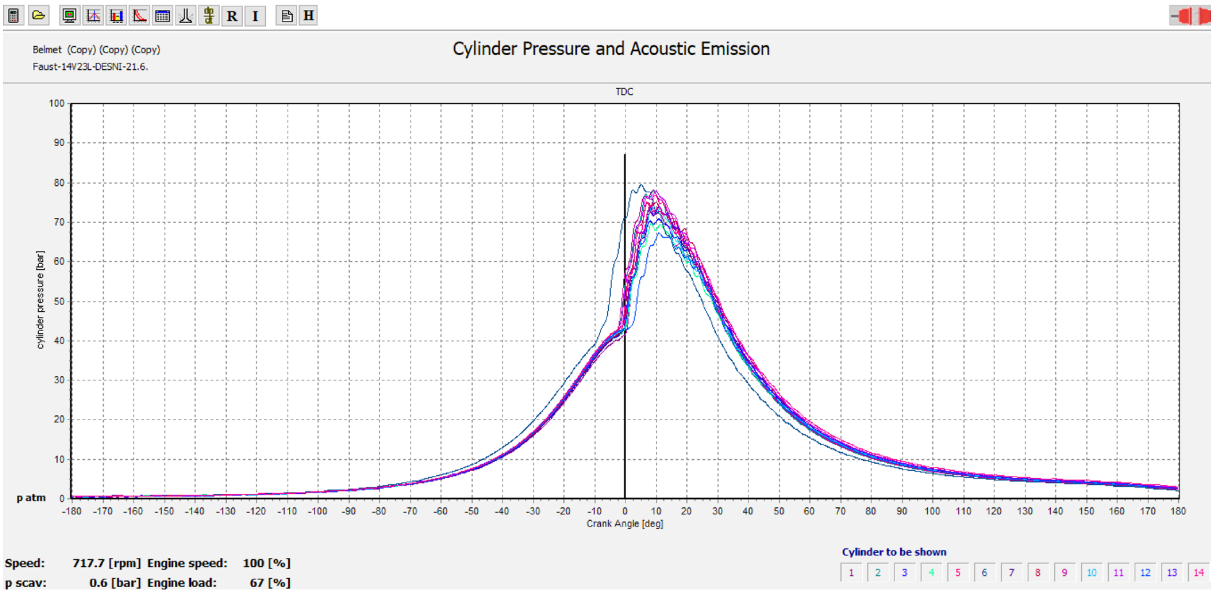

Figure 9. p-α diagrams recorded on the engine

Figure 10. Fuel injector

They were then familiarized with the device for measuring in-cylinder pressures, which is shown in Figure 8.

The device shown in Figure 8 was used to record the p-α diagrams shown in Figure 9. When recording the diagrams, the students quickly realized that the results obtained were very similar to the diagrams shown in Figure 4. In order to obtain different values of the diagram, the engine load was changed, which is visible in the diagram.

The last items that the students stated they were not fully familiar with were the fuel injectors. Therefore, they were introduced to the actual appearance on board (Figure 10), and were shown testing it on a test bench.

This concludes the last part of the hands-on training, and all that remains is to analyze the results. No formal survey was conducted among the students on the success of this teaching method, only an informal discussion on impressions and experiences. The vast majority of students felt that it was only after the practical part of the training that they understood the whole process and what the instructors had taught them. This part should be formalized in future studies in order to obtain accurate results on the benefits of such a complex teaching method.

6. CONCLUSION

This study examined the effectiveness of simulator-based training compared to real-world engine room experience. The focus was on teaching marine engineering students how to monitor and diagnose engine failure. For this study it was important to teach students how to react to the specific deviation of exhaust gas temperature and to collect more data in order to determine the cause of such deviation. Measuring the engine pressure in cylinders and recording the results in (p-α diagram) enables students to analyze possible causes for the signs of engine failure.

The results of this study highlight that while simulators provide a controlled and risk-free environment for students to develop diagnostic skills, they lack the realism and sensory engagement of practical, hands-on training aboard a vessel. Students benefit from simulator training but struggle to fully visualize real equipment and processes without exposure to actual engine rooms and equipment. The introduction of 3D simulations improved engagement but did not fully bridge the gap between virtual training and practical application. To address these limitations, a hybrid training approach that combines simulator exercises with hands-on experience aboard real ships is recommended. Such an approach ensures that students not only understand theoretical concepts and diagnostic techniques but also develop the necessary practical skills to handle real-world challenges effectively. Future studies should further quantify the impact of this integrated training model to optimize marine engineering education.

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