Development of the Australian Maritime College PC Based Machinery Space Simulator

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Abstract

The development of a PC based machinery space simulator for training and research is described. Development goals targeted the usefulness of the system for both training and R&D work. These included a distributed client/server architecture for 1-1 or 1-many client simulation operation, complete separation of visual elements from the controlling routines and the ability to work on the mathematical model (fully compileable source) independent of the controller and visual systems. A graphical interface has been developed and the mathematical model has been updated. NOx emissions and the effect of NOx control measures are simulated. Variable fuel combustion quality can be simulated. The use of the PC based simulator for training of sea going engineers and its relevance to STCW-95 is discussed. The use of the PC based simulator for undergraduate and graduate project work is also discussed.

1. INTRODUCTION

The Australian Maritime College has implemented a program to create its own PC based Machinery Space Simulator(MSS). This gives flexibility for tailoring the simulator to specific educational and training requirements, and to simulate new systems. The simulator is also a research tool.

The original Machinery Space Simulator (previously called the Engine Room Simulator) was commissioned in the early 1980s. Since that time it has been used by full time students for instruction in engine watch keeping procedures, fault diagnosis and rectification and various student projects. It has also been used in short courses for seagoing engineers attending UMS(Unmanned surveillance) and revalidation courses and pilot training short courses.

The college is fortunate in having a simulator which was originally designed as a development tool, which in turn allows the college to develop and upgrade the simulator for STCW-95 training requirements and allow research projects to be undertaken as part of undergraduate and post graduate programmes.

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2. Overall Structure and Development Rationale

The project started with the goal of creating a Machinery Space Simulator capable of running on an average personal computer with emphasis on ease of use for training and flexibility for further research. The second phase will be to re-integrate the software with the existing hardware environment.

Salvaged from the original Simulator were the Fortran coded mathematical routines. These were ported to c code and formed the basis for the new simulator. The reuse of existing simulation routines, allowed the project to be completed within a much shorter time than could otherwise have been considered.

1.1 System Architecture

It was deemed important that research and development be done on these mathematical routines without the remaining software infrastructure becoming either corrupted or unduly intrusive. To this end, the core simulation code (called an Engine) is contained within a separate and modular compilation unit. These routines can then be independently modified, updated or added to, and changes immediately run within the simulation environment. The availability of full simulation-specific source code and the power of a fully compileable system combine to form an attractive research platform.

However, while most development can be independent of the simulation infrastructure, at some point in time it becomes necessary to add visual elements to the various displays. To achieve this without requiring complex changes to the source code (or even a recompile), a great deal of generality was designed into the system. Most engine specific parameters are separately contained in engine specific data files. This includes definitions of Control Constants, Input/Output Channels, Malfunctions, Procedures, Audio, Condition Sets and even the visuals themselves.

The visual system in particular can be modified via a rudimentary layout editor (or any text editor), allowing modifications on the fly during a research project. Note, however, that the visuals are still completely separated from the mathematical code. This separation further supports the independent development of more complex mathematics.

1.2 Networking

When considering a class full of networked computers in a training situation, several interesting simulation possibilities arise. Each machine could run a stand-alone simulation, attempting to give each student full control of (and ability to destroy) their own engine. Alternately, a single simulation could be held class wide. Each student could 'observe' the activity of the engine as operated by an instructor. Each student (or group of students) could be delegated responsibility for one or more ship sub-systems. The instructor could monitor progress and impose malfunctions on the simulation.

To meet these goals, the Machinery Space Simulator was designed with a highly networkable client/server architecture. The simulation runs within one task that acts as a server to all the other simulation components. Everything from data windows, visual displays, malfunction scheduler, plotters and data access can be run remotely (and multiples, concurrently) in a distributed environment.

This software architecture also benefits code maintainability. Rather than a huge, monolithic code-base, each component is split into its own task, creating a very modular system. Additional system components can be developed and integrated by third parties easily with only the knowledge of the communications protocol. With the generality and separation of the Engine (core simulation), the Machinery Space Simulator infrastructure offers the potential for multiple, discrete simulations of various types. (It currently supports a Diesel Engine and a Predictive Emissions System)

1.3 Self Learning

While instructor controlled training is beneficial, there is similarly a need for students to train in private. For this reason, the simulation includes facilities for self-run tutorials in the form of procedure checklists. These procedures guide the student through a sequence of steps designed to meet a specific goal, showing the student what must be done and explaining why. Typically, a set of procedures mimics the checklists for normal ship operation. Instructors further have the opportunity to create situation specific procedures, perhaps a 'how-to' showing the recovery from a critical systems failure, or a work-around for an abnormal operating condition.

An extension to the procedures system is self-assessment. The Machinery Space Simulator provides some basic capabilities for instructors to create assessment-based procedures, which, rather than showing what must be done, records whether or not it was done.

For both research and training the system provides extensive data access in the form of numerical values and graphing capabilities. Every aspect, both externally visible and internal to the mathematics can be graphed either across time or against further data.

The Machinery Space Simulator is a highly modular, general and extensible simulation infrastructure with the capacity for distributed operation in either a research/development or training environment.

3. USAGE

The MSS is developed for education, training and assessment, and research.

For education, the MSS is used as a teaching tool for

- understanding the operational principles of

the machinery system, its structure and major performance parameters
- learning realistic operational procedures
- studying automatic control systems including speed, temperature, level and pressure controllers, control theory, and parameter tuning methods
- studying combustion processes and the effect of operating conditions and fuels on combustion, emissions and fuel efficiency
- studying machinery data which can be selected and viewed in a number of ways.

For training and assessment specifically, the MSS has:

- sequentially organized procedures that explain each step and guide the student smoothly from cold ship to full away operation at the sea with experienced skill
- ability to operate either the fixed pitch propeller (FPP) and controllable pitch propeller (CPP) propulsion system
- ability to show the different operating situations under normal Control Room (C/R) or Wheelhouse (W/H) control and Engine Room (E/R) emergency control
- playback and single frame tracing function for reviewing of each student's work
- ability to give control responsibility of the main engine from the W/H, C/R or E/R independently
- malfunction scheduler that introduce malfunctions into the simulation instantly, after some delay, or at a specific time in the future.

For research, the MSS program structure allows independent workers to use and/or develop sub-systems within the mathematical model. Undergraduate and graduate project work can involve discrete development tasks. New systems will be developed such as a ballast system or an inert gas generator. Some existing systems will be updated or simulated in more detail. The MSS also serves as a platform for research such as emissions modelling. It is like a calibrated engine within which fundamental research can be conducted. Simulation in itself is an interesting and challenging area of research.

4. THE SIMULATION

The Machinery Space Simulator is a PC based full mission engine room simulator which partly complies with STCW Section A-I/12 and B-I/12 and ISM Code Sections 6 and 8. STCW compliance is discussed later. Major parts of the engine room, control room and wheel house are modelled and incorporated.

The mathematical model is based on the thermodynamics, hydrodynamics, and actual physical processes of the machinery system. The model has two propeller models - fixed pitch propeller and controllable pitch propeller.

4.1 Machinery Simulated

The MSS is composed of several

components including:

- main engine that outputs 17MW at 102 rpm, with auxiliary machinery
- two 620kW diesel generators
- one 760kW turbo generator
- Mitsubishi-CE 2 drum, water tube boiler that produces 4,000kg/h saturated steam
- Mitsubishi dual pressure Exhaust Gas Economiser
- three cargo oil pump turbines (COPT)
- two starting air compressors and one service air compressor
- one Fuel Oil Purifier, one Diesel Oil Purifier.

The original main engine is a 7UEC80/200HA single acting, two-stroke, slow speed, large bore, crosshead, turbocharged, uniflow scavenged main engine. A MAN B&W 7L70MC IMO NOx compliant main engine is also being integrated into the system.

4.2 The User Interface

The graphical interface is designed to allow spacious views of machinery systems without the need for scrolling. To this end, it is divided into numerous individual windows or panels. These are:

<u>Engine Space</u> : Machinery space windows and M/E Local Control panel. The machinery space is divided into a number of main windows illustrating machinery relationships, operational data, valve settings, flow lines, control lines, machinery status, tank levels, etc.

The Engine Space main windows are: Diesel Generators, Boiler, Economiser, Turbogenerator, Main Engine, Fuel and Oil, Compressed Air and Local Control. This is illustrated in Figure 1.

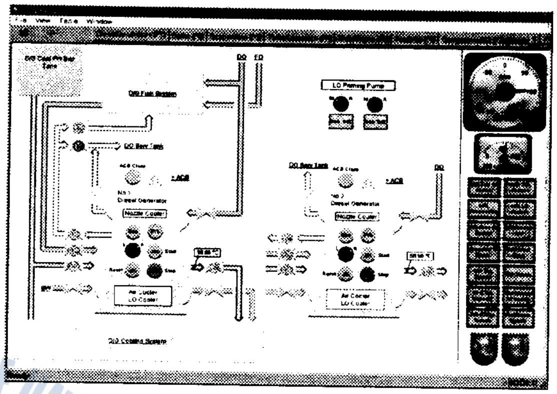

Fig. 1 An Engine Space Window

The Engine Space Windows contain jumps to other main windows as well as jumps to sub windows which illustrate the status of subsystems. This is illustrated in Figure 2.

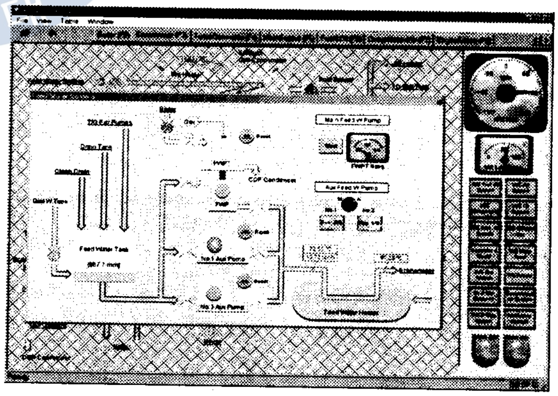

Fig. 2 Engine Space Sub Window

<u>Control Room</u> : Views of the Control Room. This is divided into three main windows: Watch panel, Engine Control panel and Generator Control panel. These are illustrated

in Figures 3 to 5.

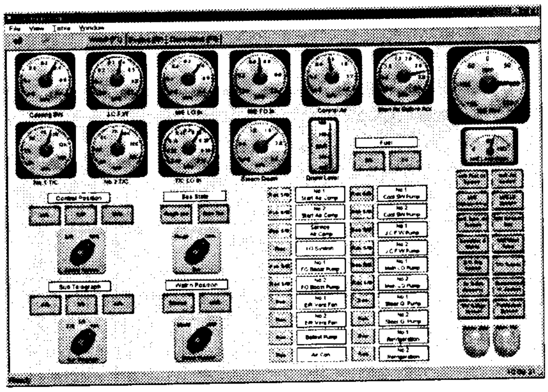

Fig. 3 Watch Panel

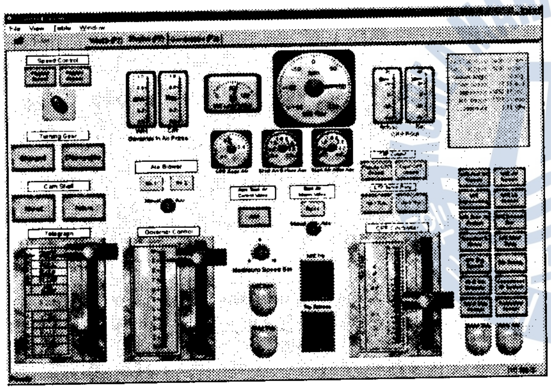

Fig. 4 Engine Control Panel

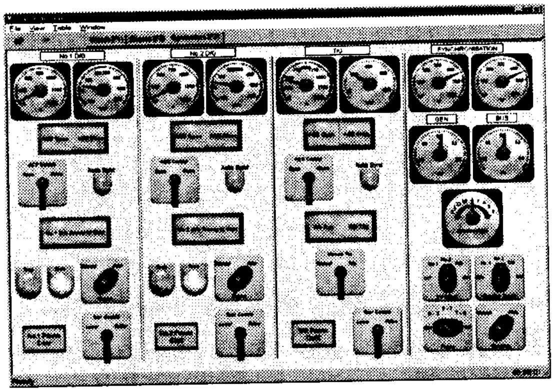

Fig. 5 Generator Control Panel

Wheel House (Instructor Station) : A view of the Wheel House control panel. When operating in FPP mode, the CPP controls are partly masked. This panel is illustrated in Figure 6.

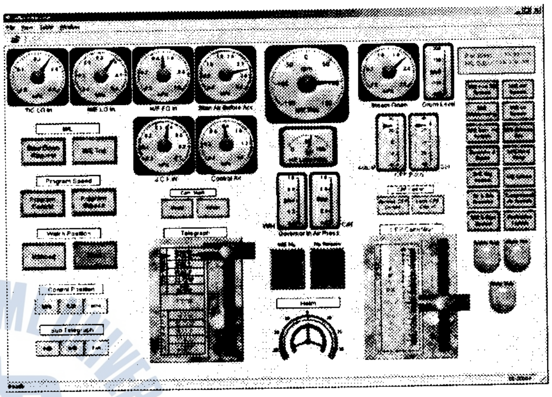

Fig. 6 Wheel House Control Panel

Simulation Control

The main control window for the simulation program itself is illustrated in Figure 7.

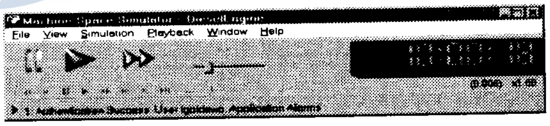

Fig. 7 Simulation Control Window

It provides access to the simulation program controls as well as machinery operational data. These data include:

Alarm List : Shows the list of alarms including the active alarm list.

Group Data : Shows the list of Data Channels and their current values.

Watch List : Shows a window capable of displaying requested Data Channels.

For the Group Data and Watch windows, current values, recent means and variability are displayed. A time trend plot can also be displayed for each variable. A typical Watch window is shown in Figure 8.

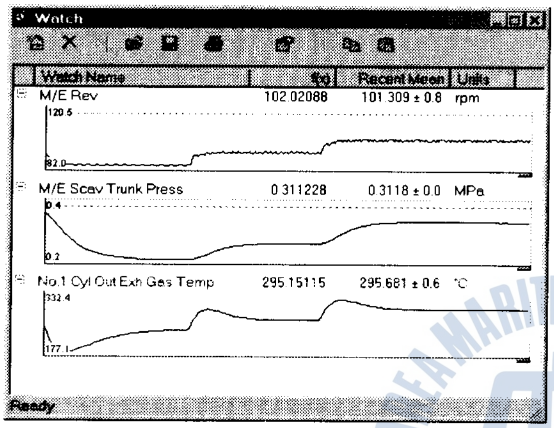

Fig. 8 Watch Window

Parameter List : Displays the set of mathematical model control parameters.

Malfunction List : Displays the currently scheduled malfunctions and allows setting of malfunctions.

The Simulation Control window also provides access to the Procedure Files.

4.3 Procedure Files

A comprehensive set of sequentially organized procedures has been created. These guide the student from cold ship to full away operation at sea (either with the FPP or CPP propulsion system), under normal Control Room or Wheel House control and under emergency Engine Room control.

At each step, the student can choose whether to execute the required task using their own knowledge, or ask the system to demonstrate the required action. A typical procedure window is shown in Figure 9. If the 'Show' button is picked, the appropriate window is displayed with the required operation highlighted.

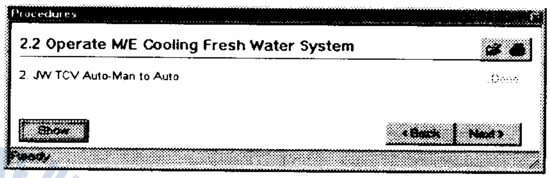

Fig. 9 Procedures Window

A set of assessment files is being integrated into the system, for which the student will have to rely entirely upon their own knowledge.

4.4 Controller Window

Various system controller settings can be viewed and adjusted. The student can then observe the effects of control theory and its interaction with an actual system. This is illustrated in Figure 10.

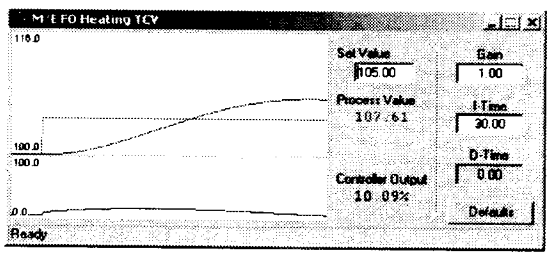

Fig. 10 Controller Window

4.5 Engine Model

The original model is simple and fairly accurate. However, it only allows output of a cylinder pressure trace for full load. This model is still in place as it has a low system resource consumption, which is useful for accelerated time modelling of slow processes in the machinery systems. An alternative model has been put in place. It follows the combustion process with a fully mixed thermodynamic model, which has variable injection timing, burn rate, heat transfer rate and engine geometry. The combustion model allows a comprehensive output of data at any load. A typical output for the MAN B&W engine is shown in Figure 11.

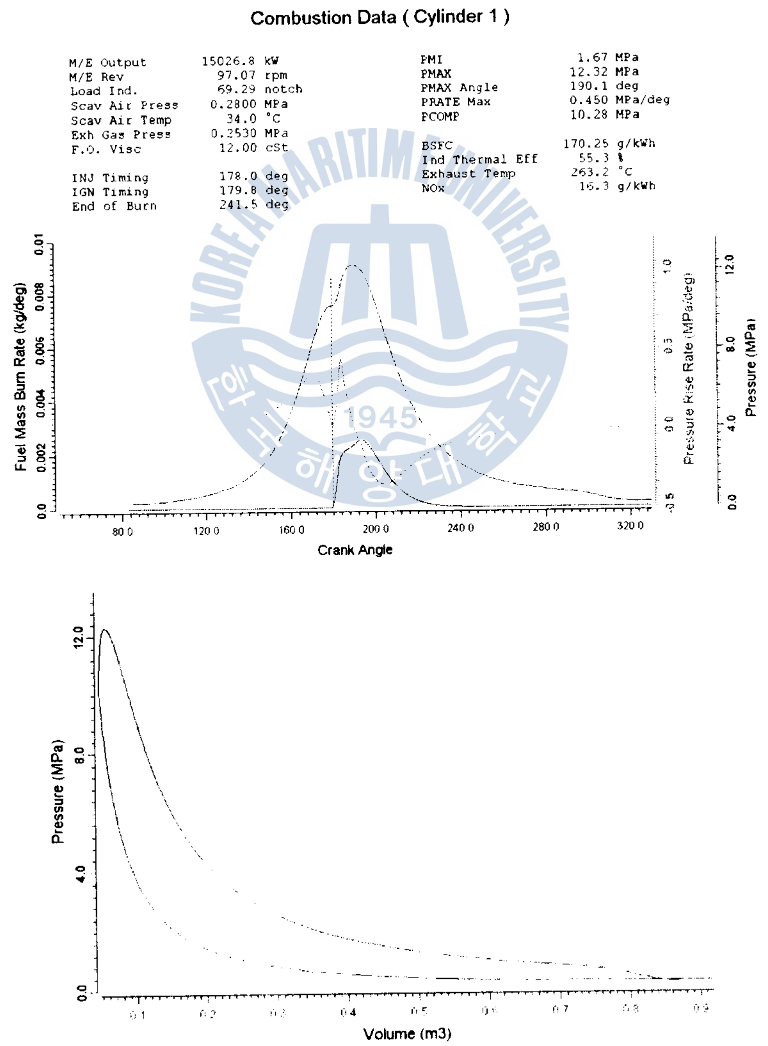

Fig. 11 Combustion Data for a MAN B&W 7L70MC at Part Load

To integrate the MAN B&W engine into the system required modification of the parts of the mathematical model which calculate scavenge pressure, exhaust pressure and air flow rate. A number of parameters are now available within the system for tuning the scavenge system to a particular engine.

4.6 NO_x Model

A real-time NOx model has been incorporated into the combustion model. This is a multi zone model superimposed onto the single zone combustion model. A correlation between NOx and adiabatic flame temperature for a number of zones throughout the combustion history gives a representative engine NOx output. This model allows simulation of the effects of NOx control measures such as water injection, humidification, exhaust gas recirculation and injection timing retard. This model has been previously described by Goldsworthy[1]. Recent data obtained for the MAN B&W 7L70MC indicates that the prediction of load dependence of NOx with the multizone correlation is not adequate, as it does not adequately allow for the increased time available for NOx formation at lower loads. A real time multi zone chemical kinetics NOx model is under development.

4.7 Fuels

A fuels model is currently under development. The combustion model allows adjustment of ignition delay time and maximum pressure rise rate. These will be linked to representative fuel properties.

5. SOLAS

In the context of SOLAS [3], the following systems are not yet adequately supported in the MSS:

- Electrical power main switchboard and distribution panel
- Emergency source of electrical power and emergency switchboard
- Fuel oil double bottom tanks and piping system
- Shaft generator for power take off (PTO)
- Ballast system and trim and heel measuring system
- Propulsion shaft arrangement and stern tube system
- Steering gear arrangement and emergency tools for manual operation
- Fire pumps, fire main, hydrants and hoses
- Bilge wells and bilge piping system
- Oily water separator and waste oil incinerator
- Refrigeration systems

6. COMPLIANCE WITH STCW-95

The use of the PC based MSS for training seagoing engineers in the context of STCW-95 [2] is assessed in Table 1.

Table 1 List of STCW-95 Competencies in MSS

STCW95 Ref	Competence	Capability of MSS
Table A-III/1.4	Maintain a safe engineering watch	Supports this competence. Simulates E/R, C/R and W/H. Logs student operation results with snapshot or playback history.
Table A-III/1.6	Operate main and auxiliary machinery and associated control systems	Supports this competence. Start, stop, control, monitor propulsion plant, electric power plant and auxiliary machinery.
Table A-III/1.7	Operate pumping systems and associated control systems	Supports this competence. Includes pump and valve operation for essential fluid systems
Table A-III/1.8	Operate alternators, generators and control systems	Supports this competence. Includes parallel operation and load sharing on control panel.
Table A-III/1.9	Maintain marine engineering systems, including control systems	Partly supports this competence. Includes propulsion plant emergency control and controller parameter tuning.
Table A-III/1.10	Ensure compliance with pollution-prevention requirements	Partly supports this competence. Includes predictive emission monitoring system.
Table A-III/1.11	Maintain sea worthiness of the ship	Not supported.
Table A-III/2.1	Plan and schedule operations	Supports this competence. Includes procedures and assessments.
Table A-III/2.2	Start up and shut down main propulsion and auxiliary machinery, including associated systems	Supports this competence.
Table A-III/2.3	Operate, monitor and evaluate engine performance and capacity	Supports this competence. Includes real-time PV diagram and performance data.
Table A-III/2.5	Manage fuel and ballast operations	Partly supports this competence except ballast operation.
Table A-III/2.6	Use internal communication systems	Partly supports this competence. Include telegraphs between W/H and C/R or E/R
Table A-III/2.7	Operate electrical and electronic control equipment	Partly supports this competence.
Table A-III/2.8	Test, detect faults and maintain and restore electrical and electronic control equipment to operating condition	Partly supports this competence. Includes alarm detection and correction function for faults.
Table A-III/2.10	Detect and identify the cause of machinery malfunctions and correct faults	Supports this competence. Includes malfunction scheduler.
Table A-III/2.12	Control trim, stability and stress	Not supported.
Table A-III/2.13	Monitor and control compliance with legislative requirements and measures to ensure safety of life at sea and protection of the marine environment	Partly supports this competence.

7. References

[1] Goldsworthy, L.C., Simulating Primary Control Measures for Oxides of Nitrogen Emissions in a Slow Speed Marine Diesel Engine. Sea Australia 2000, Sydney.

[2] STCW Convention 1978 / 1995, International Maritime Organization 1996
Section A-I/12 *Standards governing the use of simulators*
Section B-I/12 *Guidance governing the use of simulators*
STCW Code Part A Chapter III *Standards regarding the engine department*
STCW Code Part B Chapter III *Guidance regarding the engine department*

[3] SOLAS consolidated edition, International Maritime Organization 2001, Part 1,
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[6] Propulsion Plant Trainer PPT2000-MC90-III, User's manual, Kongsberg Norcontrol, 1997