NUSCOT 3

'VANGUARD' CLASS SUBMARINE CONTROL SIMULATOR

BY

EUR ING A. T. BUTTERWORTH, BSc, CENG, MIMARE
(*Link-Miles Ltd.*)

AND

M. DUMMER
(*Sea Systems Controllerate, Bath*)

ABSTRACT

The NUSCOT 3 Submarine Control Simulator for the VANGUARD Class has been recently accepted into service by the Royal Navy. This article provides an overview of the simulator and simulation, and the facilities available for the training of the ship control team.

Introduction

On June 11, 1992, the Royal Navy took delivery of its latest Submarine Control Simulator, the VANGUARD Class Submarine Control Trainer known as NUSCOT 3. Designed and manufactured by Link-Miles Ltd of Lancing, West Sussex, the simulator represents the latest in Micro-Simulation Technology as applied to submarine simulation.

The simulator is located within the Submarine Command Team Trainer facility at the Clyde Submarine Base, which will become the home port for the VANGUARD Class submarines.

Background

Link-Miles Ltd was commissioned by The Ministry of Defence in 1982 to study the training requirements of Ship Control Trainers and their crews.

The study reviewed the training methods and equipment then used and considered the training requirement for the future submarines of the UPHOLDER and VANGUARD Classes. The report concluded that ship control handling was an important skill area within the submarine crew. Future ship control handling trainers should therefore have sufficient flexibility to provide both initial and continuation training to a standard not readily available to the Royal Navy at that time.

Many of the recommendations and conclusions were adopted in UPSCOT, the UPHOLDER Class Submarine Control Simulator, and have been developed and enhanced for the NUSCOT 3 facility. Work on this simulator commenced in December 1988.

Simulator General Requirements

NUSCOT 3 has been designed against a technical requirement specified by Director Trident (DTR). The simulator allows crew to be trained in abnormal and emergency procedures which would be unsafe to allow to happen at sea.

Two types of training are possible:

- Ship Control Training.
- Damage Control Training.

Ship Control Training is the primary task of the simulator and includes both initial and continuation training. This allows the crews to develop, practise and refine operational and emergency procedures in a safe and secure environment.

Damage Control Training is a secondary role of the simulator and provides practice in the function of reverting to normal after an emergency has occurred and first responses have been made. For Damage Control Training to be realistic, the simulation software is capable of generating faults in a number of systems simultaneously in such a way as to represent a major incident such as a compartment fire.

Basic Arrangement

The simulator (FIG. 1) represents the starboard forward quarter of the control room and incorporates replicas of the Submarine Control Team's panels:

- Systems Control Console (SCC).
- Two Man Control Console (TMCC).
- Ship Control Officer of the Watch Console (SCOOW).

The panels, with all their controls and indications, are identical to those used in HMS *Vanguard*, and interact in real time with a computer model of the submarine and its systems, thereby producing a high degree of both physical and functional realism.

An Instructor Operator Console is sited immediately behind the crew's positions so as to give the instructors full visibility of the proceedings, shielded by one-way glass to preserve realism.

The consoles and instructor position are contained within a cabin mounted within a gimbal arrangement supported between two 'A' frames. A motion system moves the cabin in pitch and roll, simulating the motion of the submarine.

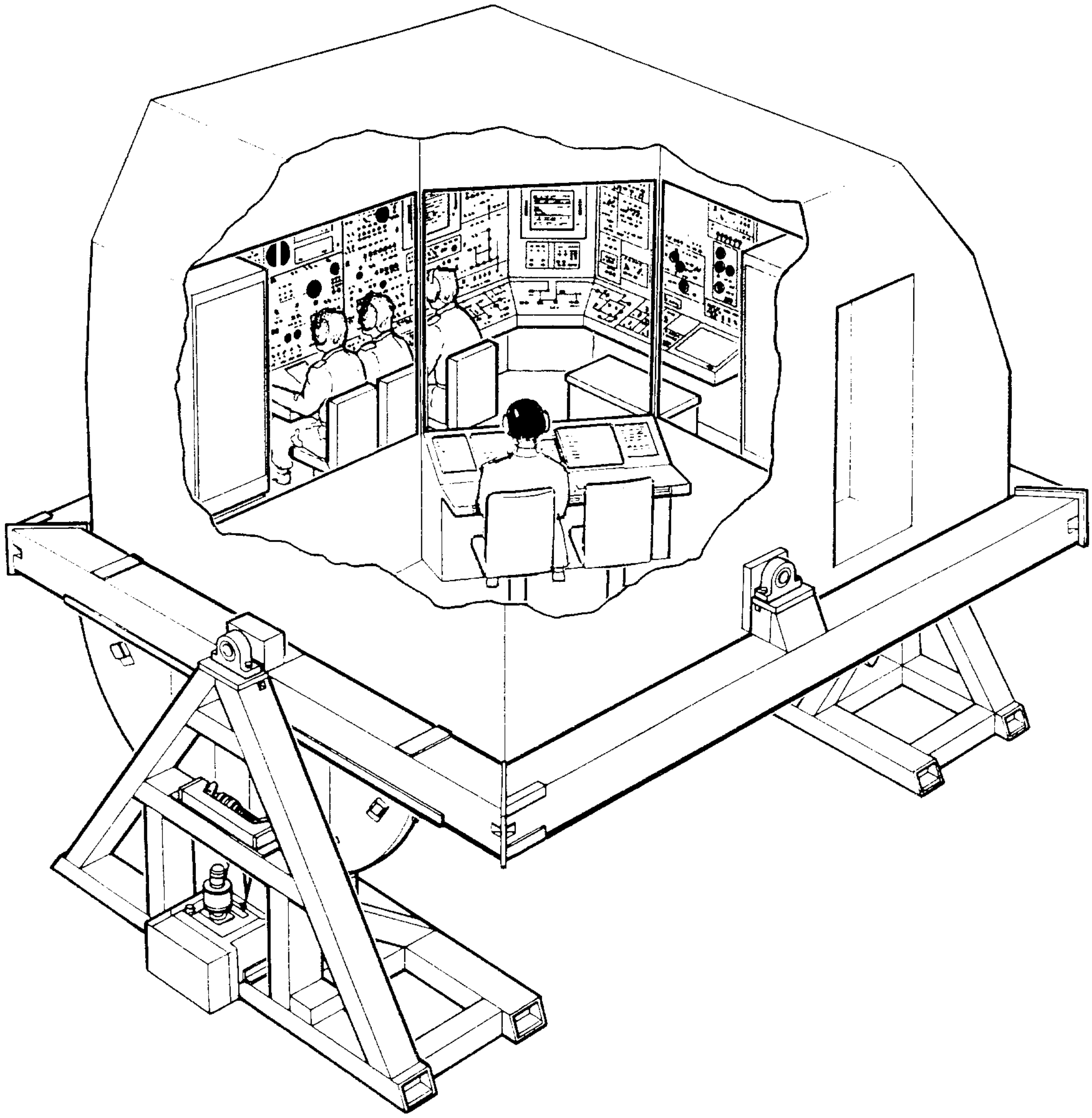

FIG. 1—NUSCOT 3, THE 'VANGUARD' CLASS SUBMARINE CONTROL SIMULATOR

Simulator Motion System

The simulator motion system is a vital component in the creation of the overall illusion. Changes in attitude can be readily interpreted by the human body and, within submarine simulation, are vital cues, as there are no obvious visual cues other than the instrumentation.

The motion system uses the Link-Miles patented two degree of freedom electric motion system, developed for the UPSCOT simulator and now delivered worldwide on six submarine simulator complexes.

The system features an electrically driven pivot-gimbal motion frame providing simultaneous independent rotational movement in two axes—pitch and roll (FIG. 2). The system is powered by resiliently mounted Direct Current electric servomotors, controlled by advanced solid-state, pulse-width modulation drive amplifiers. Electric drive was adopted due to its inherent low noise and low maintenance requirements.

The system has extensive safety features, including an emergency levelling system, independent of the primary drive system. In order to minimize the power requirement, the gimbal axes are located at the approximate centre of gravity for each respective axis, leaving only the out-of-balance torque resulting

FIG. 2—NUSCOT 3 AT THE LIMITS. THE SIMULATOR AT THE MANUFACTURER'S WORKS WITH THE CAB BOW DOWN ON THE STARBOARD BEAM. THE LARGE UMBILICAL CARRIES THE COOLING AIR FOR THE ONBOARD COOLING SYSTEM

from on-board personnel distribution and inertia torque requirements for the motor and drive system, resulting in a low power consumption. This efficiency minimizes noise generation which is important for training in the ultra-quiet state.

The system is software controlled via the simulator computing system, and follows directly the submarine performance and attitude up to plus or minus 45 degrees in pitch and roll, and plus or minus 10 degrees per second in pitch rate and roll rate.

Submarine Dynamics Simulation

The motion of a submarine may be described by a set of non-linear, second order differential equations in six degrees of freedom. These equations describe, at any instant in time, the submarine motion in terms of the total external forces and moments acting on the body and motion existing at that instant. In order to be used for simulation the equations are expressed in such a way that they can be readily integrated in real time using successive time steps.

In the dynamic model the equations are referred to a right-handed orthogonal system of moving axes, fixed in the submarine body, with its origin located at a fixed point, the centre of buoyancy of the fully submerged submarine.

The total forces along and moments about the three body axes are generated. The following forces and moments are considered in the simulation model:

- Hydrodynamic.
- Propulsion.
- Wave effects.
- Sea-bed contact reactions.
- Buoyancy.
- Gravity.
- Missile launch and compensation effects.

The sum of the forces and moments are used to produce the translational and rotational accelerations about the body axes. The velocities follow naturally as the integrated accelerations.

The body axis rotational rates are transformed into angular rates with respect to the inertial frame and integrated to form the true angular positions with respect to the earth's surface. Similarly, the body axis translational velocities are transformed into velocities with respect to the inertial frame and are integrated to provide positions on and under the sea surface.

Complementary to the dynamics simulation are the control surfaces (rudder and hydroplanes) and autopilot. The stickwheels are identical to those used in the submarine, and they interface with a computer simulation of the Ferranti autopilot and electronic enclosures and simulated ram-servo units. All backup systems for operation of the control surfaces are also simulated.

Ship's Systems Simulation

The simulation of the submarine systems covers not only those parts sited in the control room but also the elements of the relevant systems remote from it. The simulation method generally follows an Object Orientated Design approach. This enables the ship's design to be faithfully represented and easily updated as the system design is modified or extended.

Control of the systems within the control room area is via exact replicas of the ship consoles. The same manufacturer was used for the panels and most of the indicators, instruments and controls to maintain the correct visual and tactile feedback to the operator. In addition, overhead lighting, communications equipment and alarms identical to those fitted in the boat are used and interfaced to the simulation electronics to maximize the level of realism and training value that can be obtained.

To give a comprehensive simulation to the control room area, the whole of the boat systems are simulated. For systems such as the Main Hydraulics, this is a considerable task, with upwards of five hundred valves and interconnecting pipework to be simulated.

The systems simulation can be considered as of four distinct types:

(*a*) *Fluid Systems*. The basic components of the simulation of fluid systems include pump suction and discharge characteristics, valve control and networking, and pipeline flow and pressure calculation. Within this area of simulation are included trim system, bilge and ballast systems, hover and missile compensation systems and all the hydraulic systems.

(*b*) *Air Systems.* Air systems, including High Pressure, Low Pressure and Main Ballast Tank Venting and Blowing are simulated, covering all compressors, fans, valves and the storage and distribution of compressed air. Additionally the simulation of the ventilation system allows the correct operational and emergency procedures to be exercised for Containment and compartment ventilation.

(*c*) *Diesel, Propulsion and Electrical Systems.* These systems are not directly controllable from the control room but are included to maintain the fidelity of the simulation and to enable the correct operational and emergency procedures to be followed.

(*d*) *Alarm and Monitoring Systems.* The alarm and monitoring systems for the simulator include all shipboard alarm systems, including the Fire Detection System and all its sensors throughout the boat. Included within the systems area is a comprehensive simulation of the Forward Surveillance System. This interacts with all other ships systems, giving a monitoring and logging system capable of a real-time display of approximately four hundred parameters, including valve states, system pressures and temperatures, and alarm/warning level states.

FIG. 3—THE INSTRUCTOR'S VIEW. IN THE BACKGROUND ARE (LEFT TO RIGHT) THE TWO-MAN CONTROL CONSOLE (TMCC), THE SUBMARINE CONTROL OFFICER OF THE WATCH (SCOOW) CONSOLE AND THE SYSTEMS CONTROL CONSOLE (SCC). ON THE INSTRUCTOR OPERATOR CONSOLE IN THE FOREGROUND CAN BE SEEN THE TWO TOUCH-SCREEN PLASMA DISPLAY PANELS USED AS INTERACTIVE KEY PADS. KEY LEGENDS CAN BE CHANGED TO SHOW ACKNOWLEDGEMENT OF THE SELECTION OR TO RECONFIGURE THE PAD FOR MULTIPLE PURPOSES. THE COLOUR VDUS ABOVE THE PANELS DISPLAY SYSTEM SCHEMATICS WHICH CAN BE SCROLLED. SYSTEM STATUS AND THE EFFECT OF CREW ACTIONS ARE SHOWN BY THE COMPONENT SYMBOLS AND COLOUR CHANGES. THE INSTRUCTOR CAN CONTROL MALFUNCTIONS AND REMOTE/LOCAL CONTROL OF SHIP EQUIPMENT BY MEANS OF A TRACKER BALL, MENUS AND SWITCHES. IN THE CENTRE, A THIRD PLASMA PANEL CONTROLS THE COMMUNICATIONS SYSTEM, AND TO THE LEFT IS A REPEAT OF THE FORWARD SURVEILLANCE SYSTEM DISPLAY.

All areas outside the control room area are represented by the facilities available at the Instructor Operator Console. These allow the instructor to represent the remaining crew of the submarine by maintaining correct system procedures along with communications protocol to enhance the training scenario.

Instructor Facilites

The instructors control training by means of the Training Management System (TMS) at the Instructor Operator Console (IOC) (FIG. 3). The advanced instructor console utilizes a fully integrated man-machine interface and graphic display system.

The heart of the IOC is an Intel-based Multibus II graphics workstation. The dual instructor display consists of interactive pages and system schematics, dynamically driven by the instructor using a trackerball and configurable plasma display system.

The instructor facilities are enhanced by features such as Lesson Plan, Parameter Plot and a Record Replay system. The Lesson Plan system allows the instructor to construct a sequence of events that may be time- or crew-dependent and which can represent the full scope of the simulation and be saved for future use. Complete scenarios can be built, giving a much reduced instructor workload and thereby allowing a much closer observance and assessment of the crew under training.

Parameter Plot allows the instructor to monitor up to two hundred parameters in real time, and to plot a time- or event-driven history of ten parameters for thirty minutes. Record Replay allows the instructor to replay the previous fifteen minutes of the training scenario for debrief and instructional purposes.

To enhance the control facilities available, a fully interactive cordless handheld control unit is provided. Control of all the features found at the IOC is available to the instructor who has complete freedom of movement around the simulator. Communication with the computing system is achieved via a VHF radio link.

Portable miniature VHF radio equipment is used for the Instructor and Operator communication system. The VHF radio communications equipment is fully integrated with the simulated ship's communications equipment, allowing comprehensive and realistic communication protocols to be established between the control room and the simulated outstations around the submarine. For debrief purposes all control room coversation is recorded and time stamped for later playback.

To train ship control teams fully in adverse situations a smoke system is available to flood the control room. An emergency breathing air system with standard naval pattern masks is provided for use of the trainees.

Computer System

The simulator computing system (FIG. 4) is based upon the Link-Miles Functionally Distributed Simulation computing system, for which the company was awarded a Queen's Award for Technology in 1987. Within this system the simulation computing requirements are distributed throughout a number of autonomous functional computing areas, operating in parallel. Each functional area is responsible for the real-time computation and linkage requirements for a particular aspect of the simulator, e.g. ship's systems. These areas are composed of low-cost computing elements of second-generation VLSI devices based upon the Intel 80386 chip set, and industry standard Multibus II configuration.

The simulator computing system is based around twelve 386CPUs running at 16 MHz with 24 Mbytes of read/write memory.

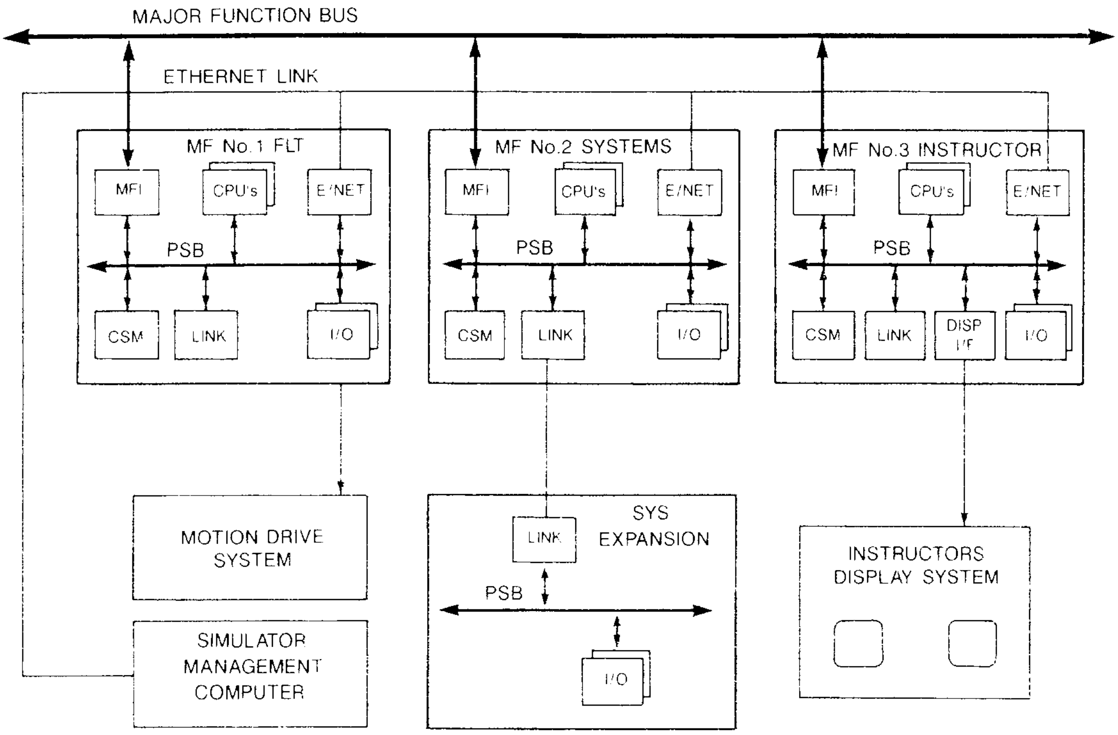

FIG. 4—NUSCOT 3 COMPUTER SYSTEM ARCHITECTURE

CPU: CENTRAL PROCESSING UNIT
CSM: CENTRAL SERVICES MODULE. CENTRAL CONTROLLER FOR ALL PCBs ON THE PARALLEL SYSTEM BUS
E/NET: ETHERNET INTERFACE. FIBRE OPTIC DATA LINK FOR LOADING AND ERROR LOGGING
MFI: MAJOR FUNCTION INTERFACE. DATABUS FOR GLOBAL DATA TRANSMISSIONS
PSB: PARALLEL SYSTEM BUS. DATABUS FOR INTERNAL MAJOR FUNCTION DATA TRANSMISSIONS

To provide the necessary support functions a Simulator Management Computer is used. The main function of the management computer is the downloading of the simulation program stored on a pair of 380 Mbyte disc shuttles, via a fibre optic Ethernet data link. The management computer is also responsible for all file management and software configuration control.

The whole computing suite represents one of the most powerful installations available to the Royal Navy in a training environment. The computing suite for the NUSCOT 3 facility has the capacity to process double the present simulation task, which will enable future upgrades to be achieved with minimal impact upon the present configuration.

Conclusion

The on-time achievement of the Ready for Training date followed an extensive testing and approval phase by MOD and RN staff. During a 90 day Availability, Reliability and Maintainability demonstration phase the simulator achieved figures of 100%, giving a high degree of confidence for the future. Although the simulator has been in active service only a short time, the initial impressions of the submarine crew are very favourable.