THE PROCUREMENT OF A NEW MACHINERY CONTROLS AND SURVEILLANCE PROCEDURAL TRAINING FACILITY FOR THE ROYAL NAVY'S TYPE 22 FRIGATES

BY

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ABSTRACT

This article discusses the procurement of a shore-based simulator for training naval staff in the operation of gas turbine propulsion plants of the Type 22 frigates. It describes the ships, watchkeeping training requirements, procurement process and trainer design. The new facility is hybrids of physical and graphical representations of controls and engineering systems. The realism of this simulator will deliver better watchkeepers through more intelligent and optimum operation of machinery. The observations and conditions generate questions over procurement strategy for future procedural training facilities.

Introduction

The objective of the project is to update, refurbish and enhance the Type 22 Frigate (T22) Machinery Controls and Surveillance (MCAS) Procedural Training Facility (TF) at the Royal Navy School of Marine Engineering (ME), HMS *Sultan*. In particular, the aim is to procure a simulator that truly reflects the machinery plant behaviour of the Batch II (Combined Gas or Gas (COGOG) propulsion plant) and Batch III (Combined Gas and Gas (COGAG) propulsion plant) T22s with high levels of fidelity and Availability, Reliability and Maintainability (ARM). This article offers an insight into many facets of the engineering associated with this project, including the Project Management aspects of the work employed to ensure that the deliverables meet the stringent requirements of the United Kingdom Ministry of Defence (MoD) and achieve the best Value for Money (VFM) for the RN. The TF will provide high quality training of varying degrees of complexity and intensity in order to coach inexperienced up to experienced watchkeepers in normal, reversionary and emergency watchkeeping procedures.

Historically the RN has procured traditional simulators specific to each class of ship.[1,2,3,4] These essentially consist of simulation environments constituting:

(*a*) Machinery Control Room (MCR) or Ship Control Centre (SCC).

(*b*) Outstations, i.e. representations of Machinery Spaces (MSs).

(*c*) Instructors' station and observation Room.

This class-dedicated design approach has the advantage of relatively straightforward optimization of the simulation environment for a particular ship type.

The technical and financial appraisals for this project recommended that the optimum solution was to procure a facility that was a compromise between conventional and advanced, novel technology in order to maximize the benefits of this renewal opportunity at acceptable risk levels. Project inception, conceptual and feasibility studies, appraisals, assessments, design, production, testing, installation and commissioning constitute a programme of approximately 4 years' work that completes in September 1997.

THE SHIPS

The Batch II and Batch III T22s were designed as specialist Anti Submarine Warfare (ASW) vessels, but are also very effective general purpose warships. Each Batch in the class has variations of ship structure, machinery installation, and weapons fit based on many common design themes. As an example of these ships, the principal particulars of HMS *Campbeltown* (BIII T22) are:

Length	148m
Beam	15m
Draught	6½m
Displacement	4850 tonnes
Complement	260 officers and men

Propulsive power is provided by independent port and starboard machinery sets, each consisting of either a Main Gas Turbine (MGT) or smaller Cruise Gas Turbine (CGT) (COGOG arrangement) or MGT or/and CGT (COGAG arrangement) driving a Controllable Pitch Propeller (CPP). (Again, taking HMS *Campbeltown* as an example, together these twin shafts can develop more than 45,000 shaft horse power yielding a speed of advance greater than 30 knots.) 4 × 1 MW Diesel Generators (DGs) supply electrical power to the auxiliary machinery, weapons systems, and hotel services. Control of the main propulsion machinery is usually effected remotely by either the set of Power and Pitch Control Levers (PPCLs) on the Bridge, or by the set in the SCC (where the ME Watch more fully control and survey the machinery plant).

The ME Department is responsible to the Command for the proper and efficient running of the machinery which is necessary for the ship to fulfil its operational role. It consists of approximately 60 people (including 2 Officers). The MCAS of the ME equipments and systems is concentrated in the SCC from where the ME Watch is co-ordinated to interact with either Remote Control Panels (RCPs) in the SCC or Local Control Panels (LCPs) in the MSs. The typical ME Watch constitutes:

- ME Officer of the Watch (MEOOW)—Supervisor (Officer or Senior Rating).
- Petty Officer of the Watch (POOW)—RCP Operator (PO or Leading Hand).
- Leading ME Mechanic (LMEM)—Local operation of machinery, with particular responsibility for fuel and fresh water, and local control of GTs when required.
- ME Mechanics (MEMs)—Normally 2 Roundsmen who conduct local watchkeeping of machinery and locally control propeller pitches when required.

NAVAL TRAINING REQUIREMENTS

Tasks

ME department staff Procedural Training (PT) must enable Watchkeepers to competently execute the following tasks:

- Oversee the plant safety
- Normal, reversionary and emergency operation of machinery
- Intelligently monitor the plant performance
- Accurately and appropriately communicate with watch members and the Bridge (this is most important, especially in crises circumstances)
- Execute 'first aid' action to emergencies (e.g. fires, floods, etc.).

Furthermore, seaman officers must acquire knowledge of the correct use and capabilities of the propulsion plant, and good understanding of the manoeuvring constraints imposed by servo-manual or local control of the propulsion machinery. Ultimately, the Bridge and ME watchkeepers delivered from this PT must convey a high degree of confidence to the Command about their abilities to conduct their duties in peace and at war.

Facility

The TF that will provide such high quality and versatile training for variably experienced watchkeepers demands:

- Highly accurate and interactive mathematical models of the propulsion plant elements which intrinsically incorporate the interdependence of discrete machines and systems on each other.
- High fidelity hardware and software representations of the various Man Machine Interfaces (MMIs) which constitute the SCC and the outstations around the MSs.

Fidelity

High fidelity simulations (that is, emulation yielding true reflection of behaviour and very close physical resemblance to the associated controls devices) are required for training safe and efficient human interactions with controls devices which:

- Involve complex—interdependent—sequential operations
- Include operators in the feedback loop (i.e. acting as moderators)
- The touch and feel affect time, magnitude and direction of output functions
- Skill of hand directly influences the successful execution of operations
- There are certain safety critical implications.

Some examples of these so called 'critical tactile' training areas for the T22 MCAS systems hardware are:

- Electrical Switchboards (SWBDs)
- Main Propulsion RCPs in the SCC
- GT LCPs and CPP Local Actuators.

Variants

The Project is complicated by the requirement for the TF to provide the same level of high quality training to ships' staff serving on board BII (older ships having earlier relay logic based Control Systems (CSs), and newer ships having more modern solid state based CSs) and BIII (having solid state CSs) T22s, thereby invoking the necessity to cover:

- 2 styles of propulsion plant

cross correlated with

- 2 generations of controls systems.

Therefore, there are 3 main variants in the Class, each yielding some deviations (of minor or more significant importance} from the common design of T22 MCAS, hardware, software, CSs, and operating procedures.

PROJECT MANAGEMENT

Organization

The main agencies involved in this project are:

- MoD, managing the work as the procurer
- HMS *Sultan*, direct user of the new TF
- T22 squadrons, ultimate recipients of the trained watchkeepers
- Contractor, TF design, development, manufacture, installation and commissioning

As the overall co-ordinator, the MoD uses its technical specialists, and considers the expertise and experience behind RN advice in order to convey the requirements to the contractor.

Plan

The Procurement Structure used to achieve the best VFM for the RN is summarized as follows:

Spring 1994	Technical and financial appraisals complete.
Summer 1994	Invitations to tender issued.
Spring 1995	Technical and commercial assessment of outline solutions complete. Project Definition (PD) contracts awarded.
Autumn 1995	Competitive PD complete.
Winter 1995	Technical and commercial assessment of proposals complete.
Winter 1995	Implementation Phase contract award for full design, development, production and commissioning.
September 1997	Ready for training.

A good deal of preparatory work (such as drafting the Statement of Requirements (SORs)) was completed prior to Spring 1994. A competitive PD phase was deemed essential for:

- Risk minimization
- Encouraging the most cost effective solution
- Securing the maximum VFM.

Research

The onerous Information and Data Collection, Collation and Interpretation (IDCCI) activities involve:

- Documentation reviews
- Ship surveys
- Consultations with RN Staff, shipbuilders, equipments manufacturers, etc.
- Information and Data (I&D) verification, i.e. cross-referencing design data with tests and trials reports, etc.

(Satisfactory pursuance of these IDCCI matters, and therefore successful project outcome, is clearly dependent on considerable effort on behalf of both the contractor and the procurer.)

DESIGN SOLUTION

System

The new TF consists of combinations of hardware and software items which form hybrids of physical and abstract (graphical) representations of the ships' MCAS systems and associated equipments. The simulations which ensure the correctly co-ordinated systems-wide responses are held in the host computer (dual 4 megabit (MB) Central Processing Units (CPUs), 192 MB Random Accessible Memory (RAM), and 2 gigabits (GB) of hard drive]. The hardware MMIs handling controls inputs (such as switches, levers, etc.) and outputs (e.g. instrumentation, warning/alarm devices, etc.) communicate with the simulations via the stimulator (electronic circuit boards containing firmware for hardware and software interfacing). Comprehensive manipulation of the simulations is achieved from a very flexible and user-friendly Instructors' Operating System (IOS) that is also resident in the host computer. (FIG. 1) illustrates the TF system configuration.

Hardware

The main high fidelity hardware items in the TF are:

- Machinery and Electrical Controls Consoles Assembly (MECCA)

  Constituting the main SWBD, auxiliaries controls panels and MGTs and CGTs watchkeeping panels which enable remote control of the plant from the SCC.
- MEOOW Console

  Essentially a communications desk.
- GT LCPs (1 for each engine type) and CPP local actuator

  These MMIs are designatable port or starboard in the TF for training flexibility and scenario unpredictability for the benefit of the students.
- ME Communications Systems

  Provides Bridge/SCC/MSs networks (augmented by eavesdropping and individual tutoring facilities).

The ships' MSs such as the Engine Rooms (ERs), Auxiliary Machinery Rooms (AMRs), Outside Machinery Spaces (OMSs), SWBDs, etc. are represented by the TF outstations. These consist of 21 inch X-Terminals (125 MHz processors and 8 MB Dynamic RAM (DRAM)) which give (Trainee) watchkeepers access to interactive graphical emulations of systems (schematics which accommodate local operation, monitoring and control of machines, instrumentation, valves, breakers, etc.) and important LCPs and local actuators (for example, DG LCPs, GT LCPs, CPP local actuators, shaft breaks, turning gear, starters, breakers, Change Over Switches (COSs), etc.); an Ethernet data bus facilitates their communication with, and therefore effective participation in, the overall simulations of the plants. The outstations are visually and audibly isolated from each other (except via the proper ships' communications networks) and equipped with the appropriate principal hardware LCPs. (The hardware and software models of the same type of LCPs enable simultaneous local control of port and starboard machinery units, for example, concurrent local manipulation of the port and starboard MGTs and/or CGTs and/or CPPs can be practised.)

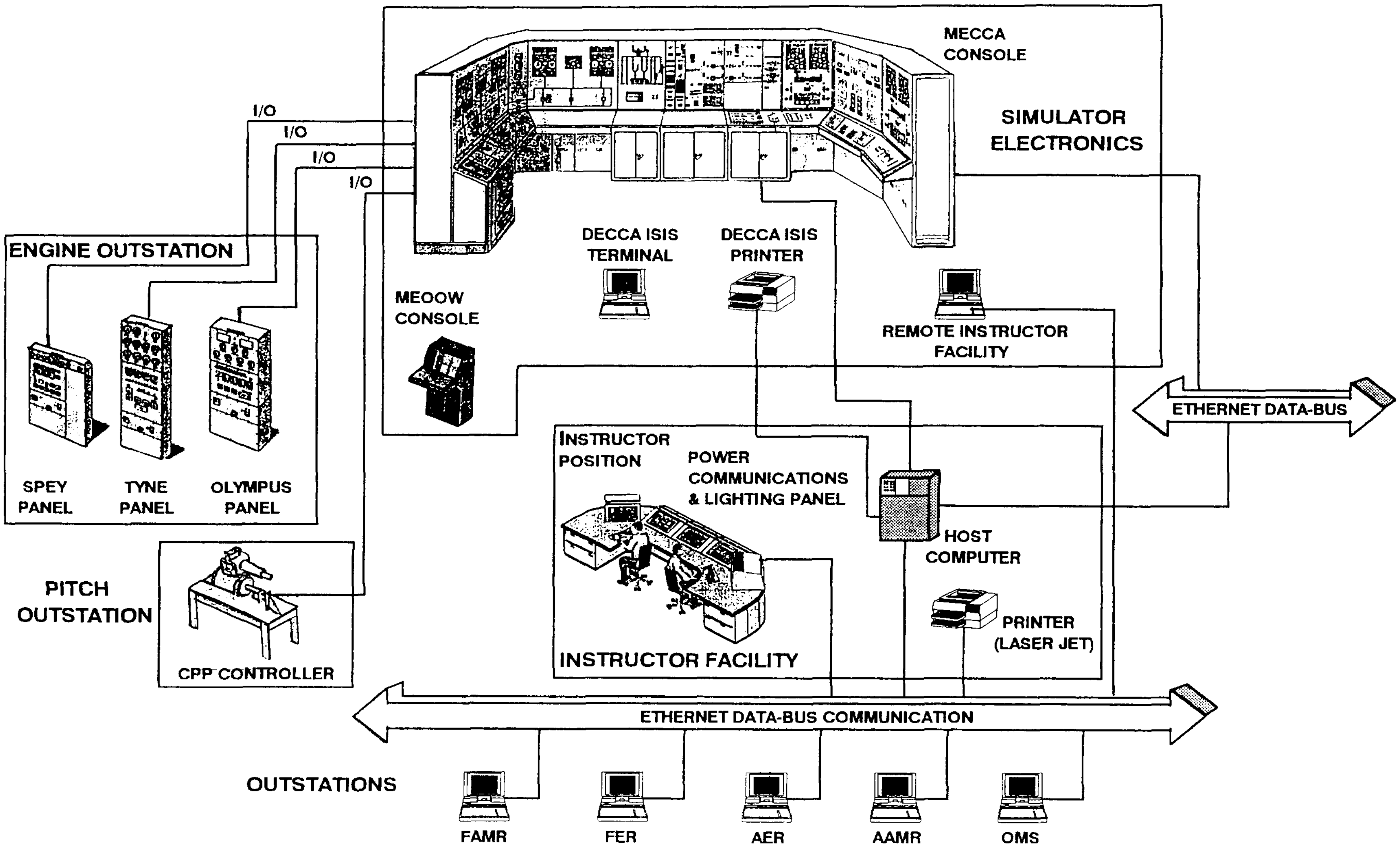

FIG. 1 — TYPE 22 TRAINER SYSTEM

The instructors' station is an ergonomically arranged console for use by up to 2 instructors that accommodates 2 screens for the control and monitoring of the simulations of the plants, and the lighting and communication systems controls. The right hand position is biased towards being a hybrid hardware–software simulation of the Bridge with appropriate controls and communications. The instructors' station is housed in a viewing gallery that enables good observation of all training areas. The TF can be run single handedly from the instructors' station, or from the SCC and outstations via the portable remote instructor facility.

Software

The TF software can be categorized into 3 main groups:

- Computer functionalisers, such as operating systems and compilers.
- Computer Aided Software Engineering (CASE) development tools, for mathematical modelling and dynamic graphics.
- Applications, such as the Common Database (CDB), Simulations, IOS, and Ethernet communications.

Development tools

Two CASE tools developed by CAE which are used extensively for building simulators have been employed in this project:

1. Real Time Object Oriented Software Environment (ROSE^{TM}).
2. The Interactive Graphics Environment for Real Time Systems (TIGERS^{TM}).

These tools consist of:

- Editors for graphics, simulation objects and schematics, processes.
- Automatic code generators.
- Integrated testers and validators.
- Configuration managed documentation drafters.
- Associated libraries for objects, schematics, tests and documents.

ROSE^{TM} and TIGERS^{TM} can be used at a Workstation or X-Terminal, and they have been designed to produce cost effective, high quality and consistent software and supporting documentation.

Simulations

The models are essentially the differential equations which describe the electrical, mechanical, fluid and thermal characteristics of the plants. The resultant highly accurate and interactive mathematical models of the propulsion plants elements, which intrinsically incorporate the interdependence of discrete machines and systems on each other, manifest themselves at the high fidelity hardware and software representations of the various MMIs which constitute the SCC and outstations around the MSs. Abnormal behaviour of the plants is simulated by causal inceptions rather than symptomatic interruptions of normality; therefore, the Simulated Faults and Malfunctions (SFs&Ms) will naturally generate the consequent cascading effects throughout the whole of the plants. (Some examples of these SFs&Ms are given in Table 1.)

TABLE 1—*Some Examples of the SFs&Ms for the models of the plants*

Fundamental/generic (Globally applied)	**Derived/specific (Contrived for particular systems)**
Structural/mechanical failure	Electrical supply failure
	Generator failure
	Total Electrical Failure (TLF)
Pipe break	Loss of power or/and pitch control
	Shaft speed probe failure
Blocked suction/strainer/filter	Telegraph failure
	GT failed start
Faulty valve	High vibration of gas turbine
	High temperature in engine module
Fouled heat exchanger	Fire in engine module
	GT trips
Irregular flow of electrical current	GT clutch fails to engage
	Oil transfer box seal temperature high
Broken electrical cable	Loss of pressure in CPP hydraulic system
	Fuel boost pressure low
Faulty breaker/switch	Abnormal pressure in compressed air systems
Faulty electrical/electronic component	Main Forced Lubricating Oil (MFLO) system temperature high
	MFLO system pressure low/lost
	MFLO system drain tank level low/lost
Faulty transducer	High vibration of main gearbox
	Bearing temperatures high
Faulty instrumentation	Stern seal failure
	Sea water cooling systems failure
	Etc., etc., etc.

[Note. The Generic SFs&Ms can be discretely applied to individual systems, or introduced as complicated sequenced events to a number of areas in the plant simultaneously (thereby being used to generate the derived SFs&Ms). The specific SFs&Ms will normally be injected into the simulations via lesson plans.]

High fidelity, completely integrated models are provided for the following systems:

- Controls
- Electrical power generation and distribution
- Fuel and oils filling, storage, transfer and supply
- Compressed air
- GTs

- Transmission
- MFLO
- Sea water cooling
- High pressure sea water.

Less sophisticated models, enabling at least START/STOP controls, for the following auxiliary systems are included (mainly on grounds of their significant effects on the electrical system):

- Steering
- Chilled water
- Air conditioning
- Steam
- Distillers
- Refrigeration.

The other ME systems' models yield the appropriate indications at their instrumentation, and are incorporated for the purposes of promoting complete and prudent watchkeeping practice; these are:

- Hydraulics
- Stabilizers
- Bilge and sullage
- Feed and fresh water
- Low pressure dry air.

Instructors' Operating System (IOS)

This 'user friendly' windows-based system facilitates intuitively effective sophisticated control of the simulations, and aids the teaching and assessment of trainees. Its versatile features include:

- Initialization and freezing (and subsequent unfreezing) of plants status.
- Instantaneous or timed injection of SFs&Ms.
- Compilation of intricate lesson plans and complicated machinery breakdown scenarios.
- Recording and playback of simulation parameters (continuous time histories) and watchkeepers and instructors actions and MCAS consequences (discrete event logging).
- Access to all graphics.

Configuration

The host computer effectively holds 3 separate mathematical models of the overall plants, i.e. one for each T22 variant (that is, HM Ships *Beaver*, *Sheffield* and *Campbeltown*). The required software simulation is simply chosen via the IOS. The TF MECCA has panels foundations which accommodate all the controls, instrumentation and some legends for the 3 variants. Three sets of associated aluminium overlay panels (1 for each of these ships), with suitable artwork and labels, are mounted on to these foundations thereby exposing appropriate constituents and hiding inappropriate devices, hence yielding the specific MECCA compatible with the chosen plant; this manual hardware configuration process takes approximately 1 hour. (Incompatibility between the hardware arrangements and the plants' models prevents the simulator from running, and such mismatches are promulgated at the instructors' screens.)

PERCEIVED BENEFITS

Realism

The sophisticated mathematical models and high fidelity hardware will yield a more convincing simulated shipboard ME environment, thereby instilling appropriate attitudes and focuses for the trainees. Furthermore, the true representations of plant dynamics (rather than earlier scenario driven algorithms) will encourage adherence to intelligent and correct procedures, and consequently a better appreciation and understanding of the ME systems operations and behaviour (i.e. the new TF should convey not only the **hows**, **whens** and **wheres**, but also importantly the **whys**). Consequently, the knowledge learnt and skills practised will be highly transferable to the operational Fleet.

Flexibility

The new TF will effectively encompass 3 different sorts of ships, albeit based on a central theme. The fundamental engineering principles approach adopted in the building of the ME systems models enables a wide range of simulated problems to be introduced; the highly developed IOS facilitates simple and swift definition and injection of:

- A single fault or malfunction.
- A number of faults and malfunctions simultaneously.
- A sequence of deteriorations and/or failures at designatable times and periodicities.

Hence, this new TF will be able to provide very basic T22 ME training whilst having the capability to fully exercise a competent and experienced watch. The associated scope of simulations requested and provided allows unusual or dangerous machinery evolutions to be practised, which would not often be permitted due to the high risks and/or ships' programming constraints, such as:

- MFLO system failure
- TLF
- Complete Propulsion Controls System failure
- Local changeover between MGT and CGT
- uncoupled engine runs, etc.

Such an uninhibited style of training means that the true and full consequences of procedural actions will be realised by the students and their instructors.

High quality training aid

The high standard of TF hardware and software is expected to impart superlative quality PT through supporting:

Learning

Knowledge acquisition, consolidation and integration.

Cognitives

Comprehension, application, analysis, synthesis and evaluation.

Psychomotors

Interaction with MMIs.

Stimuli

Appropriate environmental conditions.

Instruction

Good degree of control over events, and effective teaching aids for demonstrations and briefing/debriefing.

Valid assessments

The provision of such a high quality training aid will enable valid assessments of the watchkeepers, thereby yielding platforms for dialogue, feedback and consequent improvements and developments.

Better prepared ME staff

Ultimately, better prepared ME watchkeepers will give rise to higher operational capability through greater safety conscientiousness, more intelligent and optimum effectiveness of machinery operations.

PROJECT OBSERVATIONS

Information and Data Collection, Collation and Interpretation (IDCCI)

IDCCI preparation, arrangements, management and appreciation is fundamental to the successful completion of simulator projects. The procurer must be clear about:

- What Information and Data (I&D) is held.
- how the designers can be assisted.
- What is expected from the contractor in terms of acquiring the outstanding I&D (which could well be the largest proportion of the total set required). Significant internal effort (on behalf of the procurer) must be put into these IDCCI considerations during the project preparatory phase, in order to convey honest and accurate directives to prospective contractors.

Experience and memory

The designer's accessibility to experienced watchkeepers is an invaluable source of I&D. However, the nature and characteristics of this I&D should be put into its proper context. Memories can be unreliable, subjective and even inaccurate, and therefore I&D with such origins must be corroborated. Nevertheless, appropriate experience and memories are vital for initiating certain investigations (for example, discrepancies between design and actuality) and I&D interpretations.

Customer/contractor project team

A sensible unity of the customer's and contractor's staff must be forged for the sake of expedient engineering progress; this mixed team must exercise co-operative working practices whilst being loyal to its parent organizations' interest such that mutual benefits are reaped from the project. The procurer must consider personnel support and not just fiscal resourcing in isolation; the nature of this sort of work demands considerable customer involvement thereby making the 'hands off' management approach by the Procurement Agency often impracticable. Furthermore, realistic risk management attitudes must be adopted which identify and analyse the risks for the procurer and contractor; pure risk shift policies promote confrontational attitudes which are unhelpful to the project. Continuous dialogue between the customer and contractor is very important, however, formal design reviews are the most effective and decisive and directive forums for steering and refining the TF design. 'Wish moderation' (of the users) is an important control function of the procurer that safeguards the TF from overdevelopment.

Communications systems

The safe and efficient execution of many evolutions in RN warships relies on correct voice procedures. Therefore, proper representation of the communications systems appropriately augmented with training enhancements is of utmost importance to an effective TF. This was a very problematic aspect of design since a good understanding of the somewhat complicated protocols normally comes from experience at usage, which is not easily conveyed on paper.

Conclusions

The normal constraints of minimizing the project duration, costs and risks are being combated by:

- Using a simple but proven system architecture for the computer hardware.
- Applying an established and reliable methodology for ME systems decomposition and analyses prior to applying the purpose built CASE tools
- Adopting versatile but uncomplicated electro-mechanical designs for the hardware MMIs.
- Fostering the appropriate customer/contractor working relationship.

The implementation of this project philosophy will yield hardware and software which meets the RN requirements in a cost effective and timely manner, and ultimately contribute to a TF that reflects ME machinery operations which are almost indistinguishable from the real plants.

The trend of the evolution of marine technology and its consequences for the resultant ship designs, ME MCAS systems, and ships' complements gives rise to a number of significant contemplations emanating from this work, such as:

- The simultaneous/combined procurement of parent MCAS systems with the necessary supporting TFs.
- The amalgamation of ships' MCAS systems with their TFs (i.e. exploitation of onboard training.
- The increased use, where sensible, of carefully designed generic TFs.

And the foregoing lead to the important question:

- Is this project a watershed for RN ME procedural TFs procurement ?

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(Note this article expresses the opinions of the authors, which are not necessarily coincident with the MoD, or CAE Electronics Limited.)

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