CONJECTURE ON THE CONTINUING DEVELOPMENT OF MACHINERY CONTROL

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ABSTRACT

New technology has proved the most influential motivation for change in machinery control and surveillance systems, but can be a hard task master when it comes to implementation. Designers of such systems seek to exploit the latest technology to:

- Improve operator performance.
- Increase plant availability.
- Reduce cost of ownership.

In the past two decades it has been the practice to slavishly follow the technology 'master', in order to be seen to 'keep up with progress'. It seems appropriate to take stock and attempt to judge the success so far and learn from experience, before taking the next leap forward.

After a brief review of the development of machinery control philosophy and equipment, the authors attempt to forecast future developments with speculation on the areas of technology and application likely to take us well into the twenty first century. Their speculation is based on the extrapolation of past development, as seen against the sometimes conflicting influences of the continuing and rapid evolution of digital and display technology and increasing pressure on resources.

Introduction

It is always easier to talk about what should be done than it is to do it. Increasing pressure on the defence budget is making it ever harder to justify any speculative work. Only by exploring the possibilities of the continuing advances in relevant technology, is it possible to guarantee and maximize the true value for money in our warships. In this article comments are made, from a background of experience and perceived motivation for change, on some technology that may prove interesting to the designer of future machinery control systems.

There are competing pressures on the designer:

1. *Performance.*

   Not only must the required standards of functionality, reliability and safety in operation be achieved, but it must be done with the minimum of effectively employed operators.

2. *Cost.*

   The cost of design, acquisition and running, are all of major importance in determining the design.

3. *Risk.*

   The technical and programme risk to the warship programme must be minimized.

There are, of course, many secondary considerations under these headings. The option of staying with proven existing technology may be superficially attractive, but this may carry a high risk of increased running cost through early obsolescence. A failure to keep up with industrial practice, in the short term, may increase the risk when a future generation of equipment is forced to employ a step change in technology. It is always difficult to justify changing an apparently successful machinery control system design especially when competing for finance with the more obvious attraction of better weapons. Although the reduction of the through life cost of ownership is accorded high priority, when an increased acquisition cost is proposed for long term benefit, enthusiasm seems to wane. The process of designing improved machinery controls has gone on since the first machinery was produced, so it is appropriate to review its progress over the last 40 years.

EVOLUTION OF MACHINERY CONTROL AND SURVEILLANCE (MCAS)

Earliest forms of control

Before the 1960's, each item of plant would have a set of dedicated MCAS equipment sited near to it and be manned by a maintainer/operator standing in front of it. The equipment could best be described as:

- Simple in design.
- Manpower intensive in operation.
- High maintenance load.
- Little or no flexibility.

but

- Simple to repair.

The initial improvement came as such equipment, basically mechanical or hydraulic in operation, became centralised to form the first machinery control positions.

Growth of function and complexity

In the early sixties the introduction of Nuclear, Biological and Chemical Defence (NBCD) requirements, encouraged the adoption of remote automatic controls and surveillance in Royal Navy warships. There is no doubt that such change was already on the way, but developing weapon technology provided the spur.

The early COUNTY class machinery control room, (FIG. 1), is a good example of the first stirrings of the 'revolution' in both compartment and console design. Not until the Type 21 frigate and Type 42 destroyer, was the true technological change to machinery control systems introduced. This initial technology change, the move to analogue electronics, produced a new generation of systems. But whereas the technology displaced had enjoyed an era of some 30 years, the new analogue electronics was soon to come under threat from digital and micro processor based technology.

By the middle of the 1980's, digital technology was well established in Royal Navy design. Changes in MCAS were not however the sole province of the warship designer. The commercial market was quick to exploit the developing technology, having recognised the potential that the development of greater automation would free manpower for other tasks and eventually lead to reduced manning. MCAS systems have over the years grown in size and complexity (FIG. 2), this growth resulting in a decrease in manning.

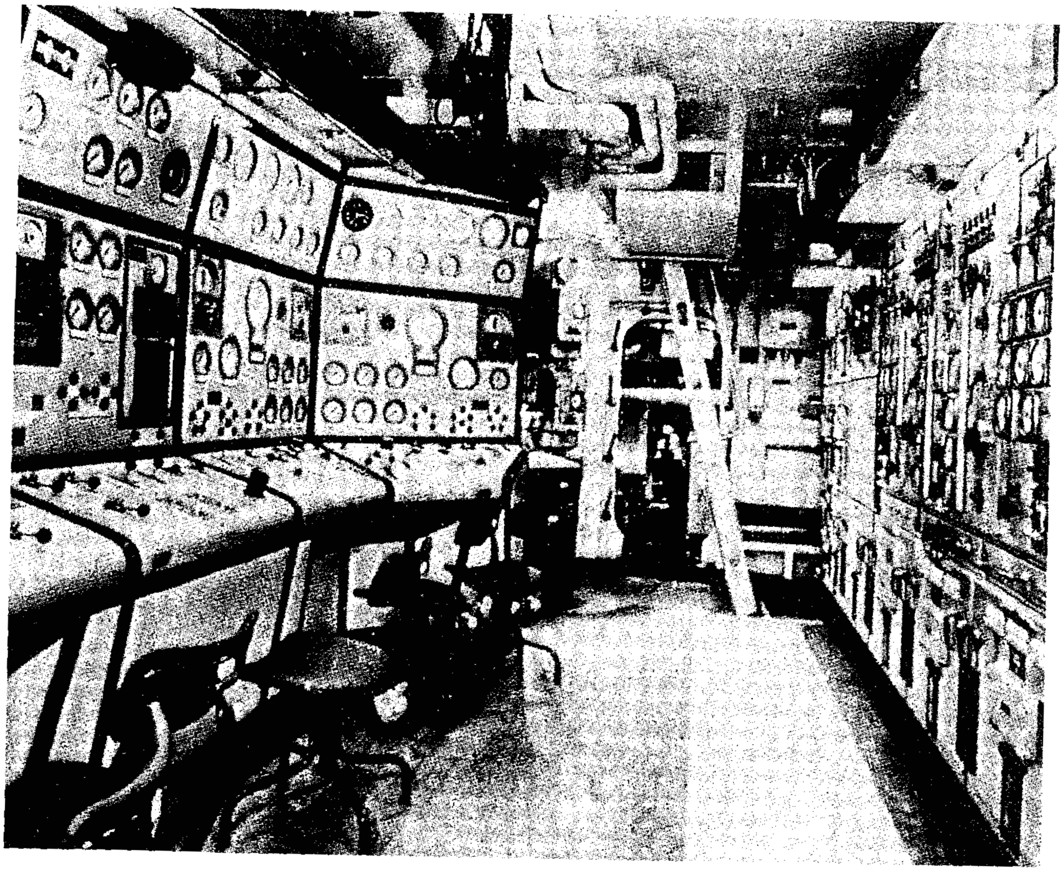

FIG. 1—COUNTY CLASS DESTROYER CONTROL ROOM

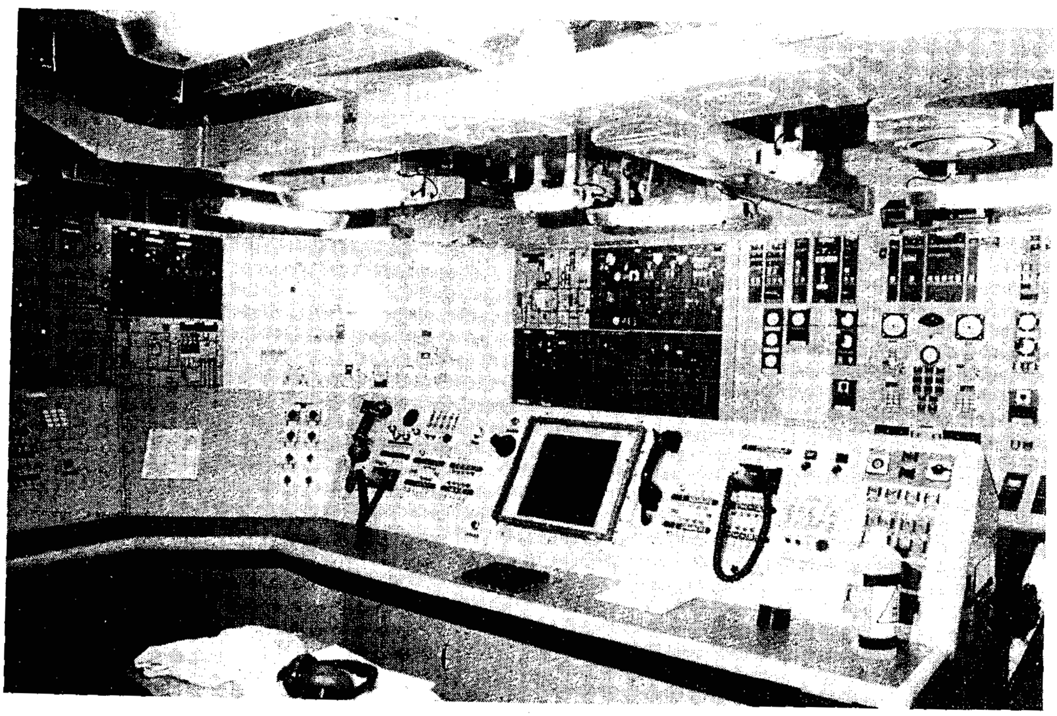

FIG. 2—TYPE 23 FRIGATE CONTROL ROOM

Rate of change

In an attempt to anticipate future development, a number of parameters, taken from existing systems, have been plotted. (FIG. 3) shows how the marine engineers watch complement has reduced over the last 40 years, whilst (FIG. 4) attempts to show the increasing complexity of control systems over the same period.

The adoption of advanced technology in the Royal Navy has been slower than in the commercial world, particularly in the last 10 to 15 years. This carries the benefit that the chosen equipment is well proven when it enters service, but suffers the disadvantage of inability to exploit the flexibility that is increasingly a feature of later developments. The time span of a warship design and build programme is such that the later the decision as to the MCAS fit is taken, the better the design is likely to be. However contractual problems must limit the project manager's ability to delay such important design decisions.

State of the Art

Digital technology is firmly established and permits distributed software based systems for a majority of functions, although it is still necessary to hard wire those considered vital to operations or safety. The design of the ship control centre is now better integrated bringing most machinery control, surveillance and damage control to a single console with a small manning requirement. The number of parameters that can be handled is increasing, making it possible to achieve present and likely future demands. Automation is available and gaining an increasing use in order to reduce unnecessary operator tasks. The technology is also available to support a link to the warship's combat and other systems where

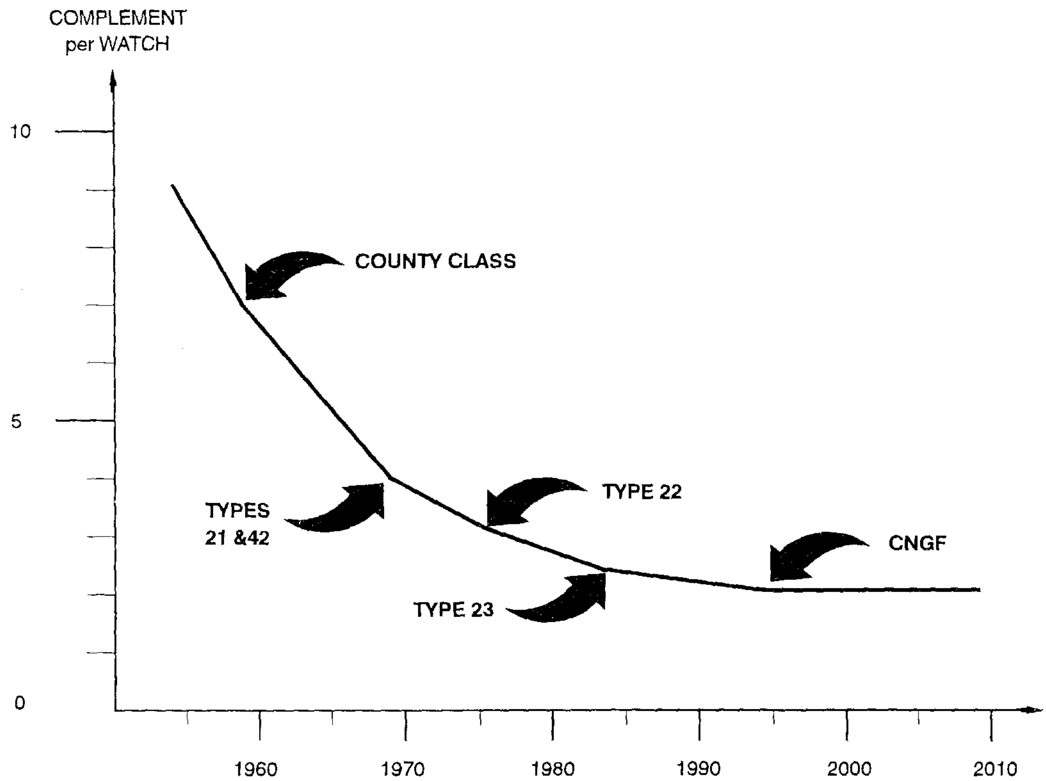

FIG. 3—MARINE ENGINEERING COMPLEMENT OF ROYAL NAVY FRIGATES AND DESTROYERS

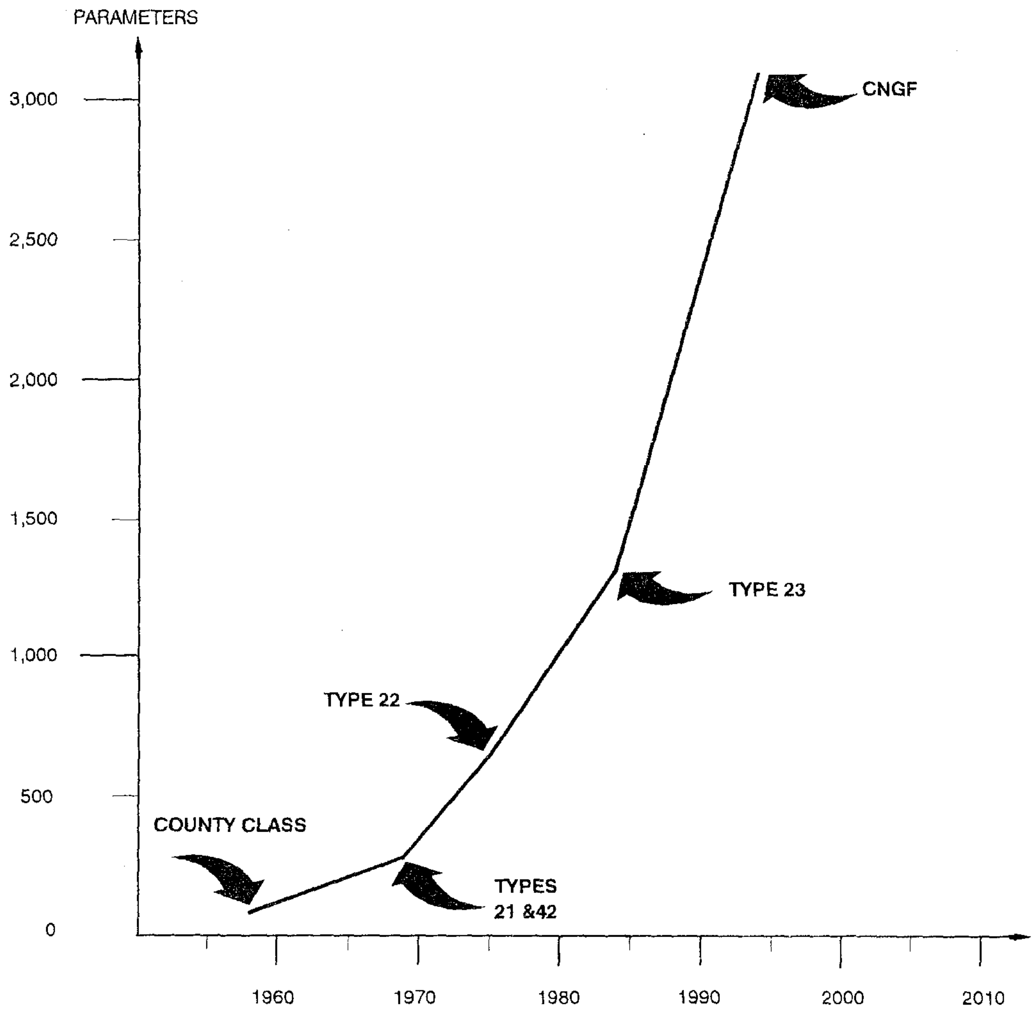

FIG. 4—NUMBER OF MONITORED PARAMETERS IN ROYAL NAVY MCAS SYSTEMS

required. This offers an exchange of data which has only previously been available manually.

The Type 23 frigate is in service with a MCAS system requiring only 3 watch keepers under cruise conditions. Fleet auxiliary and merchant vessels, can be run with unmanned machinery control in many operating states.

Influence of technology

Digital electronics

The demand for the presentation of more information to the operator and aids to its use, have grown as the technology which allows it to be provided has become available. It is only very recently that technology has outstretched the demand. In the seventies and eighties, the risk resulting from the application of new and unproven technologies was significant. Today that risk is unlikely, as technology is continuing to develop against other requirements and is available for adaption to future MCAS. It is of interest that the cost of monitoring a parameter has reduced with time and in real terms, tending towards a constant value (FIG. 5).

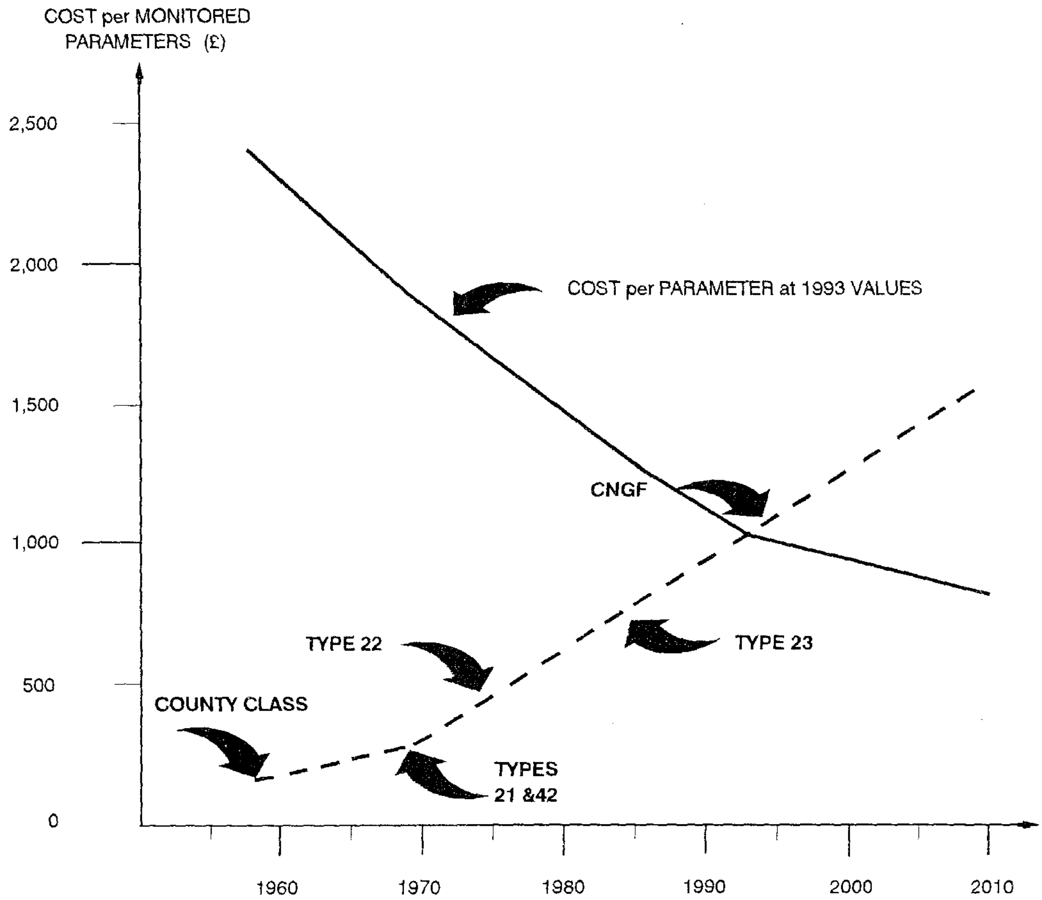

FIG. 5—COST PER MONITORED PARAMETER IN ROYAL NAVY MCAS SYSTEMS

Sensors and actuators

The rapid advance in electronics technology, from the sixties until now, has not been matched by that of actuators and sensors. Many sensors and actuators are essentially unchanged over the period and scope remains for better performance, reliability and cost savings. It is likely that there will be significant advances in these all important elements on the boundary of MCAS systems.

The most likely reason for the lag in sensor technology was the tendency, during the seventies and eighties, to purchase equipments rather than systems. Most sensors were chosen and fitted by the machinery supplier and it was left to the MCAS equipment to condition the output. It is only recently that the increased demand for data collection and the need for more automation has lead to a systems approach together with demands for more advanced, reliable and purpose designed sensors.

Over the years the prime criticisms of sensors have been with regard to accuracy and reliability. In many cases performance has been limited by the mechanics of the chosen conversion mechanism and the current developments in sensors, that are virtually without moving parts and suited to input directly to a digital system, offer great promise.

Advances in actuators make combined use of:

- The best attributes of hydraulic and electronic technology
- Electro-magnetic devices which have benefited from advances in magnetic and other materials technology.

Displays and Controls

It is not conceivable that in the future, special display technology will be developed against warship control requirements. The expense of such developments cannot be justified and commercial products will be adapted. This should not produce any significant restraint on the warship designer as the same basic technology is required in industry and commercial shipping, although seldom subjected to the shock and harsh environmental conditions of a modern warship. The whole subject of the Man Machine Interface (MMI) design remains a challenge, with significant choice available to the designer of the visual display and the means of creating that display. The many applications of information and digital technology, in office work and design, ensure that all are aware of the possibilities.

The robustness of the control panel and displays required for a Royal Navy warship, has presented problems to some manufacturers. But market forces are continuing to improve industrial standards, spurred also by some European Community directives such as that recently on Electro-Magnetic Compatibility (EMC).

Data transmission

With the large rise in the amount of data to be processed and displayed, the requirement for data transmission has also increased. Analogue signals presented no timing problem, but the installation work resulting from the number of cables was considerable. The use of digital links reduced the amount of cable and the introduction of data busses is reducing this even further.

Initially there was some limitation on performance, as the early busses were heavily loaded by the amounts of data transmitted. The growth of data bus technology and the introduction of optical fibres, has overcome the limitation of bus bandwidth. Future data transmission designs must, however, look to increase flexibility even further and seek to provide maximum functionality, once the configuration has been degraded by action damage or component failure.

Knowledge Based Systems (KBS)

KBSs have a significant capability to sort much of the data that is now available from enhanced surveillance equipment. The use of this technique by the Royal Navy is currently restricted to:

- Some simple data base applications in the damage control field.
- Filtering of data based on expert knowledge in some surveillance systems.

The use of significant data processing to provide plant information at a macro level or the use of KBS for control are currently only at an experimental stage.

The concept of artificial intelligence has fascinated writers of science fiction and is becoming more and more likely to be realised as computing technology advances. The accepted test of 'intelligence' is, in essence, that if a human interrogating the system can not detect if the system responses are produced by a machine or a human, then the system is regarded as intelligent.

In the context of MCAS systems, it has been recognised that there is no point in trying to replicate the human, with all its shortcomings. But there is point in trying to include some flexibility in response based on:

- A sound knowledge of the plant state.
- The valid options for action.
- Likely consequences.

So called 'knowledge based systems', have been demonstrated capable of providing help to a heavily loaded operator, by indicating the most probable cause of the unusual operating state indicated to him.

It follows, from the above, that in general terms 'we have the technology' so what should we do with it?

Pressures for advancement

It was proposed earlier that the designer has in mind performance, cost and risk. It has been postulated that the risk from new technology has declined, as technological capability has outstripped our application. The major pressures in performance are the manning level and reliability. Cost remains the major restraint.

Manning levels

The Royal Navy is nearing the optimum balance between manpower savings and system cost. Before 1990, advances in technology allowed savings in manning and long term support that justified the necessary investment and risk. The point has now been reached where potential savings in these areas will not alone justify further investment. There remains some scope for reducing the cost of the equipment and its installation and for improving the reliability of both the installation and operators.

Cost

The use of 'commercial' equipment is seen by many as being the answer to achieving reduced costs. This belief is analogous to expecting a prime contractor to be capable of going to a local super store and taking a MCAS system off-the-shelf. Very few MCAS system solutions can be bought as a package, individual elements may well be but whole systems are a different matter. It is even difficult to specify what is meant by 'commercial' equipment.

Most control and surveillance equipment is supplied to specific standards to meet the manufacturers declared market, 'commercial' equipment meets only those standards that the manufacturer perceives essential to maintain his position in his main market and to which his normal working practices are geared. In the past the Royal Navy has, by means of its engineering standards and quality assurance requirements, placed itself in a single market position. Whereas contractors were happy to supply the Royal Navy, they were not necessarily pleased or prepared to change their production standards.

Moves in the commercial manufacturing world brought about by market pressures have resulted in changes to many engineering standards. In a similar way the Royal Navy requirements have broadened to take in what has been previously purely 'commercial requirements'. The differences between Royal Navy and commercial equipment are no longer quite so dramatic, particularly with regard to basic construction. It is noticeable that some of the environmental requirements such as EMC and shock no longer differ so greatly. Unfortunately areas such as MMI requirements and some aspects of environmental performance specified by the Royal Navy remain different from commercial practice. These areas tend to be the cost drivers, as does the need for full supporting documentation.

In the case of the MMI technology, there seems to be the chance for the gap to be closed. Although the common elements of human factors will always apply to both areas, the adaptability and flexibility now available in all forms of MMI design allow both the Royal Navy and commercial requirements to be achieved using similar equipment. The Royal Navy operating procedures will still add complexity above most commercial requirements, but the gap in cost terms will be reduced.

The situation with regard to documentation however remains, with the support issues which dictate the documentation requirements being unlikely to change without considerable debate; therefore this costly overhead will remain for sometime.

Availability Reliability and Maintainability (ARM)

The influx of new technology into the controls field has brought a number of improvements in ARM. Apart from a simple growth in the quality of manufacture, a lower component count per function has been achieved by the ever increasing scale of circuit integration. The use of digital electronics has allowed the introduction of equipment with a self testing capability; which significantly reduces diagnosis time and combined with the modularity of current construction techniques, allows replacement in minutes. Systems are now capable of significant functionality even in a degraded state and it is the expansion of this capability that is likely to be the route for future development.

Current software has now reached a very high quality and whilst there are no true software reliability techniques in place, it is generally accepted to be significantly better than equivalent hardware. In terms of the acceptance of software in safety critical applications it is still early days and confidence will grow slowly over the next few years before wide spread application of software based safety related systems is the norm.

POSSIBLE ROUTES FOR DEVELOPMENT

Automation

Automation in various forms is present today. Many tasks are automated as normal engineering design practice, rather than as part of an overall strategy. Total automation, requiring no manual involvement, is technologically possible and in some instances can be applied quite readily but it has been slow to find naval application.

In previous MCAS designs, automation has been applied to those tasks or functions that have been defined as too difficult to be carried out reliably by an operator. The starting and shut down of a gas turbine is an example. Within the typical watch keeping duties however, such tasks occupy a small part of the operator's time. Most of the operators workload is provided by simple tasks which have not been automated. The consequence of automating these minor tasks is to leave the operator with unoccupied time, perhaps to the point where he has no routine involvement with plant control. Whilst the possibilities of further reduction in operating manpower are obvious, there are some difficulties that must be considered.

The numbers and skill levels of naval personnel are driven by various factors. Of particular concern is the plant operation under action damage where manpower is required to tackle the control of damage and minimize its effect on the operational role of the warship. As has been stated in the past, the optimum balance between manpower and automation is all important in warship design.

The operator is:

- A powerful computer with a large memory.
- A comprehensive set of standard software.
- A capable learning facility.
- Capable of high tolerance to some environmental deviations.

- Directly wired to a built in power supply
- Equipped with multipurpose sensors and actuators.

The operator can apply his skills in a flexible and adaptable way and must be combined with the stability, reliability and consistency of technology. The operator will become bored and inefficient if he has nothing to do. That is not to say that jobs should be invented for him, however, as he has to be there whether used or not, he is available to be considered as an alternative to automatic control. The less the operator is involved in plant control, the more routine training he is likely to require in order that his reaction to unforeseen circumstances in an emergency can be on a basis of instinctive and detailed plant knowledge.

It is doubtful that the case will ever be made for a zero watch keeper design, without a major change in current Royal Navy manning philosophy, because factors other than efficient plant control under specified conditions will dictate a presence.

Operator assistance

The plethora of data now available to the operator is clearly suitable for significant data reduction prior to display. A well implemented KBS system could make many of the present displays unnecessary and provide a very different HMI to that now achieved. The advent of 'neural computing' has placed a powerful technique at our disposal for smart sensing and fault tolerant self learning control. It is possible, at a price, to produce a truly knowledgeable operator's friend or even an operator replacement.

Whilst the technology is now available however, it's use is dependent on a growth of confidence by operators that they do not need sight of all information 'just in case'. The implementation of this technology is likely to be slow and the scenario of a ship control centre completely run by artificial intelligence, which can cope with a marine engineer officer's sarcasm, is certainly a long way off.

To date there has been a reluctance to trust the system to implement corrective action without operator intervention. Most applications of knowledge based systems require many lines of software, much of which becomes safety critical, and therefore costly, if the human is taken out of the loop.

Head up displays

The use of head up displays is now common place in aircraft for presenting data to the pilot, while allowing him to maintain a view of the outside world. It is difficult to imagine a similar scenario in a naval environment, but the concept of personal headsets providing displays could have some application, in combination with other new technologies.

Virtual reality

The technical press has made much mention of so called virtual reality in recent months. The growing processing power of computers, together with advances in the technology of electronic displays, has made it possible to present separate software generated images to each eye piece within a suitable headset. The arrangement enables the simulation of a scene in three dimensions, with detail that is only limited by the resolution and data handling capacity of the system. The use of digitised actual pictures can enable very realistic results.

The applications of virtual reality are obvious; within the design process the users can place themselves within a simulation of the proposed operating environment to evaluate the:

- Layout of the space.
- Adequacy of the proposed lighting arrangement.

- Colour scheme.
- The presentation of information on displays etc.

Alternative arrangements can be compared at will. But why not take it further? If it is possible to simulate realistically the control position, then the actual control position is not required. Sit the operator in a comfortable chair with headset in place and a control in his hand and he will be able to control the plant just as effectively as if he was at an old fashioned VDU based panel, perhaps more effectively. There is of course a flaw in the thinking here. There is always a tendency to use new technology to reproduce more effectively the function and form of the technology that it replaces.

Early use of the VDU sometimes resulted in a display of rows of simulated panel meters with their simulated needles oscillating realistically. The advantage was a cheaper console that didn't need to be tapped to see if the needle had stuck. Better ways of displaying the information were soon developed and displays that exploited the capability of the display to good effect resulted. The same process must be applied to the application of virtual reality. New methods of information presentation may be devised which improve effectiveness or reduce fatigue. The opportunity to use sounds for communication to reduce the visual load must also be explored.

All this presupposes that an operator is continued to be used as a very capable data processor and programmable controller. May be the job can be done more reliably with an advanced black box!

Surrogate Travel

Virtual reality is heavily dependent on considerable processor power in order to provide the pair of real time three dimensional images. In comparison surrogate travel provides a similar facility with different technologies.

An area can be extensively photographed using a conventional video camera. A large number of images are then transferred onto a video disc, typically allowing a view of a compartment form any angle with viewing points at every ½ metre. A simple personal computer can then manage this picture data base and allow rapid retrieval of individual views, to allow an operator to 'tour' the environment originally filmed.

As a training aid, it will enable the operator to experience realistic drills without the expense of a hardware based training facility. The maintainer can apparently move about the plant to practice fault location and diagnosis, without the need for actual plant in the training facility and avoiding the danger from untrained staff within operational plant. This 'surrogate travel' will aid the provision of maintainer and operator training facilities on board.

Surrogate travel will allow damage control parties to see layouts, plan operations and prepare routines before attempting them in damaged and smoke laden compartments.

Cordless data transmission

Despite the progress in data transmission in increasing data flow and reducing physical cabling, both equipments and manpower are still tied to set positions. There are currently technologies that allow cordless data transmission between computers and their peripherals in the office and these could be developed to provide advantages on board ship:

- Senior operators could walk from console to console to oversee a system, whilst retaining voice contact with their team.
- Portable electronic damage control aids could provide the benefit of total mobility to avoid hostile environments whilst remaining operational.

Speculation on the way ahead

One aim of this article is to distil the evidence and forecast the future. It seems likely that the limited scope remaining for further reduction in the marine engineering watch complement, together with the high cost of any such reduction, will prevent any continuation of the existing evolutionary development of MCAS. But there is scope for improving damage control performance and reduce the manning requirement and work is already in hand in this area.

It has been noted that potential exists for improvement in sensors and actuators and the case for such work is strong. There is no doubt that data transmission will be developed to increase the system robustness to damage.

In the longer term it will be the evolution of new technologies that will initiate change. From those new technologies mentioned in this article, it seems clear that:

- Surrogate travel will be used for training and as an operator/maintainer aid.
- Automation incorporating neural techniques will help to reduce the operator loading.
- Eventually virtual reality techniques will reduce the cost of displaying information to the operator.