ARI Research Note 90-116

AD-A227 062

Embedded Training in the Polaris SSBN Missile Fire Control System

John Annett

University of Warwick (Coventry, England)

for

Contracting Officer's Representative
Milton Katz

Basic Research
Michael Kaplan, Director

September 1990

FIFTY YEARS OF SERVICE
1940 - 1990

United States Army
Research Institute for the Behavioral and Social Sciences

Approved for public release; distribution is unlimited

U.S. ARMY RESEARCH INSTITUTE FOR THE BEHAVIORAL AND SOCIAL SCIENCES

A Field Operating Agency Under the Jurisdiction of the Deputy Chief of Staff for Personnel

EDGAR M. JOHNSON
Technical Director

JON W. BLADES
COL, IN
Commanding

Research accomplished under contract for the Department of the Army

University of Warwick (Coventry, England)

Technical review by

Michael Kaplan

Accesion For	
NTIS CRA&I	✓
DTIC TAB	
Unannounced	
Justification	
By	
Distribution /	
Availability Codes	
Dist	Avail and / or Special
A-1	

NOTICES

DISTRIBUTION: This report has been cleared for release to the Defense Technical Information Center (DTIC) to comply with regulatory requirements. It has been given no primary distribution other than to DTIC and will be available only through DTIC or the National Technical Information Service (NTIS).

FINAL DISPOSITION: This report may be destroyed when it is no longer needed. Please do not return it to the U.S. Army Research Institute for the Behavioral and Social Sciences.

NOTE: The views, opinions, and findings in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other authorized documents.

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS —
2a. SECURITY CLASSIFICATION AUTHORITY — 2b. DECLASSIFICATION / DOWNGRADING SCHEDULE —	3. DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.
4. PERFORMING ORGANIZATION REPORT NUMBER(S) —	5. MONITORING ORGANIZATION REPORT NUMBER(S) ARI Research Note 90–116
6a. NAME OF PERFORMING ORGANIZATION University of Warwick Department of Psychology 6b. OFFICE SYMBOL (If applicable) —	7a. NAME OF MONITORING ORGANIZATION U.S. Army Research Institute for the Behavioral and Social Sciences
6c. ADDRESS (City, State, and ZIP Code) Coventry CV4 7AL England United Kingdom	7b. ADDRESS (City, State, and ZIP Code) 5001 Eisenhower Avenue Alexandria, VA 22333-5600
8a. NAME OF FUNDING / SPONSORING ORGANIZATION Army Research Institute SCO, London 8b. OFFICE SYMBOL (If applicable) PERI-BE	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER DAJA 45–89-M-0368
8c. ADDRESS (City, State, and ZIP Code) U.S. Army RDS Group (United Kingdom) Box 65 FPO New York 09510-1500	10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
61102B	74F	n/a	n/a

11. TITLE (Include Security Classification)

Embedded Training in the Polaris SSBN Missile Fire Control System

12. PERSONAL AUTHOR(S)

Annett, John

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM 89/08 TO 90/03	1990, September	14

16. SUPPLEMENTARY NOTATION

Milton Katz, contracting officer's representative.

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Embedded training Simulation

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Controllers (TAC) console

Embedded training is a special facility built into operational equipment to permit its use for training purposes. This report provides a retrospective summary of the use of an embedded training facility in the Polaris Submarine Missile Fire Control System. A special embedded device, the Training Alarm ~~Control Console (TAC)~~ used in conjunction with the Fire Control Console and other operational equipment, permits the fire control team to rehearse missile countdown, including procedures for dealing with fault conditions, under realistic conditions during long sea patrols as a supplement to training on shore-based simulations.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified	
22a. NAME OF RESPONSIBLE INDIVIDUAL Milton Katz	22b. TELEPHONE (Include Area Code) (202) 274–8722	22c. OFFICE SYMBOL PERI-BR

DD FORM 1473, JUN 86 *Previous editions are obsolete.*

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

EMBEDDED TRAINING

IN THE POLARIS SSBN MISSILE FIRE CONTROL SYSTEM.

John Annett

Dept of Psychology,
University of Warwick, Coventry CV4 7AL.

This report was made possible by Contract No. DAJ45-89-M-0368 from the U.S. Army Research Institute through its European Science Coordination Office in London, England. The views expressed are those of the author, and do not necessarily represent those of the U.S. Army.

SUMMARY

Embedded training is a special facility built into operational equipment to permit its use for training purposes. This report provides a retrospective summary of the use of an embedded training facility in the Polaris Submarine Missile Fire Control System. A special embedded device, the Training Alarm Controller (TAC), used in conjunction with the Fire Control Console and other operational equipment, permits the fire control team to rehearse missile countdown, including procedures for dealing with fault conditions, under realistic conditions during during long sea patrols as a supplement to training on shore-based simulators.

Although quantitative data on crew performance and training were not available for analysis, users at the Royal Naval Polaris School, H.M.S. Neptune, report that TAC is a valuable adjunct to training. The study also provided some lessons which could lead to improvements to the design of successor systems, and for embedded training facilities generally. The less than ideal physical arrangement of workspace and the need for an additional crew member to set up problems led to the device not being used to the extent originally intended. The device did not include facilities for automatic problem setting or performance scoring and feedback, both of which would add considerably to its training value. These problems are, in principle, more easily soluble with modern technology not available to the original designers. Finally the use, and hence the potential training value of the device, could have been enhanced by the provision of an instructor's manual.

Aims of the Study.

Embedded training (ET) [1] is a training facility which is built into or added on to operational equipment permitting its use for the acquisition and/or maintenance of skills required to operate and maintain the equipment. ET is widely used in military training, particularly where there is a need to maintain a high standard of operational readiness in the absence of other facilities such as part-task trainers and simulators. ET typically offers highly realistic training insofar as the actual operational equipment itself is employed but it can also offer some of the advantages of simulation. Exercises can be repeated and infrequently occurring conditions can be produced at will, with no danger to operators or use of costly resources such as missiles. A potential cost of embedded training is normally some intervention in the functioning operational equipment, for example the introduction of known faults for the purposes of maintenance training or the injection of artificial signals or simulated outputs for operator training.

The ET operator and maintenance training capability implemented in the Polaris SSBN Missile Fire Control was one of the earliest examples of ET which was actually incorporated into the original design. The potential benefits of ET in such circumstances are obvious. It is necessary to maintain a very high standard of crew performance during patrols lasting several months yet there are obvious restrictions on truly realistic training execrises and there is not space on board a submarine for extensive simulation facilities. As the system reaches the end of its working life lessons for the design of future systems may be learned from the experience of users. The aim of the present retrospective study is to highlight the benefits and limitations of this unique example of ET. A number of Polaris submarines remain in service with the Royal Navy and the present study was undertaken through the good offices of the Directorate of Strategic Weapons Systems and with the help of the Commander and staff of the Royal Naval Polaris School, Clyde Submarine Base, Helensburgh, Scotland.

Brief Description of the System.

The Polaris Weapon System comprises (1) the Ship System, (2) the Navigation System, (3) the Missile Fire Control System, (4) the Missile Test and Readiness Equipment (MTRE), (5) the Launcher System and (6) the missiles themselves. In tactical mode these are of course interconnected but each of the first five can operate to an extent as separate subsystems for training purposes. This report is primarily concerned with 3 and 4, the Fire Control System and the Missile Test and Readiness Equipment.

The Fire Control System (FCS) governs a controlled series of checks and commands leading up to missile launch and executes the launch. These events are controlled from a console by the Weapon Engineer Officer (WEO) and his team. The state of readiness of the missles and launching system is displayed on illuminated panels on a console. If a fault is displayed the WEO may halt the countdown and make preparations to launch a different missile and so the primary job of the WEO's team is to watch for and interpret faults and take appropriate action according to strictly laid down procedures.

The Missile Test and Readiness Equipment (MTRE) Mk. 6 and Mk. 7 interrogates the missiles at each stage of countdown. The MTRE Mk. 6 monitors battery voltage levels, pressure in the hydraulic package, the missile first stage nozzle start position and the position of the switch controlling transfer of power from external to internal. It returns signals to the FCS indicating a 'green' (O.K.) or fault on the FCS console. The MTRE Mk. 6 can be programmed to return 'green' status on any or all of its associated checks whilst the FCS is disconnected from the missile and can be used in this mode during training exercises. The Mk. 7 equipment records currents and voltages in the missils subsystem and, whilst these data are retained for analysis they play no part in training.

Outline of Polaris Crew Training.

Primary or induction training is given in a shore-based facility, the Royal Naval Polaris School (RNPS) at HMS Neptune, Helensburgh. It is the practice to introduce new crew members to replace outgoing members of already trained crews after they have attended courses appropriate to their posting. In the case of some junior ratings this could be quite short but in other cases it is very extensive. Individual new crew members thus receive part of their training by joining already experienced teams and this part of their operational training is the responsibility of the Weapon Engineer Officer.

Crew training as such is organised on a cycle integrated with the duty cycle of the boats of 4/5 months duration in the following principal phases.

1. On return from Patrol there is a period (3/4 days) in which the submarine is handed over to the relief crew before brief shore leave. The now 'on crew' takes the SSBN through a Base Maintenance Period (BMP) assisted by the 'off crew'. Following the BMP the SSBN deploys for Independent Exercises (INDEX), mainly at sea training exercises. On completion the SSBN deploys for Patrol and, having done so, the 'off crew' proceed on long leave.

2. Following long leave there is a period of several weeks shore-based simulator training, at the end of which the crew take over their ship again. This phase of the cycle is known as 'continuation training'.

3. Each new duty tour begins with a BMP followed by INDEX in which the shore-based trainers or 'sea-riders' continue the shore-based training by carrying out special training exercises at sea. INDEX trials, which take place over several days, cover fire, flooding and other emergency drills in addition to the Polaris countdown procedures.

4. On patrol, the WEO is responsible for training his team and runs regular (2-6 per week) exercises in Weapon System Countdowns using 'training without guidance', that is without spinning up

the missile guidance gyros. These exercises are designed to maintain performance and check the operational reliability of his equipment.

5. Finally Weapon's Systems Readiness Tests (WSRT), which involve all subsystems, are ordered at irregular intervals. These are externally initiated and unannounced and are designed to test the readiness of the whole system.

Training Facilities and Equipment

The shore-based facility includes simulators on which training for all main subsystems can be carried out. These include realistic consoles and actual items of equipment which are controlled by instructors. These facilities were not considered in detail in the present study, however, the trainers report that they are comprehensive and include facilities for fault injection and the insertion of special modules containing known faults. This latter facility is not used at sea. Full tactical mode training can only take place on the shore-based training facility.

At sea certain kinds of training are possible using the actual systems with certain restrictions. A limitation on training the operators of the Launcher subsystem is that only the hatches on empty tubes are allowed to be opened at sea for training purposes. The operation of this particular subsystem, which is largely a mechanico/hydraulic mechanism, is a routine procedure, similar to classic gun drill rather than requiring the following of relatively complex procedures. These drills can take place satisfactorily using the limited facilities available.

The operation of the Fire Control System can be rehearsed at sea since the design of the system allows it to be isolated from the other subsystems. The WEO can take his team through a 'green board run', that is a countdown procedure which, given there are no actual faults, should proceed uninterrupted. The firing sequence is rehearsed but, of course, no signals reach the Launcher or Missile subsystems.

These exercises can be carried out in either of two modes, with or without 'guidance'. In the 'without guidance' mode the Missile Test and Readiness Equipment (MTRE) Mk6 can be set to return signals simulating (after appropriate intervals) states such as that the missile is prepared and ready, or, if required, that the missile is not ready in some respect, and this will then be indicated as a fault on the Fire Control Console and the operators must decide what alternative action to take.

In the 'with guidance' mode the missiles's guidance systems are 'spun up', that is the gyros are energised, and signals are returned from the guidance systems reflecting their true state.

A special device associated with the Fire Control Console, the Training Alarm Controller (TAC) can be used to insert faults, returning simulated 'failures' in one of the two operating channels or in any of the missiles. The device works by controlling a number of relays (19) which would be activated in the event of a real fault thus controlling the fault indicators on the Fire Control Console. This device is the only strictly non-operational equipment actually in use for training at sea. Its use is for rehearsing procedures to be followed in the event of failures in the countdown and launch sequence.

Mention should be made of another item of equipment which has a bearing on embedded training. The Patrol Analysis Recording System (PARS) includes a tape recorder linked to the countdown communication networks and 115 pen event recorder which records every event during the Weapons System Readiness Tests. These records are used, after extensive analysis, as a basis for monitoring system (including crew) readiness and can form the basis for debriefing the crew at the end of a patrol.

Use of the Training Facilities.

Fire control is taken through a 'green board run' under 'training without guidance' mode on a daily basis. The TAC facility is not used and the Fire Control Action Stations team is not closed up since the object of this procedure is not crew training but system proving.

Training with guidance with the PARS system running, an exercise involving the entire crew at Action Stations Missile, is carried out for the purpose of the WSRT at irregular intervals at an average frequency of once per week during the Patrol.

Some, but not all, Weapons Officers will use the TAC facility during the regular Weapon System Training Countdowns run for crew training. Reasons for this will be described later in this report.

The TAC is used during INDEX, the period of transition from shore-based to sea-going training, when exercises are normally run by the 'sea-riding' trainers rather than the Weapon Engineer Officers.

These facilities (TAC together with MTRE) are used for maintaining the performance of the small team, including the WEO himself and several senior and junior ratings, rather than for initial training or performance measurement. During INDEX the trainers report team performance to the Weapons Engineer Officer himself and to the Captain. The Weapons Officer is responsible for the performance of his team and feedback is both immediate and informal. Only during the WSRTs are records kept and these are packaged and returned to M.o.D. Navy for analysis. These records are not intended for nor used as means of assessing the performance of individuals.

Although TAC is built into the shore-based simulator its use in that context is limited since the sophisticated facilities of the simulator itself are available. For example on the shore-based simulator it is possible to rehearse fault finding on key equipment by inserting known faulty modules. It is, however, reported that perhaps 70% of faults occurring during missile launch countdown can be reproduced on the embedded training equipment at sea.

Perceived Value of the Embedded Training Facilities.

This section refers principally to TAC and is based on accounts provided by users including Weapons Officers, shore-based and 'sea-riding' trainers.

Problems simulated by the use of TAC are moderately realistic in the sense that the FCS shows indicator lights operating just as they would with an actual fault. There are, however, some power faults where the quality of the lights themselves would change and these cannot be simulated on TAC. It is estimated that about 70% of faults can be realistically simulated using TAC at sea.

TAC also lacks realism in so far as there some cases where the operator's response clearly does not have real consequences which would normally become known to the fire control team. However, its major failing from the users' viewpoint is that, being situated under the actual FCS console, other members of the team can clearly see the trainer (either the sea-rider or the WEO) insert the faults. A simple metal flap conceals the panel on which the fault is set from the rest of the team but the fact that a fault is being set is visible to the whole team and to this extent the occurrence of a fault is unrealistic.

The users all complain that the TAC location is very inconvenient and this is no doubt an important factor in limiting its use. In order to set up a problem the trainer should be able to see the current state of the FCS console and so the equipment has to be nearby, yet in the cramped conditions it is virtually impossible to insert a 'surprise' fault using the TAC.

The TAC device is physically situated between the Weapon Engineer Officer and the senior rating operating the FCS console and is approximately the size and relative location of a desk filing drawer. It is pulled out between the two men when in use and a metal cover hinged on the right hand side of the unit is lifted so that the man on the left, normally the WEO, can set up fault indicators by pressing pairs of buttons unseen by the right hand operator. Whilst this is relatively convenient for the WEO, the sea-riding trainer has to get down on his knees in a very cramped space in order to set up a problem.

Although the equipment is conveniently located for use by the WEO he is himself an integral member of the team and so the device cannot be used to realistically exercise the whole team except by the sea-riding trainer or by employing another suitably qualified person to set problems.

In addition to the physical inconvenience of the TAC unit some WEOs and trainers have expressed reservations about its use for the effects it might have on the system. These are of two kinds. First, every use of the equipment increases wear and hence theoretically increments the probability of failure. With this equipment there is some anxiety that relays might stick leaving spurious fault indicators in the system. Although relays do occasionally stick in elderly equipment of this kind there are no recorded instances of this actually happening to TAC and to this extent any anxiety on this account is probably not justified.

Another possible source of spurious error signals is that the Weapons Officer or the sea-riding trainer may omit to reset the fault indicator at the end of an exercise. One sea-riding trainer admitted to this error during an INDEX trial and, since the ommission of a final step at the end of a procedure is a common form of human error, mistakes of this kind are only to be expected from time to time. However, they are easily found and corrected.

Fortunately, leaving an incorrect fault signal in the system, whether due to mechanical failure or human omission, would seem to be a relatively benign error. Failing to register an actual fault will generally have more serious consequences and moreover the frequent operation of the system for a 'green board run' virtually guarantees that any spurious fault indication left in the system will quickly be discovered. All in all the anxiety about using the TAC for this kind of reason may be unwarranted.

Apart from a technical modifcation which affects one of the checking procedures the FCS appears to have remained unchanged throughout the 30-year lifetime of the system. I was not made aware of any independent equipment modifications carried out by the Royal Navy and I was assured the procedures to be carried out in the event of a fault showing up on the console are exactly as set down in the operating manuals.

Manuals and Adjunct Materials.

The technical manual describing the TAC equipment now in use at the Polaris School is the original issue. It is clearly marked as not being subject to updating and indeed contains some information which is now no longer applicable due to some changes in the system. Some of the required operator responses given in the manual are said to be incorrect. The manual essentially describes the equipment and does not set out to be a procedural guide telling instructors how best to use it in training.

Despite these shortcomings instructors who have used the manual found it contains valuable information. Unfortunately the section referring to the TAC facility is buried in a much larger document and some potential users have simply been unaware of its existence.

Users would like to see a separate manual for TAC with clearly set out instructions for its use. Users would also like to see more information in the manual about what TAC does to the system.

Trainers can and do create their own exercises for TAC but in view of the risks associated with misuse of the system each fault is closely identified before being authorised for use. All operators seem, quite correctly, to take a highly cautious attitude to innovation and reliable procedural guides are therefore held to be of great value.

Following the same general attitude procedural guides have been carefully 'anglicised' where necessary but otherwise adjunct materials have not been developed for general use at sea.

The INDEX exercises were the only items of training I saw not originating in the USA and training films available on shore are not typically used at sea.

Evaluation.

The consensus is that, despite the shortcomings outlined above, TAC is a valuable item of equipment. However, due to the way it is used no quantitative data are available on its actual effectiveness in imparting or maintaining skills. Weapon Engineer Officers are immediately and intimately aware of the performance of their teams but system performance data are only formally recorded by PARS. Since the latter only become available on return from patrol and require detailed analysis and interpretation their value in training individual crew members must be regarded as limited.

Although it might, in principle, be possible to analyse the results of WSRTs to identify the performance levels attained by particular FCS teams and to make a comparison between those teams who use TAC regularly at sea and those who do not, it is most unlikely that the relevant information could be made available. Even if the data were available it would probably be extremely difficult to isolate this factor from all the others likely to affect the operational performance of individual teams.

Conclusions.

The TAC embedded training facility is, despite certain shortcomings, regarded by the Royal Navy as a valuable item of training equipment. However, it is not possible in view of the lack of accessible data to confirm this opinion in quantitative terms.

The principal disadvantages which have come to light are (1) the physical inconvenience of the location of the TAC equipment, (2) the fact that it does not fully test or train the whole team, (3) that it lacks any accessible objective performance scoring, (4) that it lacks a convenient instructor manual. All these limit its value for use in training at sea.

Any successor system, for example aboard Trident, would have to be more physically convenient if it were be used more often and hence provide greater training value. In general new technology should mean less hardware and more software and the kinds of functions provided by TAC in Polaris ought probably to be implemented through software, or possibly some micro-circuitry, which could overcome the space problem. Whatever the case with Trident, which was not part of the present study, this observation, that embedded training need not carry a space penalty, is likely to be generally true as all complex equipment moves from 1960's technology to 1990's technology.

The Weapon Engineer Officer is part of the team as well as being responsible for training. A detailed analysis of the WEO's functions was beyond the scope of the present study but some advantage might be gained by separating his function as team leader from his function as trainer, planning and setting up exercises to challenge the team as a whole. Clearly the present system is such that it cannot be used at sea without an additional suitably qualified person to set up the exercises. A successor system which could be conveniently operated by another person, or perhaps even operate automatically so that the WEO himself could participate realistically in the exercise, could significantly enhance its training value.

During shore-based training and a patrol lasting some months the WEO becomes intimately aware of the skills of his team and in this sense is ideally placed to assess performance and provide valuable feedback. However, it has not been possible within the scope of this study to discover whether the PARS data are put to the best use in providing training feedback for individuals and the Fire Control team as a whole. The Royal Navy does not, at least in this sphere, run competitive exercises, but a facility for automatically recording actual performance data which could be fed back to the team whilst still at sea could considerably enhance the training value of exercises carried out during patrols. Again one might expect this facility to be available in the successor system, but in any case there is a lesson here for other embedded training systems. The message is that, unless there is an additional person who can act as an instructor setting up and scoring exercises, the facility for practice offered by embedded training may not be fully or most effectively utilised.

Finally, it is generally recognised that separate manuals for training equipment are required if the best use is to be made of the facilities they offer. A purely technical manual describing the physical features of the equipment is, of course, essential but a good part of the variability which has been found in the amount of use made of TAC equipment can be attributed to the absence of an instructor's manual. A separate user-friendly manual would increase the chances that embedded training facilities such as TAC would be employed on a regular basis.

To conclude, it has not been possible in this study to say whether or not this particular implementation of embedded training has been worthwhile in the sense of providing best training value for money but the investigation has documented the use made of a unique example of ET and a number of general lessons concerning the implementation ET have been drawn from the experiences of actual users and from general considerations of training technology.

The principal lessons are as follows:

1. an ET facility, when in use for training, should be fully compatible with the normal operation of the equipment permitting all operators to practise their tasks under realistic conditions;

2. an ET facility should, wherever possible, incoprorate objective performance scoring and be capable of providing immediate feeback to all operators;

3. an instructor's manual detailing appropriate training procedures should be provided with the equipment.

Note 1. Embedded Training was formally defined in a memorandum issued by General M.R. Thurman, US Army Vice Chief of Staff and James R. Ambrose, Under Secretary of the Army, dated 3rd. March 1987.

The relevant extract reads as follows:

"Embedded training is defined as training that is provided by capabilities designed to be built into or added into operational systems to enhance and maintain the skill proficiency necessary to operate and maintain that equipment end item.

Embedded training:

a. Will not adversely impact the operational requirements/capabilities of the system and should be identified early enough to be incorporated into initial prototype designs.

b. May train individual tasks through force-level collective tasks as required."