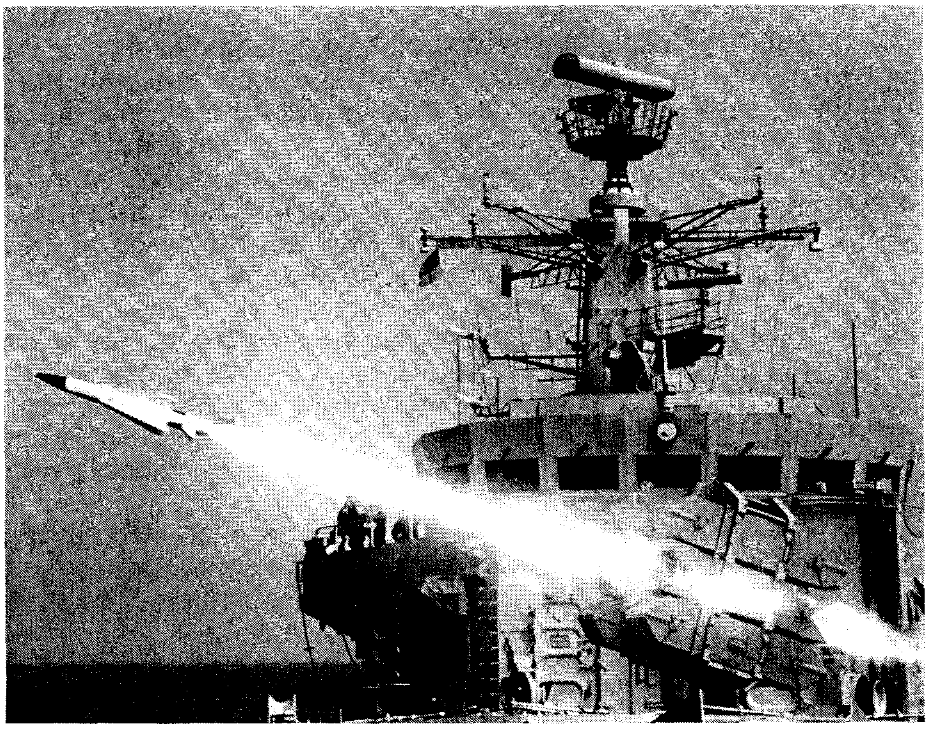

FIG. 1—THE FIRST GWS 25 MOD. 3 FIRING

SEAWOLF SITREP

BY

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Introduction

Currently there are 11 ships in the Fleet equipped with the GWS 25 Mod 0, Seawolf system. Five of these are Batch III LEANDERS and six are Type 22 frigates. Another eight Type 22 frigates either are, or will be, fitted with the GWS 25 Mod 3 system. Vertical launch Seawolf (GWS 26 Mod 1) is planned to be installed in the early Type 23 frigates and the Auxiliary Oiler Replenishment (AOR) vessels. The three carriers and later Type 42 destroyers are due to be retrofitted with yet another variant, the lightweight GWS 26 Mod 2 system. Meanwhile, concept studies for the Seawolf variant of the future, GWS 27, have been completed. It can thus be seen that Seawolf systems are here with the Royal Navy today and will continue to be well into the next century. The aim of this article is not to describe Seawolf principles of operation or reveal performance data, but rather to present a brief overview of the status of these various weapon systems whilst highlighting a number of features that should be of interest to all naval engineers.

GWS 25 Mod 0

After extensive trials at Woomera, Aberporth and on board H.M.S. *Penelope*, the first production GWS 25 Mod 0 equipment was deployed in

H.M.S. *Broadsword* in 1978. The system consists of a sophisticated D-band surveillance radar (Type 967), an E/F-band radar (Type 968), Type 910 trackers, and manually loaded launchers capable of holding six conventionally launched Seawolf missiles. In the case of Type 22 frigates the system employs two trackers and two launchers (i.e. is 'double headed') whereas in the case of the Batch III LEANDER fit there is only one tracker and one launcher (i.e. 'single headed').

GWS 25 Mod 0 was designed to be a totally automatic weapon system, capable of forming tracks on incoming targets, assessing the closing velocity and crossing distance of the threat; performing the necessary Threat Evaluation and Weapon Allocation (TEWA) functions; alerting one or both 'heads' to the threat, computing the relevant engagement criteria; then launching, gathering and guiding a salvo of two missiles to a successful intercept. It is an indication of the capability of this system that a standard performance test involves the successful detection and tracking of 4·5 inch shells fired towards the Seawolf ship. During firing practices it has often been demonstrated how a Seawolf missile can destroy a shell. The threat, of course, is not 4·5 inch shells, it is large Soviet anti-ship missiles. However, with the advent of Stealth technology and various means of Radar Echoing Area (REA) reduction it is heartening to know that the Royal Navy has a weapon system capable of destroying threats with such a minute REA.

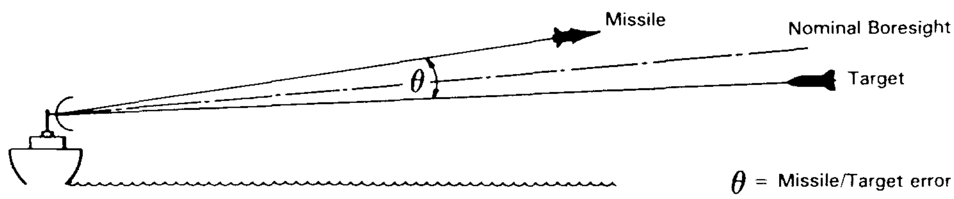

FIG. 2—ELECTRONIC DIFFERENTIAL ANGLE TRACKING

Electronic Angle Tracking. One of the interesting features of GWS 25 Mod 0 that gives the system its high degree of precision is a technique called electronic angle tracking. With a conventional conical scan tracker such as Types 903 and 904 the radar beam is centred around a boresight which is dependent on the physical positions of the feed horn and the antenna dish. Thus tracking a target across the sky is achieved by physically driving the antenna dish, and indeed for most systems this means driving the entire tracker mount. The Type 910 tracker employs an I-band radar with a monopulse feed which allows highly accurate tracking without requiring highly accurate mount follow. By using phase comparison techniques in the receiver circuits the angular offset from the nominal boresight can be electronically determined, thus enabling the Type 910 to track the beacon signals from two outgoing Seawolf missiles in addition to the conventional radar return from the incoming threat, all three signals having different angular displacements from the nominal boresight. FIG. 2 illustrates this technique. Comparing the angular error of the outgoing Seawolf with that of the threat gives a differential error which is used to produce guidance commands. This electronic differential tracking technique gives the quick response and extreme accuracy required for the Seawolf Command to Line of Sight (CLOS) guidance system.

For low level threats, however, the I-band radar of the Type 910 suffers from an effect called multipath. This effect, illustrated in FIG. 3, means that at low angles of sight the beamwidth of the I-band radar is such that the reflected image of the threat is also received. This problem, which gets worse in low sea states, is common throughout all radar systems working at low angles of sight over the sea and a number of techniques have been developed to attempt to overcome the effect. The Type 910 tracker incorporates a number of techniques in the I-band radar to reduce the problem; however for particularly low angles of sight it was found necessary to introduce a manually controlled television (TV) system. Thus for low level threats the normal mode of control in GWS 25 Mod 0 is for a leading seaman (missileman) Missile Controller sitting in the Operations Room to track the incoming threat manually. Having launched a Seawolf missile, the TV system automatically gathers and guides the Seawolf to an intercept at the aimer's crosswire. This mode, although limited to conditions of good visibility and dependent on the human factor, is most effective; indeed it was the GWS 25 Mod 0 system of H.M.S. *Brilliant* operating in TV mode that demonstrated in November 1983 that Exocet could be defeated.

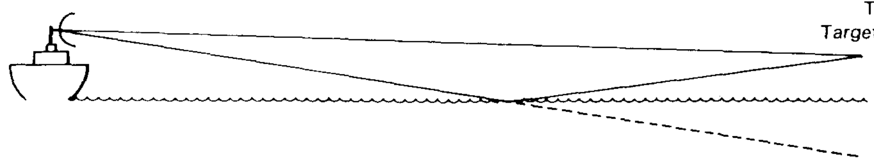

FIG. 3—MULTIPATH EFFECT AT LOW ANGLES OF SIGHT

Thermal Imaging. Nevertheless, despite the advantages of the TV system the limitations of good visibility can be significant. Over the past few years great advances have taken place in thermal imaging systems. New detectors based on Cadmium Mercury Telluride (CMT) sensors cooled to 77°K, can give reliable thermal detections at the ranges required for Seawolf systems. These detectors, which work in the far infra-red part of the spectrum (8–13 μm), are scanned at 50 Hz to give a 625 line output much like a domestic television. A whole family of CMT systems has been developed by the U.K. MOD under the Thermal Imaging Common Module (TICM) programme. TICM 2 modules are currently used in a number of Army surveillance equipments, Tornado aircraft and, under SR(Sea) 6568, will be retrofitted to GWS 25 Mod 0 systems to provide a significantly enhanced target tracking capability. It is intended that the modification will be fitted during AMPs.

Another technique to overcome the effects of multipath is to increase the radar frequency significantly. Increasing the transmitted frequency by a factor of four means that, for a given antenna aperture, the beamwidth will be quartered. A K-band radar with a beamwidth of, say 0·5°, will suffer far less from the multipath effects experienced by an I-band radar with a 2°–3° beamwidth. Studies completed in 1978 suggested that replacing the TV system of GWS 25 Mod 0 by a K-band radar would give a fully automatic, day and night, salvo performance in all weather conditions. At that time a suitable K-band radar had already been developed by Marconi to give a Blindfire capability to the Army's Rapier missile system. It was therefore proposed to replace the TV with a version of this radar, DN 181, to produce a Type 910M tracker. This tracker together with an improved surveillance radar, Type 967M, would have become GWS 25 Mod 1. A development model was produced and nine firings were completed at Aberporth in 1980 and 1981.

The Type 910M would have been a very heavy tracker. The basic Type 910 already weighed approximately 12 tonnes and a Type 910M would have been over 13 tonnes. Meanwhile, in parallel with Type 910M development, a lightweight alternative, which would have used the Dutch Signaal VM40 tracker, was being studied. This system, which incorporated both I and K-band radars, would have weighed approximately 6 tonnes and would subsequently have become GWS 25 Mod 2. Again, a series of development trials were conducted at Aberporth in 1979 culminating in three successful firings.

Whilst the VM40 proposal appeared most attractive superficially, there were however a number of areas with considerable technical risk, particularly relating to the data handling computer architecture and system interfaces. In the meantime, with Type 910M having been rejected on weight considerations, Marconi had reconsidered the requirement and offered a third alternative. This proposal was for a lightweight system based on their commercial 800 series I-band gunnery radars but including a K-band radar based on DN 181. This system, called 805 SW by Marconi, and Type 911 by the Royal Navy, was eventually selected after a thorough technical appraisal. GWS 25 Mod 3 was thus born.

GWS 25 Mod 3

Having made the decision in early 1982 to procure the Type 911 tracker, the deliveries to the first ship fit (H.M.S. *Brave*, Type 22-07) were due in September 1984. It is no mean achievement that Marconi, working under a very tight fixed price development and production contract, met this date. The GWS 25 Mod 3 system, which was originally intended for all Type 22 frigates, the early ones at retrofit and later ones on build, will now only be fitted to the eight new build ships. The earlier ships will receive the Type 967M surveillance improvements, but will retain the Type 910 trackers, albeit with the thermal imaging system. This will now become GWS 25 Mod 4.

The GWS 25 Mod 3 system consists of the surveillance sub-system with Type 967M radar, its Data Handling Outfit DBB and Type 968, two Type 911(1) trackers, two six-barrelled launchers and an outfit of conventionally launched Seawolf missiles. The Type 967M radar is an extremely sophisticated equipment which improves the capability of the original Type 967 radar. It is heavy and expensive, but it is arguably the best radar of its type anywhere in the world.

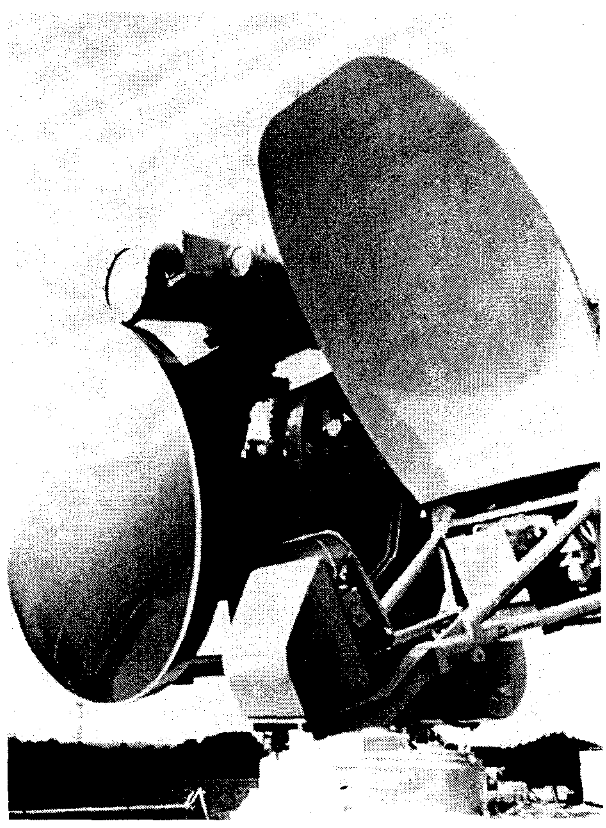

FIG. 4—TYPE 911 TRACKER

The Type 911(1) tracker (see FIGS. 4 and 5) consists of three main sub-systems: the I-band Radar A, the K-band Radar B, and the Data Handling Outfit DBE. Radar A, which is the controlling radar for all but the low angle of sight threats, has a conventional motor-driven tunable magnetron transmitter, receivers both above decks on the tracker mount and below decks in the tracker office, a mount servo control system, and a digital signal processor which is discussed in more detail later. Radar B, which is the controlling radar for low level threats, is heavily based on the Rapier Blindfire DN 181 equipment and uses an offset Cassegrain antenna with a steerable subreflector (see FIG. 5). Much of the Radar B equipment, including both

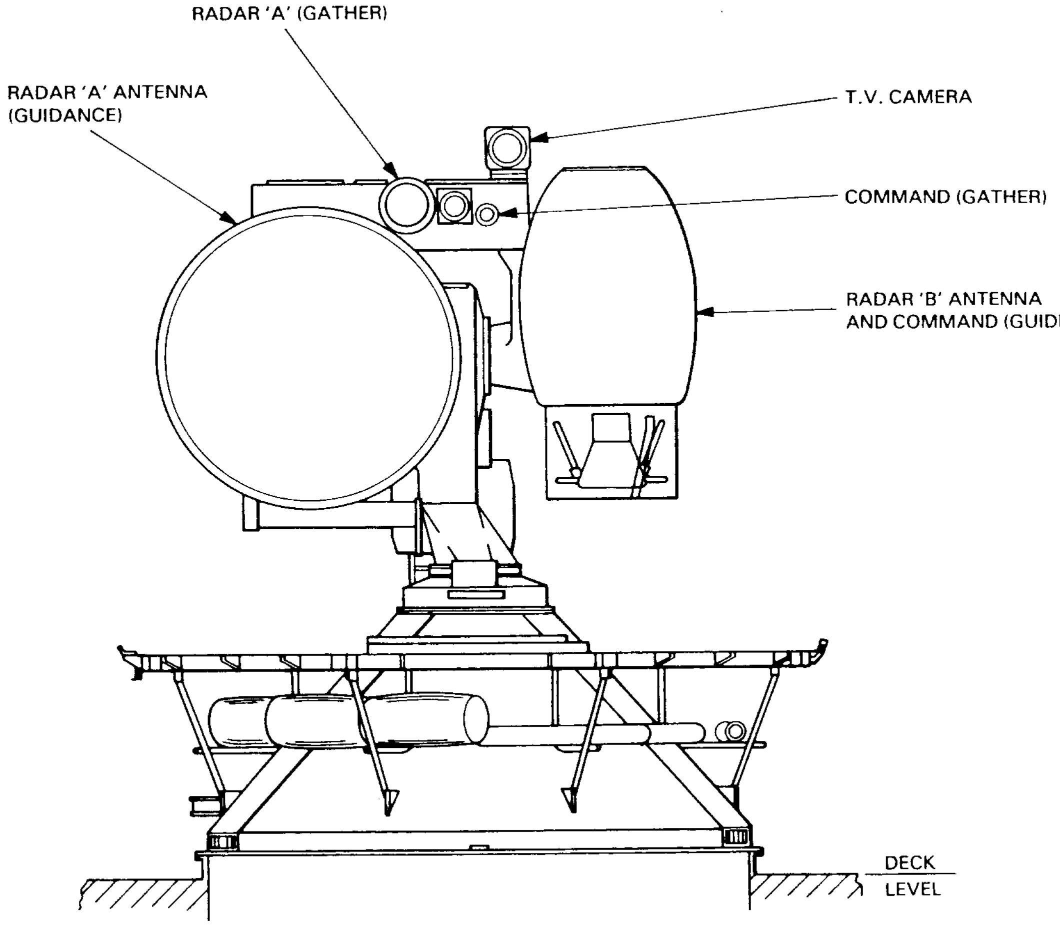

FIG. 5—TYPE 911 TRACKER

the transmitter and receiver, is located in one large Line Replaceable Unit (LRU) above decks which makes for some interesting maintainability problems. There are some lessons here about adopting other service equipment without fully taking into account the special requirements of the naval environment. The Data Handling Outfit DBE is based on a Ferranti FM1600E processor. The DBE software assembly consists of three largely independent programs, including Data Handling Control (DHC) which controls the tracker functions including modes of operation, and Data Handling Guidance (DHG) which computes the missile guidance commands; DBE also stores, but does not run, the Radar B signal processor software.

Having replaced the manual TV control facility of GWS 25 Mod 0 with the K-band Radar B it now becomes possible to give Seawolf systems the original capability requested, namely a fully automatic salvo capability against any target from high angles of sight down to sea skimmers at any time of the day or night.

The Type 911 tracker incorporates a number of novel features, available through the march of modern technology and necessary because of the strict requirement to reduce weight. One of these features is the replacement of the heavy hydraulic servo system of the Type 910 tracker by a lightweight electric motor. Another is the replacement of the conventional Doppler frequency filtering arrangements of the Type 910, with its heavy Travelling Wave Tube (TWT) transmitter, by a modern digital signal processor.

High Torque Electric Motors. The Type 910 tracker incorporated a hydraulic servo system which, in addition to being a maintainer's nightmare, was heavy and cumbersome. Modern electric motor technology has now advanced to the point where electric motors with extremely high power/weight ratios are available at low cost. The Type 911 tracker uses d.c. electric motors with samarium cobalt field magnets for both training and elevation drives. Samarium cobalt is a 'rare earth' substance which has a high magnetic density. These motors, approximately 15 cm in diameter, are run from an amplifier which provides a Pulse Width Modulated voltage of ± 150 V mean d.c. at up to ± 60 A. The motors, which also act as brakes and tachometers, are manufactured by the Inland Corporation of Radford, Virginia and are rated at 1700 watts with a peak torque of 84 Nm.

Radar A Signal Processor. Conventional pulse Doppler radars either require a large band of fixed frequency filters (as in Type 967) or a velocity tracking system whereby a voltage controlled oscillator is tuned for the relevant velocity (as in Type 910). A large bank of filters is heavy and cumbersome, but a velocity tracking system requires advance information on the target speed. In the case of Type 910 this velocity information normally comes from the Target Indication (TI) data. A modern method of achieving Doppler processing is to use digital techniques. Radar A uses these digital signal processing techniques to achieve the required clutter rejection characteristics.

One of the requirements for a digital filter is to work in the time domain rather than the frequency domain. It is therefore necessary to perform a Fourier transform on the received, digitized signals. Normally a discrete Fourier transform on N pulses would require $(N-1)^2$ multiplications; however there is a Fast Fourier Transform (FFT) algorithm available that reduces the number of multiplications to:

$$\frac{N \log_2 N}{2}$$

In the case of Radar A, N is 32, i.e. the signal processor uses a 32 pulse repetition interval FFT. The FFT algorithm, which is programmed in Firmware into a Programmable Read Only Memory (PROM), readily allows the Doppler shift to be determined for each range gate, thus building up a Range/Velocity map which can then be used by the target data extraction process. FIG. 6 illustrates a typical Range/Velocity map. In addition, the signal processor monitors the threshold noise, and thus establishes a Constant False Alarm Rate (CFAR), selects the optimum PRF to avoid blind velocities, and sends error signals to drive the EAT loops and the tracker servos. The pulse to pulse phase coherence necessary for the FFT process is performed as a rephasing operation within the digital processor (this negates the requirement for a Coherent Oscillator (COHO) as used in a conventional coherent-on-receive radar).

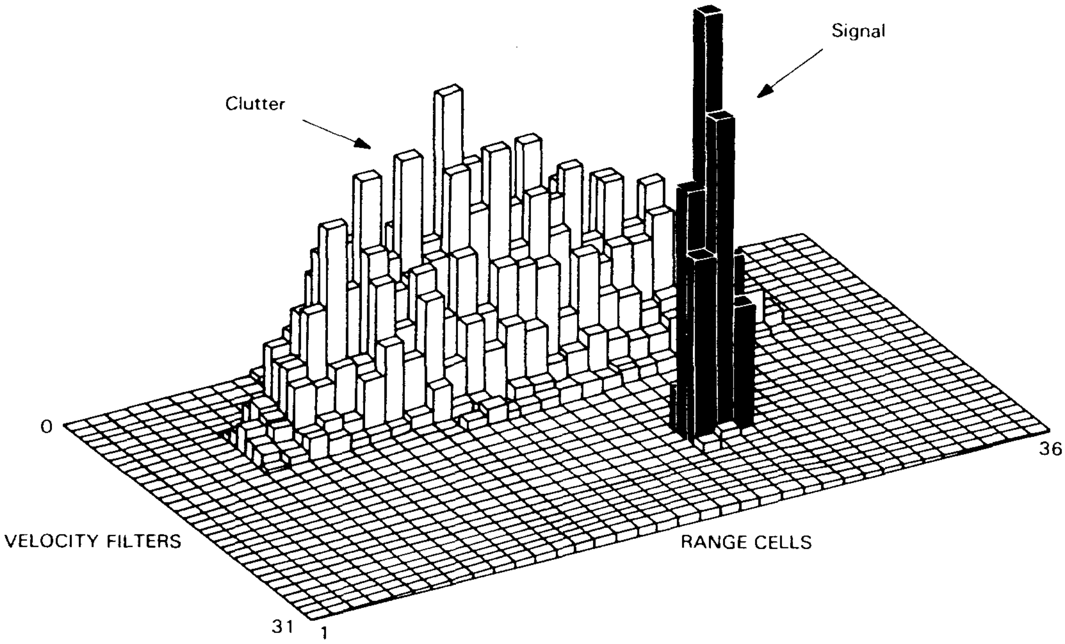

FIG. 6—SIGNAL PROCESSOR RANGE/VELOCITY MAP

The Radar A signal processor is a sophisticated, powerful device that is only made possible through the use of modern digital processing techniques. The processor performs all the calculations necessary for a 32 point FFT in less than 70 μs. Incidentally it is of note that one of the modifications from Type 967 to Type 967M is the replacement of the old Doppler filter bank sytem by a digital FFT signal processor, and that FFT processing is now used in a variety of systems including active and passive sonars and vibration analysis equipment.

GWS 26 Mod 1

In 1983 concept studies were completed for a Seawolf variant for the Type 23 frigate. The surveillance radar for this ship had already been determined as the Plessey Type 996 and the AIO system, CACS(4), was to make use of a new data highway concept—the Combat System Highway (CSH). The Seawolf system therefore had to make use of the Type 996 surveillance and interface, via the CSH, with CACS(4). A requirement for a lightweight system with a fully automatic capability led to the choice of Type 911 trackers; however the choice of launcher was not so obvious. Two alternatives were considered, one of which would have used the conventional six-barrelled launcher and would have become GWS 26 Mod 0, and the other, using vertically launched Seawolf missiles (see FIG. 7), which was referred to as GWS 26 Mod 1. After a thorough study, which included considerable tactical modelling, it was demonstrated how the requirement to manually reload the six-barrelled launcher could severely affect the survivability of a ship under stream attack. GWS 26 Mod 1 was therefore selected as the preferred option and the Vertical Launch Seawolf development programme began.

Although a version of Vertical Launch Seawolf had been studied under the SINNER programme in the mid-1960s it was soon determined that recent advances in Thrust Vector Control (TVC) technology could give a better solution to the missile turnover requirement than the original SINNER methods.

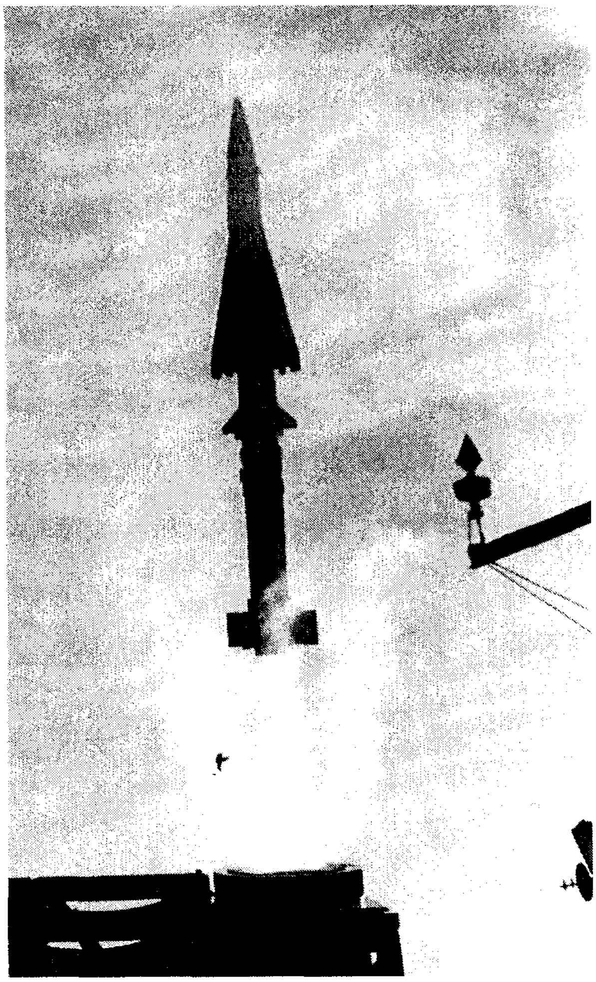

FIG. 7—VERTICAL LAUNCH SEAWOLF

Thrust Vector Control. The majority of naval missiles to date employ aero-dynamic control, i.e. they use fins much like an aircraft. However, if very rapid manoeuvrability is required the preferred alternative is to alter the direction of thrust from the propulsion motor. This technique is employed in a wide range of both tactical and strategic missiles, from the light anti-tank Swingfire missile right up to the largest inter-continental ballistic missiles. FIG. 8 shows a number of methods that could be used, from physically moving the nozzle to inserting some form of spoiler into the efflux.

One of the cheapest and most reliable means of TVC is the semaphore control system, see FIG. 8c. It is this system that has been adopted for the turnover phase of the Vertical Launch Seawolf missile. In the undeflected situation the four molybdenum spoilers do not impinge on the rocket efflux, whereas full activation of one or two of these spoilers would give an extremely agile response, enabling the vertically launched Seawolf missile to be turned over rapidly through more than 90° to intercept an incoming sea skimming threat at very close ranges. Naturally the safety aspects of the software control of this turnover system have been thoroughly studied!

Combat System Highway. As mentioned previously, one of the novel features of the ship system in the Type 23 frigate is the use of a data highway. This system, designed around triple redundant cabling, distributes all the weapon and sensor data.[1] All Type 23 weapon and sensor equipments, such as the Type 911(2) trackers, have standard Highway Terminal Units built in. These terminal units are intelligent, microprocessor-based subsystems which control all input/output functions with the DEF STAN 00-19 serial data highway. It should be noted that in GWS 26 systems the surveillance radar is not part of the Seawolf system (in GWS 25 systems the Type 967 or 967M is an integral part of the total package). All surveillance data from the Type 996 is therefore sent to the trackers via the Combat System Highway (CSH). Similarly all communication between forward and aft trackers, ship's gyros and the CACS(4) AIO, is via the CSH. A Shore Development Facility (SDF) has been established at ARE Portsdown to investigate the interface and software aspects of the Type 23 ship system, thus reducing the requirement for years of software proving in H.M.S. *Norfolk* (Type 23–01).

The development of the Vertical Launch Seawolf system necessitates the use of a dedicated trials platform moored in Cardigan Bay, some 10 km

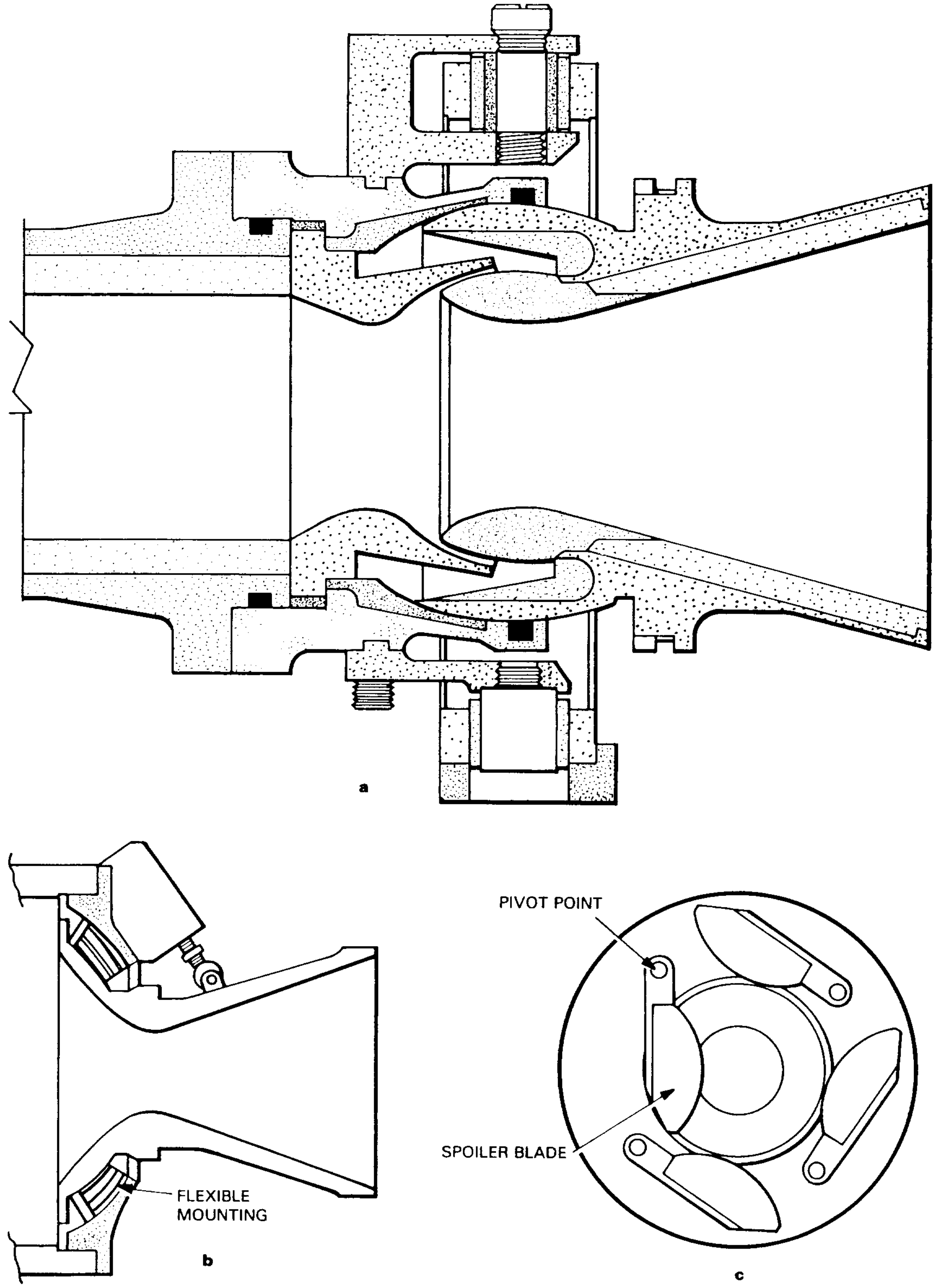

FIG. 8—THRUST VECTOR CONTROL TECHNIQUES
a BALL AND SOCKET NOZZLE
b FLEXIBLE NOZZLE
c SEMAPHORE SPOILERS

from the range at RAE Aberporth. This facility, the Trials Barge *Longbow*, which was modified from a North Sea oil rig support barge, has been used for the initial proving of the vertical launch concept, including proof of principle firings.

It is intended that the GWS 26 Mod 1, Vertical Launch Seawolf, system will also be fitted in the AOR ships of the FORT VICTORIA Class.

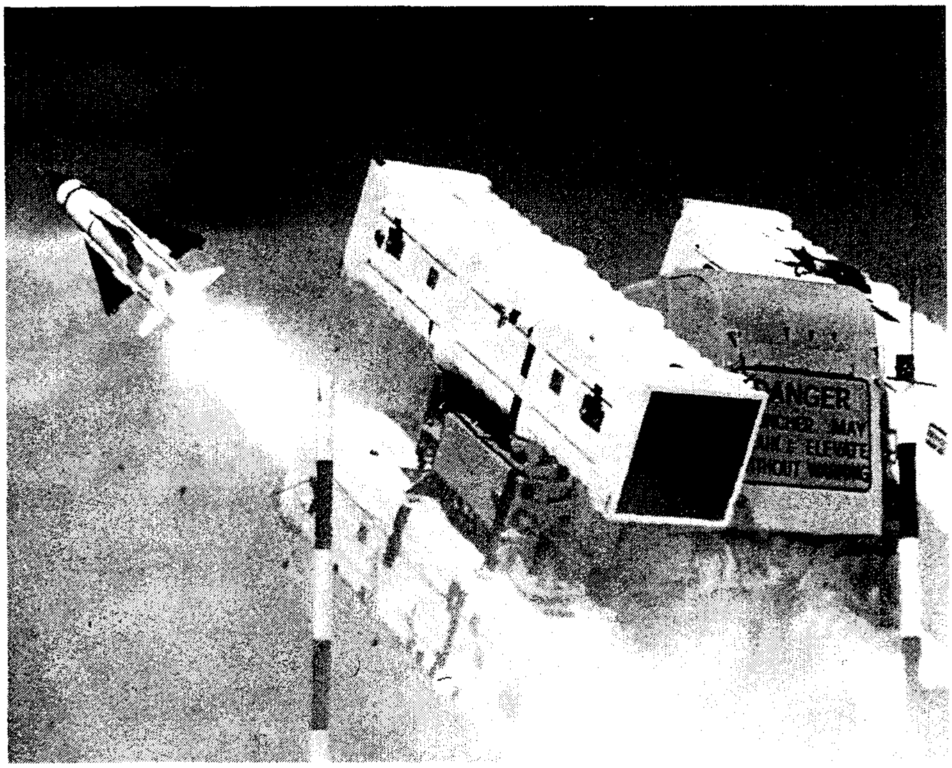

FIG. 9—GWS 26 MOD 2 FOUR-BARRELLED LAUNCHER

GWS 26 Mod 2

In addition to the systems being fitted to new construction ships it also became apparent, particularly during Operation Corporate, that other ships of the Fleet should receive the Seawolf Point Defence Missile System (PDMS). After extensive studying and debate it was determined that the later Type 42 destroyers and the three CVS should receive a Seawolf system. The requirement for these ships is for a system which will utilize the new replacement surveillance radar, Type 996, interface with the ADA Improvements proposals, and be lightweight. It soon became apparent that a GWS 26 Mod 1 Vertical Launch system was too sophisticated and too difficult a conversion for retrofit. In the meantime, however, a proposal to utilize a modified four-barrelled Seacat launcher had been studied and it was this system, to be called GWS 25 Mod 2, that was selected for the later Type 42 destroyers and the CVS. FIG. 9 shows the 'new' lightweight four-barrelled launcher. The Seawolf missiles are delivered and stowed in their containers, the containers then effectively form the launcher barrel.

GWS 27

The Seawolf variant of the future is GWS 27. Having introduced the vertical launch concept in GWS 26 Mod 1, ship survivability is no longer determined by missile availability as in the manually reloaded launchers of earlier conventional launch variants. Instead, the ability of the system to counter stream attacks is now limited by the trackers. Each tracker can only handle one target at a time. Although Seawolf systems do have a very rapid reaction time there is clearly a potential limitation when ships are presented with a number of closely spaced threats.

Phased Arrays. One solution to this limitation is to make use of a phased array radar system. The US Navy's Aegis system uses four phased array radars per ship for detection, track forming, and tracking of multiple targets. The system whilst being extremely effective, is also large, heavy, and expensive. An alternative technique, under consideration for GWS 27, is to utilize the phased array concept but to have only two small phased arrays replacing the existing Type 911 antennas. These phased arrays would still be steered by a tracker mount; thus the 90° sector available from such an array could be selected for the maximum threat. FIG. 10 shows a Marconi Radar proposal for such a system which would have considerable similarities below decks with the existing Type 911 tracker (see FIG. 11). This system, which could be made available for the later Type 23 frigates, could also be retrofitted into the earlier GWS 26 Mod 1 ships, i.e. early Type 23s and the AORs.

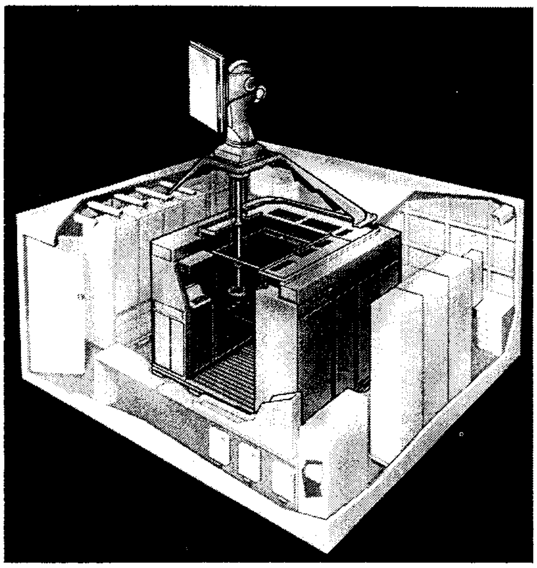

FIG. 10—PROPOSED GWS 27 TRACKER OFFICE

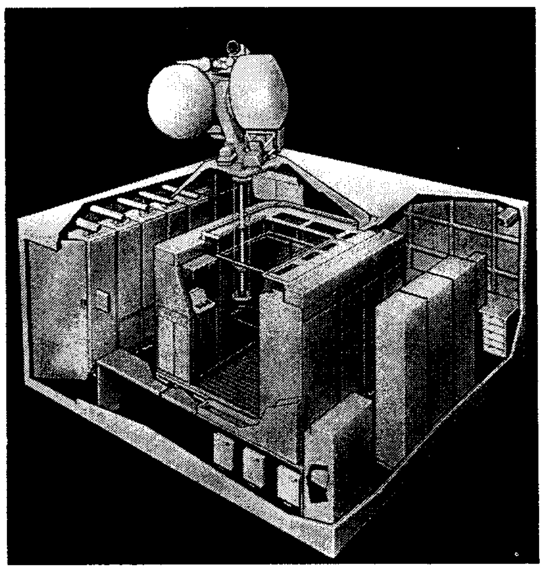

FIG. 11—TYPE 911 TRACKER OFFICE

Homing Heads. The Seawolf systems currently in service employ relatively simple missiles which use Command to Line of Sight guidance. The miss distance, and thus lethality, of these systems is reliant on the alignment accuracies of the ship system. Clearly for a given alignment error, the greater the range, the greater the miss distance. Modern advances in computing and electronic technology, however, now make it feasible to employ active or semi-active homing heads in relatively small and cheap missiles. Preliminary feasibility studies have shown that homing head technology has now advanced to the point where it may be possible to develop a homing Seawolf system.

This would allow improved lethality at greater ranges in addition to releasing the tracker from the current necessity of having to track the threat right up until intercept. The tracker could provide the initial guidance data for such a system; then, once the active homing head had locked on to the target, the tracker could be released for the next engagement.

The GWS 27 project is still at an early stage in its inception; indeed it may not even be approved. Nevertheless, it has been demonstrated that by capitalizing on the evolutionary process of Seawolf development, the Royal Navy can be given a Point Defence Missile System which will cope with the massively high threat levels of the Greenland/Iceland/U.K. (GIUK) gap at the turn of the century.

TABLE I—*Seawolf systems summary*

System	*Surveillance*	*Trackers*	*Launchers*	*Ship Fit*	*Remarks*
GWS 25 Mod 0	967, 968	910	6 BL	Type 22-01 to 06 LEANDER Batch III	
GWS 25 Mod 1	967M, 968	910M	6 BL		cancelled
GWS 25 Mod 2	967M, 968	VM40	6 BL		not endorsed
GWS 25 Mod 3	967M, 968	911(1)	6 BL	Type 22-07 to 14	also originally proposed for early Type 22s at retrofit
GWS 25 Mod 4	967M, 968	910	6 BL	early Type 22s at retrofit	
GWS 26 Mod 0	996(1)	911(2)	6 BL		not endorsed
GWS 26 Mod 1	996(1)	911(2)	VL	early Type 23s AOR	
GWS 26 Mod 2	996(3) 996(4)	911(3)	4 BL	later Type 42s CVS	
GWS 27	996?	?	VL	later Type 23s?	still under consideration

Conclusion

From this brief overview it can be seen that the current state of Seawolf encompasses everything from an in-service system (GWS 25 Mod 0), through a system just entering service (GWS 25 Mod 3) and systems under development (GWS 26 Mods 1 and 2) right through to the early pre-feasibility studies on GWS 27 (see TABLE I). Over 300 Seawolf firings have been completed, from the early experimental firings at Woomera right up to the current in-service firings of the Fleet. Seawolf has been developed from its early growing pains, with problems of reliability and logistic delay, to a system which will provide the Fleet with the defence it requires, both now and into the next century.

Reference

1. Anstee, R. J.: Combat system highway engineering in the Type 23; *Journal of Naval Engineering*, vol. 30, no. 1, pp. 85–105.