ADVANCES IN NAVAL GUN FIRE CONTROL

BY

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The Electrical Firing Wires are to be frequently tested by the Gunnery Officer . . . sending a trustworthy man to make the necessary corrections and place his hands to take the shock.

Admiralty Circular No. 135 of 27th February 1873

INTRODUCTION

As in all aspects of modern warfare, technology has made a huge impact in gun fire control—an impact in techniques, in size, in cost, in dependability. This article looks at these enormous changes by showing how the complex task of naval gunnery was solved in earlier systems, and examines how the electronic revolution of the 1970s and 1980s has been used in the latest system (GSA 8) which is being fitted in the later Type 22s and the Type 23 frigates.

This article is not the correct place to consider the merits and role of the naval gun, but it may be observed that inclusion of a medium calibre gun in these ships is a shift in policy. In the 1970s priority was given to missiles in the LEANDER conversions and design of the Batch I and Batch II Type 22 frigates. The Falklands war provided a reminder that naval bombardment is the most simple and economical method of providing artillery support to the Army's seaward flank and during amphibious operations. The provision of naval gunfire support to the Army is the prime role of the medium range gun, but an important secondary role is economical anti-ship warfare. This is particularly appropriate against minor war vessels and in peacetime police actions.

The Naval Fire Control Problem

There are three main elements to the overall task of hitting a target with a shell fired from a ship-mounted gun:

(a) Tracking

The position of the target is measured in relation to the ship's axes, and then transformed to a stabilized 3-dimensional set of Cartesian axes. Velocities are derived.

This requires the solution of lengthy equations in spherical trigonometry which, before the advent of digital computation, could only be approximated. Filtering is required to smooth the raw target data, and this filtering introduces time delays of a magnitude which depends inversely on tracking quality.

(b) Prediction

Prediction of the target's movement during the projectile's flight. This requires the solution of three simultaneous non-linear equations and compensation for processing delays.

Until recently the predictor assumed that the target would either maintain its angular and range rates; or hold its course and speed during the time of flight of the shell. This is a major source of error against fast targets.

(c) Gun Corrections

The gun has to be trained and elevated (in ship axes) so that the projectile will arrive at the future position of the target. This is done by adding corrections for effects on the projectile's trajectory. These correction and allowances include:

gravity drop

wind speed and direction (at various heights if available) air temperature, pressure and humidity

ship's latitude ship's course and speed among others, to compensate for Coriolis effect on the shell

earth curvature

ship geometry and fixed ship errors (e.g. misalignment between equipment seatings)

shell type

charge temperature

muzzle velocity.

These are clearly problems of some complexity. Today, we can be blasé about the solution; we have learnt the power of the digital computer even when applied to non-linear problems. We can perhaps better appreciate the power of modern technology by taking a short look at how the problem was solved when only analogue mechanisms were available, driven at first manually and later electrically. The effectiveness of this technology is well known. For instance, in heavy weather in the Denmark Strait, *Bismarck* sank *Hood* with her opening salvos at a range of 13 miles. In sea state 8 and snow showers in arctic twilight north of the North Cape of Norway, the Home Fleet engaged the battle cruiser *Scharnhorst*. In the opening action, the 8 inch cruiser *Norfolk* hit *Scharnhorst* with her 2nd or 3rd salvos at a range of 7 miles.

Director Fire Control

Integrated gunnery fire control systems had their origins in developments made around the turn of the century. Many of these developments resulted from the efforts of a few gunnery officers, dedicated to the improvement of the prevalent staid and outmoded gunnery practices of the late nineteenth century, which had progressed little since Trafalgar.

About the turn of the century a typical battleship's gun fire control consisted of a central command position mounted high in the superstructure. This housed the fire control instruments consisting mainly of a large clock, a Dumaresq for calculating deflection and range using plots, together with an optical rangefinder. Range and deflection were transmitted to each gun mounting and applied to the gun sights causing the gun layer's and trainer's telescope to move off the aim point. Elevating and training the gun to realign the local telescopes with the target applied the required tangent elevation and deflection for the range in use. The battle of Tsushima fought between the Russian and Japanese fleets in 1905 showed that effective long range gunfire was practicable providing fire control systems were improved, and that future sea battles could be fought at ranges in excess of British Fleet standards. The events at Tsushima helped stimulate further the need for the Royal Navy to improve its gunnery standards. One of the first improvements was the introduction of the Director Firing System whereby a master sight superseded the local gun sights. This was sited high to obtain a clear line of sight, above gun-smoke and spray. It directed all guns and fired them in salvos or broadsides.

The advantages of the director system were well illustrated in 1912 when H.M.S. *Thunderer* (FIG. 1), the first battleship fitted with a director system, was adjudged to have scored 60% hits at a range of 9000 yards during a competion firing with her sister ship, H.M.S. *Orion*. The latter's individually sighted four twin 13.5 inch gun turrets scored only 15% hits.



Fig. 1—H.M.S. 'Thunderer' in 1912. She was the first ship to be fitted with Director Fire Control—the cylindrical structure high on the foremast

Centralized Fire Control

The next significant change was the integration of fire control instruments into a Fire Control Table. The first of these, the Dreyer Table, was first installed in 1917. Between the World Wars, considerable improvements were made in fire control equipment. Hydraulics were extensively used to provide power for directors (e.g. FIG. 2) which were large armoured structures housing gyro-stabilized gun sights (which incidentally were also hydraulically powered), a multitude of fire control instruments and a crew of some eight to ten officers and men. Fire Control Tables, by now sited well below decks in the Transmitting Station, were first powered by pneumatics and then hydraulics and contained precision mechanical analogue devices for solving fire control problems in surface and bombardment modes.

The introduction of radar during World War 2 provided these quite sophisticated systems with an accurate all-weather, blindfire, ranging sensor, thus making first salvo straddle a reality, and greatly improving the timeconsuming practice of ranging shots and spotting which had been used by the Royal Navy for many years. The typical light cruiser of 10 000 tons armed with nine 6 inch guns could now deliver over a ton of high explosive per minute within an area similar in size to the Oval cricket ground from a range of 12 nautical miles.



Fig. 2—Secondary armament director of H.M.S. 'King George V'. Note the optical rangefinder

AA Prediction

Up until the end of World War 2, anti-aircraft fire control systems had developed along similar lines to the surface systems.

Predictors, (notably the Fuse Keeping Clock (FKC) fitted in destroyers and the High Angle Control System (HACS) in cruisers and above) were mechanical. They worked in conjunction with optical height-finding rangefinders (and later radar) and were goniographic systems in that prediction was based on the target aircraft's speed and course. The drawback was not only the complication of prediction in the third dimension, height, but that the greater deflection arising from the higher speeds of aircraft targets could not be predicted accurately by these manually driven mechanical systems. The 1950s saw the introduction of combined anti-aircraft and surface fire control systems based on electro-mechanical technology. The other significant innovation was that the AA predictor became a tachometric system, prediction being based on target rates. The surface predictor maintained the traditional mechanical computation of the previous decades. The progression of such fire control systems and predictors is shown in TABLE I.

Year	System name	Director Radar	AA Prediction	SU Prediction	Crew	Ships
Pre-war to 1972	US Mk 37	275	Electro-mechanical (part of system)		11	BATTLE Class H.M.S. <i>Eagle</i>
Early 1950s	MRS7	275	SEDC	AFCC 1**	10	War Emergency Destroyers BATTLE Class
Mid-1950s to 1980	FPS 5	275	Flyplane system	AFCB 10	9	War Emergency Destroyers DARING Class Type 12 Type 81 Type 41
Late 1950s to present day	MRS3	903	MRS3	AFCB 11	5	Leander Class Rothesay Class Daring Class Tiger Class
Early 1960s	MRS8	CRBFD 262	Electro-mechanical		-4	H.M.S. <i>Belfast</i> Daring Class
1960s	US Mk 63	Mk 63	Electro- mechanical	NIL		H.M.S. Victorious

 TABLE I—AA Fire Control Systems and Predictors before the introduction of digital prediction

Introduction of Digital Prediction

Digital computation became available for gunfire control in the 1960s and early 1970s, and was used in Gun System Automation 1 and 4 (GSA 1 and 4). The benefit was partly in accuracy but principally in the ease with which consistent performance could be maintained through the life of the equipment, repeated tuning and alignment of analogue servos becoming a thing of the past. Training, maintenance and other support costs reduced very notably. With GSA 1, data processing was centralized with that for AIO and other weapon control tasks.

However, time-sharing on a central main-frame computer brought unexpected problems largely associated with this lack of autonomy. Most notably, when gun control software was combined with that for other systems, it required extensive integration proving. This proving had to be done where the systems came together, namely in the ship; and ship time is expensive, hard to get, and subject to other priorities. It was also recognized that the new system was more vulnerable, both to action damage and equipment malfunction. These problems could only be solved by making systems more autonomous, and hence required more compact, less expensive processing. This became possible with the microprocessor revolution of the 1970s.

Today's Technology

There are two obvious technological distinctions between systems such as GSA 8, and earlier digital systems.

Firstly, as foreshadowed above, processing is highly distributed, and a separate computer is allocated to each specific task or closely associated group of tasks within the system. GSA 8 has seven Single Board Computers (SBCs) handling such functions as director servo-control, prediction, and operator controls. In addition nearly every panel electronic component (PEC) has its own microprocessor. By comparison, GSA 1 shared all its own functions and those of other weapons with the ADAWS 4 main frame. As outlined above, the benefits of the distributed approach are fully realized:

- (a) Software is easier to manipulate; hence proving, modification and control are greatly simplified.
- (b) System reaction time is reduced since computations can be run concurrently.
- (c) System vulnerability is reduced.

The second new feature is that digital techniques are now much more widespread. Earlier systems used digital methods principally only for computation, but now for example:

- (a) Inter-unit cabling is further reduced by the use of dedicated point-topoint serial data highways for internal communication and by the use of serial multiplexed highways for external communication. Each of these techniques require the use of only one lightweight cable (twisted pairs).
- (b) Position servo systems use digital techniques for implementation of the transfer function algorithms. This simplifies the use of more powerful shaping functions. It also removes the need for constant attention to drift and offset inherent in d.c. analogue systems.
- (c) Less immediately obvious, but equally beneficial, is the use of more processing capacity to automate operator workload and enable more functions (such as curved course prediction) to be tackled.

We will now examine these developments as they apply to GSA 8.

THE LATEST R.N. FIRE CONTROL SYSTEM-GSA 8

General Description

GSA 8 is being fitted in the later Type 22 and Type 23 frigates for control of the 4.5 inch Mk. 8 Gun. It is a variant of the British Aerospace Sea Archer 30 family of gun fire control systems developed for the late 1980s.

The General Purpose Electro Optical Director (GPEOD) is an integral part of the system and is controlled from the same console by the same operator. It is the principal tracker for GSA 8, although target data (range, bearing, and angle of sight) can be made available to GSA 8 on the Combat System Data Highway from a multiplicity of sources. It should be noted that GPEOD can transmit target data similarly to other weapon systems; Sea Wolf could, for instance, be controlled in an optical mode using GPEOD.

GPEOD is therefore the successor to a long line of gunnery directors, and will be described below with the rest of the system. It uses much technology that is completely new to the Royal Navy, and in particular is the first major fit of infra-red (IR) sensors. The system fitted in the Type 22s (GSA 8A) uses two GPEODs, mounted on the bridge roof giving overlapping arcs of view. The GSA 8B, in Type 23 (FIG. 3) has only one. Otherwise the two systems differ only in minor detail.



FIG. 3-GSA 8B SYSTEM IN TYPE 23

There is a significant degree of autonomy when compared with earlier systems. The Gun Control Interface Unit (or predictor) is the major computing element and is located in the gun bay. If either GPEOD or the Gun Control Console is damaged or unavailable, reversionary gun control is by means of the emergency fire control panel also located in the gun bay. The other noteworthy feature is the extensive use of data highways. Within the electronic cabinets a high bandwidth bus is used; between units the 1553B or RS422 data bus is used. The consequent reduction in cabling is substantial.

GPEOD (FIG. 4) presents a completely new capability to the ship's sensor suite; it complements radar by providing a passive tracking facility.

The Thermal Imager (TI) provides a video image derived from infra-red emissions in the 8-12 micron waveband. The picture quality is equally good at night since it is derived from the target's own heat emission. TV is provided so that the best source from the IR or visible waveband can be selected depending on the prevailing conditions. The operator is able to choose which video (TI or TV) is displayed on the monitor of his control console.

It is very difficult to jam Electro Optic (EO) sensors; any additional radiation from the target merely aids the imaging process. At these wavelengths, sidelobes are insignificant. Hence there is no equivalent of broad band radar jamming which obscures the target with 'snow'. Another particular value of GPEOD is that, being passive, it may be used in conditions of EM silence. Under jamming or EmCon, it may therefore be used in a surveillance mode—to investigate an ESM bearing or a threat sector for instance—using its pre-programmed search patterns. Further advantages of EO sensors are that they do not suffer from multi-path effects; and they provide discrimination between close-flying multiple targets, or between target and decoys. It has a subsidiary use for covert observation or blind pilotage (see Fig. 11).

The EO sensors are capable of detecting targets out to horizon ranges in favourable conditions. 'Favourable' conditions are of course dependent on the weather, and thus very variable; but it is expected that either the TI or the TV will be operable in winter in the North Atlantic for most of the time. IR radiation absorbtion depends on total (not relative) water content. Hence in cold conditions the TI may give better ranges than the TV but in hot humid conditions, much worse. It will not penetrate rain or thick fog, but can penetrate mist.



FIG. 4—GENERAL PURPOSE ELECTRO OPTICAL DIRECTOR, SHOWING TI, TV AND LASER SENSORS

Control of GPEOD is from the Gun Control Console below decks; it is the first RN Optical Director without an above decks operator. Lookouts are able to indicate targets by means of the visual sights when these are fitted. (Man has peripheral vision and an ability to detect moving targets against clutter, which is not yet superseded by the computer).

The director structure is designed to provide the requisite stability for the EO sensors—namely to provide a blur-free image under the most severe ship motion conditions. This demanding requirement conflicts with a need for low weight (the overall mass is less than 250 kg). Reduction in mass is achieved with a sophisticated fabrication in aluminium. The distinctive spherical cover functions principally to minimize unbalanced wind torques (a major source of servo error in unshielded systems). It also carries an outer r.f. shield and de-icing heaters.



Fig. 5—Frameless d.c. high torque servo drive motor. Stator with samarium cobalt magnets (left); rotor (right)



Fig. 6—GPEOD elevation drive before assembly of the brush gear. The Inductosyn rotor can be seen through the holes in the motor spider. Note that the main rotor is mounted directly on the trunnion

Positional control is by means of frameless d.c. motors (FIG. 5) driven from pulse-width modulated amplifiers. These latter control power to the motor rotor by switching a constant current at 20 kHz-the average power depending on the on/off ratio. They provide fine control, particularly at low speeds, without significant drift. A gear train from the motors is unnecessary since the samarium cobalt permanent magnets provide a high torque directly (5.5 newton metres per amp). The rotor can therefore be mounted directly on the elevating or training shaft, resulting in a very simple and elegant assembly (FIG. 6) with few moving parts. The absence of a gear train eliminates hysteresis and backlash as significant sources of servo error.



FIG. 7—PRINCIPLE OF THE INDUCTOSYN. THE RELATIVE ANGULAR POSITION IS DETERMINED FROM THE INDUCTIVELY COUPLED a.C. VOLTAGE APPEARING ACROSS THE AIRGAP

These advantages are completed by using Inductosyns (FIGS. 7 and 8) as the feedback sensors. These also require no gearing and are mounted directly on the shaft. They are a form of printed circuit resolver. The hairpin pattern of the stator, (which carries an a.c. at 10 kHz) is inductively coupled to a similar pattern on the rotor. Relative motion is measured by counting change in induced voltage in the rotor elements. The second track on the device has 1 less pitch, in order that absolute position may be determined by combining the outputs of the two tracks.



FIG. 8—GPEOD INDUCTOSYN ROTOR

Electronic Architecture

A major feature is the wide use of data highways and distributed processing. The use of serial multiplexed highways allows vast amounts of data to be passed over a twisted pair of cables—and the implementation is performed on a single chip. This leads to a substantial reduction in inter-cabling. For instance, the MRS 3 Director has 35 cables leading to it; GPEOD has four.

Internally a high bandwidth parallel bus is used. This eliminates the complex and bulky inter-PEC back wiring of earlier systems, and the benefits are threefold:

- (a) The obvious one of removing a source of unreliability.
- (b) Greatly simplifying the incorporation of system modifications.
- (c) Providing greater standardization between different systems using the same cabinets.

Otherwise, electronic architecture is conventional, with PECs to perform specific functions—computation, analogue/digital conversion, combat system highway interfacing, memory, etc. The computing element chosen is the Zilog Z8000 family of 16 bit microprocessor, a widely available and well supported commercial product manufactured to military standards. As will be described later, program is held in EPROM (Erasable Programmable Read Only Memory) and modifications will be issued as a hardware change with a new MOD strike number.

Engagement data, such as target co-ordinates, are held in battery backedup RAM (Random Access Memory). Ship variables are entered into RAM under a privileged entry procedure.

Seven Single Board Computers (FIG. 9) are used in GSA 8. Each has three times the power of computers used in the previous generation.



FIG. 9-THE GSA 8 SINGLE BOARD COMPUTER (SBC)

Control

The principal feature of the Gun Control Console (FIG. 10) is the monitor tube for display of the EO sensor scene. Alphanumeric data in tote format can be superimposed, displayed alone, or shown separately on the secondary display. A joystick to control GPEOD in training and elevation, alphanumeric data input keys and variable function push buttons are provided. Functions such as gun and laser firing are protected by safety key switches. One-man control of a gun engagement is a demanding task, made possible by computer assistance. Drill procedures are programmed and the operator is led by prompts which present his available options. This minimizes the possiblity of error and eases the training task. It should be noted that readily recognizable English is used; there is no need to learn manual injections as is the case with AIO systems. Fixed engagement data will probably be entered once per watch when closed up.



FIG. 10-GUN CONTROL CONSOLE

Response to Target Indication from CACS is fully automatic, including selection of a suitable preset search pattern. When the target is seen in the field of view, the operator will manually position the tracking box over the target. He will then initiate automatic tracking (FIG. 11). This is a particular strength of the system, full use being made of the high angular resolution of EO images. Target video data is enhanced in real time and target shape may then be used to give accurate track through clutter, over confused backgrounds and to ignore decoys.

Once track has been initiated, the laser can commence firing to produce range data. The laser emits pulses which are powerful enough to cause permanent damage to the human eye. Hence peacetime transmission is subject to safety precautions as strict as those for the gun itself.

While track is being established and the tracking filters are settling to provide a smooth output for the gun to follow, the gun is prepared for action. Power is applied, the appropriate ammunition and fuzing is ordered, the gun is slewed to the expected firing bearing and hoists and gun are loaded. When the target is within effective range—as displayed on the tote and when the gun is shown to be ready on the gun flow line—the operator will fire the gun using the conventional foot push.

A frequent source of error in existing systems has been in relating military grid references of shore targets to the ship's position. Charts and maps seldom agree to the required accuracy. GSA 8 makes the correction automatically by reference to the Universal Transverse Mercator conversion routines. Positional uncertainties in survey data can be compensated by tracking a beacon shown on both chart and map.



FIG. 11—EO TRACKING IS EXACT

Summarizing therefore, it will be seen that the routine and drill operations of the traditional gun engagement have been comprehensively automated, thereby enabling the single operator (the Gun Controller) to conduct the operation effectively and without error.

Program and Software

It being very important that the practice of Electrical Firing be carried out upon one uniform system throughout the Fleet, my Lords Commissioners of the Admiralty are pleased to direct as follows. In future, the Electrical Firing Apparatus supplied is to be fitted under the immedate superintendance of the Commander of the Naval Torpedo School (timely information being afforded to the Captain of the *Excellent*) and the fittings so arranged are not to be subsequently altered without the sanction of their Lordships.

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We all recognize the problems our predecessors were experiencing in introducing and controlling modifications. The problem with software is particularly acute. However, the GSA 8 program is as held as Firmware, in hard semi-conductor memory, the EPROM (FIG. 12). The program has therefore more in common with hardware than conventional software such as paper tape or magnetic media. The programme cannot be erased or corrupted, is not lost during power failures, and needs no down-line loading devices such as tape readers. Quality control is absolute, as it can only be modified at the master facility and all copies of the same batch will be identified and cannot be illicitly modified.

The software has been designed using MASCOT methodology, a true modular implementation. Each module is controlled in real time by the



Fig. 12—One of the 8K byte EPROMs (bottom) used to hold the GSA 8 operational program. Also shown, for comparison, is the paper tape program of a 1970s autonomous fire control (Sapphire), with its core ($22K \times 12$ bit) memory

Mascot kernel, allowing either data or real time stimulation of activities. The majority of the software is programmed in Assembler to reduce inherent delays; otherwise lengthy interpolation or extrapolation techniques would be required. Where speed is unimportant PASCAL is used, notably in those areas where large amounts of data are processed, such as data reduction in the off-line performance analysis routines.



FIG. 13—DATA RECORDING AND ANALYSIS EQUIPMENT FOR GSA 8

Data Recording and Analysis

The Data Recording and Analysis Equipment (FIG. 13) provides facilities to:

- (a) Record target tracking and tote data on video tape.
- (b) Record system parameters in digital format on a Winchester disc.
- (c) Record operator actions.
- (d) Playback and analyse.

The equipment is menu-driven and enables immediate on board analysis without interfering with the operational readiness of the main equipment. For the first time, gun system effectiveness may be monitored without the delay inherent in shore analysis. It is not intended totally to eliminate shore analysis, since the requirement remains for staff supervision and comparison of performance of individual Fleet units.

THE FUTURE

Modern electronic technology has greatly simplified the task of naval fire control; it has made the equipment smaller, easier to operate and more robust, and provided better facilities. Experience shows that this trend can be expected to continue. The next generation of more powerful computers with wider adoption of digital interfacing methods will enable more data to be processed, assessed and transmitted. This will enable not only gun fire control systems, but also the ship's entire weapon suite to respond more effectively and rapidly.

It is also expected that means will be found to accomplish the task more accurately, in particular increasing the probability of first round hit. The residual errors in a modern gun fire control system are:

- (a) Ballistic dispersion, i.e. variation in the shell trajectory from round to round caused by manufacturing tolerances, atmospheric effects, charge temperature variations, etc.
- (b) Static and dynamic misalignment, i.e. errors and tolerances in static alignment while the ship is alongside, and variable errors caused by ship flexure when at sea.
- (c) Heave, sway and surge. Only rotation about the three axes (i.e. stabilization) is compensated in current systems. Heave (vertical) is the predominant error source in extreme conditions, particularly with flat trajectories.
- (d) Unpredictable target manoeuvre.

Shell dispersion can be reduced—at a cost—by tighter control of manufacture. Methods to eliminate the errors due to ship flexure and motion are available. They require on-line measurement of relative motion by laser alignment techniques and of linear motion by accelerometers. The former requires a fibre optic cable to be run by two separate routes between gun and director to enable relative motion to be measured by path differences. A significant improvement in accuracy should be achievable.

Fixed bias errors may be eliminated by Closed Loop Spotting (CLS). This technique tracks the outgoing shells and compares the centroid of a group with target position. Corrections to the gun orders are then made automatically so that the next shell is fired in a corrected direction. CLS is unable to compensate for random effects (in particular, random dispersion) but it will compensate for long-term bias. 'Long term' means long in relation to the interval between shells; hence it will compensate for static and dynamic errors in (b) and (c) to an extent depending on rate of fire. Hence Closed Loop Spotting is used to best advantage in high rate of fire systems. It is employed in Close In Weapon Systems such as Phalanx and Goalkeeper.

None of the above approaches eliminates the effect of unpredictable target manoeuvre during the shell's time of flight. This is the most significant cause of error with high speed manoeuvring AA targets. Further, the above improvements are all subject to the law of diminishing returns—an exponential cost rise for further benefit. A correction to the shell's trajectory while in flight is a way of side-stepping these complications.

Gun Launched Guided Projectiles (GLGP) now exist. Copperhead is in service with the U.S. Army and the Dead Eye derivative will be in service shortly with the U.S. Navy. These are designed for use against surface targets, at ranges beyond the horizon, which can be designated by laser. Compared with SSGW, these weapons offer comparable accuracy at an order less cost per round and therefore complement the role of the gun against minor vessels. When the gun is already provided these weapons provide a most effective enhancement of capability at marginal extra cost. Accuracy is independent of range and they counter the effect of target manoeuvre. Work is proceeding in several companies to extend the principle to other calibres and to the AA role. BAe and OTO Melara, for instance, are developing a 76 mm AA GLGP which will provide kill probabilities similar to surface to air guided weapons at an order less cost. Work is also being done on smaller calibres.

Conclusion

Both the medium and small calibre gun has a firm future in the Royal Navy. The modern Gun Fire Control System has included all the usual benefits of the electronic revolution of the last decade. These are employed to give systems which are:

- more compact
- require less manpower
- operate more dependably, both in action and during the mission.

Developments particularly in the fields of data processing, digital interfacing methods and guided projectiles may be expected both to continue this trend and also to improve overall gun system lethality to a level comparable with guided weapons.

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