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NAVAL ENGINEERING ACHIEVEMENTS IN THE LIBERATION OF THE FALKLANDS

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Naval Engineering Achievements in the Liberation of the Falklands

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This lecture is reprinted with the permission of the Fellowship of Engineering who organized the meeting and the Ministry of Defence as a memorial to the 45 Engineer Officers, artificers and mechanics who lost their lives. It is also a valuable record of the remarkable engineering achievements by Royal Navy and civilian engineers.

Vice Admiral Sir Ted Horlick joined the Royal Navy from Bedford Modern School as an Engineering Cadet in 1943, qualifying at RNEC Keyham and RNC Greenwich. He served in a cruiser, carriers and small ships and at RNEC Manadon. This was followed by Admiralty service: in Special Projects; as Inspector of Gearing and Transmissions, and later as Assistant Director Submarines, responsible for nuclear and conventional propulsion.

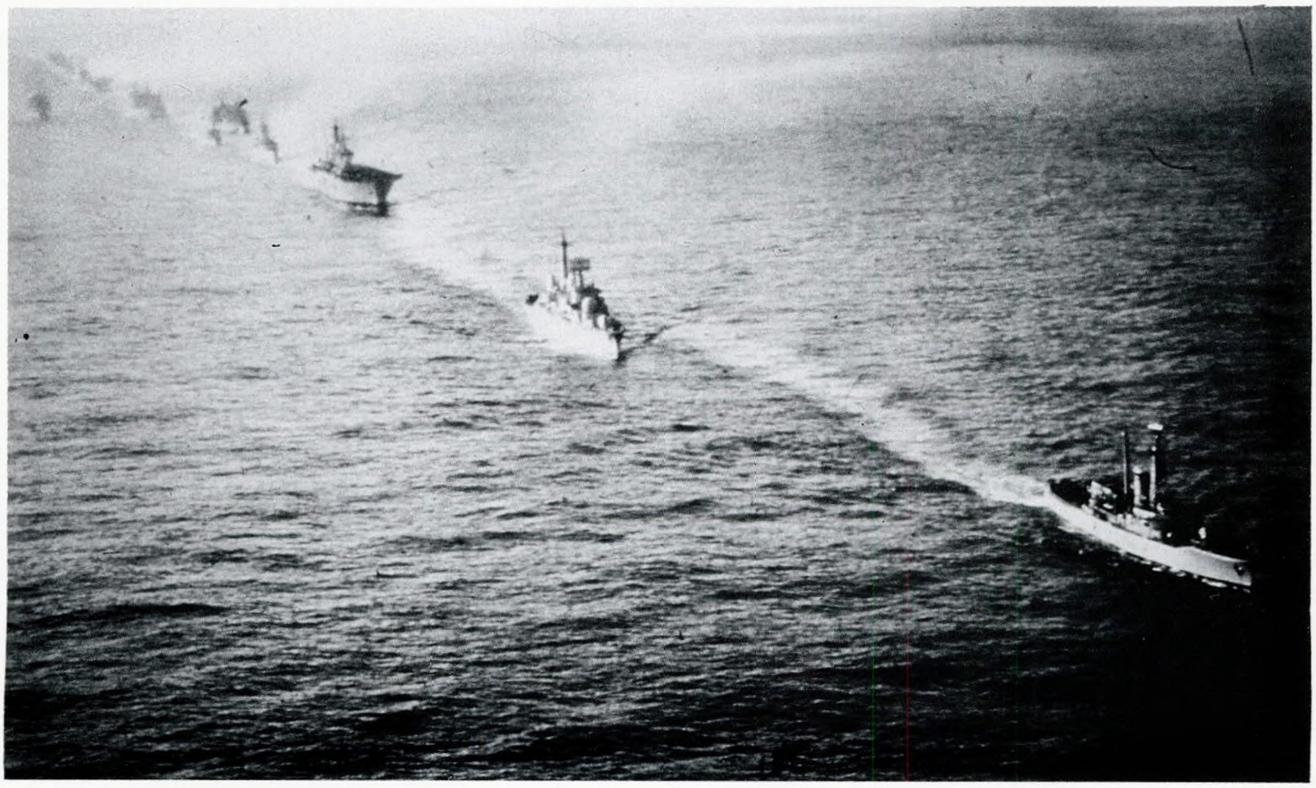
He became Fleet Marine Engineer Officer in 1973 and after the Royal College of Defence Studies was promoted Rear Admiral and Director of the Submarine Project Team in 1977. In 1979 he became Director General Ships as Vice Admiral and in 1981 also took up the duties of Chief Naval Engineer Officer and was knighted. Vice Admiral Horlick was elected to the Fellowship of Engineering in 1983 and retired from the Royal Navy in the same year.

INTRODUCTION

Lord Harding recently wrote: 'In connection with the Falklands victory, a sentence from one of Winston Churchill's wartime speeches has come to my mind; it goes—"All the great struggles in history have been won by superior willpower wresting victory in the face of odds or upon the narrowest of margins" . . . . it seemed to me that the greatest single factor in the Falklands campaign was that all ranks of all three Services had the will to take risks, the will to overcome obstacles, the will to face the final sacrifice—the will to decide and the will to win—the indomitable spirit of the warrior, fully supported by the same spirit in the Prime Minister, the Government and the public.'

This evening my subject is Naval Engineering and the men who practise it; people seldom in the spotlight but deeply involved in the Falklands campaign and people who, I believe, epitomized the spirit of Lord Harding's quote. They are a mix of professional and technician engineers, craftsmen and mechanics—uniformed and civilian—involved in the design, procurement, support, operation, repair and maintenance of naval ships, submarines, aircraft and their weapons.

The Task Force



They are employed variously by the Commander-in-Chief Fleet for operations and front-line maintenance and repair; by the Controller of the Navy for conceptual design, procurement and through-life design support; and by the Chief of Fleet Support for major maintenance and repair. The Chief of Fleet Support is also responsible for the Royal Fleet Auxiliary Service which of course has its own engineering branch.

Like other major shipowners and maritime organizations in the UK, the Royal Navy has found it necessary over the years to develop a comprehensive Engineering Corps, civilian and uniformed, often working side by side but always complementary to one another, to ensure that the Royal Navy is equipped with the best possible ships and aircraft for the money available. They also ensure that these platforms, with their associated equipments, are maintained, repaired and operated to the standards required by the Admiralty Board.

The Royal Navy trains most of its own people to carry out these tasks. Those in uniform are trained, academically and practically, from school-leaving age either at the Royal Naval Engineering College, Manadon, or the Artificers and Mechanics Training Establishments and of course at sea. The civilians are primarily trained through Navy Department training schemes involving Manadon, University College London, MOD apprentice schools and civilian technical colleges. A number also enter directly from equivalent training elsewhere.

Of course, the very complexities of the modern warship and fighting aircraft demand a much wider range of skills than does a merchant fleet, to enable the large amount of special-purpose equipment to be procured from industry and subsequently maintained.

The partnership with industry is fundamental and the Royal Navy could not exist without the design and manufacturing capability of British industry. Britain is fortunate in possessing a first-class defence industry producing a range of equipment, from ships and aircraft to gas turbines and missiles; and the engineers employed therein complete the technical partnership that keeps the Fleet at sea.

During the Falklands campaign operations took place in a hostile environment, often in appalling weather conditions (Fig. 1) with very high humidity, and thousands of miles from base support. Periods between maintenance were greatly extended and platforms and equipments were operated to, and even beyond, their design limits. Despite this the ships proved to be strong, reliable and able to operate continuously over extended periods; the weapon systems performed in some respects better than expected; and the aircraft showed themselves to be flexible, robust, reliable and effective: in fact, a real tribute to the designers, manufacturers, operators and maintainers.

It was sad, therefore, but perhaps not surprising, to read and hear so much ill-informed and indeed some downright mischievous criticism in the media, albeit there were and remain some inevitable shortcomings to remedy. For example, the Ship Department alone has an action grid of 250 items. I do not intend to dwell at great length on the criticisms but this is a good opportunity to set the record right in some important respects.

One saw and heard statements about 'firetrap ships' where 'aluminium burnt' and 'cables flared producing toxic fumes'; one heard also that HMS *Invincible* 'suffered from a host of mechanical problems'. The truth is rather different. The Type 42 destroyer, of which HMS *Sheffield* was the first of class, has a steel hull and superstructure and aluminium contributed in no way to her damage or loss.

The other RN ship in the loss of which fire played a major part was the smaller Type 21 frigate HMS *Ardent*. These ships do indeed have an aluminium superstructure but of course the aluminium did not burn and did not contribute to her loss. Nevertheless, one would obviously not use aluminium for major structural elements of a warship unless it was necessary and major modern RN warships are and will be of steel construction.

There is of course also a considerable quantity of inflammable material aboard any ship, by far the largest being the fuel and ammunition, followed by electrical cabling, deck and bulkhead linings and furnishings. I think it is obvious that there is no cable insulation practicable for warships which will not burn at some temperature and produce smoke of varying degrees of toxicity and there are 175 miles of cable in a destroyer. But there was little of the old PVC insulated cable in our ships, for the majority is insulated with silicone rubber or ethylene proplylene rubber and far less toxic when burnt.

Nevertheless, whilst the loss of HMS *Sheffield*, which understandably produced much comment, was indeed primarily due to smoke and fire, this was chiefly the product of unspent rocket fuel from the missile motor and burning oil from the ship's fuel tanks.

As to HMS *Invincible* (Fig. 2), far from being a mechanical disaster she broke all records in continuous carrier operation, spending no less than 166 days continuously at sea. I shall return to her in more detail later.

FIG. 1 South Atlantic weather

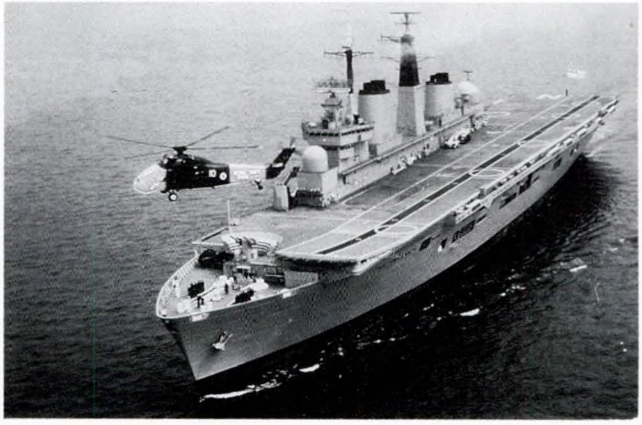


FIG. 2 HMS *Invincible* on peacetime duty

I mention only these few points to illustrate the very British tendency not only to gloss over British engineering achievements but even to denigrate them.

THE CAMPAIGN

The campaign began with the recognition that ships and aircraft were to operate in an unplanned scenario at a great distance from base support and for periods extending well beyond normal mission times. More—indeed many more—logistic support ships were required. To meet the fighting commitment, all warships were needed at sea as soon as possible: not only those already operational but also ships nearing completion in the shipyards, in dockyard refit or even those in reserve. Aircraft were obviously to play a vital part and every airframe which could be made operational was required. This was the first challenge.

At home and elsewhere, whilst operational ships were stored, ammunitioned and did as much outstanding maintenance as possible, it was vital effectively and rapidly to co-ordinate a multitude of engineering tasks in support of the Task Force. Time was at a premium and the decision-making process critical. Fortunately the organization, exercised annually in peacetime, proved more than equal to the task. The Bath Support Committee was activated to respond to the Naval Staff Advisory Group simultaneously set up in London. The Bath Committee, mainly professional engineers, under the chairmanship of a Captain, represented each major area of engineering and logistics. There was no elaborate management scheme but a small group of professional managers with deep experience of the day-to-day workings of the Navy and the MOD. They had close links with the Government machine and industry and authority to act. Delegation of responsibility was the key and very rapid decision-making was possible because the extensive administrative machine necessary to safeguard peacetime public expenditure was largely bypassed.

This is not to say that expenditure was uncontrolled or that a contractual free-for-all ensued. Far from it; the accounts were carefully recorded and contractual proprieties generally maintained. But the financial approval processes were greatly compressed against an urgent and well-defined series of requirements and financial authority was extensively delegated.

To prepare for a war with extended mission times, a very long logistic support line and no base repair facilities, the first engineering jobs were:

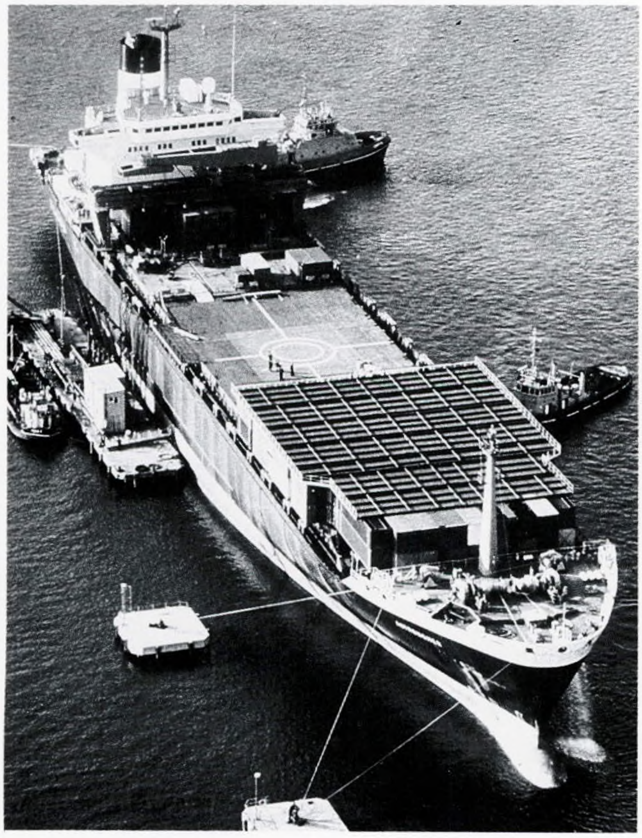
(a) To provide design advice to the operators of warships and aircraft to extend maintenance intervals safely;
(b) To procure and fit additional equipment to both warships and merchant ships;
(c) To ensure an adequate supply of spares and stores;
(d) To inspect merchant ships to be taken up from trade to assess their condition and suitability for a logistic task;
(e) The design of modifications to these ships for conversion in Royal Dockyards and the oversight of that work in commercial shipyards.

The merchant ships were needed for many duties: additional tankers, troop ships, hospital ships, aircraft ferries, solid stores support ships, repair ships, despatch ships and so on. Stability standards were a major concern. Department of Trade standards for merchant ships are considerably less stringent than those adopted for warships and it was necessary for the naval architects to assess stability in candidate merchant ships in case of damage. In some cases it was necessary to limit loads or fit additional watertight subdivisions. Much midnight oil was burnt in updating and working through the owners' calculations and the Ship Department's computer-aided design programmes were invaluable in speeding this work.

Helicopter pads and flight decks were designed and fitted. Figure 3, showing the hangars and flight deck built into MV *Astronomer*, is typical. Other changes were to add fresh water making plants, additional power generation, weapon and communication fits, replenishment-at-sea gear and additional fuel-carrying, accommodation and workshop facilities.

In all, 50 ships taken up from trade participated in the recovery of the Islands. Many more were examined and for various reasons discarded, and yet others have been taken up to support the garrison following the ceasefire.

FIG. 3 MV *Astronomer* after conversion to aircraft ferry



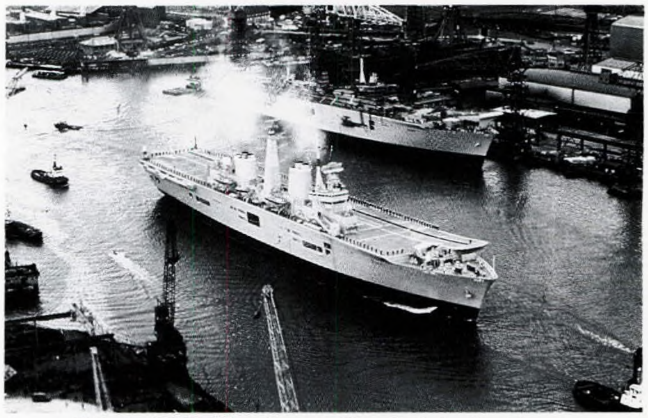


FIG. 4 HMS *Illustrious* sailing to join the Fleet; *HMS Ark Royal* in the background

Here I must pay a general tribute to the contribution of a host of engineers in industry and the merchant fleet. At all levels, from managing director to shop floor, they worked long hours with great enthusiasm. New ships like HMS *Illustrious* (Fig. 4) were brought forward ahead of time; weapon systems like Sea Skua were completed and introduced into service ahead of programme; contractors joined ships at sea to assist with trials and development or repair. The Merchant Navy engineers worked tirelessly with their ships employed on unusually heavy duties.

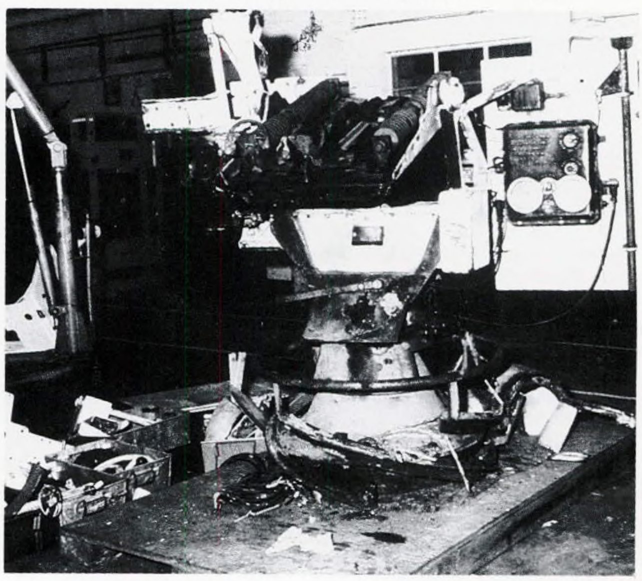
The majority of the merchant ships were converted in the Royal Dockyards to very short timescales along with extensive work on warships, already in refit or extended maintenance, and even on some already de-equipping for sale.

In Gibraltar, SS *Uganda* arrived from her Mediterranean cruise and in 2½ days was fitted with a helicopter pad, operating theatres and casualty gangways; with additional and extensive external lighting; with the livery required by the Geneva Convention, and fully stored as a hospital ship. Accommodation for 300 casualties and for the medical personnel to cover all major specialities was provided.

In Rosyth, five deep-sea trawlers, some still with fish in the holds, were converted to minesweepers; an ocean-going tug was modified for the South Atlantic and a diving ship was converted to act as a despatch vessel. Smaller naval ships were fitted with additional fuel and water tanks to extend greatly their normal range.

In Chatham, the reserve frigate squadron was commissioned. Some of the ships had been stripped of essential equipment and Dockyard

FIG. 5 An Oerlikon gun mounting prior to repair



resources were stretched to provide serviceable guns like the Oerlikon (Fig. 5), assembled from scrap. Guns, rocket launchers, ammunition lockers, mooring buoys, steel slings, scrambling nets and 34 miles of heavy manilla rope were manufactured and fitted in a matter of days.

In Portsmouth, HMS *Intrepid* had paid off towards reserve and an uncertain future. The engineer officer was called back from leave in the USA. Her equipment was restored and she was quickly recommissioned. Survey ships were converted to hospital ships. HMS *Hermes* was in an extended maintenance period with a large dockyard work package. Within 72 hours she sailed.

The merchant ships were now queueing up. Portsmouth's conversion of 19 ships ranged from fitting tankers with replenishment-at-sea gear and naval communications, to fitting out the 13 000 ton ferry *Norland* as a troop ship with 300 additional berths. As in other yards, work included the manufacture and fitting of helicopter pads, the installation of reverse osmosis water-making plants (one of the engineering successes of the campaign), floodlights, satellite navigation and communications, glide path indicators, safety equipment, replenishment-at-sea rigs, additional fuel tanks, electrical power supplies and normal defect rectification.

In Devonport, the larger merchant ships were converted, including the ill-fated container ship *Atlantic Conveyor* and her sister *Atlantic Causeway*, which were converted to aircraft ferries, with the installation of hangars, aircraft workshops and flight decks (Fig. 6). Containers were often used as part of the structure as well as to provide facilities. In Devonport alone 1000 extra bunks were made and installed together with appropriate galley, laundry and bathroom facilities; and over 600 tons of structural steel was used in large fabrications involving 130 000 m of welding.

Throughout this major effort in the dockyards, 24-hour working was maintained 7 days a week and a sense of dedication and loyalty shone through, reminiscent of 1939–45. It is worth recalling that the dockyards were then facing an extensive programme of closures and redundancy. All the more remarkable, then, were their achievements and their spirit.

The turnround time for the conversions averaged 4 days. Roving teams of engineers planned the work at sea en route to the dockyards so that work could start on arrival. That divers were still in the decompression chamber in *Stena Seaspread* when she arrived in Portsmouth is an indication of the speed of events.

Elsewhere in the UK, the same spirit prevailed. Navy Department engineers with supporting contractors formed effective teams with the shipbuilders; for instance, on Sunday morning 4 April my duty officer rang me to say that he had just set in hand at Southampton a £500 000 work package in SS *Canberra* (Fig. 7). He thought perhaps I ought to know!

A similar team fitted high-frequency satellite communications equipment (SCOT) in *QE2* in 5 days. This task, which included the installation of new deck sponsons and cooling systems, would carry a planning time of 5 weeks in peacetime. Such feats are not achieved merely by the acceleration of existing routines but require experience and engineering judgement on the spot, as well as the right mix of craft skills.

The Argentinians were thought to have sown a number of ground mines in shallow water off the assault beaches. An urgent project was set up at the Admiralty Underwater Weapons Establishment, Portland, to design, develop, make and test a novel acoustic/magnetic minesweeping system. The acoustic element was quickly tested but there was insufficient permanent magnet material. A quick design change to allow for an additional electromagnetic element solved the problem and in 10 days four sets were available for use with landing craft.

Naval Armament Depots throughout the country went on to shift working and more than doubled all previous records for the output of key weapons. I should perhaps explain that these Depots employ a strong team of resident technicians to service sophisticated missiles, torpedoes and munitions.

The Royal Fleet Auxiliary was fully mobilized and for the first time in history all RFA ships were made operational, some at very short notice. Twenty-three deployed for the operation (Fig. 8), leaving only four otherwise engaged, and despite this none were withdrawn from service through defects.

A similar flurry of activity occurred on the Air Engineering side. Aircraft were brought forward from deep maintenance and from reserve. The Naval Air Repair Organisation (NARO), consisting of a dozen naval officers and 1500 civilians, began an intensive 3 months of work. As well as undertaking the repair, overhaul and modification of helicopters for all three Services, the NARO is responsible, together with Rolls-Royce, for the overhaul of marine gas turbines which now power much of the Fleet. Working day and night, by the end of June the NARO had produced 91 helicopters of various types and many helicopter engines, marine gas turbines and other components. The RAF Maintenance Unit at St Athan brought forward in one week the six reserve Sea Harriers stored there and generated much valuable ground equipment.

FIG. 6 Conversion of MV *Atlantic Conveyor* to aircraft ferry

FIG. 7 TSS *Canberra* undergoing conversion to troopship

FIG. 8 RFA replenishment tanker *Olna* about to refuel a Task Force Ship

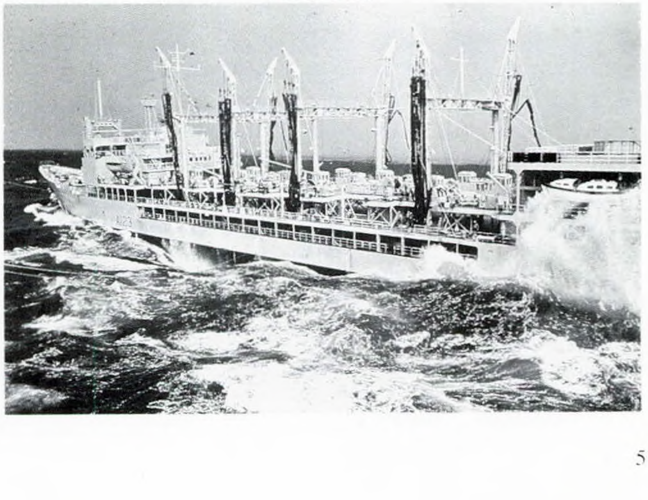


FIG. 9 Lynx aircraft armed with Sea Skua missile

In all, four new air squadrons were formed and 24 helicopters commissioned as new ships' flights. All were deployed south.

Industry, research establishments and service establishments combined to bring new weapons and equipments into service far in advance of their planned dates. The Lynx-launched Sea Skua missile, not then cleared for operational use, was a prime example (Fig. 9). Aircraft were modified and the missiles tested and deployed at the rush and it was very satisfying subsequently to observe their success against surface shipping, despite a bare minimum of training for maintenance teams. Out of eight missiles fired, eight hits were achieved. Need one say more?

For the Sea Harrier, modified weapon systems software for Sidewinder was written, flight tested and released for service and a test programme of air-to-air missile firings planned and completed in the space of a week; it contributed greatly to the success of the air battle.

Bright ideas for new equipments arrived from all quarters. For example, a thermal imager camera mounted in a 1 m diameter sphere was to be installed in a Lynx. An interface plate to mount the sphere gimbal was designed and made at Fleetlands Aircraft Repair Yard. The equipment console, containing power supply, tape recorders, TV monitors and joystick controllers, was positioned so that the observer could operate the device from his normal seat. The project was started on Maundy Thursday, first flew on Easter Monday and the aircraft returned to service the following day. Support equipment and spares were assembled and a technician trained. Within one week from project commencement the newly equipped aircraft, support and crew were deployed.

Similarly, at RAE Farnborough a small naval team, assisted by establishment staff, designed, made and proved a podded airborne radio relay station for the Wessex 5. Four complete units together with servicing documentation and test equipment were delivered 2½ weeks after being given the job.

It was vital to maximize aircraft availability and minimize logistic supply and so special wartime servicing procedures were produced. They covered three levels of operation:

- Enhanced flying rates under conditions of no immediate threat. Here the intervals allowed in peacetime between servicing operations were extended.
- Operations in an immediate threat environment in which many desirable but not essential maintenance operations were deleted.
- Hot war in which only those operations essential to flight safety and the success of the mission were mandatory.

Maintenance-intensive items like engines and gearboxes were put on condition-monitoring and generous extensions of maintenance periodicity were granted and used without any case of catastrophic failure.

Further calculated risks were taken to enhance aircraft performance by extending operational envelopes. Typical concessions were to operate the Sea Harrier, Sea King, Lynx and Wessex at greater all-up weights. These were fully exploited, not least in recovering the SAS from South Georgia in heavy snow.

In the submarine flotilla, preparations also concentrated on bringing forward new systems. Sub Harpoon, the underwater-launched anti-ship missile system (Fig. 10), was brought into service well ahead of programme and deployed to the South Atlantic. Another submarine system for satellite communication had been under trial in one submarine for just a month. It was hastily transferred to a deploying submarine and proved most valuable, even though operators and maintainers had to learn on the job.

And so, after 4 weeks, the Fleet was in the South Atlantic, the logistic train was set up and the campaign under way. But still the pace at home continued. More merchant ships were taken up from trade and reinforcement warships were fitted with additional facilities as operational experience dictated.

In the Fleet, the Royal Fleet Auxiliary and the ships taken up from trade, the engineers were under pressure. Not since the outbreak of World War II had ships undergone such heavy usage; and the comparison of 1939 and 1982 shown in Fig. 11 speaks for itself.

It is a source of some pride that, even after very heavy peacetime usage, the standards of design, maintenance and training in the fleet ensured a level of availability higher than ever before. No ship was withdrawn for defects other than battle damage. Even the First Sea Lord was impelled to say that the rigorous maintenance routines he had found so irksome when he, as C-in-C Fleet, was the operator, were more than justified by the results achieved.

Even so it would clearly not have been possible to mount the operation without the ships taken up from trade and I hope we can assume that in the future the British merchant fleet will still exist to be called upon!

It was clear to everyone at sea that, with UK support 8000 miles away, salvation lay closer to home. Improvisation and ingenuity were the order of the day. Machinery in the Fleet is normally subject to maintenance routines based on running hours and is serviced at planned maintenance periods in harbour. Many of the ships in the first wave were already due for maintenance periods when they sailed. The passage to the Falklands alone used 500 running hours and, with no prospect of entering harbour until return to Britain, a new approach was necessary. Just as for the aircraft, wartime servicing procedures were initiated, drawing on the maintenance margins designed into the ships. Intervals were much extended, and desirable but not essential

FIG. 10 Sub-Harpoon launch

maintenance was deleted. Nevertheless, with an unknown length of deployment ahead it was obvious that some work normally only possible during base support periods was likely to be necessary at sea: for example, a change of the combustion end of the gas turbines in small ships! In 4 days a rig to do this was designed and two sets made and despatched south after proving tests in a ship. In the event they were not used during hostilities but subsequently several successful gas turbine changes were completed in frigates at sea.

Of course the big ships in the Task Force, with their larger complements, had much expertise on board. The Fleet took stock of its talent and formed up repair teams and experts to assist the smaller brethren. These mobile parties not only filled the gap before the heavy repair ship *Stena Seaspread* arrived but continued to provide both manpower and expertise to allow ships to repair themselves whilst still deployed in battle order.

In HMS *Brilliant*, cannon fire severed vital multicore power and control cables to the Seawolf system. The cores were only identifiable at the terminal ends but after 72 tedious hours with megger and AVO meter the ship's staff had identified the damaged cores, rigged jury runs with twin-core telephone cable and the system was again shooting down Argentine planes. In the same ships, damage to Exocet cabling was overcome by moving the whole command panel from the Ops Room and wiring it direct into the local Exocet power room.

Software shortcomings in ship weapon systems became apparent when enemy aircraft attacked at very low level. The problem was signalled to the Admiralty Surface Weapon Establishment at Portsmouth. Attacks were simulated at a Naval firing range and software changes optimized, signalled to the ships and patched into the fire control programme by the weapon engineers.

Ships' staffs, using the limited onboard workshop facilities, made mechanical parts for 4.5-in gun turrets. For instance, in one ship a gun 'gate cam' for the ammunition hoist was manufactured from solid.

On two occasions in different ships a domestic toaster provided a vital piece to keep an important equipment serviceable, the toaster element substituting as a radar set charging choke.

An electric motor with a defective commutator was turned into a communications jammer.

In the absence of filler rod for stainless steel welding, stainless steel cutlery was used successfully instead.

The facilities and manpower of the bigger ships were especially valuable after action damage. Heavy machine shop and welding capacity was provided from *Invincible* to patch up *Glasgow* after extensive damage from an unexploded bomb which passed through the after engine room. Major temporary repairs were made to structures, pipework and cabling. The Tyne gas turbine air ducting was rebuilt successfully in plywood. Both *Fearless* and *Intrepid* rendered similar aid to *Argonaut* and other ships.

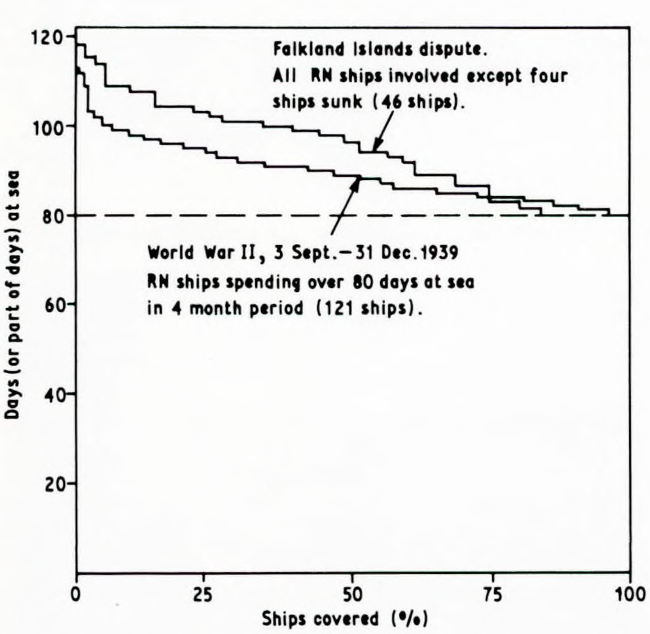


FIG. 11 RN Ship usage: comparison of first 4 months of World War II and Falkland Islands dispute

With no harbour at Ascension and the use of South Africa prohibited, a maintenance and repair ship became an urgent requirement. Unfortunately the Navy's last heavy repair ship HMS *Triumph* had been mothballed in the early 1970s and, as recently as 1981, towed away to the breaker's yard. An oil rig support ship *Stena Seaspread* filled this role, to be followed later by her sister ship *Stena Inspector*. Additional workshop facilities were installed and, as well as the usual extras, a large mobile road crane was secured on deck together with additional generators to supply power to ships and submarines alongside. The ship sailed within 6 days of charter with a party of 120 naval engineer officers and technicians headed by an Engineer Captain. This team played a key role in repairing damaged ships and since the ceasefire has been a repair base both for ships and for Army units engaged in clearing up and repair work ashore. The ship's ability to act as a floating jetty by using her dynamic positioning gear has been invaluable to the warships.

As you know, HM Ships *Sheffield*, *Coventry*, *Ardent* and *Antelope* were lost. The engineers fought hard to save their ships (and indeed had the weather been less severe the *Sheffield* might well have been towed home) but they were eventually overwhelmed by the extent of the damage. Less publicized is the fact that *Glasgow*, *Antrim*, *Argonaut*, *Glamorgan* and *Plymouth* all suffered damage as a result of enemy attacks. *Stena Seaspread* helped repair all of these but made an outstanding contribution in the cases of HM Ships *Plymouth* and *Glamorgan*. The latter suffered a hit from a land-based Exocet. Despite casualties the ship's company extinguished the major fire and with the assistance of the repair ship made good much of the damage. 60% of the galley was made serviceable, a large hole in the deck plated over and major repairs carried out to the G6 gas turbines, diesel generators, auxiliary boilers, refrigeration plant and upper deck hydraulics. Essential rewiring was accomplished and the starboard Sea Cat missile system brought back into action, albeit only in an emergency mode devised by the ship's staff which allowed her to fire down the bearing of incoming raids. Although inaccurate, pilots aborted their attacks once the missiles were in the air.

Stena Seaspread's Naval divers achieved a notable first by replacing a broken propeller blade on a frigate afloat. The broken blade was removed and, with no spare readily available, it was intended to replace it by a blade to be recovered by divers from one of the ships recently lost. In the event, a spare became available and this unusual defect was repaired more conventionally.

HMS *Arrow*, in going alongside to assist *Sheffield* in heavy weather, suffered structural damage to her ship's side during the lengthy period whilst the ship's company was being transferred. This damage necessitated a temporary repair to stiffen up the structure in way of the buckling. Teams from HMS *Fearless* and *Stena Seaspread* attached a heavy steel lifting beam to the ship as a temporary stiffener, using huck bolts to ensure sufficient pull-up to be effective. The *Arrow* continued as part of the Task Force.

I have said little about our submarines. They are by nature covert. Suffice it to say that they operated throughout the campaign without logistic support of any kind: tribute enough to their quality and reliability. Their weapon systems' effectiveness, even with some new equipments deployed, was maintained at a very high level; and the submarine *Spartan* completed the longest ever submarine patrol by a Royal Naval submarine. She sailed from Devonport on the 14 January 1982 and after a 2½ month deployment, when due to return home for leave and maintenance, was ordered to the South Atlantic. She returned to the UK on 24 June, having spent 150 days at sea and only 12 in harbour.

Perhaps the outstanding performance though was that of HMS *Invincible*, on station for longer than any other ship. It was on the journey home—on the 155th day—that the record for continuous carrier operation set by the nuclear carrier USS *Dwight D. Eisenhower* was broken. Since commissioning in July 1980, *Invincible* has steamed 120 000 miles, 52 000 accumulated during 5 months in the South Atlantic.

The engineers onboard were involved in a repair of dockyard magnitude when, just after sailing from the UK, a knock was heard in the main gearbox, which is the most powerful marine reversing gearbox in the world. An astern hydraulic coupling was diagnosed as the culprit (Fig. 12). A spare coupling weighing 2½ tons and a manufacturers' engineer were flown to the ship.

The starboard shaft was locked on 7 April and, with the ship propelling on one shaft, ship's staff worked round the clock until on 15 April power was successfully restored. In deciding to tackle this major job in the key ship of the Task Force, the stakes were high but the diagnosis was accurate. The coupling indeed was faulty—the result of a manu-

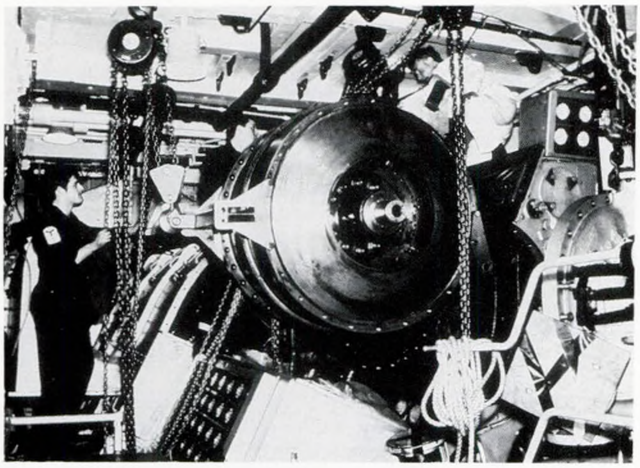


FIG. 12 Astern hydraulic coupling being removed

facturing defect—and thereafter, from an engineering point of view, operations were defect-free. Full power was used on many occasions and 578 Sea Harrier and 945 Sea King sorties flown.

On cessation of hostilities the ship withdrew from the Total Exclusion Zone to carry out self-maintenance and remained on station until August. A notable first was the change of an Olympus main engine which was well over its planned life between overhauls. A carried onboard spare was fitted and the job went very smoothly, as removal routes and associated equipment had been well designed and proven during building. Not the least contribution to the change of the 3 ton gas turbine was made by the bridge watchkeepers, who found a course to minimize ship movement during the complex lifting operation.

During hostilities the Fleet Air Arm (see Fig. 13) made a vital contribution to the recovery of the Falklands, deploying 171 Naval aircraft in 14 squadrons. ASW helicopters were employed around the clock in all weathers and commando helicopters conducted a phenomenal cross-deck logistics operation afloat and provided essential tactical mobility ashore. Lynx and Wasp helicopters demonstrated their capability in the anti-shipping role with marked success. The Harriers, without which there would have been no air cover for the Task Force, flew 2000 operational sorties and achieved 23 confirmed kills of enemy aircraft without loss in air-to-air combat. They also carried out successful operations against enemy shipping and shore targets.

On passage to the South Atlantic, whilst the ships were exercising their weapons and damage control, the squadrons prepared their aircrew and aircraft for war. Between the many training hours flown and the huge amount of airborne reshuffling of stores, ammunition and personnel around the Task Force, it was difficult for the maintainers to bring their aircraft to peak condition. But somehow major servicing was achieved, anti-corrosion treatment applied, aircraft painted in subdued wartime paint schemes and so on; although those aircraft travelling as deck cargo in STUFT ships suffered by comparison, particularly from corrosion in the marine environment.

By the time the Task Force arrived in the Total Exclusion Zone, maintainers were growing used to the punishing round-the-clock routine of 8 hours on watch and 8 off to support the aircraft. With ships at action stations frequently throughout the day there was little rest, whilst the cold and often rough weather added to the difficulty and danger of servicing and rearming aircraft.

Small ships' flights had to service their aircraft and change weapon loads on wet, slippery, moving decks, hands numb with cold and often in the dark, when the only lighting permitted was a dim glow from a red filtered torch. A grim picture, yet the flying rates were maintained and no aircraft was lost due to maintenance error. At one stage, three Lynx aircraft at sea in the San Carlos area were badly damaged (Fig. 14); one by bombs, one by fire and the third by shrapnel. The maintainers of the frigate *Broadsword*, aided by the roving engineer officer of their parent squadron, were quickly at work and within a matter of days succeeded in recovering two good aircraft out of the three wrecks. Another flight felt they needed a machine gun in their aircraft. Although there was a modification to fit one, neither the information nor the equipment was available so they designed, made, fitted and flew their own installation, consisting of the gun bolted to an upturned office swivel chair, anchored in the cabin doorway. It worked.

With relative humidity at 100% for long periods, everything was dripping wet. On board the carriers, aircraft were on deck for days at a time. Plugs and sockets were dismantled, dried, reconnected and in some cases sealed with aerosol plastic skin acquired from the sick bay, household clingfilm was used over cockpit instruments and control panels with much success and common bathroom sealant was extruded into joints. Electronic black boxes were dried out in galley ovens with the bonus that the chefs felt they had played their part in keeping aircraft serviceable.

Flying rates were intense. In one month, a nine-aircraft Sea King squadron averaged 162 hours per aircraft, compared with 30 to 40 hours in peacetime. In addition to their sortie rate, Sea Harriers were also required to spend many hours at alert on deck ready to launch and intercept incoming attacks. Indeed, in the 3 months of the campaign the equivalent of a year's peacetime flying was logged.

Valuable second-line support was provided by the workshops of the carriers and the assault ships, together with some of the ships taken up from trade. In addition, small teams of experts from the Mobile Aircraft Repair Transport and Salvage Unit were deployed among the ships and were particularly useful in repairing battle damage, using techniques and equipment recently developed by the Naval Air Technical Evaluation Centre at Lee-on-Solent. Damaged aircraft were often back in service in a matter of hours.

Some of the forward repair work went far beyond planned depth of maintenance and was remarkable in that it was done without manuals or drawings. The Sea Harrier Blue Fox radar, which had only recently entered service, was supported by a Ferranti engineer who volunteered to serve in HMS *Hermes*. Under his guidance naval ratings demonstrated remarkable diagnostic and repair skills. The continued serviceability of avionic systems became heavily dependent on these individuals, emphasizing the value of Fleet Air Arm training philosophy.

Ashore, 80 Sea King and Wessex were fundamental to the land forces' success (Fig. 15). Throughout the fighting the aircraft were flying from dawn till dusk. There was no covered maintenance area or second-line support. Aircraft were operated from dispersed Forward Operating Bases and maintenance, usually under control of a senior engineering rating, could only be performed during dusk or dawn twilight as no lights were permitted after dark. These men carried a heavy responsibility and displayed much initiative. For instance, a Sea King Mk 4 early in the campaign suffered a severely damaged tail cone in a sloping ground landing accident. Now the Sea King Mk 4 was a much valued work-horse and so the tail cone was stripped from an unserviceable Sea King Mk 2 and fitted to the Mk 4, which was soon operational again: normally very much a base workshop task. A recurrent problem was chafed and leaking pipes around the main rotor head. Without spares, they were fixed by cutting the pipe at the leak and rejoining the cut ends with connectors from the battle damage repair kits.

Before I conclude I thought you would be interested to hear the view of a non-engineer who played an important role in the recovery of the Falklands; one who has seen the engineering performance through impartial eyes. Captain Jeremy Black, the Captain of HMS *Invincible*, wished to be here tonight but unfortunately his ship is at sea. However, he has recorded some words for us.

FIG. 13 *HMS Hermes* with ASW Sea King and Sea Harrier aircraft

Remarks by Captain J. J. Black DSO, RN, Commanding Officer, HMS *Invincible*

I had the good fortune to command HMS *Invincible* for just over a year. She is a fine ship, a view held at every level on board; we are all very proud to serve in her. When I joined, little did we think that an event such as the Falklands would blow up within a few months but, it having done so, we were deeply impressed by the way the ship performed. It really was a magnificent performance and well beyond the primary role for which the ship was designed, which is to face a Russian threat in the North Eastern Atlantic.

The most striking features of her performance whilst we were away were redundancy, maintainability and reliability; reliability was of prime importance and here the design authorities and quality assurance world should take due credit. We were at sea and operating for 5½ months without pause and, with only a few days in harbour, we were at sea for 8 months during the year. On the way back, just 2 days out from the UK, we conducted a full power trial and, even after all that time and usage, the readings came up precisely as we would have wished.

We are propelled by four Olympus gas turbine engines which give a wonderful flexibility; indeed, they give the flexibility to be able to change an engine. This we did on two separate occasions and during that time I still had some 85% of the full speed available to me. This is ample for most operations so that here we have a flexibility totally unknown hitherto. It was the first time that engines had ever been changed at sea. Reliability was also manifest in the Weapons Electrical department, notably in the weapon systems and in command and control; and here it enabled me to conduct the anti-air warfare co-ordination for the entire force throughout the whole campaign. Indeed, not only during the fighting, but also throughout the time we were in the South Atlantic, we were the anti-air warfare control ship and we did that almost without pause. Occasionally overnight we put equipment down for maintenance and then turned over the duties to another ship for a matter of hours, but that was all.

Reliability also was the hallmark of the aircraft, particularly I think the Sea Harriers which were absolutely critical to our battle. However I would not want to underestimate the reliability of the Sea Kings; they flew the equivalent distance of a flight round the world in formation without the loss of a single aircraft. I served in a carrier back in 1967 with at least twice as many aircraft as we have in *Invincible* today, and I feel sure that we could not then have maintained the sortie rate that we did in the South Atlantic for so long a period. We were tempted to adopt wartime servicing schedules because we were very busy; but luckily, I think, we resisted that and I believe that is one of the reasons why we did not lose any aircraft; that's a button opinion but one which I think is worth consideration.

I would not wish to give the impression that there were no problems; of course there were. Then, the strength of the support came very much to the fore and that support was the Ministry of Defence and industry in the UK and the Royal Air Force and the Merchant Navy in getting the equipment down to us. To give one example: when we started that critical weekend at the beginning of April to pull our forces together, we had only six Blue Fox radars for the 20 Sea Harrier aircraft in the force. By the time we arrived and started fighting, we had 20 of those radars. About 24 hours before we entered the Total Exclusion Zone, a cooling condenser in the Seadart system broke. Now this condenser weighed a ton and from the time I signed that signal here on the bridge to the time the spare condenser parachuted alongside us into the water, the article had been moving at the equivalent speed of more than 100 miles an hour.

FIG. 15 Wessex aircraft disembarking troops

FIG. 14 Damaged Lynx aircraft onboard HMS *Broadsword*

Fortunately, I think, we have not been seduced by the charms of upkeep by exchange; at least not to the extent that the technical officers and ratings have become unable to make vital repairs. Indeed, there were daily examples of people making repairs to equipments for which they had little or no documentation but which helped us to keep going on the day. One example of the expertise and the ingenuity happened just after we sailed from Portsmouth and were some 3 or 4 hours out of the Dockyard, after that amazing send-off we had been given. Suddenly there were terrible noises from a coupling in the gearbox and we diagnosed that we would need to change it. Now the couplings weigh about 3 tons each and within a matter of hours, I think it was 48 hours, a coupling had been found and taken down to the far west to Culdrose; a Chinook helicopter had been deployed from Hampshire to Culdrose; the Chinook lifted the coupling and flew it out in fog over the sea. A Chinook has no radar and the pilot was not used to flying over the sea anyway, so he was guided down by a Sea King helicopter which has radar. He arrived down at the ship and made the first deck landing of his life; thereby we got ourselves a spare coupling and for the next 10 days, on passage through the Bay of Biscay during the flying operations and everything else, we changed that coupling and by Ascension we were on full power again. This I think was an amazing achievement.

Then, later in the play, *Glamorgan* was hit, you will recall, by an Exocet some 36 hours before the end of the fighting and many of the casualties were picked up by our helicopters and taken straight back to our sick bay. One of those was a Chief Petty Officer who had two broken legs, and the surgical staff on board put pins right through his legs. They then wanted to suspend his legs and they had no device for so doing. The Chief Medical Technician turned to the Air Engineering department. Within half an hour somebody there had devised and made a mechanism for hanging those pins from the deckhead in the sick bay and now I am happy to say that Chief Petty Officer is fully recovered and walking.

In conclusion, I would like to leave you with the thought that *Invincible* more than lived up to our expectations. She is a tribute to those who designed her and built her and, more widely than that, to British industry. I have only two equipments on board (and one of those is the Vulcan Phalanx gun system which has been fitted in the last 3 months) that are not made in Britain and I think the UK should take due credit for that; and I hope you, as taxpayers, are pleased with your investment.

CONCLUSION

I have tried to review the breadth of engineering ashore and afloat which supported the successful campaign to recover the Falklands. There were many lessons, few new but many relevant. To me, the prime lesson is that the age-old pressures of war at sea remain, however sophisticated the technology. In a weapon system so complex as a warship, with so many links in the chain, it is vital to maintain the complex balance between material quality, offensive and defensive armament, reliability, seakeeping, repairability, habitability, damage control, crew size and training and a host of other factors. Sad as I am at our losses, I can only welcome the way in which the operation has reminded us that, in war, the less glamorous qualities of our equipment are of vital importance.

In times of financial retreat, critical attention focuses not only on the initial quality of material but also on the extent of maintenance carried out on platforms and equipments. It was the maintenance margins built into our ships and aircraft in peacetime that enabled them to perform as they did—a factor I would not wish to see glossed over as memory fades.

We must not forget the training which taught the skills to our engineers, the procurement system which ensured the quality and reliability of our equipment and the management which formulated and directed policy from which our capability stems. The events I have briefly described were those of the moment, powerfully driven by the common sense of purpose of a nation going to war. Underlying the engineering achievement of this campaign is the permanent base constructed through years of painstaking effort, which gave us the quality of the men and of the material which is so vital in the ultimate test of war.

Finally, what of the men? I can say without hesitation that our engineers, artificers and mechanics were magnificent. Trained to high levels of professional skill, diagnostic ability and judgement, allied to skills of hand, management expertise and leadership, they were not found wanting. The Falklands campaign was no picnic and the performance of our men at all levels demonstrated just how effective investment in good training can be.

I am proud to report that among the most deserved honours were the following awarded to engineers, service and civilian, ashore and afloat: 64 for meritorious service ranging from the CBE to BEM and 41 for gallantry—the DSC and George Medal to Mention in Despatches.

It is sad that seven of these awards were posthumous and that in all 45 lost their lives. I can think of no better forum in which to salute them.

Finally, I believe I can report that engineering in the Royal Navy and its civilian support is in good shape. Albeit I am in no way complacent—who would be in view of the inevitable and continuing financial and political pressure on the Royal Navy? But I am confident that, come what may, there will always be a positive and innovative response to challenge.

Discussion

The discussion was opened by Lord Caldecote.

Professor F. D. Richardson: Would it be possible for Admiral Horlick to say a little more about the problems which are alleged to have arisen on account of aluminium alloy? Many worries have been raised and it would be interesting to hear an authoritative view.

Admiral Horlick: Aluminium did not, so far as we are aware, contribute specifically to the loss of any ship. I have to repeat, however, that for a warship one would, where possible, use steel for fairly obvious reasons. Over the years we have on the whole in our country tended more and more to use steel and exclude aluminium for what I believe are commonsense reasons; not every nation has followed our practice. I do not wish to be evasive but, for instance, one would not continue to use aluminium ladders in machinery spaces, one would use steel ladders and so on, unless one was very constrained to build a small ship to very tight standards of stability etc.

Mr J. Brass: I would like to ask whether the engines that were changed in the *Invincible* were actually carried on the ship all the time.

Admiral Horlick: We do in fact carry two spare gas turbine change units in the large carriers. In smaller ships they have to be brought in via one of the logistic vessels or by air.

Sir Kenneth Hutchinson: I was very impressed by what was said at the beginning about the danger of fire. On a visit to Portsmouth I was rather alarmed at the look of modern engine rooms as a deep pit with some very hot machinery at the bottom of it and some fairly volatile and combustible oil to be used as fuel compared with old ships with Bunker C oil and the steam turbine.

My question is, has consideration been given to the possible use of massive injections of liquid nitrogen to act as an immediate flame-suppressant and also as a coolant and to give an inert atmosphere, hopefully to create conditions under which men can get in and deal with the fire, because, as far as one could see, these fires were so violent that no man could get near them?

I received some information from BOC yesterday. For example, a free-standing pressure vessel, vacuum- and burlite-insulated and designed for maximum pressure of 200 lbf/in^2, weighing 16 tons empty and 43 tons full, measuring 22 ft high by 13 ft diameter (whether there is either room or the weight capacity in a modern ship for such a thing I do not know) could deliver a flow of liquid at almost any desired speed because the pressure in the tank would act as an injector. Such a tank full of liquid nitrogen would yield 800 000 ft^3 of gas. Whether that is a significant amount in relation to the various spaces to be inerted I do not know.

Admiral Horlick: Yes, that sort of method has been considered. First could I comment on your earlier remarks. Although you will perhaps not realize it, all our ships, with the exception of HMS *Hermes*, have been converted to burn NATO quality dieso fuel, so therefore both the gas turbine and steam ships are full of the same fuel. It is true that dieso is more easily ignited than the old-fashioned good-quality Admiralty bunker oil. I suspect, however, that with the modern crudes the volatile elements in some of the low-quality fuels are now becoming rather an important component. It is also perhaps worth saying that the ships' aircraft use aviation fuel (AVCAT) which is considerably less volatile than the RAF equivalent (AVTUR), for obvious reasons of safety on board. So we are moderately consistent in that respect.

I have no doubt that, where it is possible to use it, the best method of putting out machinery space fires is steam drench. But, of course, where there is no steam we look to the other methods. I believe that the ultimate method of putting out such a fire is by the use of large quantities of salt water with AFFF (aqueous film forming foam) or some equivalent but for specific areas we do certainly use inert gases; in weapon electronics compartments, in the gas turbine modules themselves and in the engine rooms of the gas turbine ships. We only use nitrogen in some of the submarines, where it is carried for another purpose and one can usefully use it for firefighting as well. We slightly favour halogens to nitrogen because they will operate successfully as fire extinguishers at a lower overpressure than nitrogen and, if people are involved, the people may survive rather better with halogen firefighting than nitrogen firefighting. That is why we use little nitrogen specifically but I think the general comment about inert gases is well taken.

One point I would like to make is that when a fire is caused by action damage it is very likely that there will be large hole in the ship connected to the fire. The inert gas therefore will not be as effective as if the fire were contained, as it would be, in most accidents in peacetime. And so, where there is no containment boundary, one would be very pleased to have the large quantities of salt water and AFFF. To sum up, inert gas is very much under consideration, very much used, and we obviously are using all lessons to try and formulate the best possible mix for the future, cost-effectively.

Mr E. H. Cooke-Yarborough: If you feel you cannot answer my question, I am sure we shall all understand. There has been quite a lot of comment in the Press about the effectiveness of countermeasures against Exocet and its guidance. Is there anything you would like to add to that?

Admiral Horlick: There is something I would like to add but I do not believe I can. I will turn to Admiral Croydon but it is very difficult to discuss this in public.

Admiral Croydon: I agree, I could also say a word or two but it might be rather misleading and the complete answer, which for obvious reasons I am unable to give, is the only one that is justified.

Admiral Staveley: If I may add to that, it so happens that I was this afternoon reading the Argentinian Navy News and it is very interesting because it describes the Argentinian Commanding Officer of the Super Etendard Squadron's attacks on our ships. From that we know, if you accept that it is correct as I do, that they fired five missiles. I know that only one of them hit the target at which it was aimed and that was the *Sheffield*. They remain utterly convinced even today in this publication, which is December's issue, that they hit the *Invincible*. Any of you gentlemen are extremely welcome to go and visit the

Invincible, except she happens to be mid-way across the Atlantic; now that does not give you a specific answer but it should tell you that some of our means are highly successful, although not all—for example in the case of *Sheffield*.

Mr Picot: On your missile control systems do you have redundant cables between the missile and the firing point so that if one cable is cut you can still work the missiles? Also, you mentioned repairing cables.

Admiral Horlick: Fundamentally yes, there is redundancy, though of course the cables all end up at the same point, so if you happen to be unlucky and they hit that area you have a problem. On the subject of repair, cable quite a long way away from the missile site itself was damaged, so the quick action was to take the command post nearer to the missile and reconnect, bypassing the damage.

Mr J. Dent: We were all enormously impressed by the rate at which the conversions of passenger ships and merchant ships were accomplished. To what extent had the designs been concluded and provided beforehand, together with the conversion kits? Was it all pre-planned or was all this *ab initio* right from the start of the operation?

Admiral Horlick: Aside from the fuelling-at-sea gear which was in the pipeline and we have always had that stored in readiness and small amounts of other kit, it was mostly *ab initio*.

Mr M. G. Conway: I ought to declare an interest in that I am ex-Rolls-Royce. Can you make any comment about the future of aircraft-derived gas turbines like the Olympus? Clearly they worked quite well.

What about the future? On the one hand the flexibility is good, the maintenance is reasonably good, you can change them at sea and you can even carry them with you; but what about the fuel cost? Is that critical? Are you going to continue using aviation-derived gas turbines?

Admiral Horlick: I think if we go on using gas turbines we basically have to continue in the foreseeable future using aircraft-derived gas turbines, because to start from scratch and develop a gas turbine we decided a long time ago was outwith our pocket, and I believe that is still the case. To obtain enough running hours to work an engine up to reasonable periodicities between maintenance also is not very practical without benefitting from those many hours of airline operation and so part of the answer is yes.

You asked specifically about the Olympus; it is a bit thirsty, it is also relatively simple and relatively cheap. We do have already, being installed in one of our most recent Type 22 frigates, the SM1A, which is the marinized Spey. The Japanese have already committed themselves to a fairly large buy of this engine, which is the next generation of marinized gas turbines. It is a great deal more efficient, it is somewhat more complex but a fit, for instance, of four Spey engines in a reasonably sized small vessel would be a very attractive fit, in the same way as the four Olympus are in a large ship. An important factor is that one is entirely happy to run with one of these engines at fairly high power, and therefore reasonable economy, on one shaft for much of the time and so one overcomes much of the problem.

Talking about main propulsion, perhaps it would be worth saying that I of course recognize that diesel engines can beat the gas turbine on fuel economy generally speaking but at a price in size and weight at present. We must keep our options open and so I would not like to discount in the long-term future a return to steam; why should I? Steam is beginning to make a comeback and I believe that the engineering of it is gradually getting better. One of the reasons why we moved away from steam is that we had not completely mastered the engineering of the whole system. A steam plant is a fairly complex system and we thought, I believe, that we could get propulsion more reliably through a gas turbine arrangement, using fewer people and with them working under better conditions; that certainly has been the case to date.

Commander M. B. F. Ranken: Would you like to say a word about the desalination plant, which I think is a very remarkable success story?

Admiral Horlick: The point is that one could actually buy reverse osmosis plant off the shelf in reasonable quantities and fit them. They were not trouble-free initially and our people had no operating experience. A quick crash training course was arranged for a small team which then toured the ships, making sure they were operating successfully. The plants certainly were a success story because they did solve a need at the time. We had been running a plant under trial at Portland in order to prove the process for our own ships so we have actually caught up on that development programme. Most of the membranes do still come from the USA so it is not all British, I am sorry to say.

Mr R. Butcher: I was associated with Rosyth Dockyard with the turnround of a ship up there; the cohesion and co-operation between the various bodies was truly remarkable. Is there anything happening today to ensure that if there is ever another emergency the same co-operation and cohesion will take place again at such short notice? I find that in my particular type of business there does not seem to be enough mixing between the RN service and the merchant service and the shipowning end. I wonder whether you had any views on what is taking place to bring the bodies together?

Admiral Horlick: That is quite a wide question; one must be honest and say that it was a rather special event. It is not often that suddenly everyone in the country is worked up and is really wanting to do something, pulling together. It did happen on that particular occasion and I believe that the MOD machine at low levels was fairly well-geared to work once that spirit became evident; in other words we were able, I am delighted to say, to a great extent to bypass the administrative top structure which one has to carrry to a certain extent in peacetime. I believe we carry too much but other people may not.

To answer the specific question, I do not believe that we can expect to carry on at a very much higher level in peacetime the getting together between the two sides, simply because of the practicalities of the game. The simple fact is that all the shipowners actually said 'OK, that's what I want to happen'. I do not believe that you can set that up in peacetime; what everybody has to do is to make their own organization as efficient as possible so that on the day that the emergency arises, if the people at the working level have authority delegated to them, it will happen again as it happened then. I am sure that the shipowners will continue to co-operate, I am certain that the Merchant Navy and the RNR will continue to operate as they have done for so many years and I am sure that industry will; after all, industry does make a profit out of it as well and hopefully some useful publicity too. I very much hope that British industry will profit somewhat from this unfortunate war.

Lord Caldecote: I am sure you would want me to thank most warmly Admiral Sir Ted Horlick for that splendid lecture. We really are most grateful to you. I think what struck me most was that it was of course a great engineering achievement but it was the ingenuity and the initiative of all the people involved that is so tremendously impressive and we were reminded of it in the last question. I wish we could achieve that sort of thing without needing to have that kind of incentive in front of us. Thank you very much for the trouble you took to put all this together and for all the tremendous interest it has generated.

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