HISTORY AS A DESIGN TOOL

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ABSTRACT

A study of history, using all available facts, properly analysed, can be of great value to the designers of future ships. Study of the way in which decisions were made in the past, related to the success or failure of those decisions in service, should be a guide to the future. New methods of analysis may be tested against the records of past events, particularly the records of disasters. Naval architects are well accustomed to use trend curves but do not recognize them as codified history, failing in consequence to realize both their potential and their limits. Finally, there are the simple but valuable benefits of not repeating past errors or of re-inventing the wheel.

Introduction

The fundamental nature of the design problem changes little. For example, the following quotation is from the Chatham Committee of Naval Architects in 1842:

> We apprehend that it is the object of our labours, as it is the business of science, to endeavour to produce the best effects with given means.

Historical methods can help the modern designer in five main areas, though there is considerable overlap between them.

- Design policy and decision—their successes and failures.
- Teaching and training, by examples from the past.
- Lessons and disasters, including damage in war.
- Testing new theories against records of past events.
- Avoiding the repetition of mistakes.

These areas will be discussed in turn, followed in Part II by an outline of historical methods and pitfalls.

Above all, there is the sense of continuity and common problems with great engineers of the past. These areas will be discussed by quoting specific examples, mainly from warship design.

The Eternal Verities

There are some external topics affecting design, such as the character of the sea, which do not change significantly over historical epochs though their relevance and the lessons drawn from them may change. For example, the lessons of the *Banshee* trials of 1903, (FIG. 1) remain valid. There are short-term variations and it is certainly wrong to regard the state of the sea or the resulting motions, measured over a few minutes, as having much significance. People change only slowly in physical characteristics but much more rapidly in their expectations of life style. Dr Rodger[1] has shown the dangers of reading the lessons of one era into another.

With care, other constant factors can be identified such as the dynamics of a floating body (intact or damaged) as they affect capsize and the need for subdivision. Resistance and propulsion data remain valid and, though changing requirements in other aspects may often mean that older forms are no longer appropriate, the data from them may still be useful in testing new theories or as end points to trend curves. A non-nuclear explosion and the way its effects are

FIG. 1—THIS PHOTOGRAPH OF HMS 'BANSHEE' AT SEA IN ROUGH WEATHER WAS TAKEN IN 1903 DURING AN INVESTIGATION INTO THE LOSS OF THE 'COBRA'. THE RESULTS OF THE INVESTIGATION, WHICH LED TO THE USE OF THE L/20 WAVE, REMAIN VALID TODAY

transmitted through air or water have many aspects which are the same today as in the first World War even though the way in which the explosive was delivered may be different. The results of tests such as that shown in FIG. 2 from the late 1940s may be useful today.

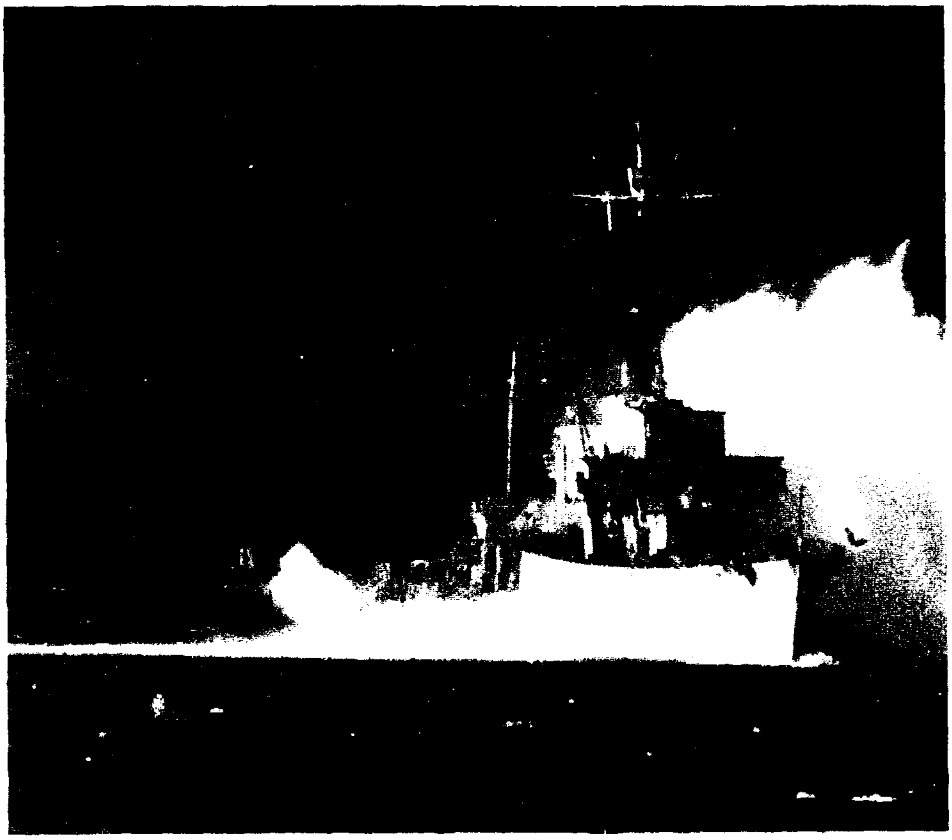

FIG. 2—IN THIS TRIAL THE EX-GERMAN DESTROYER, 'NONSUCH', HAS BROKEN HER BACK FOLLOWING A LARGE UNDERWATER EXPLOSION. IT IS ONE OF FEW SUCH TRIALS INVOLVING MODERN ALL-WELDED SHIPS HAVING A DOUBLE BOTTOM

The ways in which human beings interact in small groups such as design teams and decision-making committees change little, though today's head of design may be less autocratic and rely more on moral authority and on formal planning procedures. The way in which such groups performed in the past is relevant to planning the future.

Changes

There are other areas where changes in ship design have made the historical record of less value. The change in configuration, mainly increased depth, of modern frigates has reduced the effect of direct stress; while welding has eliminated the old problems of rivet slip and shear, leaving buckling and fatigue as the most likely causes of structural failure. Materials change more rapidly than does their description and it should not be assumed that today's mild steel has all the same properties as that of 100 years ago. Anti-fouling paint is certainly not the same as even in World War II and improvements have led to a dramatic reduction in fuel consumption.

The rapid change in habitability standards has had a major impact on the design of both merchant ships and warships. This explosive change was long overdue and the fact that it was postponed so long may be attributed to the ease with which men could be recruited during the Depression between the wars. Exhaustion due to poor living conditions and incorrect diet must have degraded operational performance in World War II. The predicted fall in the number of young people and their unwillingness to serve at sea is likely to lead to further rapid change, especially towards increased automation and redundancy in systems.

The Whole Truth

It is sometimes very difficult to identify all the relevant facts. For example it is clear that the performance of the crews of FLOWER Class corvettes was severely degraded by ship motions[2] but most of the evidence comes from the first two winters of the war which were possibly more severe than average and when a high proportion of the crews were not acclimatized to motions[3].

Even when things are changing, history can still be of value but, clearly, the data needed relates to rate of change with time and higher derivatives. Such data is hard to obtain and often unreliable. On the other hand, the management of change is a topic for study in its own right and a few examples will be outlined in the next section.

PART I—THE USE OF HISTORY

Design Policy

Introduction

The study of why some designs were seen as successful and others as failures can reveal much about the important dialogue between customer requirements and preliminary design. In particular, imponderable qualities such as versatility, adaptability and the management of technical change may be studied. There are also some specific technical lessons which remain valid.

What is a Good Design?

Viewed with hindsight, some designs are clearly seen as superior to others. Such views are generally sound but may be biased in detail by the writer's viewpoint. For example, the naval architect may see a cost-effective solution to a Staff Requirement as 'good' and ignore failings in the weapon system or in the requirement itself. The historian may tend to look through the wrong end of the telescope, attaching undue importance to the later years of the life of the ship, in roles for which it was not designed and when it was worn out and with obsolete weapons. The crew, proud of their ship, may attach considerable importance to aesthetics, in which standards certainly change with time, and to habitability.

Despite these and other similar problems, it is still possible to identify features which show up time and time again in ships generally seen as 'good'. With a few important exceptions, good ships are versatile as completed and adaptable to new roles. In general, such ships were generously sized as built, for example, the *Queen Elizabeth* of World War I.

The exceptions are those designed for a very specific and *continuing* role such as anti-submarine warfare or mine counter measures—LOCHS and TONS. The single-role ship, despite a low cost, must excel in its specialized role, and, if possible, have a limited capability in other aspects. For example, the TONS, built as minesweepers, could be adapted as minehunters and were good fishery protection vessels and patrol boats, while the HAMS were too small to have this versatility. It is possible that the otherwise excellent BLACKWOODS were over-specialized as ASW ships and would have benefited from a small gun. Ships which are designed to be second rate in overall capability, as opposed to limited in the *range* of tasks which they can carry out are almost always expensive failures; such tasks can be performed more economically by obsolescent ships.

Even if the life of an individual ship in service is only 20 years, this will imply a class life of some 35 years from the start of design studies till the disposal of the last ship. During that time the threat will change, tasks will alter and weapon technology will certainly advance. Treasuries are unlikely to agree to wholesale replacement and some form of updating will be essential. In the past, new equipments could always be squeezed in, usually at the expense of the crew's living space[4], and additions were limited by stability and sometimes strength.

Today, it is more likely that space, in the right place and of the right shape, will control the adaptability of ships. Ships capable of giving good service in middle and old age are generally those seen as spacious when new, such as the QUEEN ELIZABETH Class battleships and the V & W Class destroyers of World War I. A more recent and perhaps clearer example is the way that the older but bigger TOWN Class cruisers were preferred for modernization after World War II over the more recent, but cramped, COLONIES. Another example is the way in which the large hulls of wartime destroyers made it possible to convert them to anti-submarine frigates later. The capability to 'stretch' a ship during its life seems important. An over-large design with substantial margins of weight, space, etc. for new equipments and their crews is indicated.

Evolution and Revolution

History will also show that many of the ships described as revolutionary are equally well seen as the end of evolutionary development. *Warrior* (1860) brought together the technologies of steam, screw propulsion, of iron hulls and armour. The propulsion system was well developed but iron hulls had earlier been rejected, rightly, for warships[5]. The introduction and subsequent rejection of iron hulls for unarmoured warships in the 1840s is a particularly interesting case study in the management of change. It is hard to criticize most of the decisions but the result was a very considerable financial set-back and left the Navy short of frigates for some years.

The first point of importance is that iron seagoing ships were not possible until 1838 when Airy solved the problem of correcting a magnetic compass[6]. The Admiralty then reacted over-enthusiastically and began a large programme of iron ships without sufficient testing. When trials were finally carried out on the effect of gunfire on iron structures it was found that they frequently behaved in a dangerously brittle fashion, not fully understood until Bird's tests of 1984 during the restoration of HMS *Warrior*[7]. The abrupt stop to the iron ships programme owed much to politics but was supported by valid technical doubts.

Weight saving in *Warrior*'s iron hull and in her machinery now made it possible for the first time to armour the hull, so overcoming most of the problems of brittle iron plates. Many of these developments depended on the solution of apparently minor problems such as the correction of magnetic compasses in iron hulls, the use of lignum vitae stern bearings and finding a method of attaching armour plates to the hull in such a way that the fastenings would resist the impact of shot. Though there was little completely new technology in *Warrior*, the way in which relatively new, but proven, ideas had been combined made the whole concept novel and triggered a revolution in the next few years.

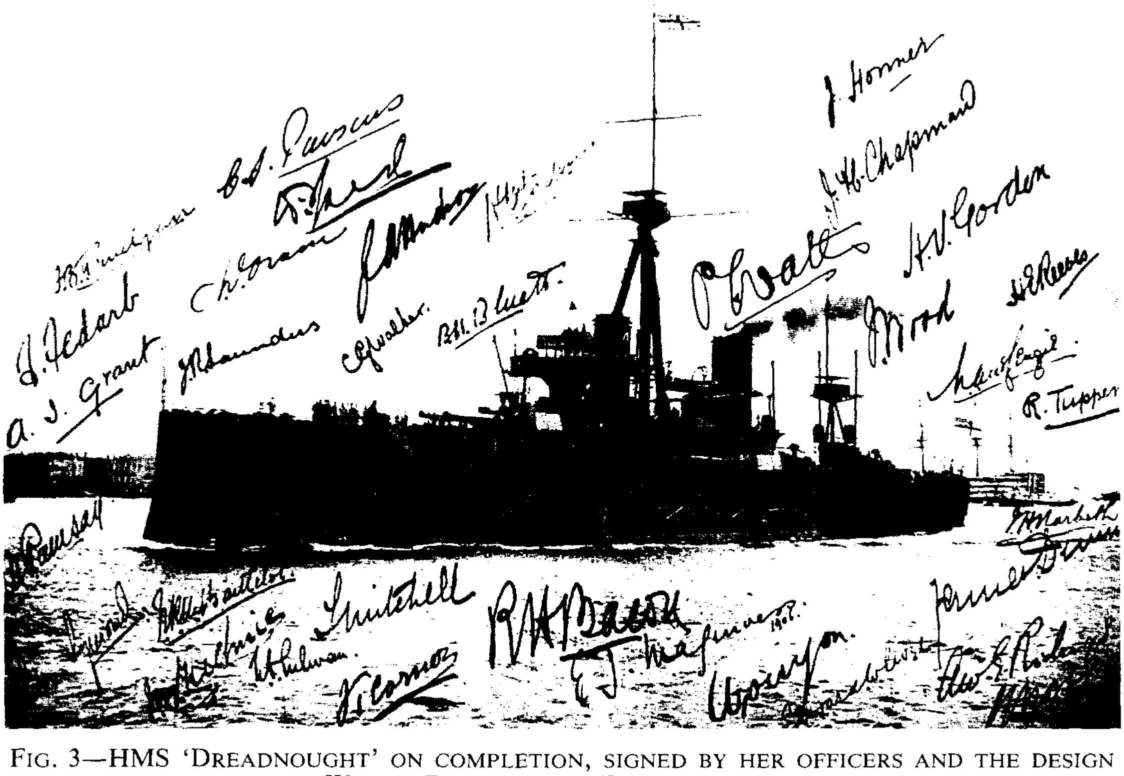

FIG. 3—HMS 'DREADNOUGHT' ON COMPLETION, SIGNED BY HER OFFICERS AND THE DESIGN TEAM, INCLUDING WATTS, DURSTON AND PARSONS

The battleship *Dreadnought* was subject to implied limits on size and cost and only able to carry a much more powerful armament than her predecessors, at a greater speed, as a result of evolutionary developments in machinery and hull. The introduction and development of turbine machinery in the RN is a good example of the management of change and reflects great credit on the Engineer-in-Chief, Durston, and his colleagues[8,9], shown in FIG. 3. Durston and the Director of Naval Construction, Watts, had followed Parsons's work closely and attended some of *Turbinia*'s trials from 1897. Once the worst of her propeller problems, associated with the very high rotational speed, had been overcome, several experimental destroyers were built and further progress made with propellers. These were followed by light cruisers and then the brave decision to use turbines in the battleship *Dreadnought*. This saved some 300 tonnes directly[10] and by 1906 turbines were universal in British warships.

There was still a mismatch between the revs/min of the machinery and that required for the propeller, solved from 1912 by geared drive. In parallel, trials with oil firing had begun about 1898 though the many problems were not solved until 1909 when the Admiralty decided that all future destroyers should be oil burning, a decision quickly extended to other classes. There had also been a steady reduction in the hull weight of battleships which made more weight available for armament. Indeed, her designer, Narbeth, saw the whole concept as evolutionary[10].

Admiral Rickover adopted a somewhat similar philosophy in the design of the first nuclear submarine, *Nautilus*. The reactor plant itself was to be the only novel feature and this was tested exhaustively in a shore-based prototype. The steam plant was conventional as was the hull, even retaining a twin screw layout despite the success of *Albacore* with a fat, single-screw form. As a result nuclear power went to sea with few irrelevant teething troubles. The RN's first nuclear submarine combined a well-proven US reactor and machinery plant with the fore end already designed for the first British nuclear submarine.

The classic failure of a novelty is that of *Captain* whose loss was due to inadequate freeboard. It had not previously been appreciated that large angle stability depends on freeboard, a failure of understanding following from the difficulty in obtaining numerical solutions to Attwood's equation[11]. The problem had not arisen before since high freeboard was needed for other reasons. It was seen as a matter of seamanship, to be decided by sailors, rather than a design parameter.

Warrior and the battleship *Dreadnought* introduced little new technology but were successful as a result of combining several technical developments in a radically new arrangement. In both cases, their success triggered rapid change which quickly made them obsolescent. Such radical changes often require novelty in a few key components but, in general, novelty must be carefully controlled. Baker[12] suggested that 25% novelty in a new design was about the right balance between built in obsolescence and unreliability. Certainly, in adopting a novel concept, the designer should try to use well-proven details to the utmost. Since safety criteria are usually based on experience, radical changes should be reviewed with great care using all available methods of risk analysis.

Design is inevitably a matter of compromise and almost the only way to learn is to study how conflicting interests were resolved in the past and to review the success, or otherwise, of such compromises. The great designer has always recognized the inherent conflict between cost and effectiveness, between quantity and quality. For example:

> Ships which in the least space carry the greatest force and have at least equal properties with others in sailing and working are to be preferred. Indeed this is to be considered as an object on which the attention of a naval architect who has to propose construction must especially be fixed.
>
> (Dr Inman, DD, MA, School of Naval Architecture. 1812)

There are plenty of useful historical examples at a more detailed level of design, such as the decision by d'Eyncourt and Lillicrap to increase the depth of the KENT Class to reduce stresses and hence keep the weight within Washington treaty limits. A study of the choice of prismatic coefficient in pre-war destroyers may well be an example to avoid rather than follow as the value chosen was that appropriate to top speed, where prismatic hardly matters, rather than that for cruising speed where it is very important. There is also a fascinating note by Watts concerning the successors to *Dreadnought* in which he points out that the design was not 'weight limited' as usually stated but by upper deck layout[13].

Warships of World War I were primitive creatures with little in the way of a central nervous sytem and hence could continue to fight as long as shells could reach the gun. By the beginning of World War II, the military capability of a warship was more dependent on power and communication systems running much of the length of the ship which, if damaged, could seriously degrade its capability. The speed with which *Bismarck* was disabled by British gunnery was due in great part to the destruction of her gunnery control circuits. After the war, the growth in electronics, sensors and command systems, all hard-wired to weapons, led to ships which were very easily disabled, but the recent introduction of multiplexing, data highways and micro-electronics give the promise of a new generation of warships, much more resistant to damage.

Decision Making

Almost all warship designs begin with a wide range of studies varying in performance, weapon fit and costs. Today, computer-aided design has vastly increased the output of studies but computer-aided decision-making has yet to prove its value. The way in which the preferred option is selected is well worthy of study. Such decisions are made, in a very short time, by busy admirals, administrators and, finally, the Minister, in the light of the then perceived political, economic and military imperatives. Though often criticized, such judgments are rarely irrational and a high proportion are seen as correct even with the benefits of hindsight. A recent example is the Type 23 design where the unwelcome (to the Navy) cash limit was the only way in which sufficient ships could be bought. It will, of course, always be said, correctly, that the cash limited ships would have been 'better' if just a little more money had been spent.

Historically, one may identify three main British design aims in the 20th century. In the early years resources were adequate to require each RN ship to be superior to its likely opponent. Due to Treaty limits between wars, which also restrained rises in unit costs, it was possible to retain this approach—at least against those nations which observed the Treaties. After World War II the aim was cost-effectiveness and, at least to some extent, extra costs could be accepted for a commensurate gain in effectiveness. The rising unit cost of warships has now made the conflict between numbers and quality more acute and a rigid cash limit has had to be imposed. Despite the difficulties, comparisons of effectiveness must be made on a world-wide basis as, in a limited scenario, big ships will always seem more economic than a more numerous force of smaller ships[14].

The remark above that a high proportion of decisions are seen as correct, even with hindsight, needs qualification. Admiralties of all nations are 'conservative' and novel solutions are not likely to be adopted. There is usually no way in which the value of an alternative strategy can be evaluated. For example, it is of interest to consider whether the resources devoted to battleships in the late thirties would have been better spent on aircraft carriers and effective aircraft for them[15,16]. To some extent, decisions are self-justifying.

Teaching and Training

The teaching of design and of the management of design is not easy. In years gone by experience could be gained on the job as new designs were frequent. Today there is much less opportunity for a young designer to learn in this way and it is suggested that tutorial teaching, using historical examples, is the only substitute. It may well be that such teaching is most valuable during refresher courses.

The teaching of design can benefit greatly from the analysis of past examples in tutorials, provided the teacher understands both history and design. Chaplin[17] says 'The designer needs to be aware of the historical development of his subject to see the current problems in perspective and as a *source of ideas*.' It will often be found that detail problems delay the introduction of new ideas, particularly the availability of suitable materials. In passing, it is suggested that such studies might form the input for discussion of the significance of engineering in general history.

The teaching of innovation in engineering is closely related to that of design and should also include case studies. The development of the *Warrior* and of the *Dreadnoughts*, battleship and submarine, discussed above, also show the influence of dominant individuals who could still interact with other bright men. The evolution of post-war frigates from *Whitby* to *Leander* with particular reference to Purvis's contribution makes a good example[18].

There are only a few really good examples of the interaction between individuals and groups as it is necessary to have the views of more than one of the participants and particularly not to rely entirely on the self-congratulatory reminiscences of the senior man, written much later. Members writing papers, describing new designs, should outline the reasons for decisions as well as recording them. They should also describe the internal organization of the design team.

One very well-documented case is the life and work of William Froude[19] who was a great writer of letters, many of which have survived. He says that the great influences on his philosophy, particularly as to the nature of proof, were his older brother Hurrell (a theologian), J. H. Newman (later Cardinal) and I. K. Brunel. Many letters to and from all of these exist showing Froude's ideas which may be summarized as 'probability is the guide of life' and that there is a 'sacred duty' to doubt every conclusion and proposition. Froude did not believe that scientific advance came from a flash of inspiration but rather from the methodical arrangement of one fact upon another, noting and explaining any discrepancies.

In his mathematical work on rolling he was greatly assisted by W. Bell and in his later experimental work by his son Edmund, Henry Brunel and A. Mallock. Their correspondence confirms both William Froude's leadership and the real contribution made by his assistants. Indeed, one may well see the inspiration and development of the next generation as a primary task for the great engineer.

Reading the lives of great engineers can be most valuable but such reading must be both wide and critical. Such reading should include a number of biographies of contemporary engineers and their work must be put in context of the technology and economics of the day. Many recent books are based almost entirely on a single contemporary source, for example, too many recent books on I. K. Brunel use only the biography by his sons and hence may be biased. Others are merely unreliable.

In years gone by, design could be learned on the job. Between the wars, a new class of destroyers was designed each year and new cruise classes every two to three years. In these circumstances, a naval architect would have worked on, and experienced the behaviour of, several classes before he took charge of a design himself. He would be backed by technicians with very many years experience on similar ships. The head of a design section would report to a director who had spent almost his whole career on design and, in carrying out a design review, would be in a position to ask the most searching question and to reject superficial responses.

Today's lengthy intervals between designs and the more varied career expected of both graduates and technicians have greatly reduced this fund of experience and to avoid grievous error or increasing repetition—re-inventing the wheel—it seems necessary to record and study the lessons of the past. It is not sufficient to write a manual which states, for example, that the boundary plate of a bulkhead should be thicker. Unless the reason is also given, such proven rules will be dropped for the sake of easy production.

It is likely that such failures to record the *reasons* for design rules, often the lesson of an earlier war, account for the need to relearn the same lessons in the next war.

Disasters

Design criteria for stability, strength, etc. are rarely absolute and are rooted in critical examination of past successes or, more often, failures. The most obvious example is the review of passenger ship subdivision rules and life-saving requirements following the loss of the *Titanic* which was so quick that it may be argued that it was not 'history'. However, it was clearly the application of the study of a past event to future design. UK government action following *Herald of Free Enterprise* has been quite rapid, not yet matched by other governments.

Intact stability standards derive from the loss of *Captain* which showed the significance of the GZ curve and led to the introduction of a formal stability statement in the RN[20]. The loss of the three US destroyers in the Great Pacific Typhoon of 1944 led to the Sarchin and Goldberg criteria[21], used so widely. The structural failure of the destroyer *Cobra* led to the general introduction of the L/20 wave loading for strength[22].

It is less easy to say what is 'enough' rather than that which is likely to lead to disaster. The great majority of RN World War II destroyers would have failed the Sarchin and Goldberg criteria, usually that for wind loading, and yet they accumulated some thousands of ship years of operation without loss from bad weather. More careful examination suggests that they only just failed to meet the criteria, that several were close to disaster and that in the Great Pacific Typhoon, only excellent seamanship could have saved them from capsize[23]. One may see the classic work of Ra'hola[24] as an early use of carefully analysed historical data to set safe limits.

The careful analysis of disasters is still a vital task and it is not clear that an adversarial, judicial enquiry, intended to apportion blame, is the best way to get at the root cause and find ways of ensuring that it will not happen again[20,25]. Royal Navy Boards of Inquiry, such as those which investigated the losses in the Falklands War, endeavour to determine the facts and make recommendations for the future without any preconceived intention to attach blame.

Similarly, the effects of enemy weapons, on warships can provide valuable lessons for the future[26]. The danger of longitudinal subdivision is clearly illustrated by the performance of Japanese cruisers in World War II[27]. They had centre line bulkheads in the machinery spaces, intended to limit the flood after minor damage on one side. In fact, most of those hit in this area capsized rapidly due to a combination of asymmetric moment and loss of stability. In the few cases of minor damage, it was usually necessary to flood the space opposite the damage to reduce the heel, negating the intent of the bulkhead. Several British cruisers capsized because the effect of flooding over several main spaces, reducing stability, combined with the asymmetric heeling moment of quite small wing compartments, had not been appreciated.

It is interesting to ponder on the value of armour, particularly in cruisers. After the Washington Treaty, most countries built heavily armed 10 000 ton cruisers with 8 inch guns and only light protection. Only the British designers had war experience and they chose to armour only the magazines; shell rooms and machinery had splinter protection and that was all. During the remaining years up to the Second World War, weight saving from improved machinery and welding was universally applied to increase the thickness and extent of armour, even at the expense of reduced speed. The lessons of the war strongly suggest that this policy was wrong and the additional armour was of little value[28].

Testing Theories

Reverse Engineering

Two recent papers have used historical data to good effect. Monk[29] studied a number of ships whose rolling had been found to be unacceptable. In most cases the bilge keels had then been deepened giving acceptable motions and calculation of the Lateral Force Estimator, before and after, gave a bracket for a criterion of acceptable rolling. Brook[30] used a well-documented trial of 1939 as a test of modern predictions of roll damping. To obtain new, full-scale data for either of these papers would have been so expensive as to be prohibitive.

In a somewhat similar manner, Brown and Marshall[3] used a large number of accounts of experience in World War II escort vessels showing that the frequency of complaints about the motion was a function of length and that 75–80 metres was likely to be acceptable for North Atlantic operation. These historical results were then compared with computed values of Subjective Motion Magnitude. This illustrates a general point that experience will give the amplitude and theory the slope of a graph. The re-analysis of the loss of *Cobra*[31] used much the same approach in testing modern theories. It will be noted that these examples all lie within the 'eternals', sea and human response.

Repeating the Error and Re-inventing the Wheel

This may be seen as a trivial use of history but failures in such use have cost the country dear in cash and waste of resources. Examples include the need shown for a high freeboard forward on submarines intended for high surface speed. The K Class of World War I had to be altered; the lesson forgotten, exactly the same modification had to be made to the A Class. At the end of World War I cruisers had trouble with spray generation—and many years later the COUNTY Class guided missile destroyers had the same problem[32]. The problems caused by structural discontinuities and sharp corners recur in every generation.

Historical data, properly organized and accessible, can save the expense of a trial to validate a new theory and may prevent the repetition of errors.

PART II—HISTORICAL METHODS

Background

The first essential is a wide background, based on extensive and critical reading into which specific topics can be fitted. Even some of the best known writers are unreliable; there are historians with no understanding of technology and engineers and sailors with no understanding of historical methods. The position is improving and there are several current authors able to bridge the gap between history and technology.

For example, many experts read the lesson of the battle of Tsushima in 1905, shortly after *Dreadnought* was designed, as showing the importance of the 'hail of fire' from medium calibre guns at close range. More perceptive analysts saw that it was the heavy projectile which did the damage but the full lesson, perceived only by the British Admiralty, thanks to their observers with the Japanese fleet, was the need to hit with heavy shells at long range[13]. This episode also shows how words change their meaning; in 1905 long range was 6000 to 10 000 yards.

Such reading should not be confined to maritime matters; the civil engineering debate following the collapse of box girder bridges around 1970 is of interest both for the technology of stiffened panels but also for the more fundamental debate on safety factors and on the moral responsibility of the engineer[33]. Similarly, the conduct of accident enquiries following rail and aircraft accidents differs from that following marine disasters and these differences are worth study.

All the Facts

It is rare indeed for historical reports to contain all the facts which an investigator would wish for and others, such as sea state will be based on subjective judgment rather than on measurement. The investigator should start by planning as for a trial, setting out what facts he would like recorded. Available data can then be weighed against those desired listing those for which reliable figures are given. Subjective estimates can often be allocated a probable range of validity. Sometimes missing or false data can be found elsewhere: for example, sea state reports can be checked against data from other ships in the area or from shore stations[34]. Historical investigations will usually be based on more than one incident so that one specific bit of information can be compared with similar records from other incidents. For example, the statement that a magazine filled with cordite in brass cartridge cases cannot explode as a result of exposure to flash can be compared with several incidents in which it is virtually certain that this has happened[35].

If only one parameter is missing, it may be possible to obtain a reasonable estimate by trial and error, checking to see which assumed value best fits the observed outcome.

History is particularly useful in providing background material on the success or failure of Staff Requirements and unquantifiable topics such as versatility and adaptability (see pp. 42–43). Wherever possible, original documents should be used, although even these may not be 'the whole truth and nothing but the truth', they are likely to be less biased than later extracts.' Wherever possible, lessons drawn from battle should use accounts from both sides.

Today, documents are more readily available than in the past, the main sources for British warships being the Public Records Office, Kew, and the National Maritime Museum, Greenwich. More than one source should be used wherever possible and all facts should be tested for consistency and weighed against engineering common sense. In some cases the originator may have a reputation for the whole truth—or the opposite.

Where relevant, a chronology should be set out as this alone can prevent the confusion between cause and effect which has happened all too often in the past. For example, it is clear that the famous tug of war between the *Rattler* with a propeller and her half sister, *Alecto*, with paddles, which took place in April 1845, was about a year *after* the Admiralty had begun ordering screw ships in some numbers and hence this trial had nothing to do with the decision[5].

The prospect of using historical material is greatly improved if adequate records are taken at the time and carefully preserved. The old Admiralty practice of the 'Ship's Cover' into which were bound copies of papers dealing with important design matters was excellent in theory and was usually valuable in reality. In using these covers, kept in the National Maritime Museum, various problems are apparent including the unwillingness of some design sections to take this task seriously. The first problem is the starting point. The early papers on a new class are often to be found in the cover of the preceding class or are sometimes missing altogether. It is the early papers which are of most value in seeing why a new class was necessary. The biggest problem is that decisions are often recorded without the reason for them. In using history to develop a design philosophy, it is the reasons which matter.

The Admiralty Experiment Works, Haslar, had the simple philosophy of keeping everything and this made the work of Monk[29] and Brook[30] possible. This practice had to be abandoned with the paper explosion after World War II but modern micro-recording systems should be able to cope with recording all technical data.

History and Regression

The scientific method of handling a large number of random data is regression analysis. In simple form this is a 'least squares fit' to a straight line representing the relation between two variables. With increasing difficulty, regression analysis can be applied to multiple variables and those with non-linear relationships. Only rarely is it possible to use such methods directly in the study of historical events but some of the rules and problems of regression should be borne in mind.

The number of co-efficients in a regression equation increases very rapidly with the number of independent variables and with the power of the polynomial. Experience suggests that the number of terms should not be more than one-third of the number of sets of data available[36].

It must never be forgotten that the resulting equation is a statistical relationship between the figures used and does not necessarily correspond to any physical connection. It is important, too, that the variables selected are truly independent. (Watch that they are not all functions of a concealed variable—prismatic co-efficient of destroyers varies linearly with date as does circ M). These two conditions make it difficult to find an 'optimum value' from a regression equation.

The only serious attempts to use formal regression analysis of historical data in naval architecture are with resistance data and, though frequently tried, the results have not usually been of great value. It is likely that the data were not truly independent and that full advantage was not taken of naval architecture knowledge in selecting the parameters; for example, several studies used total resistance instead of dividing into components. Scott[36] referred to the unthinking use of regression as the 'Kenwood Technique'—mixing unrelated facts in the hope that something would come to light.

As a generalization, experience will give the amplitude of a graph; theory gives the slope as, for example, Brown and Marshall's estimates on the length of the CASTLE Class. It is important to identify the limits of experience and the possibility of step functions.

The historian, with a small to moderate number of data from totally uncontrolled events, whose results are rarely recorded completely and all too often incorrectly, has a difficult problem. Every tool must be used and wherever possible a 'standard deviation' quoted. It is clear that historical data, used quasi-statistically, will be able only to answer simple questions with a limited range of variables.

Trend Curves

These are the only widely used example of historical method and are not well understood. For a start, it is important to be quite clear over the difference between a trend curve which shows the average value chosen for a parameter (e.g. Cp) and a locus of optimum values. FIG. 4 shows that they can be very different though both can be very useful if properly understood. It must also be appreciated that many parameters are functions of time, depending on the date of their design (FIG. 5), depending on changing requirements or, sometimes, fashion.

To obtain full value it is essential to understand what the past designer was trying to achieve. For example, the well-known curve of optimum Cp to base speed ratio (FIG. 6) shows the 'best' Cp and also the penalty in resistance for departure from it. The corresponding trend curve shows that destroyer designers followed it religiously, using the optimum Cp for top speed where it made little difference and paying a big penalty in fuel consumption around 20 knots.

The weight of hull structure can usually be expressed as F(L,B,D), often as a product, with the exponent of L greater than one for structures which are highly stressed longitudinally. If the structure is merely an envelope, dominated by local stress, its weight will vary as the square of the dimensions and the fact that the hull weight of wooden battleships depends on Σ (dimensions)^2, confirms that they were not limited by bending moment but by shear stress[38].

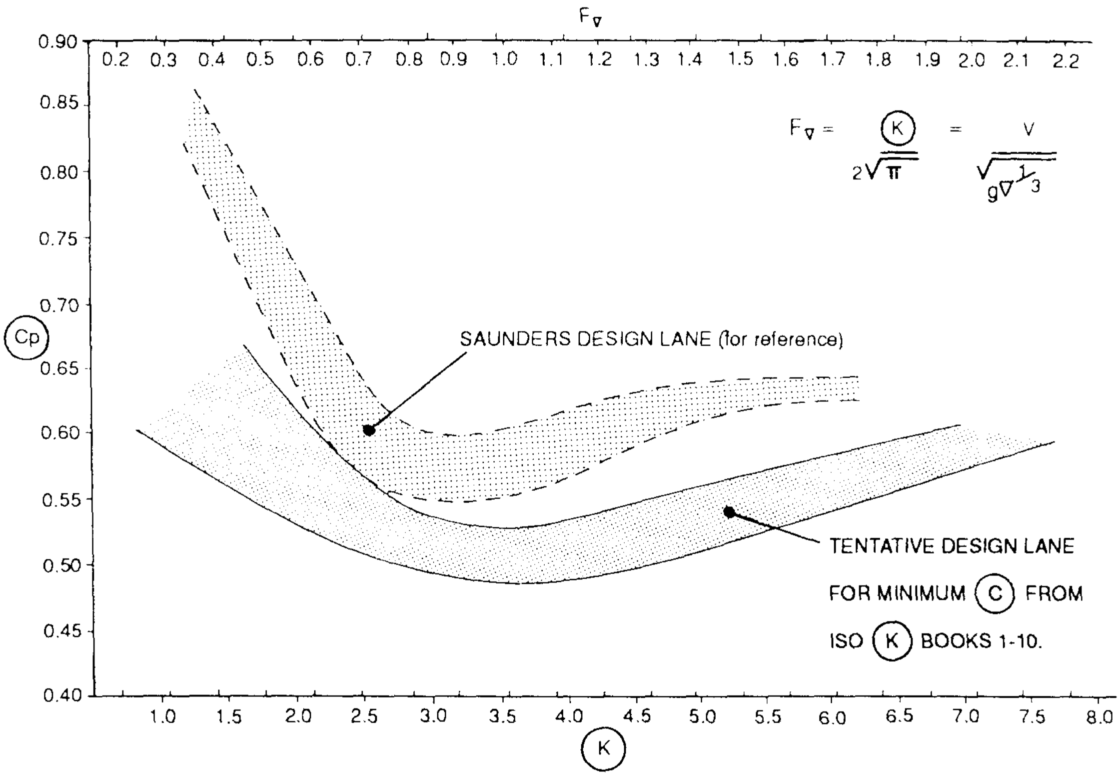

FIG. 4—TREND CURVE AND LOCUS OF OPTIMA. THE LOWER BAND, BETWEEN THE SOLID LINES, SHOWS THE OPTIMUM VALUES OF PRISMATIC COEFFICIENT FOR MINIMUM RESISTANCE BASED ON HISTORIC DATA AT THE ADMIRALTY EXPERIMENT WORKS, HASLAR. THE UPPER LANE, FROM SAUNDERS[37], SHOWS THE RANGE OF VALUES USUALLY ADOPTED. THE CURVES ARE FOR 300 FT (91 m) SHIPS IN SEA WATER AT 12°C

Answering Questions

There remain a number of questions which satisfy the guide lines of the previous paragraph. The separation of warship machinery into two or more independent units increases the chance of retaining mobility after damage[26]. If the units are widely separated, vulnerability to damage in the engine rooms is further reduced but it is often argued that longitudinal separation of the engine rooms of a warship increases the overall vulnerability of the ship to underwater attack because of the danger of damage to the long shaft from the forward space. TABLE I, extracted from British World War II records[26], shows that this risk is small. The figures refer to non-contact under-water explosions in which the ship whipped. Of the fifteen cases of shaft line damage, five were due to fracture of cast iron plummer blocks no longer used, and two were due to fracture of the shaft brackets which would not be affected by the length of shaft. Only in eight cases was bending of the shaft reported though there may have been unreported cases when the machinery itself was inoperative.

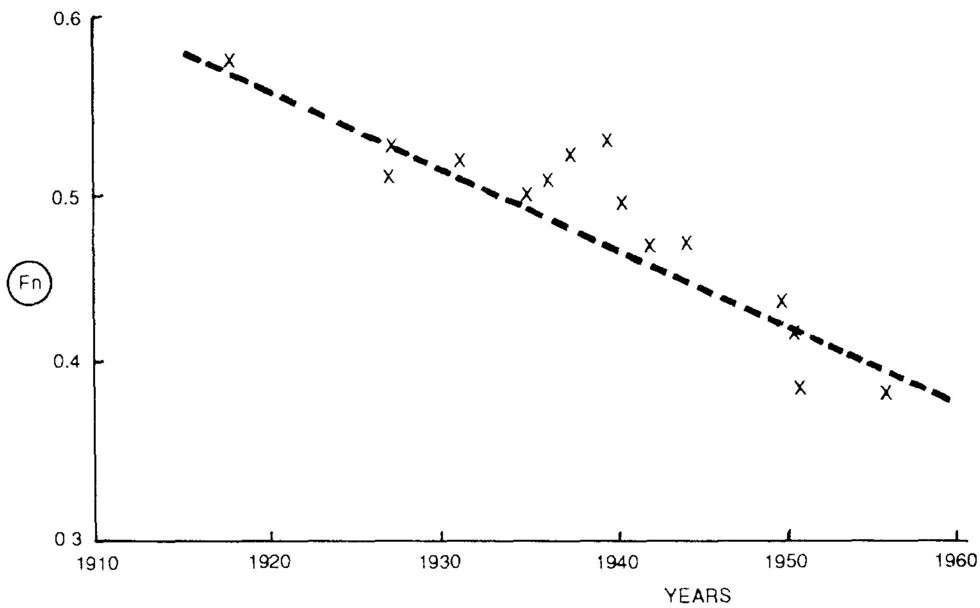

FIG. 5—VARIATION OF DESIGN FROUDE NUMBER OF RN FRIGATES AND DESTROYERS OVER THE YEARS. BETWEEN 1910 AND 1960 THIS DECLINED ALMOST LINEARLY WITH DATE, A POINT TO BE BORNE IN MIND WHEN USING REGRESSION ANALYSIS

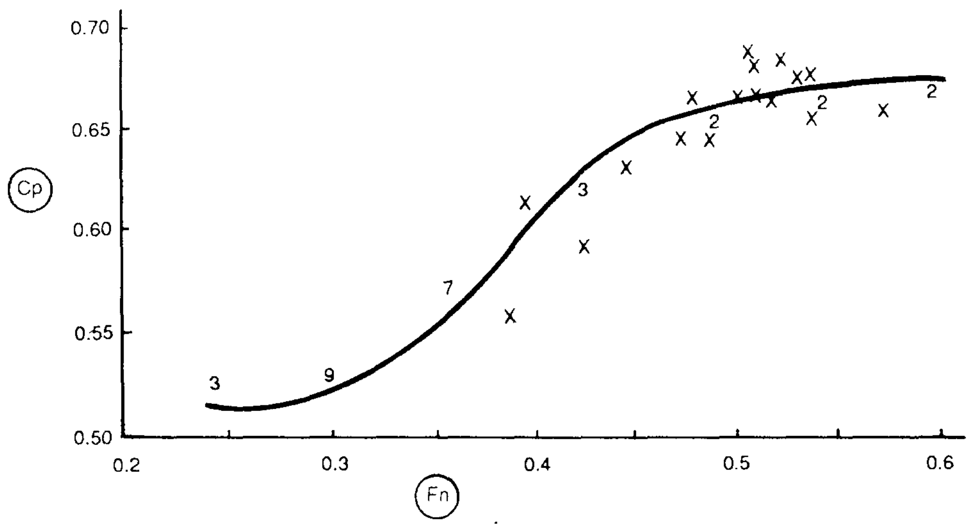

FIG. 6—THE OPTIMUM PRISMATIC COEFFICIENT PLOTTED AGAINST FROUDE NUMBER, SHOWING THE PERCENTAGE PENALTY ON RESISTANCE FOR DEPARTURE FROM THE OPTIMUM VALUE. THE CROSSES REPRESENT SPECIFIC CLASSES OF RN SHIPS AT FULL SPEED AND SHOW THAT THE PRISMATIC WAS CHOSEN FOR TOP SPEED REGARDLESS OF THE PENALTY INCURRED AT CRUISING SPEED

TABLE I—*Non-contact explosions causing serious damage*

Number of incidents	56
Number sunk	9
Shaft line damaged (surviving ships)	15

In addition there were seven cases of damage to shafts from conventional weapons, bombs, shells and torpedoes exploding in contact with the shaft line. Finally there were thirteen cases of the propellers and tail shaft being destroyed by acoustic torpedoes homing on the propeller, also independent of the length of the shaft. Overall, the risk of shaft line damage was low in World War II. The contemporary reports make it clear that whipping was a normal response to World War II non-contact explosions and hence these data can be read across directly to modern weapons. There is, of course, a much greater chance of these modern weapons exploding in the right place but it is still valid to conclude that shaft damage is unlikely. This low probability is further reduced by flexible bulkhead glands, developed late in the war and proved in post-war trials[39]. The *Penn* whipped through 20 inches and broke her back but the shafts could still be turned. Conversely, the evidence for the success of the division of machinery plant into two or more units is conclusive.

Further examples can be quoted but as the paragraphs above show, it is a lengthy task to marshal the evidence, comment on its validity and relevance, and draw conclusions. The consideration of the stability of British destroyers touched on earlier and detailed recently[40] arose from the specific question of their apparent failure to meet current stability standards.

It is clear that correct marshalling of facts can produce specific answers which would be expensive to obtain in any other way. Solutions are most likely in the 'eternals' discussed in the introduction. Full scale trials are inevitably expensive and, wherever possible, previous trials should be re-analysed to give the required information.

Conclusions

The historical approach is not an emotional attachment to the past nor does it mean sticking with past practice; indeed the lessons of history reflect the need for continual change. The first step—the gathering, recording and analysis of all relevant facts—is not easy and the lessons learned must be recorded and kept in such a way that they can be recalled many years later. The paper mountain and its almost inevitable sequel of mindless destruction makes it difficult to identify the essential data and almost impossible to retain it beyond the memory of an individual, say ten years.

Ship design and shipbuildings have long histories. Most ideas have been tried before and it is very often possible to test a new idea against past experience. Changes in knowledge and materials may give a different answer but often the verdict of history is correct. Design should be closely linked to shipbuilding on the one hand and to success in the market place or battle on the other. Analysis of performance in service is never easy but, if it is to be more than an accountant's balance sheet, it requires a broad, catholic but penetrating knowledge of the subject, including background aspects.

The sense of continuity with a living past obtained by the study of the work of previous generations of ship designers, realizing that many current problems were their problems, too, is both valuable and satisfying. The author studies history for its interest but has frequently been able to use this material in guiding decisions for future ships. History can be a very useful and cheap tool but it cannot alone solve all the designer's problems.

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