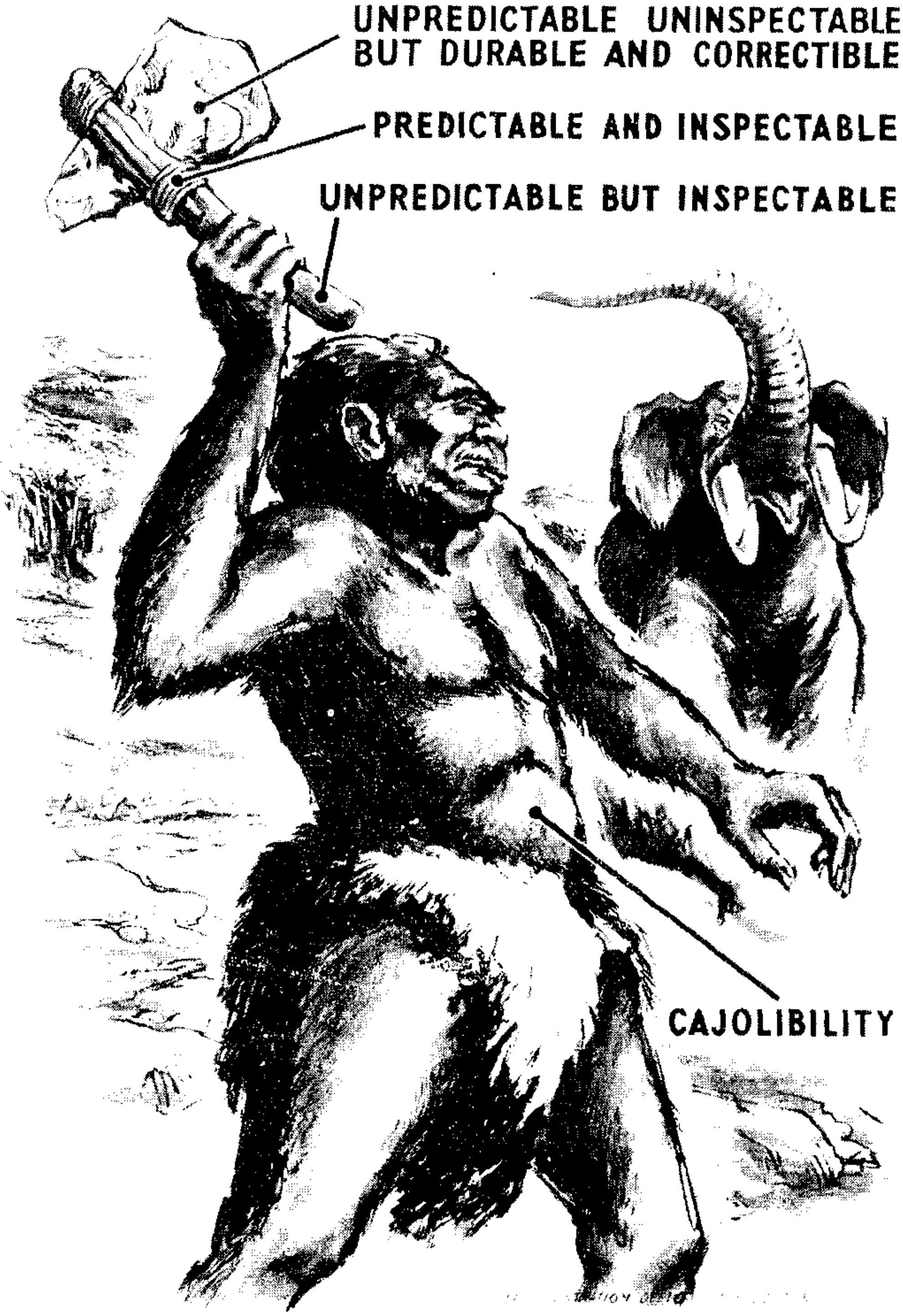
MAINTENANCE QUALITIES IN MATERIAL



Usage

The percentage usage of a ship is, for the purpose of this paper, defined as being that proportion of her life during which she is actually used at sea. The usage may be training or showing the Flag in peace, or in her full designed function in war.

In the case of a merchant shipping line, usage is earning power and the maximum usage is always sought. The efficiency of operation is denoted by the ability of the operators to achieve a usage as close as possible to the availability. Thus the *Queen Mary* has an availability of about 80 per cent and a usage of about 66 per cent. In the Navy in peace, however, the usage demanded is normally very low and because of fuel economy or other reasons, is often only 100 or less days or part days at sea a year. In these circumstances, a low potential availability is entirely concealed. The dangers of this, with reference to the time when war comes, have already been illustrated.

Upkeep

'Upkeep' is here defined as the whole range of activities undertaken in order to ensure that the designed performance of a ship and its equipment is retained throughout its life. It may be categorized into 'maintenance' undertaken by ships' staff and by support ship or base, or 'repair' undertaken under the direction of a non-operational authority, whether Royal Dockyard or civilian ship contractor.

There are only two methods of upkeep, the first being a 'preventive' and the second a 'breakdown' method. Both have been in use at least from the Stone Age onwards, and I have used in FIG. 11 a Stone Age man and his weapon to show the principles involved.

The Stone Age man who renewed the lashing of his stone axe-head to its shaft at regular intervals used preventive upkeep. His more foolish fellow who waited till it broke and the axe-head flew off into the jungle, preferred to use breakdown upkeep. This man, whose only weapon failed him perhaps in action, sometimes no doubt did not survive the occasion. When he did, he first had extra work to do finding the axe-head, and then he had to carry out the normal rectification ; but like as not, a suitable lashing was available only at his base.

No matter how complicated the equipment, this balance in favour of preventive upkeep remains the same today. It is always better to be able to conduct maintenance or repair when one wants to, at a convenient and predetermined time and under satisfactory working conditions, rather than at a moment which cannot be predicted and may therefore be anything from the merely inconvenient to the disastrous. Unfortunately, under pressure, upkeep always degenerates into the breakdown method, since it is not in human nature to continue preventive upkeep on equipment still capable of running or working, in face of other broken down equipment in the same ship. Hence one has the absurd situation that, as equipment gets less serviceable so upkeep gets less efficient, and it actually requires greater effort to maintain ships at 50 per cent efficiency than at, say, 80 per cent. This fact takes some swallowing, but is more easily digested if one thinks in terms of the old adage that a stitch in time saves nine.

To complete this probe into the factors affecting upkeep (and hence, ship availability) it is necessary to examine the qualities in material which determine the method of application and extent of the work involved.

The first two, 'predictability' and 'inspectability', are best regarded jointly. Predictability means the extent to which one can forecast the length of service which will be given before failure occurs, and inspectability the extent to which looking at a piece of equipment will tell one how well it is lasting. Returning to the Stone Age man's axe for illustration, the head of the axe, the piece of flint from which it is made, is subject to fatigue failure and is neither inspectable nor predictable. The lashing is both inspectable and predictable, and the shaft is one but not the other. On this score the lashing is the best of the three items of equipment, but this judgement must be qualified by consideration of the third quality, 'durability'.

Although the axe-head is not predictable or inspectable it is nevertheless a reasonably satisfactory piece of equipment because it possesses good durability. It is nearly always possible to obtain this quality of durability by just making machinery larger ; but it is then usually slower, less powerful for its weight, and so on. One obtains durability in this way only at the expense of operational performance. However, it is also possible to obtain durability by good design without loss of performance. If the shaft of the stone axe is made so that the grain of the wood runs the right way along the shaft, and if it is shaped to give equal stressing at each point, good durability can be obtained without loss of performance. But the design effort involved may often be tremendous and only to be afforded for mass produced articles. As an example of what may be involved and achieved today, more design manhours were put into the little Renault 8 h.p. motor car than into the large four-engined York bomber. The percentage availability of these two classes of equipment so achieved were about 95 per cent and 40 per cent respectively. This means that, of each twenty of these cars built, one only would be out of action on the average, but, of each twenty aircraft built, twelve would on the average be grounded for essential upkeep. This is of course not to say that, by planning the maintenance in conjunction with use, all twenty cars or aircraft could not be made serviceable for predetermined journeys at particular times ; but the opportunities would be far less in the case of the aircraft.

The next item is 'correctability', or ability to be rectified. If the axe-head got a dent in its cutting edge it could be re-faced and so was a correctable item. If, on the other hand, the lashing of the axe got badly chafed it could not be repaired and so was not correctable. We are moving today, not as a matter of choice, but because of the specialist techniques and materials in manufacture demanded by the search for high performance, light weight and small space, steadily away from correctability and towards upkeep by replacement. The bayonet socket electric light bulb is a fine example of design for upkeep by replacement, in a class of equipment which cannot be made susceptible to preventive maintenance. It must not be overlooked however that liability to unpredictable breakdown is never a desirable quality in the equipment of a warship.

The last item is of the utmost significance. Cajolability is not a familiar word and you probably won't find it in the dictionary, nor in fact will you find it in any material other than human. If you put a man on the parade ground and shout at him, 'Faster!' and if you have the right personality, or authority, the chances are that he will move faster. If, however, you put a Diesel generator on the parade ground and shout at it, 'Faster!' it will merely look at you with dumb insolence. Machinery cannot be persuaded, and the Commanding Officer who says, 'Oh, go on, Chief, you will manage,' is not persuading the machinery to become serviceable, he is persuading his Engineer Officer to accept a reduction in his overall serviceability state. A ship, or even a part thereof, has a considerable reservoir of serviceability. But the upkeep bill is not in this way avoided ; its payment can only be delayed, and it is always larger in the end.

Serviceability

Material, whether simple and inanimate like hull structure or complex as an electronic computer, cannot be persuaded, hence it follows that the condition of serviceability is that upkeep effort supplied shall equal upkeep effort needed. It is of course possible to supply more upkeep effort than is necessary, in which case it is just wasted, and this has not infrequently occurred in the past ; but today, in ships, with a deficit of overall upkeep effort becoming ever more marked, it occurs but rarely.

Below is a tabular statement of a typical serviceability diminuendo in one part of the ship :—The items at the top of the list, the main engines and main engine auxiliaries, will be found serviceable, but the items at the bottom of the list will be found less serviceable in many ships of the Fleet today. This situation arises when there is a deficit of the total upkeep effort in relation to the upkeep requirement, and because of a natural tendency on the part of ships' officers to concentrate on things most essential for going to sea. It is obviously quite possible to steam round the ocean with leaking joints and valves, with salt water pumps at a low state of efficiency, with leaking air casings on the boilers or even with a proportion of the generators out of action and the ship at a very low state of water-tight integrity ; and in peace no obvious penalty is paid for such a state of affairs.

SERVICEABILITY DIMINUENDO

Main Engines

Main Engine Auxiliaries

Turbo-Generators

Evaporators

Boilers

Sea-Water Pumps

Valves

Joints

Hull Items

If the whole of this group of equipment is serviceable at outbreak of war it is possible, by concentrating maintenance effort on the items at the head of the list and allowing the rest to deteriorate slowly, to achieve a very high operating tempo for a time with little or no support. This is what was done in 1939, but as soon as the serviceability reservoir was exhausted, the availability of the ships for use declined sharply. The size of the reservoir in terms of time before it is exhausted by sea-going varies, being longest for large ships and shortest for small ships.

Summarizing these thoughts on the problem, therefore, four lessons suggest themselves. They are :—

(*a*) A need to design ships with the nature and extent of subsequent upkeep, as well as the more obvious requirements, in mind.

(*b*) The right amount of upkeep must be determined for each and every item in, or of, a ship by collation of experience and its evaluation.

(*c*) This right amount of upkeep cannot be avoided and the final effort and cost will be larger, and the availability lower, if attempts are made to ration what is supplied (except of course in the case of a deliberate run down to the scrap state).

(*d*) A reservoir of serviceability exists in all ships and, if it is kept full, it can be used to tide over a period of emergency, as in the first months of war. But, in the case of small craft, the reservoir is small and will last only weeks rather than months.

SHIPS : FIELDS FOR ACTION

The Design of Ships for Minimum Upkeep and Their Evaluation

When a ship is designed and built its subsequent upkeep need is designed and built into the ship, item by item, as surely as its weight, but, unlike the weight, it usually goes unrecorded in any way. The whole ship must be designed with weight in mind and weight must be, and is, recorded as construction proceeds, otherwise the ship may turn turtle on completion. But no such healthy sanction applies itself to upkeep and there seems little doubt that, in the design of much of our ships' equipment today, inventiveness outstrips practical wisdom, and subsequent upkeep is not considered in a meticulous manner.

Experience indicates that upkeep costs for a Naval ship are not less than 5 per cent of its building costs per annum. Upkeep is time not available, and reduced upkeep costs mean improved availability. The table headed ' Design for Upkeep ' which is entirely suppositious, shows how an improvement in availability from 60 per cent to 80 per cent, effected through a reduction of built-in upkeep, would justify nearly doubling initial design and building costs. There is here a large and, so far as I have been able to ascertain, an almost unexplored field for research and improved method.

Costs and availability are important in themselves, but so also are the size of the teeth a ship carries in relation to its own size. One ready method of increasing the teeth per ton displacement in the Fleet is by a reduction of the maintenance men, since the demands of weight and space for accommodation of personnel tend to limit the weapons which can be carried. Reduction of built-in upkeep would reduce complements and so improve the fighting power per ton of the Fleet.

Design for minimum upkeep requires first of all a clear target of ship availability to which all those designing parts of the ship shall work, together with an indication of the usage-upkeep pattern required of the ship to which all important equipments must conform. It would, for example, be foolish to build a minesweeper in which the main engine required laying off for upkeep every three weeks and the sweep every two weeks. Once these requirements are laid down, the designers can approach reduced upkeep through the use of more durable materials, even at much greater expense, and by provision of machinery and equipments adapted to preventive maintenance, and in which essential replacements can be effected rapidly with minimum effort.

Design for minimum upkeep, or, as it is more commonly known, maintenance design, is a relatively new activity in engineering. It is a large subject of its own, upon which it is here possible to say only that a clear case seems to exist for a special section to be provided in every design department, *not* to act as a brake on development, but to apply practical wisdom and ensure that inventiveness

DESIGN FOR UPKEEP
An Illustration of Financial Considerations

Requirement : An Escort Force of 100 frigates actually available for service.

Assumption : Each ship has a life of 20 years.

Alternative I : Designed for 60 per cent availability and 5 per cent upkeep costs.

Availability is 60 per cent, therefore it is necessary to build 167 ships (since 100 is 60 per cent of 167).

If each ship costs £1,000,000, then building costs	=	£167,000,000
Upkeep costs at 5 per cent per annum for 20 years	=	£167,000,000
Total costs	=	£334,000,000

Alternative II : (Same total expenditure) Designed for 80 per cent availability and consequently reduced (say) $2\frac{1}{2}$ per cent upkeep costs.

Availability is 80 per cent, therefore, it is necessary to build 125 ships (since 100 is 80 per cent of 125).

Assuming that Total costs may again be	£334,000,000
and that each ship costs	£C.
Building costs	= £125 × C
Upkeep costs at $2\frac{1}{2}$ per cent per annum for 20 years	$= \frac{£125}{2} \times C$
Total costs = £334,000,000	$= £125C + \frac{£125C}{2}$
$£187\frac{1}{2}C$	£334,000,000
Therefore amount which may be spent on each ship to effect improved availability and halving of the upkeep costs—£C	= £1,780,000 approx.

Conclusions

(i) It seems reasonable to assume that upkeep costs could be halved if it were permissible nearly to double the first cost of a ship.

(ii) Consideration of the fact that a ship is safer at sea than in harbour in a nuclear war adds weight to the need today for designing high availability – low upkeep ships.

(iii) There is at present no evidence to indicate the point of diminishing returns as higher availabilities are sought. There is a clear need to evaluate this question so that Naval expenditure on new construction will produce the maximum striking power *at sea*.

Note : No allowance has been made for additional financial savings obtainable by the reduced numbers of men in complements of low upkeep ships but *one* artificer in 20 years allowing for training and wastage costs at least £20,000.

is not wasted by the development of equipments which are subsequently inadequate in respect of availability. The motor car industry has shown clearly that high performance can be matched by high availability and one eminent aircraft engine manufacturer has now the confidence to sell to its customers not engines but engine hours.

It has already been remarked that neither a high availability nor a high usage may be required of Naval ships in peace. It has also been noted that it may take some years to learn how to attain a high availability in war unless the lessons are learned in peace. It seems that the learning of the lessons would be best achieved by a really thorough evaluation in 'first of class' trials, in which war conditions were simulated for at least six months of time. The process of learning in peace could be accelerated by careful planning and statistical control of the trials and, provided maintenance work was forbidden at stipulated times, there would be no need to make the simulation too rugged a duty.

The Usage-Upkeep Pattern of Ships

In war, an operational commander may use ships with or without regard to their upkeep. Sufficient experience is now available to show that if he uses ships without a very careful regard to their upkeep he will soon get less usage. But is there not perhaps an insufficiency of information on the best methods of usage ? We have found, for example, empirically in the Korean war that a certain class of cruiser maintains its serviceability best, and therefore gives best availability, if it is allowed six days stand off a month ; and that this is better than, for instance, two weeks every two months ; but the reasons remain somewhat obscure. The periodicity of dockyard refits varies between the large fleets of the Navy for reasons perhaps not entirely connected with the needs of ships or the optimum pattern. Is there not room for a fuller evaluation here also ? And one almost instinctively questions the wisdom of 'Monday to Friday' daily sea-going in local flotillas when upkeep is not all it should be. But instinctive questioning is not enough, and a proper analysis, taking account of training requirements, welfare, as well as the upkeep balance, is needed in every case. Further, it should be reviewed frequently as circumstances change.

Turn Round Times Under Repair

When a ship is taken in hand for repair, a certain quantity of upkeep effort is applied. This effort may be given by a large number of men working for a short time or a small number of men working for a long time. In peace, if there is a large Reserve Fleet from which serviceable ship replacements can be provided, there may be little objection to long turn round times under repair, since there is no compelling demand for high availability ; but, in war, rapid turn round times under repair are vital to high availability. Last war experience, already quoted, showed how long it took to master this activity, among others : and every new class of ship presents new problems. A large civil air transport organization will turn round a four engined aircraft on its annual overhaul in five days. But, to do this, more than one hundred men must be employed concurrently and their every operation must be scheduled, arranged in the right order, and closely controlled on a time basis. Does not, for example, the coastal minesweeper present a very similar problem, and should not a planned repair be developed and tried on a few craft until it is proved ? Should not the procedure and facilities needed be set out in book form for issue to the many small yards which would undertake the task in war ? There is clearly an interesting field for effort here, too. It would be an application of Work Study in its most direct form and possibly in the form where there is the widest experience to call on from outside the Service.

Administration of Upkeep

In general, ships of a class are spread among many fleets. No one fleet authority, therefore, has access to experience of ship usage and upkeep for the whole class. For many years, however, in the case of the submarine, co-ordination of experience has been exerted by Flag Officer, Submarines. Following the success of this arrangement, and of the equally successful United States Naval experience of Type Commanders, the establishment of Class Authorities for all other types of ship in the Royal Navy has now been approved.

The Class Authority is an administrative aid to the efficient performance of upkeep ; its tools are orders, records, and reports. It is perhaps unnecessary to observe that the development of efficient documentation for material upkeep in the Service has lagged far behind the development of the equipments themselves, and that any considerable improvement of upkeep methods or reduction of upkeep in new design, requires an equivalent improvement in the flow of co-ordinated facts from the fleet. It is now hoped with the introduction of the Class Authorities to revise with expert advice the whole of the present paper work used in connection with the material of the fleet. To comfort those who have a horror of paper it may be added that there is reason to believe, by using modern methods, an improved efficiency in the transfer of information can be obtained without any increase in office work.

Control of Ship Upkeep in the Fleet

In the days of sail the Executive Officer was responsible for the tactical and strategic use of his ship and weapons and was also the only authority on their upkeep. Today he is no longer the authority on their upkeep, and his training reflects primarily the use of the ship or weapon. The technical officer of today is trained to consider the design and maintenance of his *part* of ship or weapon. It is perhaps hardly surprising if the matter of availability for use of the *whole* ship or its overall serviceability state has had in recent years less thought than it deserves.

Although the allocation of responsibility is clearly debatable, I believe myself that the questions of overall ship availability and serviceability, and the methods of achievement would be best embraced as a task by the Technical, as opposed to the Executive, Officers. In every ship or fleet the Technical Officers jointly should be able to present to their Commanding or Flag Officer the state of the upkeep balance in terms which he can understand and appreciate quickly. The Commanding or Flag Officer should be informed factually of how the overall material state is changing and of whether, and how much, it is improving or declining under his command. Inspection reports should make quite clear the changes in overall state which have occurred.

It is perhaps worth noting in this connection that about two thirds of all skilled upkeep measured in man hours is repair, and only one third is maintenance and that the opposite is true in respect of unskilled and semi-skilled work. Fleet Technical Officers must know not only the total upkeep man hours needed but also what has been provided in repair, as well as in maintenance, in earlier months and years. The provision of complete maintenance schedules for every ship, their costing in man hours, and the records of achievement held by the Class Authority should help improve the grip of the Fleet Officers over these matters ; but further developments are needed, particularly in respect of the manner of presentation or display of material state.

THE EFFORT OF THE MEN

By paying more attention in ship design to the subsequent upkeep burden, by improving the administration of upkeep and the tools used in administration, and by harnessing the machine to perform maintenance operations previously done by hand, many concrete improvements in ship availability are attainable. But our ability to hold an upkeep balance, at least as far as maintenance is concerned, finally remains in the hands of the individual seaman, electrician, stoker mechanic and artificer, the human being to whose superior complexity I referred at the outset of this paper. As officers we cannot be successful unless our men are successful, since it is their work which constitutes success.

Some years ago I assisted in the control of a year long experiment in the Fleet Air Arm to determine the relationship of numbers of maintenance men per aircraft to percentage serviceability attainable. We had a distinguished statistician in the Admiralty conducting team who was perhaps not the least surprised of us all to find, at the end of the trial, that each man was doing in the same time just twice what he was doing at the beginning. It was, of course, no more than that the squadron, ably led, had decided that the Admiralty trial party was testing them by taking men away month by month leaving the task the same, and, despite the fact that overtime was forcibly prevented, they were not prepared to be broken. They themselves found ways and means of improving output. Any naval officer can cap this experience with a tale of an earthquake or other emergency which has made men seem to do the impossible, but which has in fact only illustrated what they are capable of, if inspired. The difficulty is to know how to inspire without external and temporary stimulant, and how to make wider application of the evident fact that 100 men in one ship do half as much more work again as 100 men in many others.

The basic characteristics which we require in our men borne for operation and maintenance of ships' equipment are :—

(*a*) Knowledge.

(*b*) Skill, mental and physical, in the application of knowledge.

(*c*) Ability to apply (*a*) and (*b*) under adverse circumstances. This demands physical toughness and physical and mental courage.

(*d*) An inner driving force which will compel men to give of their best at all times. This is a matter of the spirit.

And from our officers we need the ability to induce these characteristics, not only in Training Establishments, but everywhere and always in the Fleets.

There is no serious problem about (*a*) and (*b*), and those concerned with the administration of training have the development of these characteristics well in hand. Such development indeed receives a very large proportion of training effort although it is only half the task. But, in the other half of the task, we may sometimes rely too much on external compulsions and, since pressure externally applied is a poor substitute for what comes from within, it is perhaps not surprising that there is a disparity between what men do and what they can do. Lord Montgomery has said that ' the morale of the soldier was the most important single factor in war.' I think that the Chairman of any large industrial undertaking, transport or production, would apply a similar valuation to his business today, and it can hardly be doubted that it applies equally to the Navy in peace or in war.

In looking to the future, there is much encouragement to be gained from such Naval developments as the Mediterranean Outward Bound Association. The basic purposes of this scheme, the development of physical fitness, the heightening of vitality in young men provided by adventure, the community of endeavour of officer and man engendered by a joint enterprise in natural surroundings, the provision of opportunities for officers to transmit a sense of moral values informally, are all within the powers of other Fleets or Flotillas to achieve.