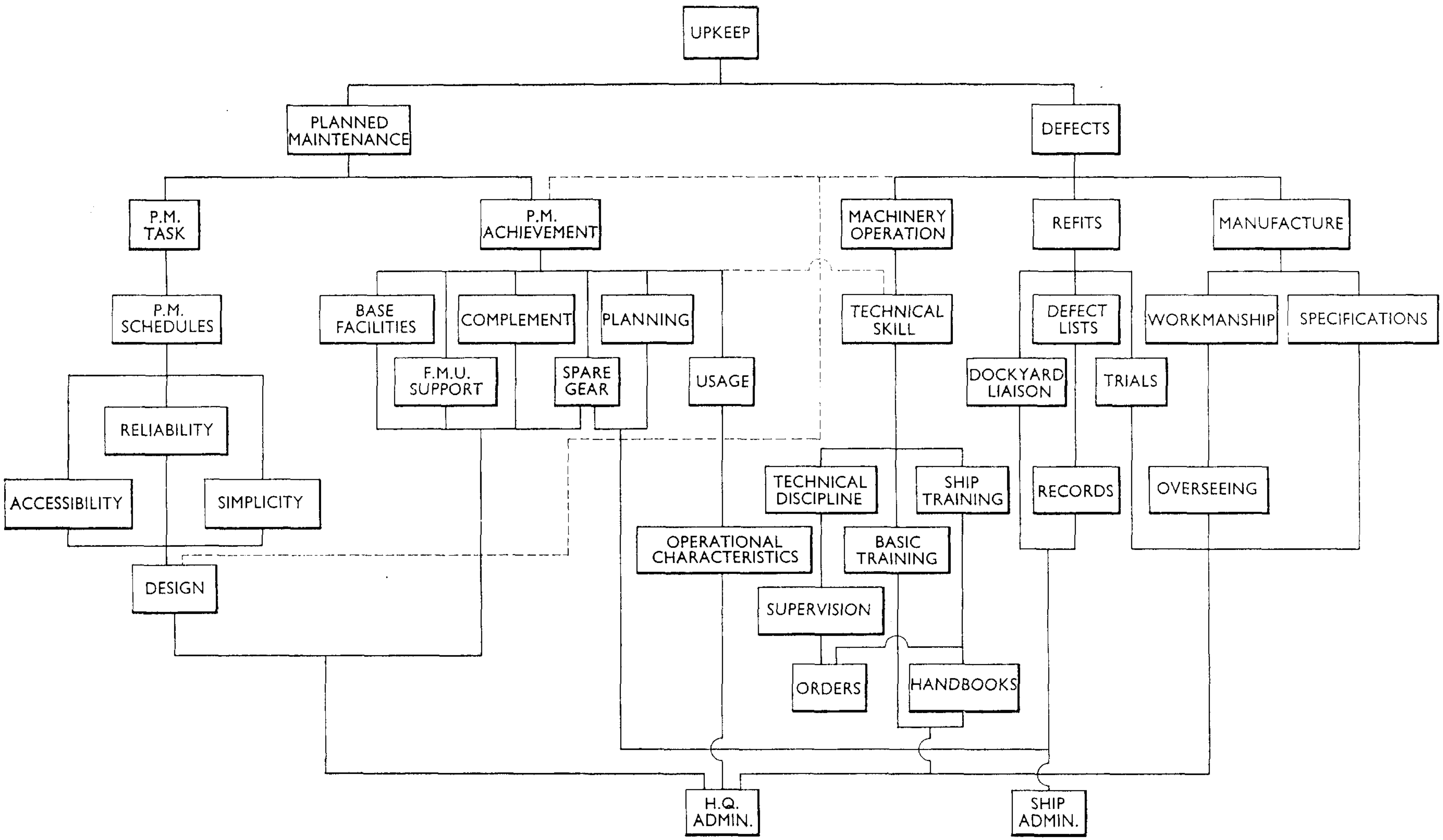

FIG. 1—FAMILY TREE DIAGRAM OF FACTORS AFFECTING UPKEEP

THE PROBLEM OF MARINE ENGINEERING UPKEEP

BY

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OBJECT

Upkeep is a problem and, in its widest sense, is a major problem in running an efficient modern Navy. A Navy in a high state of upkeep must inevitably have a high morale and be proficient operationally. The effect on a ship of poor upkeep is well known—defects proliferate, usage diminishes, morale deteriorates and operational efficiency, in all its aspects, can virtually disappear. The object of this article is to trace out the various factors involved and to show their effect and interdependence in the whole spectrum of upkeep. A 'family tree' diagram of these factors is shown in FIG. 1. It will be seen that many factors are built into a ship and cannot be changed, but some can be changed and a method is proposed for calculating the effect of these changeable factors so that they could be modified to suit varying operational conditions. This article is particularly slanted towards destroyers and frigates and it is not claimed that all factors affecting upkeep are mentioned or shown in FIG. 1, but any others could easily be fitted into the overall pattern. Some of the comments in this article may be considered to be, and indeed are, obvious, but they are included in order to provide a complete and balanced picture of the whole problem.

DEFINITION OF MAIN FACTORS INVOLVED

Upkeep

Upkeep is defined for the purpose of this article as the whole process resulting in machinery being in a good and efficient state so that it can always perform adequately when required to do so within the operational characteristics laid down for the ship. This means that during the usage period of the operational cycle, there should never be a significant backlog of outstanding planned maintenance or defects which would prevent the optimum performance of the machinery.

Planned Maintenance

Planned maintenance is defined as the programmed work, i.e., programmed at fixed periodic usage or calendar intervals, which is required to service, inspect and replace worn components in machinery so that it is maintained in optimum condition and is not allowed to deteriorate to such an extent that breakdown occurs.

Defects

Defects are defined as departures from design conditions which are found other than during the course of planned maintenance, and will include faults in machinery which may not be covered by planned maintenance schedules, e.g., porosity, joints, glands, fractures, etc.

Usage

Usage is defined as the number of days on which the main machinery is in use or at immediate notice and therefore subject to wear and deterioration and not available for maintenance or repair of defects.

General Effects on Upkeep

Upkeep depends on two aspects of planned maintenance: the actual task and the actual achievement. If the achievement equals the task, and the task is accurately assessed in the planned maintenance schedules, then the machinery should be in optimum condition, i.e., capable of optimum performance, provided there are no defects. The greater the disparity between the task and achievement, the greater the risk of machinery not being capable of optimum performance and of defects occurring which may result in breakdown or impaired performance.

The Planned Maintenance Task

(i) Planned Maintenance Schedules

The planned maintenance task is detailed in maintenance schedules which list the periodical servicing and inspection which should be carried out on the machinery by ships' staff, base staff and dockyard. This work should be evenly spread over the whole period of service of the machinery, and the task for any given shorter period can easily be obtained by selecting the appropriate proportion of the schedules, i.e., in a 4-month period, all schedules of 4M periodicity must be completed plus half the 8M items plus one quarter of the 16M items, etc. To keep the work involved in planned maintenance to a minimum, scheduled items should be given the maximum periodicity which experience shows is compatible with the wear rate. This in turn depends on:

(ii) Reliability

All machinery should be designed for maximum reliability which in effect means a low wear or deterioration rate, and thus maximum intervals between inspections.

(iii) Simplicity

Machinery should be kept to a minimum except for essential duplication and operate on simple principles, thus requiring less knowledge and skill for maintenance. It should also have as few moving parts and components as possible. This will reduce the work content and technical skill required to carry out inspections.

(iv) Accessibility

Each machine, as a unit, and each component which requires or is likely to require attention, should be readily accessible for operation and maintenance with the minimum effort using simple tools.

(v) Design

All the above factors are features which should be taken into account in the design of any machine. Unfortunately, to some extent cognizance of these factors often mitigates against design for efficiency and minimum weight and size, i.e. design for performance, and it is at the design stage that a proper balance must be struck between design for upkeep and design for performance. This is not easy and comparison of designs must take into account besides performance and upkeep, initial cost, space required, skilled personnel to operate and maintain the machine, and its relative importance in the machinery installation to justify advanced performance or complicated design. Ultimately this is a matter of Staff priorities as laid down in the Staff Requirements.

Planned Maintenance Achievement

The planned maintenance achievement is dependent on:

(i) Usage

This is one of the major factors since it affects both the time available for maintenance and the incidence of defects, and should be clearly specified in the operational characteristics for a ship. The effect of usage will be discussed separately later in this article and it is not intended to elaborate on this aspect at this stage.

(*ii*) *Base Facilities*

To enable machinery to be shut down and available for maintenance and to assist ships' staff with their work, it is essential that a ship should be provided with power, distilled water, domestic water, domestic steam, and preferably have access to workshop and repair facilities, stores, spare gear and technical advice and assistance. Lack of some or all of these facilities will reduce the amount of work which can be completed during a maintenance period.

(*iii*) *Fleet Maintenance Unit Assistance*

Assistance with planned maintenance and defects is provided by Fleet Maintenance Units during maintenance periods and is a valuable contribution to a ships' upkeep.

(*iv*) *Engine Room Complement*

This is another important factor affecting the planned maintenance achievement since the major part of the upkeep task is carried out by the ships' staff both at sea and in harbour.

(*v*) *Spare Gear*

The term spare gear is used to cover all the components, whether obtained from S.P.D.C.s or Naval Stores, which are required to be carried onboard or at bases for the repair of the machinery. The maintenance of 'onboard' spare gear up to establishment, in a good condition, correctly identified and catalogued, is a ship's responsibility, and the provision of complete and adequate stock at bases is an H.Q. responsibility. Non-availability of spare gear can have a most adverse effect on maintenance and result in machinery being out of use until the appropriate spare can be procured.

(*vi*) *Planning*

It is important that planned maintenance should be planned in advance and a good achievement is in no small measure dependent on good planning. Fortunately, a good tool to achieve this is available and being installed in ships in the form of the E.2 Bring-Up and Planning System which provides a visual statement of the planned-maintenance state at any time. This system was fully described in Vol. 15, No. 2 of the *Journal.*

(*vii*) *Technical Skill*

Even when all the foregoing conditions in (*i*) to (*vi*) are satisfied, the actual achievement still depends on the technical skill of the maintainers. This question of technical skill will be discussed further in the paragraph headed 'Machinery Operation'.

DEFECTS

General Effect on Upkeep

Assuming that planned maintenance is kept up to date and usage is kept within the operational characteristics of the ship—conditions which should normally apply to any ship—the major problem of upkeep is one of the incidence of defects. Defects are particularly detrimental to upkeep because they are unprogrammed and cause a heavy additional load on ships' staff apart from their effect on the performance of the machinery. The occurrence and rectification of defects depends upon:

Planned Maintenance Achievement

As previously mentioned, if the backlog of planned maintenance becomes excessive, or important schedules are not carried out, the risk of breakdown increases and defects will occur which could have been prevented by timely inspection. Consequently all the factors affecting planned maintenance achievement listed above can also have a bearing, albeit indirect, on the incidence of defects.

Design

Besides the effect of design on the work content of planned maintenance schedules, bad design can cause defects, although the schedules should take account of, and provide for, frequent examination of parts subject to excessive wear or risk. However, particularly with new machinery, the weak points of design may not become apparent until the machinery has been in use for some time, and other features may always be unsuitable for planned maintenance or be subject to unexpected failure, e.g., steam joints, corrosion, porosity, etc. The work content of rectifying defects is also dependent on design and the previous remarks with regard to the effect of design on planned maintenance are equally applicable to defects.

Machinery Operation

(*i*) *Technical Skill*

Experience shows that a large number of defects are caused by maloperation of machinery. This is or should be a diminishing liability as a commission progresses due to increased experience and thus increased technical knowledge and expertise of the operators. The technical skill actually depends on the following factors:

(*ii*) *Technical Discipline*

Provided the correct operation of machinery is detailed in Engine Room Orders and inculcated by training, so that all ratings know their task, the standard or quality of machinery operation depends on the technical discipline, or integrity, with which these orders and practices are observed. Ideally there should be no need for supervision, but this is not always the case and the quality of technical discipline will depend on:

(*iii*) *Supervision*

Human nature being what it is, it is necessary to apply adequate and conscientious supervision to important aspects of machinery operation and maintenance. In a small ship, this requires regular rounds and visits to work in progress by the Engineer Officer and senior ratings. Rounds are vital and besides affording an essential check on machinery operation, provide opportunity of early correction of malpractice. The amount of supervision required must be detailed clearly in the Engine Room Orders.

(*iv*) *Ship Training*

Despite the background experience and training of Engine Room ratings, it is always essential to round this off with detailed training onboard on the operation of the particular machinery fitted and to ensure that the particular requirements of the Engineer Officer are met. In addition, of course, it is also necessary to train junior ratings to qualify for higher rating so that they can carry out more responsible jobs in the department and shoulder a larger share of the upkeep load. Ship training is a powerful and major factor in the standard of technical skill and has an important bearing on the upkeep state of a ship.

(*v*) *Basic Training*

All ratings receive a basic training ashore before first joining a ship and at intervals in their career thereafter. This training should acquaint men with the basic principles of construction and operation of machinery that they are likely to meet and provide a foundation on to which ships training can be grafted. However, more than this is required of basic training, particularly for newly entered ratings. Basic training should also instil discipline, loyalty, common sense, reliability, enthusiasm and 'guts', and this last term is used because it embraces the essential qualities of determination and endurance. Physical guts are required to carry through arduous jobs, and there are many of them, and moral guts so that unpleasant tasks will be carried out and mistakes honestly admitted. Ship training should follow on with the development of these qualities. No engineer officer expects a newly entered rating to be highly competent technically but he does expect him to have the basic qualities which will cause ship training to be both sought and profitable. When these qualities are found lacking it may be because the rating has not been properly prepared for the rigours of life at sea and the humble position he will occupy for the first few years. Basic training should therefore concentrate as much on character training and preparing a man for life at sea, as on purely technical training.

(vi) Orders

Orders should provide all the detailed instructions and information for the operation of the machinery, and organizations and conduct of the Engine Room Department, which are not covered in the more general instructions and details found in the handbooks. Orders should be specific and detail precisely what is to be done, when, by whom, and to whom reports should be made. They should provide for all important functions to be signed for by the rating responsible, and for engine-room registers to be expanded where necessary to provide both a record of the operation of the machinery and a check-off list for its regular servicing and inspection by watchkeepers. The more inexperienced the Engine Room staff the more detailed and specific must be the orders. It is absolutely impossible to expect anyone to carry out a job properly, or reprimand him for inadequate performance, unless he has been precisely instructed in his task, and it is certain that unless the task is detailed in this way, it will rarely be carried out satisfactorily.

(vii) Handbooks

To assist ships staff to operate machinery correctly and carry out repairs, they must be provided with all relevant instructions and details of construction in the form of handbooks and drawings. In particular, handbooks should include dimensional details, permissible wear limits and setting-up instructions.

Refits

(i) General Effect on Defects

A bad refit leaves a ship with a backlog of known and incipient defects which imposes an unacceptable burden on the ships staff in addition to their other work. Most of these defects usually manifest themselves soon after the end of the refit, but some can remain undisclosed for a long time. The standard of refit depends in the main on the dockyard, but ships staff can help to ensure a good refit by attention to the following points:

(ii) Defect Lists

No ship will get a good refit unless a good defect list is prepared which accurately includes all known defects and inspections required. The main defect list, submitted in advance, should be as comprehensive as possible so that supplementary items are kept to a minimum and the dockyard is able to plan and carry out the refit without dislocation from unprogrammed work. In writing out the defect list, ships' officers should put themselves in the place of those who receive and read it and ensure that items are clearly specified and include all relevant information which will assist dockyard officials to assess the priority and work content of each item.

(iii) Records

It is difficult, if not impossible, to prepare a good defect list unless good records are kept in a ship. It should be possible to produce a defect list at any time at short notice without prolonged 'devilling' to collect items, and correct observance of the Standard Documentation procedure will facilitate this.

(iv) Dockyard Liaison

Ships staff should 'liaise' with the dockyard to assist them in identifying the work and provide all assistance possible in stripping down in wake, provision and identification of spare gear, and plan their own work to phase in with dockyard work. A keen watch should be kept on progress as the ships staff are in the best position to assess the effect of late completion of items on the setting to work programme. It is important that the ships staff should be fully employed so that no feeling of 'feather bedding', however unjustified, may be felt by the dockyard. There is no doubt that the attitude and assistance of ships staff is a major factor in obtaining a good refit.

(v) Trials

In order to detect bad workmanship and prove the work carried out during a refit, a comprehensive series of post-refit trials should be carried out on both main and auxiliary machinery. The results obtained should be commensurate with those obtained on acceptance trials or laid down by the Ministry of Defence. Since the ships staff may have been changed during the refit, and in any case will have become somewhat unfamiliar with operating the machinery, these trials also fulfil a useful subsidiary purpose of post-refit familiarization. It is essential that several days' steaming at low powers be carried out before attempting a full power trial.

Manufacture

(i) General Effect on Defects

Bad manufacture will cause defects and in the main these will occur in the early days of a ship's life. However, during the life of a ship there is a steady programme of replacement of worn parts and these themselves may be badly made, or even the wrong parts supplied. Bad manufacture can be minimized by the following measures:

(ii) Specifications

A firm must be supplied with detailed and unambiguous specifications so that it knows exactly what is required in respect of materials, methods of manufacture and performance.

(iii) Workmanship

The workmanship and firm's facilities must be of adequate standard to ensure that the specifications can be met.

(iv) Overseeing

A production check is required at appropriate intervals during manufacture to ensure that the specification is being met.

USAGE

General Effect on Upkeep

Usage is one of the major factors affecting upkeep because of its effects both on the planned maintenance achievement and the incidence of defects.

(i) Effect on Planned Maintenance Achievement

The planned maintenance achievement depends in large measure on the time available to carry it out. Planned maintenance can be and is carried out during the usage period, but the achievement possible during this time is limited by the number of non-watchkeeping staff to carry it out and the extent to which machinery can be taken out of service and made available for maintenance.

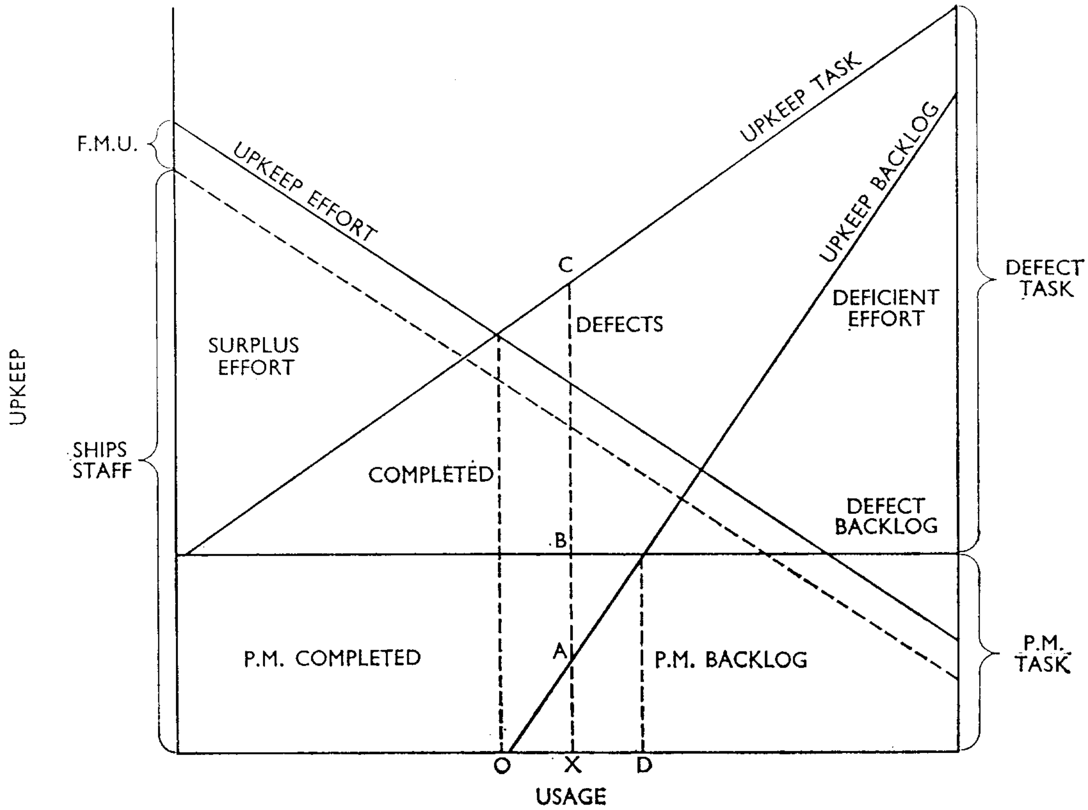

FIG. 2—CHARACTERISTIC UPKEEP/USAGE DIAGRAM

0 = Optimum Usage

Percentage backlog of P.M. $= 100 \times \frac{XA}{XB}$ } for excessive Usage X

Percentage backlog of Upkeep $= 100 \times \frac{XA}{XC}$

D = Usage for 100 per cent backlog of P.M.

(ii) Need for Precise Definition

Because of this question of availability of machinery, it is important that usage should be defined in terms which give an accurate indication of the machinery available for upkeep. Usage can thus be best described as the number of calendar days on which the main machinery was in use or at immediate notice. A practice has grown up of defining the usage as the number of 24-hour days on which the main machinery was in use, i.e., the number of hours underway or at immediate notice, divided by 24. This gives a false estimate of the time available for upkeep, however accurate it may be for assessing wear rates in relation to the time in use. For instance, a ship which steams from 0800 to 1600 daily for three days would have a usage of three days by the first definition but only one day by the second definition. By the latter definition, two days out of the three would appear to have been available for upkeep which, from the practical aspect, is not the case and is misleading.

(iii) Effect on Defects

Investigation carried out into the incidence of defects has shown that defects increase with increased usage. This is because of the increased wear, lighting-up stresses and greater opportunity for maloperation, and, if usage increases to such an extent as to seriously affect the planned maintenance achievement, because of lack of planned maintenance.

Operational Characteristics

Because usage has such an important effect on upkeep, it is essential to evaluate and define the usage to which a ship can be subjected without detriment to upkeep, i.e., to define the operation characteristics. Ideally, usage should be such that the upkeep effort can exactly match the upkeep task. Operational staffs should be able to recognize clearly the effects on the backlog of upkeep which usage in excess of this figure will produce or, providing the ships staff prevent a backlog from accumulating, the extra work required to do this. In practice, because the rectification of known defects is usually more important than the possible prevention of defects by planned maintenance excessive usage up to a certain limit will not result in a significant increase in the defect backlog but will result in an increased backlog of planned maintenance.

The effect of usage on upkeep is shown in the characteristic upkeep diagram in FIG. 2. It can be seen that the upkeep load of planned maintenance plus defects increases directly with usage, while the upkeep effort of ships staff plus Fleet Maintenance Unit decreases with usage. The point where the two lines cross is the point of optimum usage. As usage increases beyond this point, the deficiency of effort to cope with the upkeep task, on the assumption that defects are completed in preference to planned maintenance, results in a backlog of planned maintenance which rapidly increases. It can be seen that up to the point of optimum usage, effort exeeds task, and this fact can be used by operational staffs to balance excessive usage over a previous period or provide for leave periods and visits.

In order to make use of the diagram in FIG. 2, it is necessary to establish the respective values of the upkeep task and upkeep effort, and this is described in the next paragraph.

EVALUATION OF UPKEEP CHARACTERISTICS

Establishment of Upkeep Task

The upkeep task is compounded of the planned maintenance task and the defect task. The assessment of the task can be done in two ways: either by work measurement of each individual task, or by summation of the number of jobs. On the face of it the former method would appear more accurate, but a little thought shows that it is subject to approximations and not applicable to most defects which can seldom be rehearsed and work measured in advance. It is important that the work measurement should be carried out for the average rating with average organization and preparation for the job. Secondly, an allowance must be made for the cooling down of the machinery to enable it to be worked on and the effectiveness of the maintainer, and these will vary between cold and tropical climates.

The method of summation of jobs is a variation of the 'random sampling' principle of work study, and takes no account of the actual work content of each job. This is satisfactory since in using this method no absolute measurement of task is required but a comparative assessment of tasks over equal periods. The only requirement is that the work content should be directly proportional to the number of jobs. The 'random sampling' principle states that if a random number of samples are taken from the whole, the proportion of different units in the sample is the same as the proportion of different units in the whole. Thus if each job was considered to be a counter numbered with its work content, then if one picked out at random a given number of counters from the total number, each sample selected would contain the same proportion of jobs, measured in effort, as the total number. Thus the effort for each sample would be the same, and the total effort would be proportional to the number of samples, i.e., total number of counters selected. If, out of a total work task of 600 jobs, 400 jobs are extracted at random, i.e., completed, only four-sixths of the total work task measured in effort will be completed. This method is not completely accurate as the accuracy depends on the number of samples, but its accuracy is considered to be commensurate with the accuracy of the other details on which the following calculations are based and for the results which are required. Of course, in this application, this method of work assessment is not entirely random since maintenance is 'planned', and it would be possible to plan a numerically good planned maintenance achievement of items which have low work contents. In practice, however, it is believed that this does not happen to any significant extent and also the greater the upkeep achievement each quarter, the more chance there is that work effort can be accurately assessed in number of jobs.

The accumulation of all the data necessary to be able to establish and predict the upkeep task in man-hours is a formidable task which would take years, and the results would inevitably hang behind reality as new machinery comes into service. It is not suggested that this cannot be done with reasonable accuracy but it is considered that the summation of jobs method can give reasonably accurate results with less research and be based on selected records which already exist. This is borne out by the consistency of the work factors and defect factors evaluated from even the scanty records for an Escort Squadron shown in TABLE I and which will be discussed in the subsequent paragraphs.

(*i*) *The Planned Maintenance Task*

For the purpose of this article the 'summation of jobs' method is used for assessing work and the planned maintenance task is thus the total number of jobs planned for a given period. Because the records, on which the calculations described later in this article are based, are for three-monthly periods, the planned maintenance load is assessed for this period and is designated as 'M' in the following calculations.

(*ii*) *The Defect Task*

The defect task is one which is more difficult of evaluation, since, on the face of it, the occurrence of defects could be considered to be haphazard. However, analysis of a *Daring* Class records over a fifteen-month period shows that, where good records are kept, defects can be related to usage with reasonable accuracy. Thus the number of defects divided by the number of days at sea gives a 'defect factor' which is remarkably consistent, and this is shown in TABLE I. The defect task for any usage can be estimated by multiplying the number of days at sea by the defect factor of the particular ship, i.e., S x D, where S is the usage and D is the defect factor.

(*iii*) *Total Upkeep Task*

The total upkeep task per three months in defects and planned maintenance of 3M items and above is M + (S x D). This selection of jobs is made because it is considered that this is the work which is carried out by skilled effort, i.e., artificers and mechanicians. In general, the unskilled effort is adequate to cope with the unskilled machinery upkeep task and the shorter periodicity skilled tasks are less likely to have a backlog because of their importance.

Evaluation of Upkeep Effort

(*i*) *Ships Staff Effort*

The upkeep effort depends on the number of maintainers, the time available and the 'work factor' of the maintainers. This factor, defined as number of jobs completed per day per E.R.A., has to be established from ship's records as with the defect factor. Analysis of Squadron records shown in TABLE I shows how this factor is obtained and that over a long period of time it remains

TABLE I—*Analysis of Escort Squadron Upkeep Records*

Ship Class	*Daring*				*Type 12*		Ca				*Type 61*		
Quarter ending	9/63	6/63	3/63	12/62	9/63	6/63	9/63	6/63	3/63	12/62	9/63	6/63	3/63
1. Total P.M. load (3M and above) .	606	535	530	530	307	290	231	260	236	160	367	325	320
2. P.M. items not completed . . .	108	151	45	83	Nil	16	58	33	25	32	Nil	90	23
3. P.M. items completed (1—2) . .	498	384	485	447	307	274	173	227	211	128	367	235	297
4. Total defect load	305	224	301	160	192	211	164	117	125	118	156	225	180
5. Defects not completed . . .	56	58	30	41	71	50	67	38	38	16	9	21	Nil.
6. Defects completed (4—5) . . .	248	166	271	119	121	161	97	79	87	102	147	204	180
7. Total upkeep completed (3 + 6) . .	747	550	756	666	428	435	270	306	298	230	514	439	477
8. Upkeep done by F.M.U. . . .	89	82	100*	55*	39	55*	Nil	50	55*	55*	33	39	55*
9. Total upkeep completed by ships staff (7—8)	658	468	656	611	389	380	270	256	243	175	481	400	422
10. No. of days usage	48	51	29	29	48	51	60	49	38	44	17	46	30
11. No. of E.R.A.s/Mechs. . . .	11	11	12	10	9	9	9	9	9	9	7	7	7
12. Defect factor 4 ÷ 10	6·3	4·4	10·0	5·5	4·0	4·1	2·7	2·4	3·3	2·7	9·1	4·9	6·0
13. Work factor $\left(=\frac{\text{Work Done (9)}}{\text{9ON} - \text{NwS}}\right)$.	0·94	0·69	0·62	0·84	0·6	0·58	0·43	0·39	0·35	0·26	0·83	0·82	0·78
14. Average defect factor . . .	6·5				4·0		2·8				6·6		
15. Average work factor	0·77				0·58		0·38				0·81		

*Estimated—average known figures.

remarkably consistent, and averages out at 0·8, which is regarded as the optimum value. The low work factors shown for the Type 12 and *Ca* are due to an overbearing of E.R.A.s in relation to the task and some under-usage, as will be shown later. The benefit of the work factor described above is that it is derived from results actually achieved and thus no artificial weighting factors are required.

In a 90-day period the upkeep effort available from ships staff is:

$NW(90 - S) + (N - Nw)WS$, i.e., Effort in harbour + effort at sea,

where N = No. of maintainers

S = Usage in days

Nw = No. of watchkeeping maintainers

W = Work factor

This expression can be resolved to read: $90NW - NwWS$

Equating this to the total achievement in TABLE I, having deducted the assistance of Fleet Maintenance Units mentioned below, gives the work factor for E.R.A.s.

(ii) Fleet Maintenance Unit Support

This is also assessed in number of jobs, although, of course, valuable additional assistance is given in the form of workshop facilities, and designated as 'F'. Scrutiny of the records of the Squadron in TABLE I shows that this assistance is of the order of 55 items for each maintenance period.

(iii) Total Upkeep Effort

The total upkeep effort can be written as:

$$\text{Effort} = 90NW - NwWS + F$$

The Characteristic Upkeep Equation

Optimum usage occurs as shown in FIG. 2 when the upkeep effort equals the upkeep task, and thus the characteristic upkeep equation can be written:

$$M + SD = 90NW - NwWS + F$$

from which:

$$\text{(A)} \quad S = \frac{90NW - M + F}{D + NwW}$$

$$\text{(B)} \quad N = \frac{M + SD + NwWS - F}{90W}$$

$$\text{(C)} \quad W = \frac{M + SD - F}{90N - NwS}$$

(D) Percentage backlog of P.M. =

$$\frac{100(S(D + NwW) + M - 90NW - F)}{M}$$

(E) Percentage backlog of Upkeep =

$$\frac{100(S(D + NwW) + M - 90NW - F)}{M + SD}$$

TABLE II—*Table of Upkeep Factors and Optimum Usages for an Escort Squadron.*

Class	*Daring*	*Type 12*	*Ca*	*Type 61*
M	550	300	250	350
D	6·5	4·0	2·8	6·6
F	55	55	55	55
W	0·8	0·8	0·8	0·8
Nw	6	3	3	3
N	9	5	7	8
S	13	17	59	30
Sc	12	12	23	17

(F) $F = M + SD - 90NW + NwWS$

Values of all the constants in these equations are known from the records shown in TABLE I, and the appropriate values can be chosen for the other factors, S and N, to suit the required operating conditions.

The records in TABLE I are out of date since the revised periodicities for planned maintenance were promulgated in A.F.O. 1694/63 but are used in this article for the purpose of illustration. Also, the number of E.R.A.s shown in TABLE I are in excess of the approved scheme of complement in most cases. For the purpose of this article all calculations are based on the number of E.R.A.s specified in the scheme of complement, as far as they are known. These are shown in TABLE II.

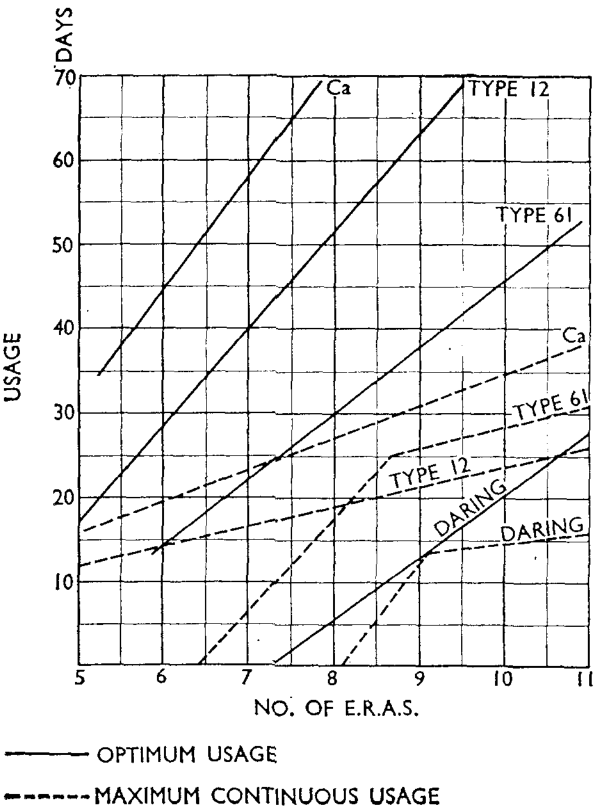

FIG. 3—EFFECT OF NUMBER OF E.R.A.S ON USAGE

Optimum Usage

TABLE II lists the average values of 'M', 'D' and 'F' shown in TABLE I, the optimum value for 'W' and the assumed values of 'N'. The calculated values of 'S' are found by applying Equation (A).

(*i*) *Effect of Number of E.R.A.s on Optimum Usage*

By using Equation (A) and substituting different values of 'N', the effect of 'N' on usage can be found and are shown in FIG. 3 for the ships listed in TABLE I.

(*ii*) *Establishment of Adequate Complement of E.R.A.s*

To achieve this it is first necessary to decide for what usage the ship is to be complemented. For the purpose of this article it is considered that optimum usage

TABLE III—*Table of E.R.A.s required for Optimum Usage of 50 days.*

Class of Ship	*No. of E.R.A.s*
Daring	14·6
Type 61	10·4
Type 12	8
Ca	6·4

should be 50 days in every 90-day period. Substituting this value in Equation (B) gives the number of E.R.A.s required and these are shown in TABLE III. It can be seen that an overbearing of E.R.A.s existed in the *Ca* and Type 12 ships listed in TABLE I.

(iii) Maximum Number of E.R.A.s who can be Effectively Employed at Sea

Analysis of planned maintenance schedules and defects for a *Daring* and a Type 12 shows that up to 40 per cent of the total upkeep load could be carried out at sea if the machinery could be made available, i.e., during independent passages and cruising, and it is considered that this assumption applies also to *Ca.s*, while in Type 61s with multiplicity of main engines which could be worked on at sea, it is considered that this proportion could be increased to 70 per cent. It is important that the number of daywork E.R.A.s can be fully employed at sea. If this were not so it would be necessary to reduce the number of E.R.A.s allowed, even though required by the Equation (B), so that there is no under-employment at sea. In this event there would not be enough E.R.A.s to cope with the upkeep load and it would be necessary to make up the deficient E.R.A. effort by increased Fleet Maintenance Unit support during assisted maintenance periods which could be calculated by Equation (F).

The formula for calculating the maximum number of E.R.A.s who can effectively be employed at sea can be easily deduced, viz.:

$$\text{Upkeep load at sea} = 0{\cdot}4(M + SD)$$

$$\text{Upkeep effort at sea} = (N - Nw)SW$$

For economical use, effort must equal load:

Thus $(N - Nw)SW = 0{\cdot}4(M + SD)$ and

$$\text{(G)} \qquad N = \frac{0{\cdot}4(M + SD)}{SW} + Nw \text{ or}$$

$$\frac{0{\cdot}7(M + SD)}{SW} + Nw \qquad \text{for Type 61}$$

The numbers of E.R.A.s who can be economically employed at sea in the ships shown in TABLE I are shown in TABLE IV.

Effect of Excessive Usage

(i) On Percentage Backlog of Planned Maintenance

By applying Equations (D) and (E) the percentage backlogs of planned maintenance and upkeep can be found for varying excessive usages and the results are shown in FIG. 4 assuming that no extra effort is put in by ships staff and the work factor remains 0.8.

TABLE IV—*Table of number of E.R.A.s who can be economically employed at sea for Usage of 50 days.*

Class of Ship	*No. of E.R.A.s*
Daring	14·75
Type 61	9·8
Type 12	8
Ca	6·9

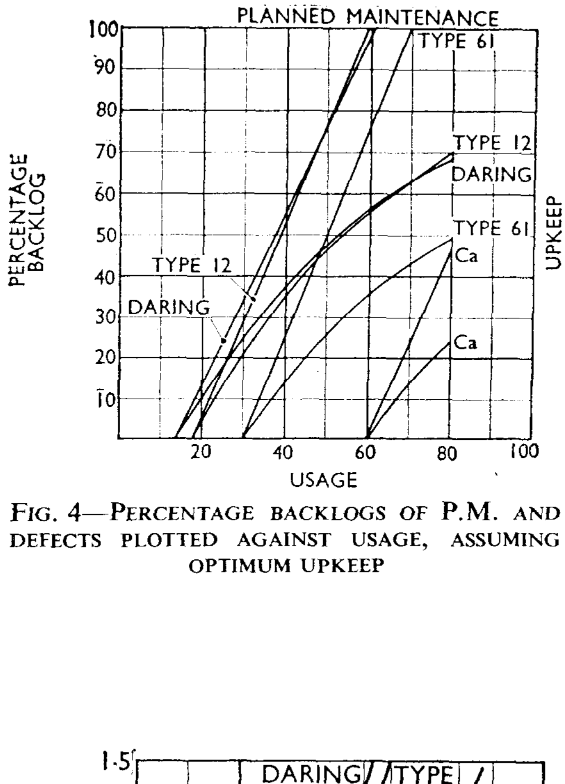

FIG. 4—PERCENTAGE BACKLOGS OF P.M. AND DEFECTS PLOTTED AGAINST USAGE, ASSUMING OPTIMUM UPKEEP

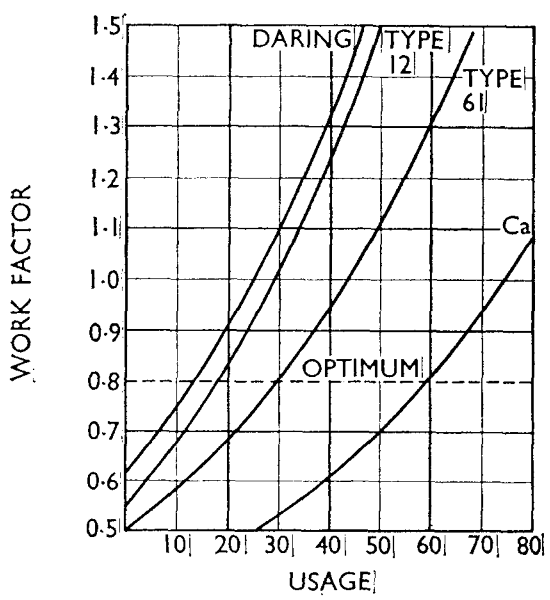

FIG. 5—EFFECT OF EXCESSIVE USAGE ON WORK FACTOR ASSUMING OPTIMUM UPKEEP

(*ii*) *On Work Factor*

On the assumption that optimum upkeep is maintained for excessive usages, the increased work factors can be found by using Equation (C) and are shown in FIG. 5. However, it is unlikely that a ship will be able to maintain optimum upkeep with excessive usage and more likely that the ships staff will work harder but still have a backlog of planned maintenance. The resulting work factors can be found by assuming a series of given excessive usages, and for each value of usage, drawing graphs of the work factor plotted against percentage backlog. It is easy from the graphs to measure off the effort the ship has put in when its usage and percentage backlog are known. These curves are shown in FIG. 6 for *Daring* Class only. The effect of an increase in E.R.A.s would be to push the curves to the right in FIG. 5 and to lower the curves in FIG. 6, in each case reducing the work factor for given usage.

Operational Cycle

(*i*) *Definition*

The operational cycle consists of alternating periods of usage and harbour time in a quarter. The total usage and the maximum continual usage are defined in the Operational Characteristics for the ship. The previous calculations enable the values of optimum usage and the effects of excessive usage to be calculated.

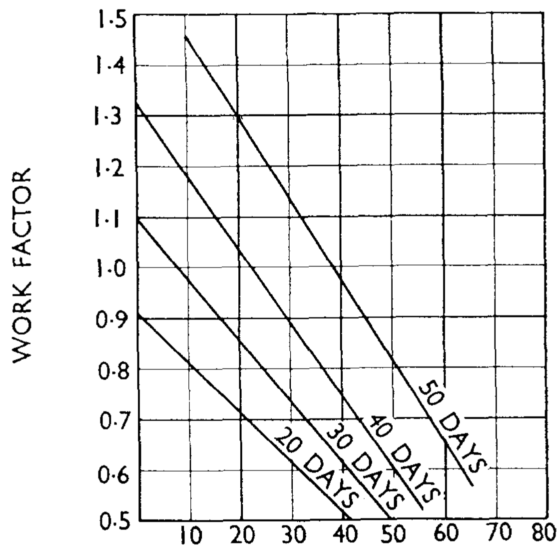

FIG. 6—EFFECT OF USAGE ON WORK FACTOR ASSUMING LESS THAN OPTIMUM UPKEEP (FOR DARING CLASS ONLY)

(ii) Typical Upkeep Task and Achievement

Although the calculations are valid for calculating the optimum usage and backlogs of upkeep at the end of the quarter, in practice, at any intermediate stage in the quarter, the backlogs may be quite different since the pattern of usage will be irregular. A graph of typical upkeep task, achievement and backlogs of planned maintenance and defects is shown in FIG. 7. It can be seen that, although there is no upkeep backlog at the end of the quarter, there is an appreciable backlog at intervals within the quarter. These backlogs depend on the difference between the upkeep task and the upkeep effort at sea, which in turn depends on the number of E.R.A.s, number of watchkeepers, the defect factor and, most of all, the continuous usage. Note that the backlogs shown in FIG. 7 are measured in number of jobs and not in percentages.

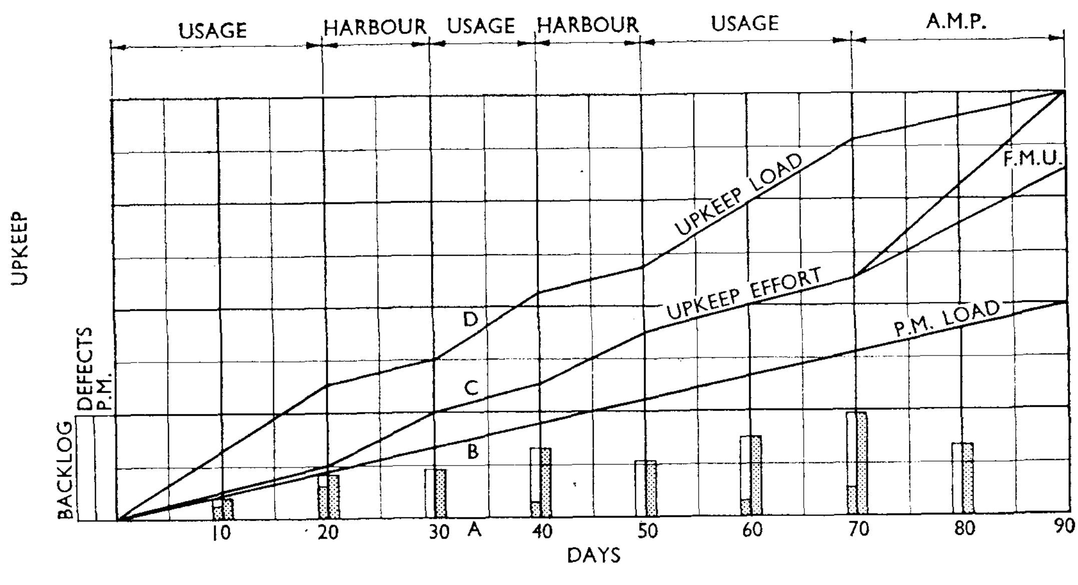

FIG. 7—TYPICAL UPKEEP TASK AND ACHIEVEMENT DIAGRAM—BLOCKED COLUMNS REPRESENT BACKLOG OF DEFECTS AND P.M.

It can also be seen that the phasing of the assisted maintenance period in relation to the rendering of upkeep returns has an important bearing on the backlog reported. Thus, for the mythical ship whose state is shown in FIG. 7, returns rendered at the end of the period would show a 'nil' backlog whereas if the returns were rendered in the middle of the period there would be an appreciable backlog. So long as this phasing is maintained, as it probably would be, it would be impossible for this ship to render a 'nil' backlog return.

(iii) Maximum Continuous Usage

With optimum usage, i.e., no upkeep backlog at the end of a 90-day period,

TABLE V—*Table of Optimum and Maximum Continuous Usage.*

Ship	*Optimum Usage*	*Maximum Continuous Usage*	*Percentage Defects Comp. at Sea*
Daring	13	12	37
Type 12	17	12	40
Type 61	30	17	73
Ca	59	23	40

the maximum interim upkeep backlog during the quarter is produced by continuous usage equal to the optimum. If the optimum usage is broken down into shorter periods, then the respective backlogs will be smaller. It is necessary to decide what maximum upkeep backlog is permissable, and adjust continuous usage to suit. A backlog of planned maintenance within the optimum usage is not serious as it can be made up by the end of the quarter, but a backlog of defects is serious. For the purpose of this article it is assumed that a backlog of defects which will take the ships staff one week to rectify without assistance is the maximum permissable. Using this definition it is possible to calculate the maximum permissable continuous usage as follows:

Let S_c = Maximum continuous usage

Then S_cD = Incidence of defects

and $S_cW(N - Nw)$ = No. of defects rectified during this period

Therefore backlog of defects = $S_c(D - W(N - Nw))$

Work effort in harbour per week = 7NW

Therefore $7NW = S_c(D - W(N - Nw))$ and from this

$$\text{(H)} \quad S_c = \frac{7NW}{D - W(N - Nw)}$$

Application of the values in TABLE II to this equation gives the values of continuous maximum usage. This is true provided not more than 40 per cent or 70 per cent of the defects are completed at sea (see 'Establishment of Upkeep Task', sub-paragraph (iii).) In cases where the upkeep effort at sea exceeds this proportion of the defect rate, i.e., W(N – Nw) is greater than 0·4D, the provisions of sub-paragraph (iii) of 'Optimum Usage' apply and the following equation can be deduced:

Backlog of defects = $0{\cdot}6S_cD$

Harbour effort = 7NW

$$\text{(I)} \quad \text{Therefore } S_c = \frac{7NW}{0{\cdot}6D}$$

Values for the maximum continuous usage of the ships under review are shown in TABLE V. The effect of the number of E.R.A.s on maximum continuous usage is shown in FIG. 3. The 'break point' in the curves for *Daring* and Type 61s indicates where 40 or 70 per cent of defects can be completed at sea, and additional E.R.A.s above this number will not be able to complete any more defects.

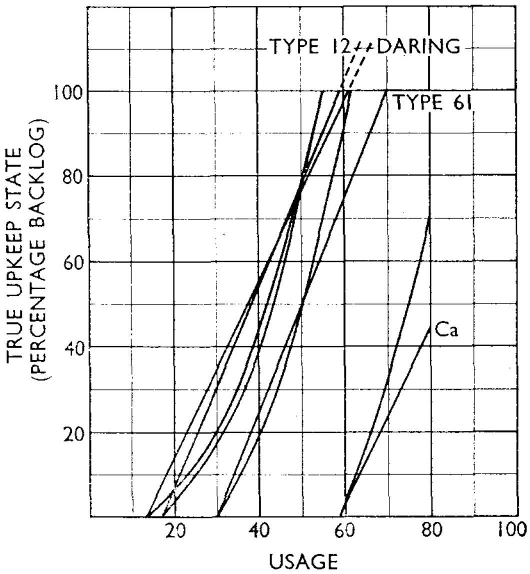

FIG. 8—EFFECT OF USAGE ON TRUE UPKEEP STATE —CURVED LINES REPRESENT TRUE UPKEEP STATE

Upkeep State

The backlog of upkeep (P.M. + Defects) at the end of a quarter for excessive usage are shown in FIG. 4. On the assumption that the backlog contains no defects up to 100 per cent backlog of planned maintenance, since defects will be completed in preference to planned maintenance, the percentage backlog of planned maintenance gives a guide to the upkeep state of the ship. The planned maintenance calendar periodicities, however, must have been related to an expected number of running hours, since deterioration and wear in nearly every case is proportional to use. In assessing a particular schedule as three-monthly, it must have been thought that the running hours of the particular machine in three months were such that the wear-rate would require it to be examined every three months. If the machine runs for a lesser period then the urgency to carry out the inspection after three months and the risk to the machine is lessened. It is assumed that the calendar periodicities are based on a 50-day usage per quarter. Thus failure to carry out a 3M item after usage of 13 days would only be 13/50 as serious as if the usage had been 50 days. This is not necessarily arithmetically true for items over 3M periodicity, unless the usage in the preceeding and subsequent quarters is 13 days, but on average can be assumed to be true for all items. The percentage backlog of planned maintenance must therefore be corrected for usage to give a true indication of the upkeep state by multiplying the percentage backlog shown in FIG. 4 by the actual usage divided by 50. Graphs of the corrected percentage backlogs of planned maintenance (i.e., the true upkeep state) for given usage are shown in FIG. 8.

HEADQUARTERS ADMINISTRATION

This term is used in this context to refer to the administrative influences, external to the ship, both at M.O.D. and Command level which determine the upkeep characteristics and contribute to the upkeep state of a ship. It is thus the responsibility of the H.Q. administration to create the conditions under which good upkeep can be achieved. More than this, it is important that the H.Q. administration should be able to recognize and accept the implications of the upkeep characteristics it has created for a ship as expressed in the Characteristic Upkeep Equation and shown in FIG. 9. Every effort should be made to keep the planned maintenance task and the defect factor to a minimum, compatible with design for performance. Once the design is finalized, the training, complementing and usage obligations must be discharged or, where this cannot be done, the upkeep limitations must be appreciated and accepted, and extra Fleet Maintenance Unit assistance provided to compensate.

SHIP ADMINISTRATION

Just as it is the responsibility of H.Q. administration to create the conditions for good upkeep, so it is the responsibility of the Ship Administration to take advantage of these conditions and, by efficient work, good planning and correct

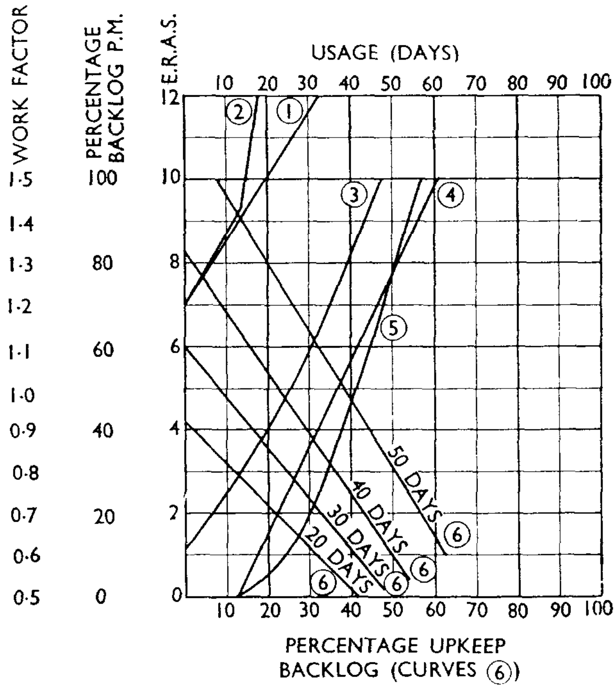

FIG. 9—CHARACTERISTIC UPKEEP CURVES FOR DARING CLASS

Curves (1) Optimum Usage for No. of E.R.A.s
(2) Maximum continual Usage for No. of E.R.A.s
(3) Work factor for excessive Usage assuming optimum Upkeep
(4) Percentage backlog of P.M. for excessive Usage
(5) True Upkeep state for excessive Usage
(6) Work factor for varying percentage backlog of Upkeep and given Usage

Note: Curves (3) to (6) are calculated for nine E.R.A.s, the approved scheme of complement.

machinery operation ensure and achieve good upkeep. This is a harder task than it sounds, and good upkeep will only be achieved by the earnest endeavour of all members of the Engine Room Department, co-ordinated and directed by the Engineer Officer and senior ratings towards a known goal which all can recognize and take pride in achieving.

CONCLUSIONS

Many assumptions, based on practical experience, have been made in establishing and solving the foregoing upkeep equations. Readers will readily note them, but it is not considered that they invalidate the arguments in principle providing the results obtained are applied to problems involving the same order of magnitude in numbers and time scale. Upkeep and operational characteristics obviously cannot be evaluated with a high degree of accuracy in this article, in view of the scarcity of records available, and the imponderable effect of the human effort, but it can be evaluated with reasonable accuracy to match the practical realities. One quarter—a 90-day period—has been chosen for the basis of these equations because it represented the periodicity of the returns available and it is considered that it represents a reasonable operational period for establishing and checking a ship upkeep state. If a longer period such as a year were taken, it would be more difficult to obtain adequate records and intermediate upkeep backlogs could become excessive if the pattern of usage changed during the year. It is evident that the planned maintenance load has a major bearing on the operational characteristics of the ship and it is important that there should be no over-insurance in the schedules. For the purpose of this article, it has been assumed that all schedules of three months and above are carried out by skilled effort, but it is apparent that the more of this task that can be carried out by semi-skilled or unskilled effort, the greater the usage that can be obtained, and full advantage must be taken of any M(E) rating who has been trained, or shows an aptitude for maintenance. In practice some skilled effort is devoted to shorter periodicity schedules such as weekly creep tests and essential supervision and rounds, but the work factor of 0.8 derived from actual results allows for this.

In regard to design, standization, provided it is not prejudicial to advance, should assist upkeep by requiring a narrower based expertise from operators and maintainers, who would thus be more likely to be proficient, and by reducing the training and spare gear commitments. The designer's problem is a very real one to relate improved performance to upkeep requirements and to ensure that the law of diminishing returns does not take effect so that improved performance does not result in an unacceptable reduction in usage or increase in the numbers and skill of maintainers.

To end on a note of hope, it must be encouraging to read recent Fleet Orders, technical articles and Minutes of Engineer Officers' Meetings and see that most of the comments in this article have been, or are being implemented, but the battle of upkeep, like so many other battles, is one which can never be won. The most that can be hoped for is to achieve and secure a position of decisive advantage on the commanding slopes of upkeep.

Departmental Comment

As stated by Commander Peaver, much of the subject matter in his article is already undergoing earnest and indeed heart-searching investigation at Headquarters. Much of it has been said before but the more often it is repeated, the more likely it is to make and retain its impression.

His complementing formula makes as many assumptions as does our own and is just as likely to produce the right answer or the wrong one for that matter. If we are truthful, we will recognize that complement evaluation will never be an exact science but will always remain an art.

Once we have our ship at sea and have collected data about her, his other formulae would be most useful to the Command and it is in this field that its real application can be seen.

It is pleasing to see several facts quoted which support opinions which we have recently expressed.