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# THE ACTION OF AN ARTHROPOD MOULTING HORMONE ON BARNACLES AND ITS APPARENT NATURAL ROLE IN THE CONTROL OF DEVELOPMENT AND GROWTH

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## Abstract

*Crustecdysone, a major arthropod development and growth hormone, increased moulting activity in adult Balanus balanoides when injected at doses of 0.02 and 0.2 µg per animal. A synchronization of moulting was imposed by the hormone and more than one cycle of accelerated activity was evident; differences were apparent between the effects of single dose and sequential injection. The possible mechanisms involved in these responses are discussed. From the evidence it appears that barnacles possess an ecdysone system which controls moulting. Sustained increases in activity, of a different nature to the hormone effects, occurred in sea-water injected controls; these were apparently due to wound or irritant effects arising from the injection technique. Evidence was found which suggests that an ecdysone or associated hormonal system controls calcification. The significance of these results is discussed in relation to anti-fouling studies.*

**Introduction** As part of the anti-fouling research programme, studies are being made of the biological mechanisms controlling the development and growth of barnacles. The aim is to determine how these mechanisms can be exploited in an anti-fouling system. Present studies are concerned with the role and characterisation of what is apparently a major hormone system—that controlling moulting.

Barnacles are crustaceans and belong to the animal phylum known as arthropods. In this group a basic pattern has emerged for the hormonal control of the major physiological activities. A dominant activity in these animals is the periodic moulting, or shedding, of the outer cuticle covering the body. This is the

mechanism for development through the larval stages and for adult growth. It has been established that this process is under the hormonal control of a group of steroids known as ecdysones (for a review, see Horn, 1971). Although the outer calcareous shell of the barnacles is permanent, it increases in size as the body grows and the cuticle covering the body is moulted periodically. It has been shown that the activities of the shell and cement glands correlate with these moulting cycles (Bocquet-Védrine, 1965, 1970). Larval development and the metamorphosis to the adult stage are also brought about through moulting. It can be seen, therefore, that this process plays an important part in barnacle biology.

Although the role of hormone systems in the control of crustacean development and growth has been well-established for a number of years (for reviews, see Carlisle and Knowles, 1959, Waterman, 1960, Kurup, 1963, Highnam and Hill, 1969, Novak, 1969, and Adiyodi and Adiyodi, 1970), little is known of biological control mechanisms in barnacles. Evidence as to the nature of their hormone systems is limited to observations on the presence and possible function of neurosecretory cells in the nervous system (Barnes and Gonor, 1958 a & b, and McGregor, 1967), the production of chromatophorotropic factors within the nervous system, in association with the moulting cycle (Sandeén and Costlow, 1961 and Costlow, 1963) and the possible presence of an endocrine mechanism for the control of breeding (Tighe-Ford, 1967). Although the moulting activities of a number of species have been studied in relation to growth, breeding, seasonal cycles, light, temperature, etc. (Costlow and Bookhout 1953, 1956, 1958, Crisp and Patel, 1960, Patel and Crisp, 1961, and Barnes, 1962) there is no direct evidence as to the nature of the biological processes involved.

Injected ecdysones have been shown to induce and accelerate moulting in a number of crustaceans (Carlisle, 1965, Lowe *et al.*, 1968, Krishnakumaran and Schneiderman, 1969, and Jegla and Costlow, 1970). It was observed by Carlisle (personal communication) that an extract of the barnacle *Elminius modestus* Darwin induced moulting when injected into Y-organ-ablated shore crabs. It appeared, therefore, that an ecdysone system might be present in barnacles and evidence is presented here that injections of crustecdysone into adult *Balanus balanoides* (L.) will increase moulting activity. This hormone has been shown to be structurally the same as  $\beta$ -ecdysone, ecdysterone and 20-hydroxyecdysone (Galbraith *et al.*, 1967), and is present in crustaceans (Hampshire and Horn, 1966), insects (Horn *et al.*, 1967) and plants (Staal, 1967). Its formula is given in Fig. 1.

#### Materials and Methods

Adults of the inter-tidal barnacle *B. balanoides* were collected in October 1970, when moulting activity was relatively high, prior to the annual breeding (Crisp and Patel, 1960). The population had settled on non-toxic panels during the previous spring. They possessed well-developed ovaries

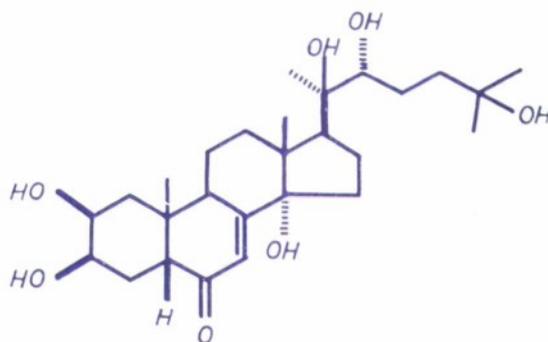


FIG. 1. The structure of the arthropod moulting hormone crustecdysone.

and had a mean carino rostral diameter of  $11.6 \pm 0.9$  mm. The panels were cut so that small groups of barnacles of approximately equal size were obtained: these were cleaned and all other organisms were removed. Groups of 20 adults were placed under constantly flowing sea-water conditions in parallel compartments of a transparent tray, standing over a sink. From here seawater was pumped through an ultra-violet sterilizer into a weir across the head of the tray and returned to the sink after flowing through the compartments. Cast skins were retained by a nylon mesh across the end of each compartment. The system was continuously replenished with filtered fresh seawater, with an overflow to waste and the temperature was kept in the range  $12.5 - 16.0^\circ\text{C}$ . Details of the system are shown in Fig. 2. No additional food was added. The barnacles were maintained under ambient laboratory light conditions and acclimatized for four days prior to the start of the experiment.

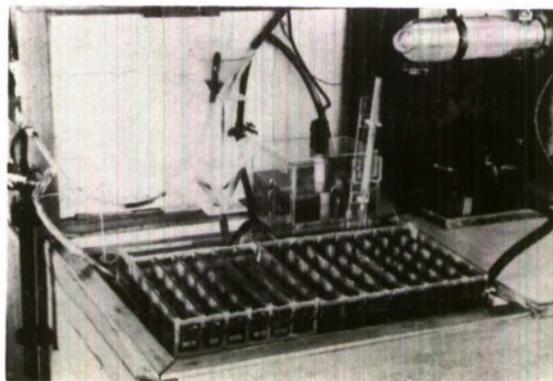


FIG. 2. The experimental system used for investigating the moulting activities of barnacles.

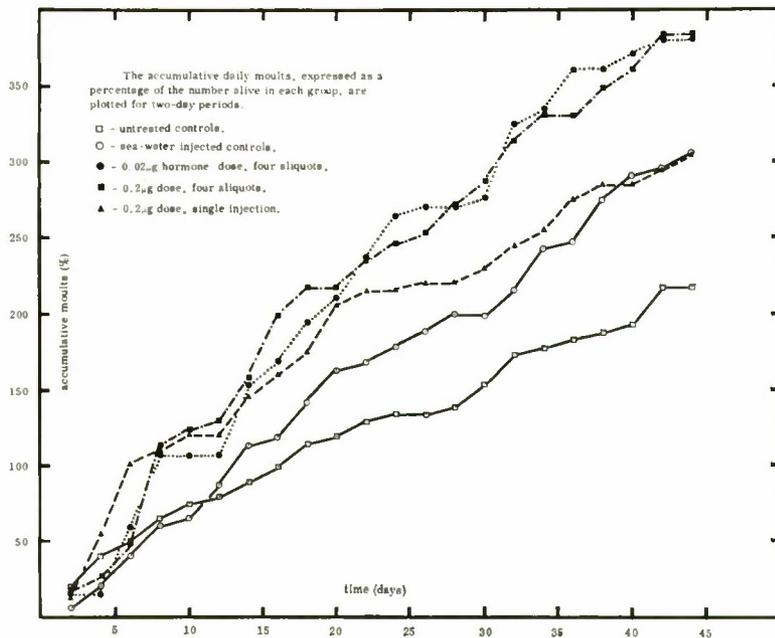


FIG. 3. The effects of injected crustecdysone upon moulting activity in *B. balanoides*.

The barnacles were divided into five groups of 20 animals, two of which were injected with doses of 0.02 and 0.2  $\mu\text{g}$  crustecdysone per animal, spread over four aliquots on successive days, *i.e.* 0.005 and 0.05  $\mu\text{g}$  per injection: a third group was injected once only, with a 0.2  $\mu\text{g}$  dose per animal, on the first day. The hormone was dissolved in sterile seawater and the volume injected daily was 2  $\mu\text{l}$ . The fourth and fifth groups acted as controls, the former being an untreated group and the latter being injected on four consecutive days with 2  $\mu\text{l}$  sterile seawater alone. The lower hormone dose was based on an approximate equation of the tissue weight of the barnacles with that of the larvae of the blowfly *Calliphora erythrocephala* Meigen, in which pupariation can be experimentally induced by 0.0075–0.02  $\mu\text{g}$  ecdysone (Karlson and Sekeris, 1966).

The injections were made through a 0.52 mm diameter hole drilled close to the base of a lateral plate (Tighe-Ford, 1968). A micro-syringe was inserted horizontally into the basal mantle tissue, without penetrating the cuticle lining the mantle cavity, so that the injected material had access to the haemolymph system. Injection into the basal mantle tissue has an advantage over penetration through the operculum, the only apparent alternative, in that no damage is caused to the prosoma or the muscles controlling the opercular plates. After each injection a few crystals of the antibiotic "Crystamycin" were

added to the hole in the shell, to inhibit bacterial infection. The hole was then dried and plugged with unplasticised gutta-percha, which was removed with a hot needle for subsequent injections.

The number of cast skins in each group was recorded on the day following the first injections and thereafter was recorded daily for 44 days. The adults and the sea-water system were cleaned twice weekly to remove sediment and algae growth. After the experiment had been terminated barnacles from the sea-water and 0.02  $\mu\text{g}$  hormone injected groups were kept in

flowing sea-water conditions for approximately five months. These were then sacrificed and examined for long-term effects of the injections.

The hormone injected was crystalline crustecdysone JLI (see Horn, 1971 for nomenclature) which had been prepared from the plant *Podocarpus elatus* (Galbraith and Horn, 1969).

## Results

The daily moulting activities throughout the experiment are given in Table 1 and are plotted accumulatively in Fig. 3. To facilitate analysis the results in the table are divided into periods or "cycles" in which the number of cast skins is approximately 90% or more of barnacles alive in the group. For this purpose, the probability that one or more animals had moulted more than once in such a period was not taken into account. It is difficult to define the "cycles" precisely, but they were determined on the basis of the overall pattern of the response in each group. Moulting was virtually continuous in the untreated and sea-water controls; whereas there were periods of marked activity in the hormone groups, associated with periods of inactivity or only the occasional moult. Thus the first cycle in each hormone group was taken as beginning on the day when marked increase in moulting was evident.

TABLE 1.  
Crustecdysone action on the moulting activity of *B. balanoides*.  
(Number of cast skins per day)

Day	Controls		Crustecdysone ( $\mu\text{g}/\text{barnacle}$ )		
	Untreated	Sea-water	0.02(4x)	0.2*(4x)	0.2(1x)
1	1	0	2	3	2
2	3	1	1	0	1
3	2	2	0	2	1
4	2	1	0	0	7
5	1	3	0	0	6
6	1	1	9	4	3
7	1	3	D 6	D 9	2
8	2	1	3	3	0
9	1	D 1	0	2	0
10	1	0	0	0	2
11	1	2	0	0	0
12	0	2	0	1	0
13	0	2	4	2	2
14	2	3	5	D 3	3
15	1	1	1	6	2
16	1	0	2	1	1
17	1	2	1	2	1
18	2	2	4	1	2
19	1	2	2	0	3
20	0	2	1	0	3
21	1	1	3	1	1
22	1	0	2	2	1
23	0	1	2	1	0
24	1	1	3	1	0
25	0	0	0	1	0
26	0	2	1	0	1
27	1	0	0	2	0
28	0	2	0	1	0
29	1	0	0	0	2
30	2	0	1	3	0
31	2	2	5	4	3
32	2	1	4	0	0
33	0	2	0	1	0
34	1	3	2	2	2
35	0	1	1	0	2
36	1	0	4	0	2
37	0	3	0	1	0
38	1	2	0	2	2
39	1	0	1	1	0
40	0	3	1	1	0
41	3	1	1	3	1
42	2	0	1	1	1
43	0	1	0	0	2
44	0	1	0	0	0

Note: \*19 adults in original group. D—a death. 4x—dose injected as four aliquots. 1x—single dose. I—represents a moult "cycle", or period, in which the number of cast skins is approximately 90%, or more, of the number of barnacles alive in the group; however, some barnacles may have moulted more than once during such a period.

Although the activity was increased in each of the injected groups the response in those injected with hormone differed markedly from that of the sea-water controls. The crustecdysone not only further accelerated activity but also imposed a pattern in which more than one "cycle" of such acceleration was evident. The initial responses to the hormone were strongly sigmoidal, as seen in the results of the induced moulting "cycle" which occurred in each group during the first 12 days. (Fig. 4).

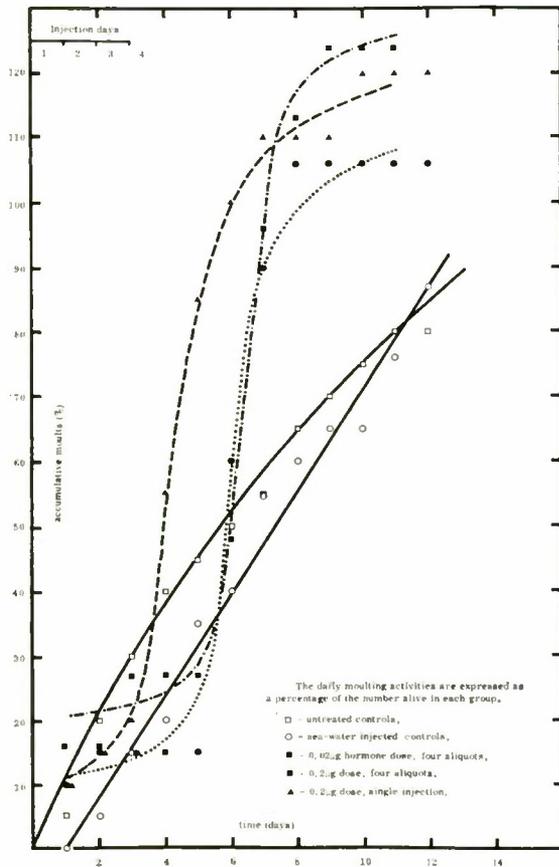


FIG. 4. The nature of the response to crustecdysone during the first induced moulting cycle in *B. balanoides*.

Reaction to the single 0.2  $\mu\text{g}$  dose was rapid, whereas in both of the sequentially injected groups there was an apparent reduction in moulting during the first five days when compared with the controls. A marked acceleration of moulting then occurred in all hormone groups, with 18 moults (approximately 90%) in each, within 3-4 days. This synchronization of moulting imposed by the crustecdysone was

followed by a short period of inactivity. Second "cycles" of moulting then followed in each hormone group which, although less synchronized than in the first, were accelerated in relation to the corresponding "cycles" in the controls. This attenuation of the synchrony imposed by the hormone was most evident in the single dose group. Third "cycles" of activity were evident in both the sequentially injected hormone groups; these were still further attenuated, but were apparently no longer accelerated in relation to the sea-water controls. These "cycles" are shown in Table 1 and are summarised in Table 2. There was also evidence of some residual synchrony of moulting in the sequentially injected groups during days 30-36.

Increased moulting activity following hormone injection was evident only during the first 25 days or so in those sequentially injected (and for a rather shorter period in the single dose group). The activities of each group during this period are summarised in Table 3, together with those during the remainder of the experiment (days 26-44).

Moulting activity in the sea-water injected animals was higher than in the untreated controls. This increase was sustained, being evident after approximately the first fortnight (Fig. 3): the apparently lower activity during the first few days was offset during the second week. It appeared that once the acceleration of moulting had disappeared in the hormone injected animals, activity in those sequentially injected fell to that of the sea-water group, whereas activity in those injected with a single dose fell to that of the untreated controls (see also Fig. 3).

The total mortality throughout all the groups was 4%, with one death in each of the sea-water and 0.02  $\mu\text{g}$  hormone injected animals; two deaths occurred in those sequentially injected with 0.2  $\mu\text{g}$  hormone.

When the sea-water and 0.2  $\mu\text{g}$  hormone injected barnacles were removed from their substrate (after approximately five months) portions of the gutta-percha plugs were found to protrude into the mantle tissue. In each individual an area of dense brown tissue was present around the gutta-percha and outside this there was marked calcification, extending from the shell into the mantle, which in some cases completely surrounded the brown tissue and the plug. No apparent difference was observed between the sea-water and hormone injected adults.

TABLE 2.  
The moulting "cycles" induced by crustecdysone in *B. balanoides*.  
Days

Cycle	Controls		Crustecdysone ( $\mu\text{g}$ barnacle)		
	Untreated	Sea-water	0.02(4x)	0.2*(4x)	0.2(1x)
1st	16	13	3	4	4
2nd	23	15	7	7	10
3rd	—	15	13	13	—

NOTE: The term "cycle" and symbols are as given in Table 1.

TABLE 3.  
Moulting activities of *B. balanoides* after injection of crustecdysone.

Activity	Controls		Crustecdysone ( $\mu\text{g}$ barnacle)		
	Untreated	Sea-water	0.02(4x)	0.2*(4x)	0.2(1x)
Total moults days 1-25	27	34	51	45	43
Mean daily activity	5.4%	7.1%	10.6%	10.1%	8.6%
Total moults days 26-44	17	24	22	22	18
Mean daily activity	4.5%	6.7%	6.2%	6.9%	4.7%

NOTE: Symbols are as given in Table 1.

**Discussion** From the role of ecdysones in arthropod moulting cycles, the synchronization of activity arising from the injection of crustecdysone strongly suggests that the increase in *B. balanoides* was a true hormonal effect. It appears, therefore, that barnacles follow the general arthropod pattern of a hormonal control of moulting. The synchronization and acceleration of activity during the first 12 days suggests that the initial "cycle" in each hormone group was a result of the crustecdysone acting directly upon the barnacles, possibly on the cuticular epidermal cells, as is the case in insects. However the nature of the mechanisms involved in the responses by the barnacles is not yet clear. Injection of the hormone

resulted in more than one cycle of accelerated activity and differences were apparent between the effects of single and sequential doses. Acceleration and induction of moulting by single injections of ecdysones has already been established in crustaceans (Carlisle, 1965, Lowe *et al.*, 1968, Krishnakumaran and Schneiderman, 1969 and Jegla and Costlow, 1970); although both single and sequential injections were effective in *B. balanoides*, the responses apparently differed in the nature of the initial and subsequent moulting cycles.

Injection of a single dose of hormone resulted in a rapid response, whereas there was an initial reduction of moulting in the sequentially injected animals (compared with the controls) and a longer period before marked

activity (Table 1). Results from other arthropod species suggests a possible explanation of these observations. *In vivo* experiments have shown (i) that there are rising titres of ecdysones during moulting stages of the crab *Callinectes sapidus*, indicating a sequential triggering of the moult process (Faux *et al.*, 1969) and (ii) that critical thresholds of ecdysone are absent during pupariation of the fleshfly *Sarcophaga peregrina*, suggesting that the response is a summation of ecdysone effects over a period (Ohtaki *et al.*, 1968). Although similar mechanisms need not necessarily be operating in barnacles, it is possible that the first moulting cycle in *B. balanoides* which resulted from a single injection of 0.2 $\mu$ g crustecdysone was due to an effect imposed by a high, non-physiological dose and that the initially slower (but equally marked) response to sequential injection resulted from a more natural summation of hormone action. Furthermore, the apparent lack of difference between the effects of 0.02 and 0.2 $\mu$ g when injected sequentially (Table 3) also suggests that the 0.2 $\mu$ g dose was higher than physiological and that 0.02 $\mu$ g (injected as four successive daily aliquots) was nearer the natural titre during a moulting cycle. As marked moulting activity after single or sequential injection of hormone did not begin until 3-4 days after the only or last injection in each group, it appears that several days were required before the tissues responded to the crustecdysone. Presumably apolysis, new cuticle formation and ecdysis would occur during this period. The subsequent moulting "cycle" in each hormone group was not only synchronised (as would be expected, following the first "cycle") but also accelerated in relation to those in the control groups. It appears unlikely that this was a result of injected crustecdysone persisting in the barnacles for up to 1-2 weeks. Although at present there is no evidence to indicate the presence of an ecdysone-inactivating enzyme in barnacles it has been shown in insects that injected ecdysones are inactivated *in vivo* within a few hours (Ohtaki *et al.*, 1968 and Karlson and Bode, 1969). A possible explanation for more than one cycle of accelerated activity in the barnacles might be that the injected crustecdysone not only acted directly (at cuticular level?) but also stimulated a natural site of hormone production through a feed-back system. The observations on natural ecdysone titres made by Ohtaki *et al.* (*loc. cit.*) and Faux *et al.* (*loc. cit.*) may help to explain the different

patterns imposed in *B. balanoides* by the two injection schedules. The greater activity arising from sequential injection may have been due to a more effective stimulation of an endogenous system. It should be noted that these cyclic effects may depend upon the seasonal activities of *B. balanoides*, as natural moulting was relatively high during the period of this study: Crisp and Patel (1960) found that maximum activity in this species occurred during April-May and September-October. The action of injected crustecdysone appears to be complex and the observations discussed above undoubtedly offer only partial explanations of the mechanisms involved. The use of "Crystamycin", to inhibit bacterial infection after injection, apparently did not affect the action of crustecdysone or moulting activities. Although some antibiotics, such as actinomycin and mitomycin, can block moulting processes through inhibition of nucleic acid synthesis (Highnam and Hill, 1969) the use of "Crystamycin" (penicillin with streptomycin) in the barnacle injection technique appears to be acceptable. The marked response in *B. balanoides* (with a wet tissue weight of 0.05-0.1g in the experiment) to a 0.02 $\mu$ g crystalline hormone dose shows a relatively high sensitivity, being comparable with a Calliphora unit of 0.01 $\mu$ g ecdysone, as defined by Karlson and Sekeris (1966).

Moulting activity was also affected in sea-water injected barnacles. There was a sustained increase in relation to the untreated group, which became proportionately greater with time. The most likely explanation of the long-term nature of the response appears to be wound or irritant effects arising from the injection and plugging technique. Increased moulting in association with the calcification and dense "wound" tissue in the mantle around the gutta-percha plug, suggests that the original wound and/or the presence of a gutta-percha "irritant" induced a system which stimulated hormonal activity within the barnacles. Although production of more than one hormone may have been stimulated, the increase in moulting suggests that an ecdysone is involved. As it has been shown that ecdysone induces calcification during pupariation of the face-fly *Musca autumnalis* (Fraenkel and Hsiao, 1968) and that cyclic activities of the shell gland in *Elminius modestus* are associated with the moulting cycles (Bocquet-Védrine, 1965) it is suggested that this hormone may be associated with the control of calcification in

barnacles. It is interesting to note that the studies by Bocquet-Védrine (1965, 1970) on the cement apparatus indicate that cementation processes may also be under an ecdysone or associated hormonal control.

Wounding or irritant effects appear to explain why, once the effects of injected hormone had disappeared (after approximately 25 days), the moulting activity in the sequentially injected hormone group fell to that of the seawater group, whereas activity in the single hormone dose group returned to that of the untreated controls. However, the effects of wounding appear to be complex and are being investigated further.

Although there can now be little doubt that barnacles possess an endocrine system similar to those generally established for the arthropod phylum, little is known of possible sites of hormone production. The central role of neurosecretory phenomena in arthropod endocrinology indicates that such cells in barnacles (Barnes and Gonor, 1958) have a role in co-ordinating external factors, such as light and temperature, with hormone activity. Nevertheless, despite many studies of the adult and larval nervous systems (Cornwall, 1936, 1953, Gwilliam, 1965 and Walley, 1969), adult photoreceptors (Fales, 1928 and Fahrenbach, 1965) and larval eyes (Kauri, 1962, Mortlock, 1968 and Walley, 1969), no organs have yet been found in barnacles which are comparable with the crustacean sinus-gland or Y-organ. However Kauri (1966) suggested that frontal filament bases in nauplii were sensory-papilla-X organs: if this is the case, they could be cirripede neurohaemal organs. Barnes and Gonor (1958b) suggested that in the apparent absence of an adult storage organ neurosecretory material was released direct from the central nervous system into the perineural blood sinus. Uncertainty still remains, however, as to the tissue responsible for the possible production of ecdysone(s) or other hormones which may be involved in the control of moulting.

### Conclusions and Future Work

The results given in this report establish the action of an arthropod moulting hormone in barnacles. They suggest the presence of a major hormone system which is not only responsible for the mechanism of development and growth, but may also be associated with the control of shell formation and cementation. As the establishment of barnacles as fouling

organisms depends upon (i) the initial cementation of the cypris onto its substrate, (ii) a metamorphosis moult to the young adult, followed by (iii) a continued moulting and production of shell and cement, the possible exploitation of any or all of these processes has obvious application in antifouling investigations. Similar studies are also currently being made in the field of insect control, with the aim of developing "third generation" insecticides which exploit natural hormone mechanisms. Work is continuing on the role of ecdysone in barnacles and on the factors which may control its production and action. *B. balanoides* appears to be a particularly interesting species for studies on barnacle hormone systems, because of the nature of its moulting and reproductive activities. The relationship between light and temperature in the control of breeding (Crisp, 1957, Barnes, 1963, and Crisp and Patel, 1969) and the nature of the non-moulting period which then follows (Crisp and Patel, 1960, Patel and Crisp, 1961, and Barnes, 1962) suggest endogenous rhythms similar to those found in other arthropods and the possibility of a moult-inhibiting system.

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# THE EFFECT OF UNDERWATER BREATHING APPARATUS AND ABSOLUTE AIR PRESSURE ON DIVERS' VENTILATORY CAPACITY

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## Abstract

*Maximum voluntary ventilation studies were undertaken using three divers. Measurements were made at 1, 2, 4 and 8 atm abs, breathing air in all cases. In addition to measurements under normal conditions, the tests were repeated with the subjects partially immersed in water and wearing underwater breathing apparatus. A two-stage open circuit supply system (SABA) of the type used by RN divers was used in the experiments.*

*The relationship obtained of normal MVV to absolute air pressure for the three subjects was in agreement with that established by previous investigators. When breathing from the underwater breathing apparatus the value of maximum ventilation at each depth was reduced but the form of the relationship was not greatly altered. At 8 atm abs maximum ventilations of over 60 litres/min were achieved. The mean results of three subjects indicate that in general, at any given pressure within the range of 1 to 8 atmospheres absolute, when breathing air from an open circuit demand valve of the type used, a diver can expect to achieve between 85% and 95% of his normal maximum voluntary ventilation at that pressure.*

## Introduction

In operational diving, one of the main factors governing man's performance is the ability to obtain adequate ventilation when breathing dense gas mixtures supplied from underwater breathing apparatus. In view of the increasing limitation of breathing capacity with depth, a limit must be set on diving when breathing various gas mixtures. When oxygen-helium gas mixtures are used it is probable that ventilatory capacity presents a problem only at depths somewhat greater than 1,000 feet. Breathing air or oxygen—nitrogen mixtures however it is most likely that ventilatory capacity limits the work output of divers within the present range of such diving (*i.e.* < 300 ft.).

A useful index of breathing capacity is maximum voluntary ventilation (MVV)\*. The relationship of MVV to gas density has been reported by several investigators<sup>(4, 7, 12, 14)</sup> and their findings have been summarized by Lanphier<sup>(3)</sup> as shown in Fig. 1. In relating this index to maximum sustained breathing capacity,  $\dot{V}_E$  max, of the working diver, two further factors must be considered. Maximum ventilation,  $\dot{V}_E$  max, which can be maintained during a prolonged period of exercise may be somewhat lower than that attained during a short MVV manoeuvre. A reduction of both MVV and sustained ventilation,  $\dot{V}_E$  max, would be expected as a result of external resistance to ventilation imposed by underwater breathing apparatus. In the studies of MVV mentioned above the external resistance to ventilation due to measuring equipment was maintained as low as possible.

\* Maximum voluntary ventilation indicates a subject's maximum ventilatory capacity in litres/min. It is normally measured over a period of 15 seconds of maximum breathing effort.

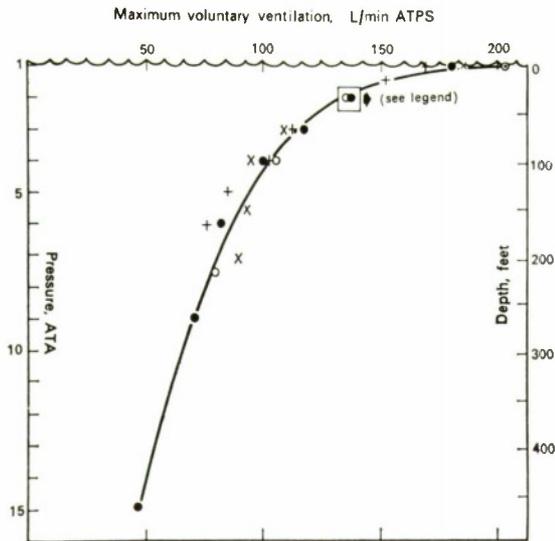


FIG. 1. The relationship of maximum voluntary ventilation to absolute air pressure. Results are taken from four separate investigations. Where results were reported as percentage change from 1 atm abs (+ and X) the results were correlated using values at 2 atm abs as the common point. Reproduced by Lanphier<sup>(3)</sup>.

Miles<sup>(7)</sup> and Lanphier<sup>(3)</sup> have postulated that sustained ventilation may be reduced to 50% of MVV when working under pressure. In later work Miller *et al.*<sup>(8)</sup> maintain, however, that when breathing dense gas mixtures it is possible for an individual to perform work at a ventilation equivalent to his MVV. The data of Mead<sup>(5)</sup> and Miles<sup>(7)</sup> indicate that external resistance imposed by breathing apparatus represents a major component of air flow resistance in the underwater situation, which should further limit respiratory capacity under pressure. It is considered that further study of the interaction of respiratory function, gas density and underwater breathing apparatus is important in clarifying ventilatory and work capacity of the individual within the present limits of diving using air and oxygen-nitrogen gas mixtures.

To this end a series of air dives was undertaken in which maximum voluntary ventilation was measured at 1, 2, 4 and 8 atmospheres absolute pressure. The experiments were performed under normal conditions in a dry pressure chamber and also with the subjects breathing from an open circuit demand valve whilst partially immersed in water.

## Description of Experiment

### Instrumentation

A major problem in the measurement of ventilation obtained from breathing apparatus is the difficulty of incorporating normal measuring equipment into the breathing circuit. It was considered that the pneumotachograph was the only accurate instrument which could be realistically incorporated into the breathing circuit without major alteration to the breathing apparatus characteristics. Experience had been gained in the use of the pneumotachograph to measure normal ventilation whilst under pressure<sup>(9)</sup>, and the experimental methods used during those experiments were further developed and adapted to produce successful measurements of ventilation from breathing apparatus.

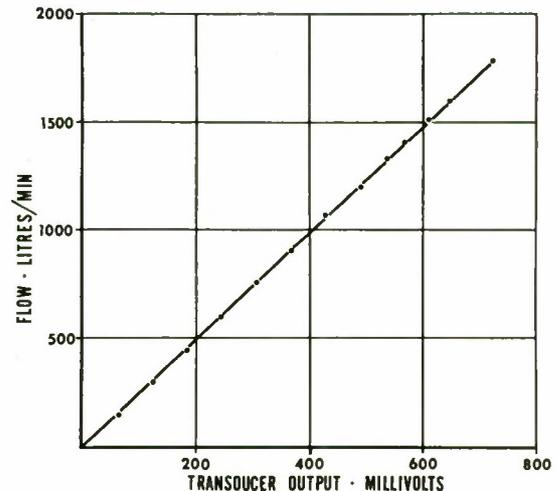


FIG. 2. Calibration of pneumotachograph. Depth: 200 ft. Flow is measured as equivalent volume per minute at surface pressure (1 atm abs).

Linearity between pressure drop  $\Delta P$  across the pneumotachograph and gas flow,  $q$ , is limited to the region of laminar flow, *i.e.*, where Reynolds number  $N_R < 2000$ . A calibration curve measured at 200 feet is shown in Fig. 2. To measure ventilation from open circuit breathing apparatus the inspiratory tube from the demand valve was split and the pneumotachograph inserted. Inlet and exit cones with O ring seals were fitted to the pneumotachograph to adapt the instrument to the breathing tube diameter and ensure a smooth flow of gas. The pneumotachograph and cones are shown in Fig. 3.



FIG. 3. Subject positioned on couch and breathing *via* pneumotachograph from the demand valve.

The following is a brief summary of the recording instrumentation used with the pneumotachograph. A more detailed description of the instrumentation and experimental techniques is available from a previous RNPL Report <sup>(10)</sup>. Pressure drop across the pneumotachograph due to gas flow was measured by a sensitive differential pressure transducer. Transducer output was amplified and recorded in FM mode by magnetic tape recorder. The recorded signal was monitored during the experiment by an oscilloscope.

#### Computer Analysis

The experimental data thus recorded was replayed as input to a LINC 8 computer. An oscilloscope display of the analogue signal was used in the control of computer operation. The computer program used to analyse maximum voluntary ventilation data was a modified version of that developed to analyse normal ventilation in previous experiments. Programming methods are described in detail in a previous report <sup>(10)</sup>. At each inspiration the information printed was tidal volume, time, total ventilation and number of breaths. To increase accuracy the time clock in the computer was set to four times real time and ventilation was measured from computer results over a period of  $60 \pm 4$  seconds (representing approximately 15 seconds in real time). Ventilations were then corrected to litres per minute BTPS\* conditions.

\* BTPS: Existing barometric pressure of the environment, gas saturated with water vapour at body temperature (taken as 37°C).

#### Experimental Procedure

The pressure chamber used for the experiments has a pressure capability of 10 atm abs and a volume of 500 cubic feet. A water tank was constructed which could be assembled inside the chamber. The tank was designed to have a maximum water depth of three feet and a volume of 70 cubic feet.

The experiment was performed on three subjects. In all tests respiratory measurements were taken with the subject positioned on the couch of a bicycle ergometer in the water tank, as shown in Fig. 3. Measurements at each depth were performed on separate dives. During each dive at least four tests of MVV were carried out on one subject. Calibration was performed between the second and third tests. To calibrate the pneumotachograph a steady flow of gas was passed through the instrument inside the chamber, thence through the chamber wall and measured by a rotameter external to the chamber. Air temperature at the rotameter was measured by a thermistor probe.

Measurements of normal MVV were made under dry conditions with the subject breathing directly from the pneumotachograph. When wearing breathing apparatus, the subject was immersed in water to neck level as shown in Fig. 3. In this manner, the subject inspired from the demand valve at a slightly lower pressure relative to lung centroid pressure, as is normally the case when swimming or working underwater and breathing from a demand valve. The pressure differential was maintained at approximately four inches of water.

Maximum voluntary ventilation was maintained by the subjects for a period of about 17 seconds, of which the first 15 seconds was used in calculating the results. Each subject was instructed to breathe at the rate and depth at which he felt subjectively that maximum ventilation was obtained. Prior to commencing the experiments the manoeuvre was practised both at surface and under pressure until the subject was competent. Trials were conducted on six subjects, of whom three were chosen for the experiments.

The breathing equipment used was the Royal Naval two-stage open circuit supply system used in Swimmers Air Breathing Apparatus and also Surface Demand Diving Equipment. High pressure air is supplied to a servo reducer AP No. 0434 and then at 75 psi to a demand valve. This equipment is described in the RN Diving Manual <sup>(11)</sup>.

## Results and Discussion

### Experimental Results

All three subjects used in the experiments had previous experience as divers. The age, height, weight and vital capacity of each subject is given in Table 1.

**TABLE 1.**  
Physical characteristics of subjects.

Subject	Age	Vital Capacity (Litres)	Height (Metres)	Weight (Kilogrammes)
A. Gisborne	36	5.8	1.83	79.7
J. Towse	37	6.0	1.83	95.0
I. Mayo	21	4.3	1.63	64.5

during the four tests. In the last column of each table the percentage of normal MVV attained when wearing breathing apparatus is given for each depth.

It can be seen from Tables 2 to 4 that the mean respiratory rates adopted by the individual subjects in performing maximum voluntary ventilation were significantly different. The effect of varying the respiratory rate of each individual was examined. It was found that change of respiratory rate from that chosen by the individual to within the (mean) range of 50 to 70 breaths per minute made little difference to ventilation achieved. The effect of varied respiratory rate is demonstrated in the results of Towse at 1 atm abs (normal) and Gisborne and Mayo at 8 atm abs (SABA).

DEPTH ATM ABS (FEET)	NORMAL					SABA					
	TEST NUMBER	VENTILATION L/MIN (BTPS)	RESP RATE PER MIN	MEAN TIDAL VOLUME $V_T$ LITRES	MAX VENTILATION L/MIN	TEST NUMBER	VENTILATION L/MIN (BTPS)	RESP RATE PER MIN	MEAN TIDAL VOLUME $V_T$ LITRES	MAX VENTILATION L/MIN	PERCENTAGE OF NORMAL VENTILATION
1 (0 FT)	1	193.5	60	3.2		1	163.6	50	3.3		
	2	179.5	57	3.2	193.5	2	158.0	51	3.1	166.9	86%
	3	173.9	66	2.6		3	166.9	58	2.9		
	4	162.3	41	4.0		4	142.3	50	2.9		
2 (33 FT)	1	144.7	56	2.6		1	137.6	52	2.6		
	2	146.2	60	2.4	146.2	2	127.3	52	2.4	137.8	94%
	3	134.8	57	2.4		3	137.6	58	2.4		
	4	144.5	62	2.3		4	137.8	71	1.9		
4 (99 FT)	1	116.0	54	2.1		1	103.4	50	2.1		
	2	104.3	53	2.0	116.0	2	110.3	70	1.6	110.3	95%
	3	115.6	51	2.2		3	104.0	62	1.7		
	4	107.6	45	2.4		4	108.3	68	1.6		
8 (231 FT)	1	93.1	46	2.0		1	87.7	58	1.5		
	2	93.5	80	1.2	93.5	2	90.6	54	1.7	90.6	97%
	3	90.8	59	1.5		3	86.5	84	1.0		
	4					4	88.8	94	0.9		

**TABLE 2.**

Results of MVV tests at each pressure under normal conditions and with breathing apparatus (SABA). Subject: A. Gisborne.

From the tidal volumes measured over the first 15 seconds of each maximum voluntary ventilation, the value of minute ventilation, mean tidal volume,  $V_T$ , and respiratory rate per minute was calculated. Ventilations and tidal volumes were corrected to BTSP conditions. For this purpose it was assumed that the vapour pressure of the chamber air was 19 mm Hg (*i.e.* 70% saturated at 27°C) and that dry air was supplied from the underwater breathing apparatus.

The results of four tests at each depth, measured under normal conditions and with open circuit breathing apparatus, are presented in Tables 2, 3 and 4. From these results, the value of MVV under each condition was taken to be the maximum ventilation achieved

In general, respiratory rates when breathing from SABA were slightly slower than under normal conditions. Although in some cases respiratory rates tended to decrease with depth, the reduction of tidal volumes was the more significant factor in effecting change of ventilatory capacity. In Fig. 4, curves relating mean maximum ventilation of the three subjects to absolute air pressure are presented. In this figure the mean values of maximum voluntary ventilation under normal conditions and when breathing from underwater open circuit breathing apparatus (SABA) are shown.

The relationship of normal MVV to absolute air pressure (or gas density) measured for each of the three subjects is in agreement with that established by previous investigators (4, 7, 12, 14). As expected, breathing from underwater apparatus reduced the value of maximum ventilation at each depth but did not significantly alter the form of the relationship.

The equipment used by the divers is normally limited to a depth of 180 ft. At the maximum test pressure of 8 atm (231 ft) the valve proved capable of supplying the divers with in excess of 60 l/min of air. At this depth one of the divers (Mayo) expressed difficulty in obtaining a higher flow of air from the valve with increased effort and this fact may be reflected in his reduced performance (77% of

higher than expected and considerably greater than predicted values<sup>(3)</sup> based on data of breathing apparatus resistance<sup>(5, 7)</sup>. One factor relative to the mechanics of breathing against an external resistance may in part explain these results. Over a section of the breathing cycle, maximum expiratory flow may be effort independent at increased gas densities due to partial airway collapse. This effect described by Mead *et al.*<sup>(6)</sup> is dependent on internal resistance to gas flow. Added external resistance due to breathing apparatus may therefore, up to a point, be overcome by increased muscular effort and would not necessarily reduce maximum expiratory flows<sup>(3)</sup>. Secondly, increased respiratory resistance may be partly

DEPTH ATM AND (FEET)	NORMAL					SABA					
	TEST NUMBER	VENTILATION L/MIN (BTPS)	RESP RATE PER MIN	MEAN TIDAL VOLUME $\bar{V}_T$ LITRES	MAX VENTILATION L/MIN	TEST NUMBER	VENTILATION L/MIN (BTPS)	RESP RATE PER MIN	MEAN TIDAL VOLUME $\bar{V}_T$ LITRES	MAX VENTILATION L/MIN	PERCENTAGE OF NORMAL VENTILATION
1 (0 FT)	1	164.0	47	3.5		1	143.7	45	3.2		
	2	166.9	42	4.0	173.0	2	152.0	56	2.7	152.0	86%
	3	169.2	47	3.6		3	139.5	56	2.5		
	4	173.0	67	2.6		4	143.5	40	3.6		
2 (33 FT)	1	125.0	60	2.1		1	123.3	50	2.5		
	2	116.4	58	2.0		2	122.4	50	2.5	124.0	94%
	3	132.0	59	2.2	132.0	3	124.0	43	2.9		
	4	131.6	62	2.1		4	123.0	54	2.3		
4 (99 FT)	1	100.0	61	1.6		1	84.0	43	2.0		
	2	92.4	58	1.6	100.0	2	92.4	43	2.2	92.4	92%
	3	92.8	51	1.8		3	90.3	38	2.4		
	4	91.5	60	1.3		4	82.6	42	2.0		
8 (231 FT)	1	74.4	55	1.4		1	65.1	34	2.0		
	2	69.4	32	2.2	75.2	2	59.7	31	1.9	65.1	87%
	3	72.2	63	1.1		3	64.9	39	1.7		
	4	75.2	62	1.2		4	59.6	39	1.5		

TABLE 3.

Results of MVV tests at each pressure under normal conditions and with breathing apparatus (SABA). Subject: J. Towse.

normal) in comparison with lower pressures. The other two subjects, Gisborne and Towse, experienced no problem in obtaining air from the valve at 231 ft and attained 97% and 87% of normal maximum ventilation respectively.

When breathing from underwater breathing apparatus, the maximum ventilation attained was in all cases greater than 75% of normal MVV (Tables 2 to 4). Referring to the average results for three subjects, shown in Table 5, it can be stated that when using underwater breathing apparatus of the type tested, a diver can expect to attain 85 to 95% of his normal maximum voluntary ventilation within the depth range of the experiment.

#### Discussion

Ventilations achieved from breathing apparatus in these experiments were on the whole

overcome by the increased muscular effort available at lower gas flow rates<sup>(1, 2)</sup>.

It should be stated at this point that the results presented for SABA are considered to be fairly representative of open circuit demand valve type breathing apparatus. It is likely, however, that the performance of open circuit venturi type valves would be subject to more variation than the two-stage tilt valve used. Resistance to breathing of a venturi valve has been shown to be dependent on back pressure at the valve<sup>(13)</sup>. The exact setting of the jet will also have considerable effect. The breathing characteristics of semi-closed and closed circuit sets differ considerably from those of open circuit equipment. An extension of the present studies to include such equipment is under consideration.

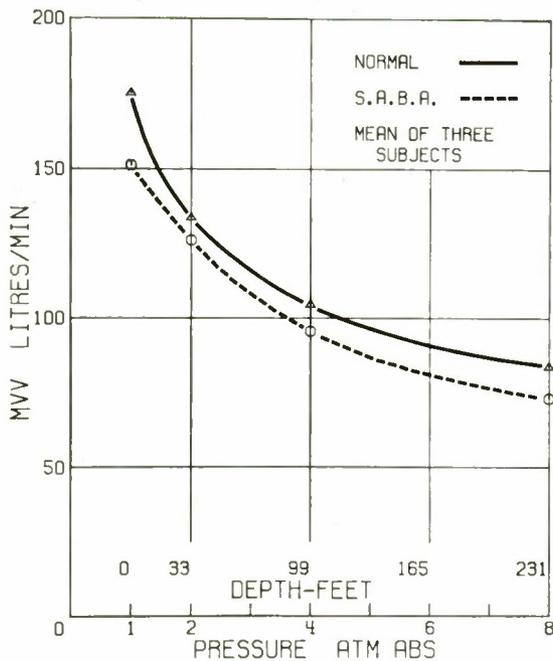


FIG. 4. The relationship of maximum voluntary ventilation to absolute air pressure. Continuous line—normal conditions, broken line—breathing apparatus (SABA). Mean results of three subjects.

TABLE 5.

Summary of Results: Maximum voluntary ventilation at each pressure under normal conditions and with breathing apparatus (SABA). Mean results of three subjects.

Depth ATM ABS	Maximum Ventilation Litres/Min BTPS		Percentage of Normal Ventilation
	Normal	Saba	
1	175.2	151.2	86%
2	133.6	126.1	94%
4	104.5	95.6	92%
8	83.7	73.1	87%

ventilation,  $\dot{V}_E$  max, is somewhat lower than MVV, safe diving would be limited to shallower depths. Subjectively, none of the subjects considered that they could do useful work and sustain the ventilations achieved in these experiments. In this connection it should be noted that the mean value of maximum voluntary ventilation achieved by the divers in the present investigation was approximately

DEPTH ATM ABS (FEET)	NORMAL					SABA					
	TEST NUMBER	VENTILATION L/MIN (BTPS)	RESP RATE PER MIN	MEAN TIDAL VOLUME $V_T$ LITRES	MAX VENTILATION L/MIN	TEST NUMBER	VENTILATION L/MIN (BTPS)	RESP RATE PER MIN	MEAN TIDAL VOLUME $V_T$ LITRES	MAX VENTILATION L/MIN	PERCENTAGE OF NORMAL VENTILATION
1 (0 FT)	1	158.4	104	1.5	159.1	1	134.6	88	1.5	134.6	86%
	2	145.9	81	1.8		2	123.8	75	1.7		
	3	155.0	92	1.7		3	133.8	80	1.7		
	4	159.1	92	1.7		4	126.4	81	1.6		
2 (33 FT)	1	112.7	80	1.4	122.5	1	113.0	70	1.6	116.5	94%
	2	112.8	63	1.8		2	116.5	69	1.7		
	3	108.9	69	1.6		3	108.3	68	1.6		
	4	122.5	65	1.9		4	103.0	70	1.5		
4 (99 FT)	1	93.8	77	1.2	97.4	1	84.0	52	1.6	84.0	86%
	2	93.8	67	1.4		2	82.6	57	1.5		
	3	90.3	77	1.2		3	82.1	63	1.3		
	4	97.4	83	1.2		4	75.7	56	1.4		
8 (231 FT)	1	79.0	79	1.0	82.4	1	56.9	47	1.2	63.6	77%
	2	74.6	112	0.7		2	58.3	65	0.9		
	3	82.4	79	1.0		3	56.7	52	1.1		
	4	77.3	95	0.8		4	63.6	110	0.6		

TABLE 4.

Results of MVV tests at each pressure under normal conditions and with breathing apparatus (SABA). Subject: I. Mayo.

Assuming that a diver must be capable of obtaining at least 65 l/min from his breathing set, the relationship of MVV to absolute pressure would not appear to limit diving down to a depth of 8 atm where average results give a MVV value of 73 l/min. If, however, as it has been suggested<sup>(3, 7)</sup> maximum sustained

40-50% greater at 8 atm than that achieved in the investigation<sup>(8)</sup> where maximum sustained ventilation,  $\dot{V}_E$  max, equal to MVV was achieved at pressures of 6-8 atm. Given that the MVV values reported are of a different magnitude, the observations of the two studies are not necessarily incompatible as the rela-

tionship of  $\dot{V}_E$  max to MVV may depend upon both the value of MVV and gas density.

Allowing that it may be possible for divers to work to their level of MVV, however, it would seem prudent to insert a margin of safety for the diver. Assuming therefore as a safety margin that  $\dot{V}_E$  max = 65 l/min should not exceed 80% of MVV on the type of equipment tested, one might postulate from Fig. 4 that a safe limit for the working diver would be in the region of 6 atm abs (165 ft) and beyond this depth, if possible, less dense gas mixtures should be introduced.

### Conclusions

The maximum voluntary ventilations of three subjects were measured at 1, 2, 4 and 8 atmospheres absolute. The experiment was repeated with the subjects wearing open circuit breathing apparatus (SABA) and partially immersed in water.

At all pressures the subjects achieved in excess of 75% of their normal maximum voluntary ventilation at that pressure when breathing from the apparatus. The mean results of three subjects indicate that in general when breathing from an open circuit demand valve of the type used, a diver can expect to achieve between 85-95% of his normal maximum voluntary ventilation at pressures of 1-8 atmospheres absolute. At 8 atm abs ventilations achieved were in excess of 60 l/min.

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## THE ROLE OF COMPONENT FAILURE RATES IN RELIABILITY PREDICTION

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### Abstract

*This article details various sources of failure rate data illustrating their uses and limitations. Examples of failure rate data from eight sources are included. The principles involved in using this data to predict equipment reliability are outlined, and examples of the type of calculation involved for various systems are fully described. The applications and limitations of the data at present available are discussed, with particular reference to the Naval environment.*

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**Introduction** The prediction of reliability is an essential part of any reliability programme carried out during the feasibility, design, development and production phases of an electronic equipment. Such reliability programmes are becoming increasingly important with the growth in equipment complexity and will inevitably be incorporated in many future Naval contracts<sup>(13)</sup>. Accurate prediction is becoming increasingly difficult as the equipment designer is faced with a proliferation of unrelated sources of component failure rate data, with very few guidelines to the application and significance to his particular problem. Correspondingly, establishing that a contractor has met a design specification by reliability demonstration tests becomes that much more difficult due to the increased time, at high cost, required for the tests. Most reliability prediction techniques depend on establishing the basic component failure rate data to be employed in the assessment, and the K factors to be applied to these failure rates. The K factors must be included to take into account the various stress levels, temperatures and environmental conditions which the equipment and components will experience during their service life. Even if the greatest care is taken in the choice of the source of data, the actual results of "component count" predictions must be treated with caution. There also appears to be some confusion on the use of component failure rates in prediction methods. This article will clarify the position and highlight many of the problem areas.

## Component Failure Rate Data

### Basic Failure Rates

There are many sources of component failure rate data available to the designer. These include data supplied by the component manufacturer, in-service records kept by the equipment manufacturer and, in the case of the Navy, the Ship Maintenance Authority and the Ship Upkeep Information System. There are also other general sources such as S.R.D.E., R.R.E., U.K.A.E.A., and several American sources, etc. Table 3 gives examples of component failure rates from eight such sources. The variation between the predicted reliabilities of an equipment when these different sources are employed can be as much as 10:1, and specific failure rates of a given component can differ by several orders of magnitude<sup>(1)</sup>. Most component failure rate tables give basic component failure rates. These represent the average failure rate expected from repetitive use, at a standard electrical stress level, at temperatures in the range 10-20°C and for components working in a laboratory environment. It is usually considered that 0.1 is the minimum de-rating factor (the ratio of operating to rated electrical stress level) which should be applied to components. The failure rate is not expected to decrease significantly for stress levels below this level of 0.1. This is true for most components, although carbon composition resistors should not be so lightly loaded, and there is some indication that the failure rate for electrolytic capacitors in fact increases as the stress level is decreased<sup>(2, 3)</sup>.

### Failure Rate Modification Factors

Failure rate modification factors are usually quoted in the published tables of component failure rates. In addition, some tables from American sources have included modification factors which are applied according to the manufacturer concerned. Particular examples are switches and relays, this is obviously a very complicated procedure which has not been adopted in this country.

Reliability predictions are carried out using failure rate data which is usually based on previous results or experience. This data may not be applicable to the components in current use since they may be of a new technology. Generally it can be assumed that component reliability increases with developing technology, and experience of use.

## Factors Affecting Equipment Reliability

### Component Reliability

Equipment reliability is defined as the probability that the equipment will perform its specified function under the specified conditions for which it is designed, for a specified period of time. A predicted reliability for an equipment, based on component failure rate data can take into account the "specified conditions" but does not usually include any "unspecified conditions" such as degradation introduced by the user, by transport hazards or by the maintenance personnel. Any attempts to include factors to allow for such conditions would require a knowledge of the users works facilities, what sort of maintenance organisations and personnel skills existed, and many other factors difficult to define.

These external factors must be borne in mind by the equipment designers during the design, development and production of an equipment. The effects of such external factors should be minimised by ensuring that the equipment is difficult to misuse and simple to maintain. The *predicted* reliability of an electronic equipment is largely dependent on the individual components that form the equipment, together with the wiring and interconnections. The *achieved* reliability is governed largely by the manufacturers organisational procedures, such as purchasing, inspection and quality control, and implementation of his reliability programme, partly by the mechanical design and layout of the components in the equipment, and partly by the users ability to maintain the equipment adequately.

An equipment designer may achieve the required performance for a given function by means of several different circuit configurations, but it is the number and type of components involved in that circuit that will primarily influence the reliability. Sub-division of the equipment into separate units and considerations of the method of connecting these units together with the use of redundancy has an important bearing on the reliability and will be discussed further in the Reliability Prediction Section.

### Component Failures

The causes of equipment failures can be divided into two categories. The first category is "equipment manufacturers error". This includes broken wires, unsoldered joints,

incorrect component tolerances, setting up errors etc. The second category is "component failure". This latter may be further subdivided to include the cause of the component failure. For example:—

- (a) User error, *e.g.* misuse.
- (b) Equipment manufacturers error, *e.g.* incorrect component choice.
- (c) Design error, *e.g.* incorrect tolerance, overload, or poor circuit design.
- (d) Failure due to physical properties of the component—(end of life).
- (e) Component manufacturers error, *e.g.* faulty batch etc.
- (f) Random failure.

### Equipment Reliability

If the equipment is of sufficient importance to warrant extensive reliability studies in the design phase the number of failures associated with the component stress levels will be comparatively small. Such failures, if they occur unexpectedly, are usually design errors, and because the causes are known, they can be rectified before the equipment goes into production. If it has already gone into production before the fault is discovered, a post design modification can be carried out to prevent a recurrence of the failure. If the frequency of occurrence of the failures is acceptable and in general agreement with the predicted reliability, these could be assumed to be random failures and there would be no need for any action. However, if the frequency of failure is unacceptable and the equipment reliability does not come up to the predicted required value, a major modification might be necessary and consideration should then be given to the possible use of redundancy. Size and weight limitations might rule out its successful adoption. The breakdown of a large equipment into various identifiable sub-units can be useful to determine which units are the least reliable and where extra attention should be focused.

### Use of Burn-in

The type of failure where the cause is discoverable and assignable, although troublesome and undesirable, can nearly always be designed out (given enough time and money). Eventually these faults and failures become less predominant than those failures due to manufacturing defects and random failures. These latter failures are unpredictable and are not necessarily accelerated by the stresses in the working environment. However, the

use of burn-in at the component level can greatly reduce the number of components in a new equipment developing these defects. The added cost of carrying out the burn-in tests must be compared with the expected gain in reliability and availability in order to determine its cost effectiveness. For example, at a cost of approximately 5p per transistor it would represent value for money if the number of premature failures is reduced as a result.<sup>(14)</sup>

### Other Failures

All electronic equipment contains other sources of failure apart from component failure—*e.g.* soldered, welded, wrapped joints, connecting wires and even setting up and adjusting procedures can be considered as faults. These all contribute to the potential unreliability of an equipment and should be included in any reliability prediction. Failure rates for these "hidden components" are found in most failure rate data tables but they are often found to vary by as much as 500:1.

### Element of Doubt

If the basic failure rate for components was defined as the failure rate that would be achieved by the components operating under the most suitable conditions for their physical and mechanical structure, then the inherent reliability of an equipment composed of such components would be determined solely by the reliability of the components working under their own individual conditions. All the activities involved in preparing the component to become part of an equipment, designed to fulfil a specified role, *e.g.* assembling the components on to printed circuit boards, operating the components under stresses that are likely to affect their basic reliability, and subjecting them to vibration or shock can only degrade the inherent reliability of that component. Whilst there are variations in the procedures for derating and applying failure rate corrections for different electrical stresses and ambient temperatures, these are not as serious as the variations that exist in the common basic failure rate tables from various sources.<sup>(14)</sup> and Table 3). There are several reasons why these basic variations exist; the prime one being the implementation of usage data from different sources. These variations in basic failure rate are so diverse that they have created an element of doubt about the value of prediction as a useful tool. Many people believe this

doubt will only be overcome when a British failure rate handbook, on the lines of the US documents<sup>(5,6,7)</sup> is compiled. To create such a handbook, which if available would enable every equipment manufacturer to accurately predict the reliability of his equipment and which would enable a user to assess the reliability of an equipment that he has ordered, is a very difficult problem. Even if such a handbook could be produced, reliability prediction would still be looked upon as an incomplete and suspect procedure, until valid measurements have been carried out to determine the magnitude of the factors affecting reliability, *i.e.* the application factors to allow for non perfect conditions. The exclusion of an application factor, such as the human error factor, can result in large differences between the predicted reliability and the reliability actually observed in use. A single handbook employed generally, however, would be an improvement over the present situation where the most convenient source of information is often chosen with little regard to the validity of the data for the particular equipment under study. Assuming such a handbook could be produced, the next need would be for a set of rules to apply application factors. In order to achieve these application factors it would be necessary for all component failures observed in the use environment to be related to user error, equipment design, manufacturers error, known failure modes for the component etc. then it might be possible to achieve accurate values for these application factors which would then be applied to the basic failure rate data. It is unlikely and probably impractical for all failures observed on board H.M. Ships to be assigned to a specific "cause of failure" category. Another major difficulty would be the assessment of the ability of component manufacturers, since it is highly improbable that all manufacturers could produce components, to a specification, which all had identical failure rates. Thus even if the components are manufactured to meet the same specification, the failure rates for different manufacturers are still likely to vary. A fully comprehensive common source of failure rate data for components would therefore have to specify the manufacturers, the electrical and mechanical stress and the temperature which would apply for that given component. The final outcome in practice is likely to be some compromise of a given failure rate for a generic type of component.

Failures caused by defective manufacture cannot be controlled by the equipment manufacturer (unless burn-in is employed) because they are dependent on the component manufacturers processes<sup>(9)</sup>. This leads to a basic requirement discussed above for a failure rate handbook, which in addition to identifying the component by the specification to which it is designed and manufactured, would also name the manufacturer and allocate failure rates based on his manufacturing processes and controls, or specify a failure rate which must be modified by a given factor related to the component manufacturers capability. This appears an impractical requirement. With the adaptation of BS 9000, however, any variation in the manufacturers processes which result in varying component quality and reliability will be immediately observed by reference to the Certified Test Records for samples which will be taken from every production lot. This in itself should help keep variations between manufacturers to a minimum, but components outside of BS9000 will be more difficult to assess.

### Reliability Prediction

A reliability prediction based on a simple count assumes that the component failures will occur independently and that no component failure will influence the chance of failure of other components. It also assumes that the component failure rate will be constant during the useful life of the equipment. This assumption implies a mathematical model based on the exponential distribution. This is the most widely used distribution in the field of reliability and may be expressed as follows:

$$R(t) = e^{-\lambda t}$$

where  $R(t)$  is the reliability function, *i.e.* the probability that the equipment will function without failure during a time  $t$ , and  $\lambda$  is the failure rate for the equipment.  $\lambda$  must be assessed by an acceptable method if the equation is to be valid.

### Series Systems

The simplest method of estimating the reliability of an electronic equipment is to assume that all the components are capable of causing equipment failure and that they are connected in series. The equipment reliability is determined by summing the component failure rate data and substituting in the exponential expression. The result is derived from the product rule of reliability which states that the

reliability  $R(t)$  of a circuit consisting of  $n$  components, is the product of the reliability of the individual components.

i.e.  $R(t) = R_1(t) \times R_2(t) \dots R_n(t)$  (2)

or  $e^{-\lambda t} = e^{-\lambda_1 t} \times e^{-\lambda_2 t} \dots e^{-\lambda_n t}$  (3)

i.e.  $\lambda = \lambda_1 + \lambda_2 + \dots + \lambda_n$  (4)

This expression indicates that in order to obtain the reliability of an equipment ( $\lambda$ ), consisting of a series system, in the same terms as those used for components, it is only necessary to add up all the component failure rates. If the application factors are the same for all the components, it can be applied to the overall failure rate, but if the application factors are different then they must be applied at the component level and not at the system level.

**Reliability Index**

A reliability index often quoted is the mean time between failure, MTBF. This usually represents the average time between failures which can be expected for an equipment during the portion of its life cycle in which the exponential law applies. The value of the equipment MTBF is determined from the integral:

$$MTBF = \int_0^{\infty} R(t) dt$$

In the special case of the exponential distribution  $R(t) = e^{-\lambda t}$

$$\therefore MTBF = \frac{1}{\lambda}$$

Thus MTBF of a series system in the exponential case is given by

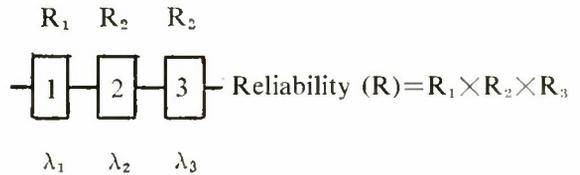
$$MTBF = \frac{1}{\lambda} = \frac{1}{\lambda_1 + \lambda_2 + \dots + \lambda_n}$$

The same rule applies when the failure rate of an equipment consisting of several sub-units is required. The failure rate for each sub-unit is calculated, assuming a series system for the component within that sub-unit, and then these failure rates are summed to give the equipment failure rate.

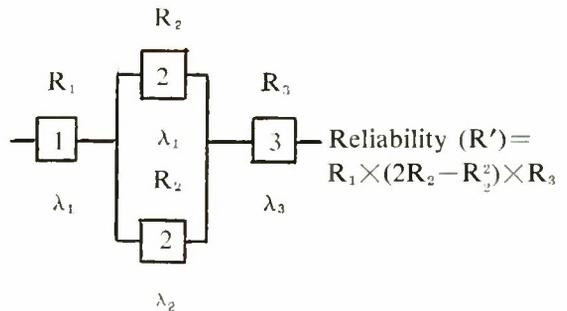
**Redundancy**

If the reliability of a sub-unit contained in an equipment is low, the equipment reliability does not come up to the required level, then a similar sub-unit may be connected in parallel

either as an operating unit or as a standby unit, in order to improve the reliability. These methods of connections are known respectively as active and sequential redundancy. The active redundant case is now considered by examining an equipment consisting of three sub-units, 1 to 3, in which the failure rate unit 2 is too high:



If a second, similar sub-unit is connected in parallel with 2, the reliability increased as shown below:—



**To Calculate**

The effective reliability of sub-unit 2 is calculated as below:—

Let  $R_2^1$  be the new reliability of the parallel combination then  $Q_2$  is the unreliability of a unit  $R_2$ , where  $Q_2 = 1 - R_2$ . Thus unreliability of the parallel combination  $R_2$  with  $R_2$  is  $(Q_2)^2$ . Hence  $R_2^1 = 1 - (1 - R_2)^2 = 2R_2 - (R_2)^2$

and the equipment reliability becomes:—

$$R' = R_1 \times (2R_2 - R_2^2) \times R_3$$

But since reliability index can never be greater than 1, then  $R_1 R_2^2 R_3$  must be less than  $R_1 R_2 R_3$  and hence the original reliability  $R$  must be less than the new reliability  $R'$ .

The mean time between failure of the two units in parallel is determined as follows:—

$$MTBF = \int_0^{\infty} (2R_2 - R_2^2) dt = \int_0^{\infty} (2e^{-\lambda_2 t} - e^{-2\lambda_2 t}) dt = \frac{3}{2\lambda}$$

i.e. the MTBF of two similar units connected in parallel is one and a half times the MTBF of one such unit.

Another type of redundancy often employed is sequential redundancy in which one sub-unit operates until failure and then another takes over after a switching operation. The simplest way of representing the reliability of two identical units with failure rates  $\lambda$ , assuming 100% reliability for the sensing and switching device is obtained by taking the first two terms of the Poisson distribution:—

$$R = e^{-\lambda t} (1 + \lambda t)$$

$$\text{and } MTBF = \int_0^{\infty} e^{-\lambda t} (1 + \lambda t) dt = \frac{2}{\lambda}$$

The MTBF is seen to be twice the MTBF of one unit—as expected for a system with perfect switching. In practice, the reliability of a sequential system can be determined only if the reliability of the switching device is known.

Taking the reliability of the switching device into account the expression has to be modified to:—

$$R = e^{-\lambda t} (1 + R_{ss} \lambda t)$$

where  $R_{ss}$  represents the reliability of the switching device.

### Estimation of Equipment Failure Rate

The principle of estimating the failure rate of an equipment is relatively simple, although the manner in which it is carried out can become very complicated. It is usual to predict the equipment reliability at specified stages of design where various K factors are applied. These K factors can be any or all of the following: electrical stress, temperature effects, application and operational conditions, failure mode distribution, packaging, transit hazards etc. There is very little data available to support the choice of the values which are assumed for the above K factors, but it is usual to adopt generally accepted figures such as those given in MIL STD 217A<sup>(5)</sup> etc. The reliability prediction techniques described in this report are indicated in the following example of an amplifier circuit.

### Example of Reliability Prediction

During a feasibility study, it is estimated that a proposed circuit to be manufactured will consist of 8 resistors, 4 capacitors, 2 transistors, 2 diodes, 1 variable resistor and 30 soldered joints.

The predicted MTBF for this circuit is determined as follows:—

TABLE 1.

Anticipated type of Component	No off	Failure rate % per 1000 hrs.	Total failure rate % per 1000 hrs.
Resistors, Fixed Composition	8	0.005	0.04
Capacitors, Metallized paper	4	0.05	0.2
Transistors Silicon <1W	2	0.008	0.016
Variable Resistors Wirewound	1	0.3	0.3
Soldered Joints	30	0.001	0.03
Diodes Silicon <1W	2	0.005	0.01
TOTAL			0.596 per 1000 hours

$$\therefore MTBF = \frac{10^5}{0.596} = 167,800 \text{ hrs. This purely}$$

on theoretical grounds using basic failure rates which assume that the components are operating at 0.1 stress level.

A revised prediction of the MTBF is then carried out during the design stage and when the circuit diagram is available and the components have been selected and their characteristics are known, together with the stresses. The stress and rating would result from a computer design exercise performed on the circuit.

The modified reliability prediction based on the actual circuit diagram (Fig. 1) is shown in Table 1. The various K factors are assumed to be known, or available from some source.

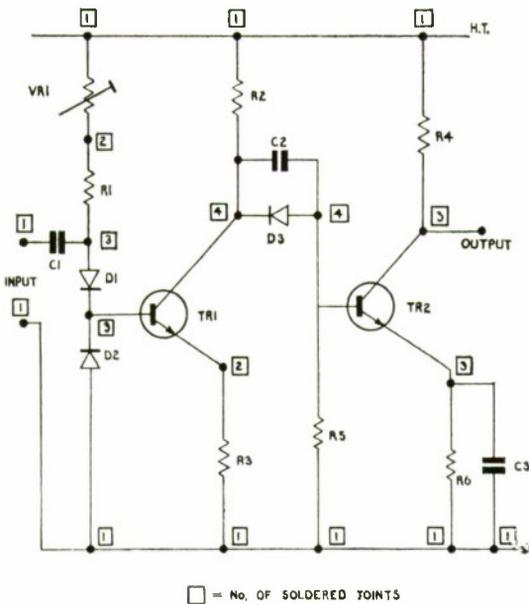


FIG. 1. Theoretical circuit of amplifier for reliability analysis.

A comparison of the two predicted MTBFs indicates that the estimated MTBF has decreased from the initial value of 167,800 hrs. to a final value of 70,921 hrs. when the actual circuit diagram is available and the component stresses etc. are known and allowed for. It should be noted that the final circuit chosen had a slightly different component count.

### The Use of a Computer for Prediction

From Table 2 the simplicity of the method is obvious, but the designers' great difficulty is in obtaining the data to put into the table.

The calculations etc. can be very easily performed using a computer, and a program exists<sup>(8)</sup>, in which allowance can be made for the various K factors shown in Table 2.

### Conclusions

The predicted MTBF calculated by the technique described is based on data which assumes random failures, and, therefore, any component failures which are due to design faults cannot be allowed for in the prediction. The general disillusionment with the value of reliability prediction is probably due to the fact that the predicted value is expected to be within 5% of the actual value. In fact, the most worthwhile outcome of a prediction, at the design stage, is the influence it has on the

thinking of the designer and on the design, rather than the actual result. Reliability predictions are a very worthwhile endeavour if carried out without bias and the correct interpretation placed on the outcome. Where a competitive type of assessment is acceptable (when one design is compared with another) the use of general failure rate data is permissible, but where serious attempts are made to estimate with reasonable accuracy the reliability of an equipment, failure rates should be used with extreme caution. To make an assessment of reliability meaningful, the component failure rates employed should be representative of the failure rates observed in the Fleet. At present, accurate detailed information on component failure rates is not available<sup>(15)</sup>, and the absence of such data represents the largest single hurdle in the implementation of effective Naval reliability predictions. It cannot be too strongly emphasised that until such information is returned by the user, the full potential of any Reliability Programme cannot be realised.

When an attempt is made to assess the accurate expected failure rate (by including 'in-use' conditions, Bayesian techniques, etc.), it should be appreciated that the statistical distributions of failure assumed may not be valid concepts at the 'single item' level. In the overall prediction, a certain amount of 'swings and roundabouts' takes place, so that the final result is often acceptably close to the observed result. This effect does not operate in the case of individual components.

Table 3 lists examples of basic failure rates from a number of sources. An approved Naval list is at present being prepared. This list has been prepared by carefully analysing and combining all existing failure rate sources to provide a comprehensive and coherent source of data. The basic list relates to a "ground stationary" environment, which is carefully defined, and for each individual component type a series of K factors are listed to relate the operational behaviour of that component to other environments. The list is incorporated in a manual which explains in detail how it should be used.

Where the existing failure rate data is inadequate, it is possible to apply other methods of prediction. One promising one is the use of multiple regression techniques together with feedback from the Fleet. In this method, an accurately known component failure rate is not essential to the prediction.

TABLE 2.

Circuit Reference	Failure Rate (each) % per 1000 hrs.	Maximum Stress	In use Stress	$K_1$ (rating)	$K_2$ (environment)	$K_3$ (temperature)	Total in use Failure Rate % per 1000 hrs.
R1	0.01	1.5 W	0.36 W	1.2	1.5	1.5	0.027
R2, R4	0.005	150 mW	15 mW	1.0	1.5	1.5	0.0225
R3	0.005	150 mW	10 mW	1.0	1.5	1.5	0.01125
R5	0.005	150 mW	5 mW	1.0	1.5	1.5	0.01125
R6	0.005	150 mW	36 mW	1.2	1.5	1.5	0.0135
C1	0.05	120 V	12 V	1.0	1.5	1.5	0.1125
C2	0.05	100 V	8 V	1.0	1.5	1.5	0.1125
C3	0.04	12 V	5 V	3.0	1.5	1.5	0.1125
TR1	0.008	125 mW	6 mW	1.0	1.5	1.5	0.018
TR2	0.008	125 mW	15 mW	1.0	1.5	1.5	0.018
D1, D2	0.005	150 mW	1 mW	1.0	1.5	1.5	0.0225
D3 (Zener)	0.01	150 mW	10 mW	1.0	1.5	1.5	0.0225
VR1	0.03	1 W	30 mW	1.0	1.5	1.5	0.675
Solder Joints =33	0.033	-	-	1.0	1.5	1.5	0.7425
TOTAL							1.41075

*i.e.* MTBF=70,921 hrs.

### Warning

The engineer may often find, after completing a predicted reliability exercise, that figures obtained for the MTBF are grossly optimistic when compared with the first models of the equipment. Typically, he may find that his prediction gave say 500 hours MTBF and in practice he is obtaining 20 hours MTBF. This has been shown by work in the United States<sup>(6)</sup> to be typical. However, after a running in period it is usually found that an accuracy of 2:1 or better is possible.

**TABLE 3.**  
**Examples of Component Failure Rate Data**

Basic failure rate data (in % per 1000 hours) from several sources has been collected and tabulated. The failure rates quoted in A, B, C, D and F refer to a "fixed ground" environment, *i.e.* equipment operating under ideal laboratory conditions. The failure rate data quoted in E, G and H refers to airborne equipment.

Failure rates tabulated assume the following ratings:

<b>Source A</b>	resistors	$\frac{1}{10}$ th max volts	
	capacitors	$\frac{1}{10}$ th max volts	
	transistors/diodes	$\frac{1}{10}$ th max power	
	temperature	10°C to 20°C	
<b>Source F</b>	resistors and transistors	75% of rated power at operating temp.	
	diodes	50% of rated power at operating temp.	
	transformers	80% of rated power at operating temp.	
	capacitors	75% of rated voltage at operating temp.	
<b>Source E</b>	transistors	75% of rated power	
	diodes	50% of rated power	
	resistors	80% of rated power	
	capacitors	75% of rated voltage	
	transformers	80% of rated power	
<b>Source D</b>	resistors	(i) power derating factor	0.2 to 0.5
		(ii) ambient temperature	40°C
		(iii) relative humidity	<60%
	capacitors	(i) voltage derating factor	0.2 to 0.5
		(ii) ambient temperature	40°C
		(iii) relative humidity	<60%
	semi-conductors	(i) in between	0.3 and 0.5
		(ii) relative humidity	<60%
		(iii) failure rates apply only to digital circuits, for analogue applications, multiply failure rate by 2	
	ICs	(i) ambient temperature	40°C
		(ii) relative humidity	<60%

FIXED CAPACITORS

TYPE \ SOURCE	A	B	C	D	E	F	G	H
Paper	0.1	0.1	0.1	0.004	0.5	0.06	0.02	0.003
Metallized Paper	0.05	0.08	0.05		0.3	0.06		
Plastic Film	0.01							0.038
Glass and Mica	0.03	0.05	0.03	0.004	0.2	0.03	0.03	
Ceramic	0.01	0.07	0.01	0.001	0.2	0.03		0.006
Electrolytic, Al. Foil	0.2	0.4	0.1	0.08	1.0			
Electrolytic, Tant. Foil	0.1	0.1	0.1	0.01	1.0			
Electrolytic, Tant. Wet	0.02	0.05	0.05	0.002	1.0		0.02	0.007
Electrolytic, Tant. Solid	0.04	0.07	0.01	0.015	0.5		0.04	0.023

CONNECTIONS

Crimped	0.002	0.005			0.005	0.001		
Welded	0.004	0.0005			0.001	0.0005		
Wrapped	0.0001	0.001		0.000007	0.001	0.0007		
Soldered, Hand				0.00007	0.02	0.005		
Soldered, Machine	0.001	0.005	0.002	0.00005	0.003	0.001		0.00073

CONNECTORS

Coaxial	0.2	0.1		0.05	1.0			
Multipin (Per Pin)	0.005				)0.05 )sealed )0.03 )non- )sealed			
Edge (Per Pin)	0.01	0.005		0.0002		0.001		
Multipin, Circular (Per Pin)		0.02						
Multipin, Rectangular (Per Pin)		0.01						
Printed CCT Contact (Per Pin)			0.01		0.01			
External Connectors (Per Pin)						0.01		

MOTORS

Small, General	0.5		1.0					
Small, Stopper	0.3							
Small, Brush					2.0	1.1		
Small, Brushless					0.1	0.7		
Generator A.C.						1		0.38
Generator D.C.			0.9			1.1		3.37
Servo		2.0			)Inte- )grating )2.5 )Position )0.5	0.5	0.5	



**FIXED RESISTORS**

TYPE \ SOURCE	A	B	C	D	E	F	G	H
Composition	0.005			0.0007	0.1			
Carbon Film	0.05				0.5			
Metal Film	0.005		0.02		0.3			
Oxide Film	0.002	0.01	0.01	0.0005	0.05		0.005	0.008
Film Power	0.01							
Wirewound GP	0.01	0.05	0.05		0.3		0.1	0.034
Wirewound Precision	0.1	0.7		0.02	0.5			
Wirewound Power	0.01			0.03				

**VARIABLE RESISTORS**

Composition	0.2	0.3		0.025	0.5	0.07	0.02	
Wirewound GP	0.3	0.5	0.1	0.05	1.0	0.16	0.02	0.336
Wirewound Precision	0.6	0.8	0.3		0.3	0.25		
Lead Screw	0.5							

**TRANSISTORS**

Germanium PNP 1 watt	)0.01	)	)	0.015	)	)	)	
Germanium NPN 1 watt	)	)	)	0.015	)	)	)	1.0
Germanium PNP >1 watt	)	)0.15	)0.1		)0.5	)0.2	)	to
Germanium NPN >1 watt	)0.05	)	)	0.025	)	)	)	7.0
	)	)	)	0.03	)	)	)	
Silicon PNP 1 watt	)0.008	)	)	0.008				)
Silicon NPN 1 watt	)	)	)	0.004				)
	)	)0.05	)0.05					)0.0785
Silicon PNP > 1 watt	)	)	)	0.02				)
Silicon NPN >1 watt	)0.08	)	)	0.007				)
Silicon Planar					0.05	0.01		
Silicon Other					0.25	0.05		
Field Effect				0.1				

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## A NAVAL ELECTRICAL MUSEUM

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Charles Kenneth Aked was educated at Pudsey Grammar School, Leeds; and Leigh and Southall Technical Colleges; joining the R.N.S.S. in 1947 at the A.S.E. Extension at Risley to work in the Radar and W.T. sections, and later the Quartz Crystal section. He moved to the Admiralty Engineering Laboratory in 1955, transferred from the Technical Class in 1958 to become E.O., promoted to S.E.O. in 1962 and took up the post of Works Manager (L) in the Electrical Department. From 1967 - 9 engaged in the development of "Quaver", returning to works management and took over the two posts previously held by the Works Manager (L) and (M). Interested in horology and historical research, and is currently Librarian and Curator to the Antiquarian Horological Society and also Chairman of the Electrical Horology Group.

A special feature of the Golden Jubilee Open Days held at the Admiralty Engineering Laboratory July 14 - 18, 1970, was the display of early electrical equipment arranged to give the visitor a glimpse of the naval electrical world of the past. Mr. F. R. Mansell, Head of the Electrical Department, made the decision to have the display in order to provide a grand finale to the exhibits presented by the sections of the Electrical Department and to provide some relief from the heavy technical bias of the Open Day's programme.

In the event it did not prove easy to collect suitable material for the museum for it has not been the past practice of the Laboratory to retain equipment once it has served its intended purpose. Moreover a great deal of equipment potentially useful for museum display is still in use in the Laboratory. For example there are three submarine main motors in daily use that were manufactured in 1918. Cases of spares were held for these but are unlikely ever to be required since the machines exhibit no signs of wear whatsoever after over half a century of use! There are also air compressors of the early 1920's vintage in constant use which are about to be removed only because of obsolete d.c. motor drives. They have already been earmarked for a naval engineering museum.

A nucleus of early electrical equipment had been secured in 1967 on the closure of the E.E.M. Department at Portsmouth. Some of the items thus obtained were already on display in the entrance hall of the A.E.L. Electrical Office Block but the majority had been placed in storage. These were unpacked and cleaned in readiness for the museum display.

Additionally the Deputy Head of the Electrical Department persuaded H.M.S. *Collingwood* to make a temporary loan of some early electric motors and a set of early electric light fittings from the Royal Yacht *Victoria and Albert*, some of these being resplendent in a gold-plated finish! H.M.S. *Sultan* was also persuaded to loan what proved to be a star attraction of the museum display, the Parsons' Steam Turbine Driven Generator of 1888.

Another outstanding feature of the museum display was the collection of early electric lamps on loan from G.E.C. Wembley through the efforts of the Head of the Telecommunications section. An effective display of the large range of lamps used in the Navy collected over the years by the Illumination section was also presented.

One of the remarkable facts about the museum display was the speed of execution. The many stands, special display cases and all other arrangements were completed in less than two weeks from start to finish thanks to the large amount of voluntary effort provided after working hours. As a result the museum opened on the scheduled date of July 14, 1970.

### Description of the Exhibits

#### *Electrical Generators and Motors*

- (i) Pride of place was given to the Parsons Steam Turbine Driven Generator illustrated in the foreground of Fig. 1. It is a veritable masterpiece of early electrical and mechanical design and execution. The technical description is as follows: 8.0 h.p., double steam flow, impulse blading, plain bearings, double helical reduction gearing, reciprocating forced lubrication, steam pressure 80 psi, non-condensing steam consumption 50lb. per kWh, r.p.m. 18,000, electrical output 6 kW. The separate part is the top cover of the gearbox, whilst the top part of the turbine case is supported by metal straps in order to display the rotor with its blading and the helical gears forming the one-stage reduction. The d.c. generator has both series and parallel field windings, *i.e.* it is fully compounded. The commutator is peculiar in design inasmuch as the surface is deeply grooved in order to maximise the contact area with the copper gauze brushes used. An output voltage of 80 volts, the standard voltage



Fig. 1. Parsons Steam Turbine Driven Generator.

of the period was used, and the total weight of the turbo-generator is approximately 6 cwt. It was kindly loaned through the courtesy of Captain Barton, H.M.S. *Sultan*.

- (ii) Another interesting electrical generator can be seen on the left of Fig. 1. An illustration of the machine has been shown in these pages before, *J.R.N.S.S.*, Vol. 23, No. 4, p.231. Originally fitted in H.M.S. *Inflexible* in 1880, the first Royal Navy vessel to be fitted with electric power, the generator was wound to give 800 volts and the lamps, carbon filament type, were connected in series. Later the output voltage was reduced to 80 volts following the first fatality from electric shock in the Navy caused by a rating changing a lamp which had failed. Eighty volts was the lowest voltage that could be used in conjunction with the arc lamps and stabilising resistors then used. The electrical design of the armature is extremely interesting. Flat copper strips make contact with the commutator. A belt drive was used to drive the stepped pulley on the shaft.
- (iii) The large electrical generator, top centre Fig. 1, has an interesting history. It has a four volt output at a maximum current of 180 amperes and was used in the workshop of Portsmouth Dockyard for electroplating purposes from 1904 until the destruction of the workshop through German bombing in 1941 from which fortunately the machine was salvaged.

- (iv) To the left of the previous item is a group of electric motors. The two largest are of the early 1920s and were kindly loaned by H.M.S. *Collingwood*; the two smaller motors are respectively a General Electrical Company, Crocker and Wheeler Patent Model—May 1881,  $\frac{1}{4}$  h.p., 1400 r.p.m., 80 volts at 3.4 amperes using a Gramme Ring armature; and an even earlier motor of 50 volts, 3 ampere rating, at 2,500 r.p.m., also with a Gramme Ring armature.

### *Electric Lamps and Lamp Fittings*

- (i) A large range of electric lamps used in the Navy from 1885 - 1965 was most skilfully arranged by Mr. E. Lloyd Thomas in the nearest display case, shown in Fig. 2. Due to reflections in the front plastic panels, the photograph does not do justice to the displays. The oldest lamp is in the centre of the shelf and is circa 1885, having a coiled carbon filament and two platinum loops for attachment to spring loaded hooks in a lampholder. This lamp is of the type used in *Inflexible*.



Fig. 2. Electric filament lamps.

- (ii) The furthest display case had a display of early electric lamps loaned by G.E.C., Wembley. Dated 1885, the earliest lamp has a huge wire protected envelope. Other interesting early lamps were those from the legislative chamber in the South Africa Parliament Building.
- (iii) To the left of the previous case is a hand-signalling lamp of the early 1940s.
- (iv) Various electrical fittings, including gold-plated pendant fittings, an early

waterproof fitting, a push button assembly with ivory covers used in the State Bedroom, tumbler switches, and several junction boxes, one marked "SBD No. 2 Queen's Dressing Room" from the Royal Yacht *Victoria and Albert* were displayed on the centre stand. The nearest large round object on this stand is an early electric wall-mounting radiator, whilst the largest item is an early electric fire, circa 1900. It has a satin gilt finish and is interesting for the use made of the Robertson 250W carbon filament lamps as heating elements. These lamps, using an 80 volts supply, were still in use until 1955 in the writer's memory. They were exceedingly useful for making up artificial aerials when it was required to dissipate several kilowatts of radio frequency energy. At least 90% of the energy appeared as heat in the lower infra-red spectrum.

### *Electrical Switchboard*

Returning to Fig. 1, the extreme right hand item in the background is an interesting early example of a ship's d.c. switchboard. Weighing about 8 cwt. and mounted on a massive 2 in. thick slate bed, this switchboard from the *Victoria and Albert* controlled the output from several direct current generators. An ingenious interlocking system was fitted to prevent switching errors. The switchboard was manufactured by Clarke-Chapman and is circa 1900.

### *Telephones*

A number of early ships' telephones were shown covering the period 1900 - 20 and a small selection of the display may be seen on the right-hand side of Fig. 3. These were firmly secured in place to prevent antique collectors acquiring them! Fig. 4 shows a rather dainty telephone handset from the State Bedroom of the Royal Yacht *Victoria and Albert*. It is nicely engraved and silver-plated, a fitting reminder of more elegant days. Bulkhead fitting telephones of 1910 - 20 using a four-wire system with call-up facilities were displayed, also two engine room telephones with large brass tubes for clamping over the listener's ears. A label on these bears the proud title—"Alfred Graham & Co.'s Patent Navy 'Phone," Admiralty Pattern 2461. The weight of these brass telephones has to be experienced to be believed.



Fig. 3. General view of Museum.



Fig. 4. Telephone handset.

*Silverware from the Victoria and Albert*

Various items of silverware can be seen in the case illustrated in Fig. 5. From top left to bottom right the items are:

*Top Shelf*

- (i) Cigar Lighter, electrically operated, with a button switch.
- (ii) Electric Kettle 80V 10A, re-engraved George V. (Patent No. 6148 of 1902).



Fig. 5. Items of silverware.

- (iii) Electric Coffee Percolator made by Crompton & Fox Ltd., 80V operation serial No. 6333.

*Middle Shelf*

- (i) Electric Saucepan, 220V 300W, Patent No. 28779 dated 1911 Serial No. 325.
- (ii) Electric Kettle 80V 7.7A, circa 1905, engraved Edward VII, Serial No. 124527, made to the "Archer system".
- (iii) Electric Hair Curling Tongs Heater, 80V operation, circa 1905. Serial No. 5574.

*Bottom Shelf*

- (i) Silver-plated Telephone Hand Set, circa 1905. (Described earlier.)
- (ii) Silver-plated Free-standing Radiator, shown separately in Fig. 6. A most elegantly executed design. Made for use on an 80 volt system.
- (iii) Silver-plated 5 ampere watertight rotary electric switch, circa 1905.



Fig. 6. Free-standing Radiator.

### Miscellaneous Items

An excellent example of Lord Kelvin's Electric Balance circa 1880 for measuring large electric currents was on display, also a small astatic detector (galvanometer) of the same period. An item which caused some surprise to the writer was a Vickers step-by-step receiver, reputedly dated 1908. If this is correct it seems uncommonly early. Other early transmission elements were shown, together with early naval cathode ray tubes and other electronic components recognisable only to those born to electronic engineering a considerable time ago. A Claudburn-Doodson tide recorder made by Claudburn's (Ship) Telegraph Co. Ltd., consisting of a large drum driven by clockwork and bearing a chart to provide a permanent record of the tides week by week was another unusual item. A "History of Electrical Generation" display illustrated the progress of electrical generation from 1885 onwards, see Fig. 3. A link with the past research at A.E.L. on searchlights was the 60 in. parabolic reflector manufactured by C. A. Parsons in 1937. It had to be placed outside the museum proper as it was unexpectedly found to have a most disconcerting mental effect on some visitors. The last of the 44 in. searchlights, believed used on the beaches of Dunkirk 30 years ago, is also preserved and was displayed outside the main office building.

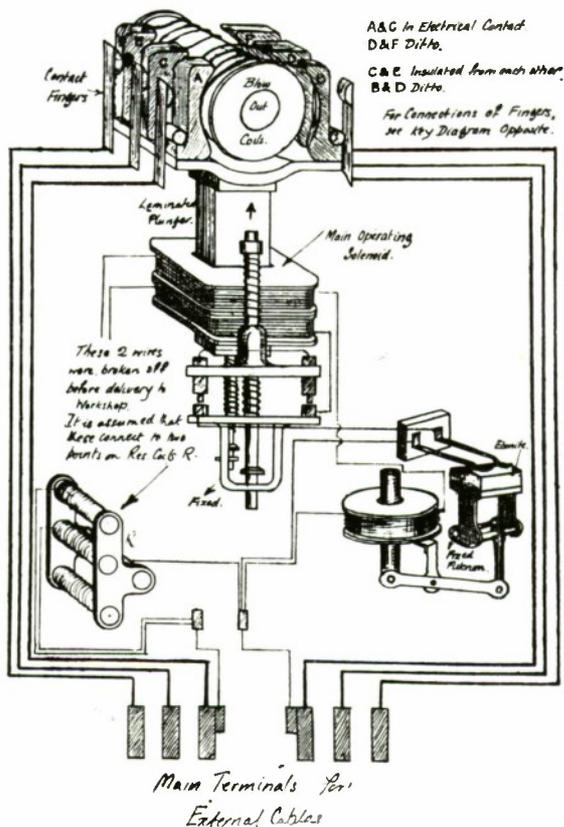


Fig. 7. Mr. Duckworth's "rough drawing".

### Early Records of the Electrical Department

A complete record of the early experiments in the Electrical Laboratory from its inception up to the late 1920s exists in the form of leather bound volumes, a few of which arc on display on the oak lectern shown in Fig. 3. This lectern was designed and constructed by Mr. Len Rookes, one of the A.E.L. carpenters, in the short period of two days. On the top of the lectern may be seen the notebook used by the late Mr. H. L. Duckworth who was the first member of the Electrical Laboratory in 1919, joining as a draughtsman. A man of immense talent, he eventually became Head of the Electrical Department in 1954, retiring in October 1959. His first experiment at A.E.L. is dated 22-7-1919 and his neatly written notes and drawings in his "rough book", see Fig. 7, would serve as a model to anyone commencing experimental work today. Unfortunately Mr. Duckworth passed away in 1966 and so did not live to see the Golden Jubilee of A.E.L.

As a result of the great interest shown in the Museum during Open Days, viewed by over 3,000 visitors, many of the exhibits have been put on permanent display in the Electrical Laboratory's Conference Room and form a pleasant background over which the eye of a jaded committee man may wander discreetly. The Electrical Laboratory is pres-

ently searching for additional items to add to the collection and the writer would be grateful to receive details of any old electrical and electronic items that other establishments may have for disposal or loan. Permission to view the present collection may be obtained from the Head of Electrical Department on written application.



**CORRESPONDENCE:**

To The Editor,  
*Journal of the Royal Naval Scientific Service*  
 Dear Sir,

With reference to Mr. Kirby's most interesting article on the History of the Torpedo, Part 3, may I be permitted to correct a slight error. The main source for the supply of torpedoes in World War II was the RNTF at Alexandria, Dunbarton, not RNTF Greenock. The RNT Works at Alexandria (ex Argyll Motor Works) having opened in 1936 and production gradually moved from RNTF Greenock to Alexandria. All torpedoes from Alexandria had the letters AA and were of excellent quality. An order of merit out of 100 for the various manufacturers would be:—

<i>Firm</i>	<i>Identification</i>	<i>Order of Merit</i>
RNTF Alexandria	AA	90
Whitehead (Weymouth)	AW	75
Morris Motors	ER	70
USA	CL	50

The writer agrees with Mr. Kirby on the mixed bags carried by submarines in the early years of World War II. Serving in the submarine *Tribune* in 1941 my outfit of 17 torpedoes consisted of:—

- 2 — 21in. Mk II RNTF (1917 vintage)
- 2 — „ Mk IV AW (1918 vintage)
- 1 — „ Mk VIII RNTF (1936 vintage)
- 1 — „ Mk VIII\* AA (1939 vintage)
- 11 — „ Mk VIII\*\*AA (1940 vintage)

For preparation, fitting of pistols, and settings we had to think carefully and it also meant carrying several tool boxes. Best wishes and many thanks for these interesting articles.

W. Y. McLANACHAN, Cdr. R.N. (Retd.)



# NON-DESTRUCTIVE TESTING IN DEFENCE

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After an Engineering Apprenticeship in H.M. Dockyard, Portsmouth, during the war, Don Birchon gained an external B.Sc. Degree from London University. He worked at the Central Metallurgical Laboratory, Emsworth from 1945-1956, since when he has been at the Admiralty Materials Laboratory in Dorset. His metallurgical experience has been principally in service failures, fatigue, boiler and reactor corrosion and stress-corrosion, the development and application of hidamets and, latterly, structural validation. His spare time interests are the normal masculine ones with special emphasis on small boats, amateur photography and Do-it-yourself.

The Advisory Council on Materials (now disbanded) requested a survey on NDT in the UK for discussion at its August 1971 meeting. Mr. R. S. Sharpe of the NDT Centre Harwell wrote on the Civil side, whilst the present author discussed Defence aspects in a joint paper, which is now to be published in an amended form. The following abstract is concerned principally with Defence aspects.

The UK NDT industry has a turnover of £12M p.a. but is highly fragmented, so that much effort is spent in developing and marketing competitive but technically similar products, and too little in originating new designs. Our researches indicated that about £1.5M p.a. is spent on R & D by Civil industry and Defence, of which about £0.2M p.a. is spent on special Defence requirements, many of which have valuable civil benefits.

There is certainly a need for sustained R & D effort on NDT by viable, competent and established groups, since the technology of the subject has developed largely as an empirical art, and has achieved a measure of notoriety as a happy hunting ground for the "instant expert"; it is also a process which, if incorrectly applied, can result in very large costs to the fabricator or customer, through either unnecessary repairs or equally unnecessary failure—or occasionally both in the same component!

### Organisation—The Defence Quality Assurance Directorate (DQAD)

Non-destructive testing is merely one of the tools used to measure and control quality; each of the Defence Services has been developing quality assurance organisations and control procedures for a very long time. Broadly speaking, the arrangements were good and workable, but inevitably there were some areas of overlap, and even an occasional instance where the same contractor could be subjected to differing standards of inspection on similar products by representatives of different branches of the Defence Services, perhaps reflecting differing environmental conditions associated with the use of the equipment.

The situation was therefore reviewed recently by the Raby Committee, and the principle that the "customer" should be responsible for specifying performance, reliability and maintainability applicable to the hardware concerned was recognised.

The Defence Quality Assurance Board<sup>(1)</sup> of the Ministry of Defence has the responsibility for determining that the customer obtains his requirements, and the system developed is both flexible and closely integrated. As an example of the way in which it works, the Aeronautical Quality Assurance Directorate has three main tasks:—

- (a) To ensure quality assurance during manufacture—which it does by delegating responsibility through the Approved Firms system.
- (b) Issuing Certificates of Safety for Flight, which it does by direct inspection in close co-operation with the Air Registration Board.
- (c) Acceptance of goods purchased under contract.

NDT is involved in each of these functions. The Army and Navy also use the Approved Firms system and have their own methods for implementing their additional and specialised requirements for quality assurance, e.g. the Quality Handbook for Naval Ship Production<sup>(2)</sup>, etc.

### The Defence Approach to NDT

This differs from that of industry in that Defence Services are major and leading users of NDT as both an essential tool for quality assurance and as a highly cost-effective aid to maintenance. This attitude to quality assurance is illustrated by the long-standing

recognition of the need to specify quality control requirements in procurement contracts (e.g. the Admiralty contract for the building of H.M.S. *Jersey* in 1696—no doubt reflecting the hand of Pepys—embodied a price linked to quality control requirements, and earlier precedents could probably be found, especially for ordnance).

More interesting, however, is the way in which the Defence Services have recently become more concerned with the philosophy and technical management aspects of NDT in order to minimise unnecessary inspection and wasteful, or even damaging "repair" operations, whilst maximising cost-effectiveness in both maintenance and ship/aircraft/weapon availability, etc. This concern reflects both the wealth of experience within the services and the benefits now deriving to them from sustained effort by established groups of people at fixed centres of expertise.

For example, the RAF studied the problems of maintaining aircraft and their equipment throughout their life cycle<sup>(3)</sup> and found that only 5-10 per cent of all defects were being discovered during routine examinations, despite the fact that these routine examinations absorbed 20 per cent of all the engineering manhours expended (NDT is, of course, only one of the techniques employed during such inspections). Further, their studies showed that 60-65 per cent of all defects were reported by air-crews, and they concluded that the significant problem was really one of over-servicing, and recommended that a "Datum Servicing Schedule" be introduced in which the structural integrity of all aircraft should be ensured through a more logical, much cheaper and potentially safer method of determination of the item, method and sampling schedule, etc, to be used, in which NDT plays neither more nor less than its proper role. This enables the maintenance staff to work on the basis of knowing *where* to look, and *what* to look for, and to build this knowledge into their servicing schedules for present and future aircraft, so that servicing requirements are simplified. The recommendations of the report were accepted and established with DCI/S179/70(RAF), and the method is now in use for existing and new aircraft including the MRCA (multi-role combat aircraft), and retrospective action is in hand.

Again, the Navy research at A.M.L. resulted in the development of the LEO technique<sup>(4,5)</sup>, a simple, formalised, quantitative

approach to the management of NDT, which is also directed at avoiding the ignorant and costly (but all too common) approach of "inspection for defects". The symbol  $L$  = the critical defect size at which the structure concerned would fail in service (e.g. length of crack, wall thinning in tubes, vibration level in equipment, etc. as appropriate);  $E$  = the rate of defect extension which must be allowed for between the inspection concerned and the life required of the structure; and  $O$  is a factor quantifying the total efficiency to be expected from the NDT team and available techniques. In this way the product  $L \times E \times O = LEO$  is a logically derived rejection criterion, and the  $LEO$  arguments, based as they are upon anticipation of the most likely failure modes and identification of the most useful and reliable inspection techniques, bear close similarities in philosophy to the NDT requirements of the RAF Datum Servicing System and to the conclusions of Weldon<sup>(6)</sup> in his recent paper describing the management and practice of NDT in American Airlines.

Again, the Navy view of NDT as primarily an aid to maintenance rather than as a function in its own right is explicitly recognised in the handbook<sup>(7)</sup> entitled "Aids to Maintenance" which is sub-titled "Nondestructive Testing Methods and Equipment"; this book is issued by DG Ships to ships' staff, overseers, contractors, and others, and is revised annually.

### **R & D and Field Activities**

Since defence NDT field work is so closely integrated with R & D, it is convenient to discuss some aspects of their relationship together in order to put the "field-work" into proper perspective. For all services, common stores (e.g. ordnance and explosives) are examined by techniques laid down by the appropriate QAD's. The NDT of ordnance and filled stores which are in the R & D stage is supervised at RARDE, Fort Halstead, where a team of six led by a PSO divide their time between research and non-routine supporting services. In this way the RARDE team can advise QAD on the correct techniques, procedures and rejection criteria applicable to subsequent production control, and a similar procedure applies to the inspection of rocket motors, where RPE Westcott take the lead. It is worthy of note that contractors sometimes then choose to contract the inspection to Government establishments because they lack the necessary

equipment and expertise to meet the quality assurance standards at acceptable cost.

In the Army, the special requirements for the inspection of fighting vehicles, bridging and other engineering equipment is the responsibility of QAD(FVE)—i.e. Fighting Vehicles and Equipment. For instance, all welders are approved by the QAD(FVE) Materials Laboratory examination of a series of specially designed test welds which represent the geometry of the equipment to be welded; and NDT examination is carried out on stressed welds during manufacture, using QAD(FVE) techniques.

In the Navy, special problems are the province of DGS Section 251(a), where a dozen men provide a centralised pool of expertise, training and technique development potential, and a world-wide "flying doctor" service. This is supplemented by 12 men in shipyards (reduced from 25 as firms' competence has increased over recent years) and five units totalling 52 men in dockyards and the Naval Construction Research Establishment. Section 251(a) also runs an extensive series of training courses, currently 38 per annum, each course catering for from 6 to 20 people, with the emphasis on junior MOD engineers and designers, but also including Naval staff, some Army and RAF personnel, and Commonwealth officers, as appropriate. These courses have two main aims: to train MOD(N) operators, and to acquaint MOD(N) engineers and designers with the capabilities and limitations of NDT techniques.

This "front office" conducts some of its own R & D as appropriate to its needs and resources, and this flexibility is a valuable spur to the initiative of staff who might otherwise be frustrated if they were confined to routine problems and instruction. It is supported by "back-room" research at a number of establishments, primarily at A.M.L., where a team of three to four scientists have developed equipment such as the *Amlec*<sup>(8)</sup>, *Magneprint*<sup>(9)</sup> and techniques for the continuous surveillance of critical areas in structures and for the detection of changes of compliance at welded joints and intersections, and where the effort is now directed principally to the development and application of stress wave analysis for the structural validation of complex structures, sub-assemblies, and simple welded joints.

The Royal Air Force develops and proves NDT procedures for aircraft structures at the Central Servicing and Development

Establishment (CSDE), Swanton Morley, where two Flight Lieutenants and four Chief Technicians appraise new equipment, develop inspection techniques and schedules and operate the RAF world-wide service, which is supported by eight field support teams of three to four Chief Technicians in each area of operation. In addition, three instructors at the CSDE Training School run courses ranging from acquaint courses for Senior Officers through one week courses for Junior Officers, to four-month courses for Chief Technicians from MOD(N)(Air), the QAD's, some friendly foreign air forces and Army Technicians. A subtle distinction is that they are able to take advantage of the special constraints under which aircraft operate to write precise procedures for specific components, in such a way that the procedures apply only to that component and specify the precise rejection limits applicable to that component. This is a most advanced and well proven system, admirably adapted to RAF requirements, and well co-ordinated with the results of NDT research, (on both methods and detailed applications) conducted by RAE, etc, and by the aircraft manufacturers.

### Specialised Field Activities

Some techniques are highly specialised and/or expensive, so that when Service requirements plus the enterprise of individual officers results in a major advance in a given area, a technique becomes available which can be immediately shared with other Services having similar requirements. An outstanding example is the Sustained Oil Analysis Programme (SOAP). This technique, for studying wear metal debris in closed lubricating oil systems of machinery, is well-established at NAML, Fleetlands, where two members of staff are responsible for the analytical requirements of the Navy and for selected units from the Army and Air Force. This little-publicised activity has been shown to have a cost-effectiveness ratio of 1,000:1, and demonstrates a high degree of effective co-ordination in the research, development and use of NDT techniques in Defence.

### Research on NDT for Defence

To sustain Defence requirements and because UK industry conducts insufficient R & D to maintain an appropriate level of aggressive and progressive research, Defence R & D has to range from fundamental studies to the development of equipment and techniques.

A compilation of total Defence inspired R & D would be very time-consuming and of doubtful value. However, major defence-sponsored research in NDT is summarised in Table 1, in which the DGS ultrasonic weld-scanner costs have been included, although they are principally for development and initial procurement. The table shows clearly a heavy commitment to the study, development and use of stress wave analysis techniques. From 1969 - 1974 direct Defence expenditure on this technique will be of the order of £0.3m, and should have resulted in the production and use of equipment ranging from low-cost weld quality monitors to the A.M.L. Structural Validation equipment having a computer on-line for real time defect location and grading, with built-in logic modules for transducer checking and calibration, and the rapid identification of significant sources of emission. It will also provide a steadily increasing data bank of material correlation studies for both metallic and non-metallic composite materials.

Another example is provided by the work of RARDE in developing cine radiography or closed circuit TV radiography for the study of solidification processes (and flaws arising therefrom) in explosives and metals.

A cost benefit analysis of NDT throughout Defence and UK industry would be most interesting, but was unfortunately beyond the resources of the authors; but Warren and Tabb<sup>(10)</sup> stated that the labour content of quality control varies from 2% of the total for surface ships of varying sophistication, to 8% for submarines. As examples, the following indicate the savings which can accrue from properly co-ordinated NDT; (these examples are drawn from the Navy Department, no doubt similar case histories could be quoted for other Services).

- (a) The introduction of the non-destructive wear and waste testing procedure for Naval boilers has reduced the work load from four men for four to six weeks, to two-and-a-half men for one week, with consequential savings in excess of £1,000 per boiler (since dislocation of other aspects of refit is reduced). On the basis of 25 boilers examined per year, total savings in direct dockyard costs exceed £25K p.a. and there are considerable "invisible bonuses" from the saving in time and effort.
- (b) The DG Ships ultrasonic weldscanner operates at a rate equivalent to 10 fully equipped and trained men, and pro-

duces immediately intelligible permanent records whilst only requiring two operators, thereby freeing eight operators and eight sets of equipment for other work, whilst reducing the effort required to maintain proper records.

- (c) The *Amlec* Crack Detector has reduced the time requirements for a standard MOD(N) survey from 178 to 28 man days, and has shown other, though less dramatic, savings on other inspections.

Other NDT techniques now being introduced (*e.g.* SOAP for marinised gas turbines and vibration analysis for selected machinery items) offer considerable savings in cost and improvements in ship availability for the future and it is considered that the use of stress wave analysis will soon yield increasing benefits through both reducing the cost of locating defects and assisting in determining their significance.

#### **Working Level Co-ordination in Defence**

A series of committees operate to ensure proper co-ordination and dissemination of information in defence, in particular:

- (a) The Materials Panel of the DQAB, chaired by QAD/FVE, has representatives of QAD(Mats), AQD, EQD, QAD(Weapons), NOIMU (Naval Ordnance Inspection and Materials Unit) and DG Ships.
- (b) The DG Ships Working Party on the Application of NDT to Warships, Hulls and Machinery is chaired by DGS/251 and has representatives of Fleet, design, dockyard, support and scientific services as well as liaison officers from the R.A.F. and the Commonwealth.
- (c) The Defect Evaluation Working Party is an MOD(PE) body designed to give background support to (b) above and to identify fertile areas for progress in the techniques and implementation of NDT in the Navy.

In addition, a joint register of NDT (and destructive testing) equipments is maintained<sup>(11)</sup> so that different Services can share local facilities to the maximum benefit.

#### **International Co-operation**

The Technical Co-operation Programme Panel P4 (TTCP-P4) is concerned in the Defence field with "Methods of Test and Evaluation of Materials, and Materials in Structures"; and the two UK members (serving at RARDE and A.M.L.) have the task of

assisting in co-ordinating programmes, identifying common targets and disseminating information. This has resulted in good information exchange and a growing number of collaborative exercises, especially in evaluating equipment, and, in one noteworthy case in a proposal to join the better half of a U.S. automatic system to the complementary, but technically better half of its UK counterpart—an unusually altruistic technical "marriage".

#### **Areas of Opportunity**

Whilst it would be inappropriate in a review such as this to make recommendations, it would be equally inappropriate to conclude this task without comments upon some areas of opportunity or neglect which suggest themselves.

A TTCP P4 report, issued in May 1969, reviewed the research promise of 14 new NDT development areas and we considered that the following techniques referred to there are certainly worthy of continued study and evaluation; holography, stress wave emission, exoelectron emission, neutron radiography, internal stress determination, and the use of liquid crystals, microwaves and lasers. It is encouraging to note that of these techniques, holography, stress wave emission and neutron radiography are already becoming areas of energetic study.

In addition, we suggest that in the more established areas of the technology,

- (a) A better understanding of the character of transducer materials and the influence of mounting and coupling systems upon them would enable their performance to be improved by design and prediction, rather than by trial and error. This would apply to both ultrasonic and stress wave emission.
- (b) Dye penetrant inspection, which is intrinsically simple and cheap, and very widely used, requires support from better methods of calibration and standardisation.
- (c) The science of radiography would be considerably enhanced if automatic radiograph evaluation techniques could be developed.

Non-destructive testing is generally limited to locating defects; evaluating them correctly and understanding their significance still lags behind our ability to find them and this is one obvious complementary area urgently requiring further support and attention.

TABLE 1. Some Defence Sponsored NDT Research for 1971/72

Technique/Objective	Establishment	Sponsor	Costs* of men plus Equipment		Status†	Total Expend. 1971/72
			Intra-mural	Extra-mural		
<u>Acoustic Emission</u>						
Material Studies—metals	AML	—	10	—	C	£119.5K
	Liverpool University	AML	—	1.5	S	
—composites	AML	—	10	—	C	
Source Location Studies	AML	—	20	30	C	
Weld Quality Monitoring	WI	AML	—	12	C	
Defects in composites	NDT Centre	RPE	—	5	S	
	RPE	—	15	—	S	
SWE for Ordnance	RARDE	—	5	—	S	
Adhesive Bond Strength	NDT Centre	MOD(AS)	11	—	C	
<u>Ultrasonics</u>						
Automatic Weld Scanning	DGS	—	—	20	C	£67K
Holographic examination of bonds and propellants	NDT Centre	RPE	—	5	S	
	RPE	—	15	—	C	
Data Reduction and presentation	RPE	—	20	—	C	
Degree of cure of resin	NDT Centre	MOD(AS)	5	—	C	
Ultrasonic goniometry	NDT Centre	MOD(AS)	3	—	C	
<u>Radiography</u>						
Development of Neutron Radiography for Explosive Stores and composite Materials	RARDE	—	3	—	C	£24K
Neutron radiography of Propellants	NDT Centre	RPE	—	3	S	
Improvement of Sensitivity and Resolution	RPE RARDE	—	3	—	C	
Improvements in equipment (micro focus, image intensifiers, etc.)	RARDE	—	15	—	C	
<u>Eddy Current</u>						
Improved Bar and Tube Testing	AML	—	5	—	C	£5K
<u>Eddy magnetics</u>						
Crack depth studies	RARDE	—	2	—		£2K

† S=Starting  
C=Continuing—not necessarily at level shown

\* 1 Professional grade plus supporting services assessed at £10K p.a.  
1 Technician grade plus supporting services assessed at £5K p.a.

This list is not exhaustive, and does not include many items of NDT R & D of a local nature arising when a laboratory/establishment is faced with a parochial problem and is able to generate and apply local expertise, nor does it include the use of, and further research on special techniques such as X-ray diffraction; electron probe microanalysis etc, for which facilities exist at a number of Defence Establishments.

We also considered that there would be some merit in providing short, practical courses on "Welding Technology for NDT Operators" to help them to understand the problems of those whose work they are inspecting. But such a course would require to make it very clear that the NDT people were not being transformed into welding supervisors or engineers.

However, we considered that the greatest rewards would derive from using NDT with a high level of professionally competent and adequate management, rather than (as can occur in industry) permitting it a grudging existence under some relatively low-level manager; this would also stimulate industry into developing, producing and marketing NDT equipment and services instead of relying so heavily on overseas suppliers. Also we felt that there is a great need to train young engineers and designers in NDT techniques and quality assurance principles so that they can incorporate this experience into their daily activity and project the concepts into their forward thinking.

#### ACKNOWLEDGEMENT

This brief review has been compiled from information generously provided by a host of busy men, to whom the author is indebted; however, the views

expressed reflect the author's own interpretation, blended with Roy Sharpe's views in the "Areas of Opportunity". The paper is published by permission of the Director, A.M.L.

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#### Obituary: Hugh Clausen, O.B.E., I.S.O.

We regret to report that Hugh Clausen died on January 19. Born 1888, he studied engineering at the Regent Street Polytechnic and the City and Guilds Engineering College. After an engineering apprenticeship and some design experience at Siemens Brothers, he joined the RNVR in 1914 and spent the Great War in the Grand Fleet being awarded the O.B.E. in 1918 for improvements in the gunnery fire control gear in ships. In 1920 he joined a newly formed section of the Admiralty dealing with low power electrical systems in ships. He was in general charge of the design of all Naval gunnery surface fire control gear until the Second World War and was responsible for the invention and development of many improvements whilst at D.N.O. The Floating Rolling Platform for testing guided missiles at Aberporth in which he was actively engaged, was named after him as a tribute to his 40 years' work for the Royal Navy.

Hugh Clausen went into retirement in later years acting as an Engineering Design Consultant and was a frequent contributor to the Technical Press and to our Journal. He performed great services to both professional and technical engineers in stressing the importance of design and in showing how these problems can be tackled.

# CHINESE UNIVERSES

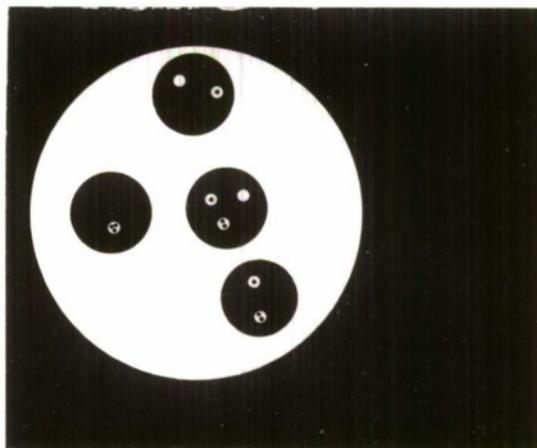
## *A Synthesis of the Steady State and Big-Bang theories*

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From the unreasonable assumption that change is impossible, Parmenides<sup>(1)</sup> inferred about 500 B.C. that the universe had no beginning, in itself a reasonable belief. In fact the notion that the universe came into existence either with a big bang or with a whimper might one day seem as droll as that earth rests on an elephant that stands on a tortoise. Any evidence that the universe had a beginning can be more reasonably interpreted by saying that some cataclysmic event occurred, perhaps some 10 billion years ago, which completely transformed the observable universe. The speculative theory that I shall put forward in this note is of this form.

According to General Relativity, a heavy enough body of given size cannot be communicated with from outside and becomes a "black hole" or "Schwarzschild singularity". I shall argue here that the whole of our *observable* universe is probably a black hole. For, on the assumption of continual creation, a galaxy eventually becomes so heavy that it collapses into a black hole, so, in infinite time, we are *certain* to be in a hole (with *physical* probability one). Therein the density of matter should be almost infinite, and this provides a feasible explanation for Dirac's concept of an ether of infinite negative density in which ordinary elementary particles are very small holes.<sup>(2)</sup> These small holes might be formed by a process of continual destruction, which can also be regarded as a process of continual creation of negative matter (not antimatter). The notion that there is continual destruction as well as continual creation is a familiar one especially emphasized by Kapp.<sup>(3)</sup> The expansion of the observable universe can be ascribed to the creation of more of the "ether" in Dirac's sense. Since, in this theory, the ether



consists of tightly packed particles, the creation of new particles forces the expansion of the black hole. This black hole is embedded in a universe in which the ether again consists of tightly packed particles, but of the opposite sign, and this larger universe can be regarded as a "white hole" in a yet larger universe. The "big-bang" origin of the "universe" is here interpreted as the transition of a heavy galaxy into a black (or white) hole within a larger universe. It even follows by this argument, with physical probability one, that we are inside an infinite sequence of holes, one within the other, like carved Chinese spheres, consisting alternately of ivory and ebony. The diagram should clarify this description. The notion that an *elementary* particle might be a universe, combined with the notion of infinitely nested universe, is an old science fiction idea. But the present theory interprets collapsed galaxies, *not* elementary particles, as sub-universes, and it is intended to resolve the conflict between the big-bang and steady-state theories of the origin of the universe. Although the theory seems grandiose, as far as I can see it is the only possible consistent interpretation of the steady-state concept, and it is not purely speculative since it gives a reasonable explanation for Dirac's "ether".

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Dr. Good joined G.C.H.Q. in 1952, and served at A.R.L. from 1959 - 1964.

### References

- <sup>(1)</sup> For example, *Masterpieces of World Philosophy* (ed. Frank N. Magill, London; George Allen and Unwin, 1963), 16 - 22.
- <sup>(2)</sup> P. A. M. Dirac, *The Principles of Quantum Mechanics* (3rd edn., Oxford, 1947), 273.
- <sup>(3)</sup> Reginald O. Kapp, *Towards a Unified Cosmology* (New York; Humanities Press, 1960).

### **H. J. Elwertowski, C.B.E., Dip. Ing. (Warsaw)** —An Appreciation



**Henry Elwertowski**, lately Head of Admiralty Compass Observatory, has retired. Joining A.C.O. in 1958 as Chief Scientist, he took over from Captain T. D. Ross, R.N., the last Naval Director, in 1971. His tenure of office has been marked by continued technical progress at the Observatory and by an increase in its national and international esteem in the field of navigation science.

H. J. Elwertowski was born at Dabrowa, Poland. After his education at Warsaw University, graduating in mechanical engineering, he joined the Polish Optical Co., and became chief designer of fire control equipment.

When the German invasion of Poland was imminent, he joined the Artillery of the Polish Army and was engaged in the fight against the Germans between 1938 and the end of September 1939, when he was captured and interned in Hungary. Escaping from internment, he made his way to France via Yugoslavia and Italy and enrolled in the Polish Army formed in Paris. However, the occupation of France by the advancing Germans forced the disbandment of the exiled Polish Army and Elwertowski again escaped and made his way by cycle and on foot to the unoccupied south. Here he was marooned until December 1941, enduring further privation and working in the meantime as a stoker in hotels and at salt extraction from the sea. Eventually he was able to cross the Pyrenees to Saragossa in Spain and continue with a series of illegal journeys by train and ship to Gibraltar via Madrid and Lisbon. At Gibraltar he took passage by troopship to Britain, landing at Greenock early in 1942.

Elwertowski's Admiralty career began in 1942 at the Admiralty Research Laboratory, Teddington as a temporary S.E.O. His duties there were concerned with the design of fire control equipment for Army A.A. guns. In

1948 he was promoted to S.S.O. and in 1949 to P.S.O. A noteworthy achievement with Teddington group, which had become Admiralty Gunnery Establishment was the design of a ball resolver, basic unit of an anti-aircraft flight predictor.

When AGE moved to Portland in 1954, Mr. Elwertowski became leader of the Stabilisation Group. In 1955 he was promoted to S.P.S.O. One of his major responsibilities at Portland was the vertical stabiliser incorporating the then novel American flotation gyro units.

When AGE was dissolved in 1958, Elwertowski succeeded Dr. W. F. Rawlinson as Chief Scientist at A.C.O. Shortly afterwards, following decisions by the Government's Barclay Nihill Committee, the Establishment was reconstituted a Directorate under the then DGW, Admiral Le Fanu.

At A.C.O., one of Mr. Elwertowski's first major tasks was the re-organisation of the team developing Ships' Inertial Navigation Systems, a project which has made and continues to make steady progress. From the early experimental 4-gimbal SINS, lessons learned in H.M. Ships *Steady*, *Dreadnought*, *Eagle* and *Valiant* led to the very successful Mk. I system, which embodied gas bearing gyros and a navigational monitoring computer. Elwertowski, in his capacity as a mechanical engineer, was personally involved in the design of both gyros and computer. The successful visit of H.M.S. *Dreadnought* to the North Pole was made with the assistance of SINS, Mk. I and this system is installed in H.M. Ships *Warspite* and *Fife* and extensive further submarine and surface ship fittings are planned. An experimental Mk. 2 3-gimballed SINS, using microcircuits and digital computation, has had sea trials in H.M.S. *Penelope* and a laboratory prototype is being constructed.

In 1962 following the Nassau agreement with the U.S.A. on Polaris submarines, a Polaris Navigation Mission to America was led by Capt. Ross and Mr. Elwertowski. Two of the many improvements recommended by the mission, and subsequently adopted, were the reduction of American Polaris SINS systems from three to two per boat and the elimination of type 11 periscopes. These changes saved Britain over £2m. per vessel. A.C.O.'s Polaris work later became specialised in developing accurate heading transfer systems, the best of which has been adopted for British bases and has been successfully demonstrated at Cape Kennedy.

In magnetics, Mr. Elwertowski not only fostered the continuing improvement of various types of compasses used by the three Services, but built up extensive collaboration with other organisations, particularly with D.A. (Nav) [Mintech] on *NIMROD* aircraft Magnetic Anomaly Detection, with R.A.E. Farnborough on *Sonobuoy* and with the assessment and advice services offered on aircraft compasses and compass base sites to the R.A.F., B.E.A., B.O.A.C. and others. It is characteristic that Elwertowski found time personally to carry out a magnetic survey, for the R.A.F. at Singapore, after mastering details of the procedure.

In gyro compass matters, Mr. Elwertowski's era at A.C.O. has seen the phasing out of older types of instrument, the bridging of gaps in the Service by American units and the inception and launching of the new all-British Compass Stabiliser project.

As a result of Elwertowski's negotiations with the American firm of Nortronics, the world's most sensitive gyro test station, known as Ultra Precision Test Equipment was installed at A.C.O. U.P.T.E. is now used to assess not only high performance gas bearing gyro units used in SINS, but many others including laser gyros. The important but less publicised SINS accelerometer used in conjunction with these gyros was designed and is constructed at A.C.O.

A decision by Mr. Elwertowski to develop self-acting gas bearings for SINS gyros in place of ball bearings, to prolong gyro life, led to a perhaps more important improvement in system accuracy. In this pioneer activity a very close liaison has been built up, both with British gas bearing organisations and with American groups under the sponsorship of the U.S. Office of Naval Research. An annual information-sharing Anglo-American gas bearing conference was inaugurated by Elwertowski as well as domestic meetings of the British Gas Bearing Panel, which he founded.

Under Mr. Elwertowski at A.C.O. some important new responsibilities were assumed by the Establishment. The post-design of weapon stabilisers and the design of new ones incorporating gas bearing gyros were among new tasks as well as the design and development of a new Ship's Acceleration Computer.

After a visit to U.S.A. to study American practice in the field of ring lasers. Mr. Elwertowski took over responsibility from SERL

Baldock for ring laser gyros. This has led to a major contract with EMI and a test programme of EMI and A.C.O. instruments.

Henry Elwertowski's progress at A.C.O. in addition to the technical advances made, has been marked by a number of important milestones. A.C.O.'s golden jubilee in 1967 saw the opening of a new laboratory block by Sir Horace Law, Controller of the Navy. Personal promotion followed in 1968 when he became a DCSO. In 1970 a new R & D workshop was opened. In 1971, when the last naval director retired and A.C.O. became the Navigation Department of ASWE, Mr. Elwertowski became A.C.O.'s first "Head".

Official recognition of his services came with the award of a C.B.E. in the 1972 Birthday Honours.

Two farewell ceremonies marked Henry's departure. At the first, primarily domestic, A.C.O.'s senior Naval Officer, Commander A. E. Fanning paid tribute to Henry's qualities and his achievements over his 14 years at A.C.O. On behalf of local staff he presented a gold watch, an armorial plaque and a photograph of the Establishment. In a brief reply, Mr. Elwertowski expressed the great pleasure derived from his task at A.C.O. and his appreciation of the happy team-work of all groups there.

At an evening party attended by VIP guests as well as A.C.O. staff and their wives, Mr. H. W. Pout, Director of ASWE, spoke of Henry's achievements in building up A.C.O. to its current level of activity and handing over to ASWE such a thriving concern. Mr. Pout presented a cheque as the gift of ASWE and other headquarters staffs. Again expressing his thanks, Mr. Elwertowski said he was confident that even greater times were in store for A.C.O. A final touch was a presentation of a bouquet to Mrs. Elwertowska by Henry's Secretary Mrs. Dorothy Brown.

Not least remembered of Henry's characteristics will be his sense of humour and fund of anecdotes in lighter vein, whether true or apocryphal.

Although the departure of Henry Elwertowski from A.C.O. is a severe loss, many who value its activities recognise with appreciation that he left the place greater than he found it. In wishing him and Mrs. Elwertowska all the best for the future, those that remain and many others who know him will surmise that he is looking for fresh fields to conquer.

## NOTES AND NEWS

### Admiralty Compass Observatory

#### *Navigation Department of ASWE*

The Under Secretary of State for the Navy, Mr. Peter Kirk, MP, accompanied by a member of his staff, Mr. L. A. Richardson, and by Mr. J. R. Thomas, Deputy Director ASWE, visited ACO during April. After discussions with senior members of ACO the party toured laboratories and workshops to inspect work in progress and meet section leaders in the R & D and Production departments. Other visitors to ACO from at home and abroad have included the following: Captain le May of the Chilean Navy to discuss ship-fitting of Omega radio navigation receivers, now being carried out by Chile. Mr. Rex Stout of the U.S. Navy's Omega Project Office, Washington, in course of a European tour, to discuss matters of common interest with ACO's Omega team. Mr. Michael Wapner and Mr. Jack Fulcrest of NAVSHIPS Department, U.S. Naval Strategic Systems Navigation Facility, Brooklyn N.Y. to exchange information and discuss development in the field of inertial navigation systems and components. Dr. David Fleming of the Lubrication Department, Lewis Laboratory NASA Cleveland, Ohio, to discuss gas bearing research. M. Udole and M. Cantarel of the Laboratoire de l'Armement, Paris, together with M. Geneste of the Laboratoire de Recherches Aerodynamiques, Paris, to discuss the boundary lubrication of gas bearings.

Fifteen members of the US Office of Naval Research Gas Bearing Committee, to attend the Anglo/American Gas Bearing Liaison Conference at ACO. This meeting will be reported in detail in the September issue of J.R.N.S.S.

Mr. A. G. Anderson and Mr. R. D. Ramsay of the Australian Weapons Research Establishment, accompanied by Lt. Cdr. G. D. Bessel-Browne, R.A.N., and Sq. Ldr. A. Basset, R.A.A.F., to discuss provision of compasses for BARRA, the Australian Sonobuoy project.

The Engineering Societies of Kings' and Imperial Colleges, University of London, who were given conducted tours of various ACO laboratories and workshops.

Mr. J. R. Brinkley, Managing Director of Redifon, the firm supplying receivers for Omega radio navigation, to discuss future British interests in surface ship-fitting of receiving equipment.

Mr. T. M. Sneddon, Managing Director, Mr. R. R. Wyke, Technical Director, and Dr. D. L. Brooke, Chief Engineer, of S. G. Brown Limited, who were making a liaison call to include particularly visits to UPTE and Gas Bearing Laboratories and Gyro Test Rooms.

The Deputy Controller, Polaris, Rear Admiral C. W. H. Shepherd, accompanied by Captain A. R. Manvell, for discussions with ACO Management.

The Deputy Controller, Establishments and Research (C), Mr. Norman Coles, accompanied by Mr. F. S. Stringer and Mr. J. Briggs, who made a general tour of ACO and had discussions with senior staff.

Cdr. B. C. May, U.S.N., Lt. Cdr. R. Burgent, U.S.N., Mr. Rex Stout and Mr. J. R. Cliffe, of the Omega Project Office, Washington, attended an Anglo American radio navigation liaison meeting at ACO, together with members of British H.Q. Naval and Air Staff.

Visits abroad by members of ACO staff have included the following:—

Mr. R. Weatherburn attended a special International Symposium held in Washington where a number of papers were presented on topics associated with Omega radio navigation.

Mr. C. V. Hardy and Mr. J. E. Smith to Cape Kennedy, Florida, U.S.A., to take part in the post refit Demonstration and Shake-down Operation (DASO) of H.M.S. *Resolution* involving successful Polaris missile firing. The ACO heading calibration system was used to make a precise transfer of true bearing from a shore facility to submarine, in order that the boat's navigation system could be accurately calibrated.

Mr. A. G. Patterson to Cambridge, Mass., U.S.A., to attend a meeting of the U.S. office of Naval Research Gas Bearing Committee at MIT and to spend a few days in the Draper Laboratories of the Institute.

Mr. H. J. Elwertowski, Mr. C. J. Gulland and Mr. E. Hoy visited a number of organisations in the U.S.A. under IEPB.11, covering liaison in strategic naval systems. The tour included Navy Department Washington, Sperry New York and the Naval Strategic Systems Navigation Facility at Brooklyn. Subsequently, Mr. Elwertowski visited Teledyne, Northridge, California, for a joint meeting with the firm and representatives of BAC to discuss "dry" gyros and Mr. Hoy visited the U.S. Omega Station in North Dakota.

### Admiralty Experiment Works

Mr. Derek Rayner, Chief Executive (PE), Sir Michael Carey and Admiral Sir George Raper visited A.E.W. on 9 June. The visitors were shown a wide range of experiments in progress, which included flow measurements behind a new submarine form and developments in fin stabilisers for surface ships in the two Ship Tanks and rudder force distribution study together with conventional propeller testing in the Cavitation Tunnels. A sequence of experiments was run in the Manoeuvring Tank which comprised new frigate and submarine control experiments followed by sea-keeping experiments with a frigate model using a new telemetry system.



### Admiralty Surface Weapons Establishment

Admiral Sir Anthony Griffin, Controller of the Navy, visited the establishment on 9 June for his annual visit when the opportunity was taken to show him a number of activities which he had not been able to see at first hand on earlier visits. He was accompanied by Rear-Admiral P. A. Watson, Director General Weapons (Naval) and Mr. A. R. M. Jaffray, Assistant Under Secretary of State (Material-Naval).

On January 26 Mr. J. M. Foley read a paper to the Royal Institute of Navigation, on "Navigational Aids, the means and the end", and in December 1972 Mr. P. J. Houseley reads a paper to the Institute examining the problems of sensor errors in collision avoidance systems.

Mr. Foley, Mr. K. Morgan, Mr. D. R. Jarman, Mr. N. G. Evans and Mr. J. D. Bowyer are presenting papers at the IEE Conference on Advances in Marine Navigational Aids in July 1972.

Mr. Foley also presented a short paper on shipborne navigational aids to the Marine Traffic Engineering Symposium at NPL in May 1972.

A paper on "The extraction and presentation of collision avoidance data from marine radar" by W. H. Shuffleton was published in the *Journal of the Institute of Navigation*, 25, No. 2, April 1972, following its delivery at the Liverpool Polytechnic at a conference on "The application of computers to Ship Operations" held in March.

Mr. A. V. Bryant read a paper on "Naval Shipborne HF Receiving Arrangements" at

the IERE Conference on Radio Receivers and Associated Equipment which was held at the University College of Swansea, 4 - 6 July 1972. At the same conference, Mr. H. P. Mason read a paper on "Multiple Channel UHF Reception on Naval Ships".

**Mr. S. F. E. Byrne** retired from the RNSS on 25 May 1972 after nearly 45 years' service. He originally joined in 1927 and served an apprenticeship with the Mechanical Engineering Department of Portsmouth Dockyard. After completing his training, he subsequently served in the Department for nearly 20 years, and prior to joining ASWE in 1959, he also served at ULE, UDE, UCWE and AUWE. His wide variety of experience led to his promotion to Chief Draughtsman in 1967. Since that time, he has been responsible for over 50 staff in the Installation Division at Ports-down.

To mark his retirement, the Director, Mr. H. W. Pout, presented him with a cheque on behalf of his friends and colleagues and also an inscribed ASWE plaque.

**Mr. Arthur Leslie Whiting** retired on 26 April 1972 after almost 50 years continuous service to the Crown. He started his career in 1922 when he joined the RN as an Engineering Artificer Apprentice. After 25 years in the Navy he left and joined ASRE at Witley as a Lab Mechanic in 1947. In 1955 he was promoted to Leading Draughtsman and in this capacity he contributed to the design of the first UHF Trans/Receiver in the RN. His many friends and colleagues in the RNSS will wish Arthur and his wife a long and happy retirement.

**Arthur Potten** retired in May 1972 after 21 years in the RNSS. Following training at Kingston Technical College and an engineering apprenticeship at NPL, Mr. Potten worked in the Experimental Department of Venner Timeswitches during the 1930's and was employed by the Aeronautical Inspection Directorate during the war at Vickers, Weybridge and in Inverness and Dumbarton. He joined the RNSS in 1951, working in the Carrier Equipment Department at RAE Farnborough, and moved to NCRE in 1954. For the last 18 years he has worked in the large structural testing facility at NCRE, becoming an expert in his field and providing an important service, which will be very much missed, in organizing and supervising structural experiments.

Out of office hours Arthur Potten was an active member of the Civil Service mountaineering group and was a mainstay of the local sailing club. He was also an active participant in the scouting movement and organized many adventure expeditions of his Sea Scout group to the Scottish Highlands and overseas. Mr. and Mrs. Potten have now retired to Plockton in the far North-West of Scotland to run a bed and breakfast establishment and to explore the Hebrides in a newly acquired cruising yacht. His many friends at NCRE and in the Rosyth area wish Arthur and his wife a long and happy retirement and look forward to visiting them at their new home.

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#### Naval Construction Research Establishment

The Hull Committee of the Maritime Warfare Advisory Board of the Defence Scientific Advisory Council—Chairman, Professor E. W. Parkes, Cambridge—visited NCRE on 1st and 2nd May 1972. The object of the visit was twofold, to discuss the NCRE Applied Research Programme on Glass Reinforced Plastics and to observe the final underwater explosion test on the series of whipping shots against the destroyer H.M.S. *Defender*.

Recently NCRE assisted the Institute of Geological Science to carry out a further series of Seismic shots by providing the services of their instrument vessel R.M.A.S. *Barfoot* and their Explosives Officer, Mr. C. C. Moore, O.B.E. A series of 300 lb charges were fired off the North of Scotland and in the Minch and a single 10 ton charge was fired off the Island of Rhum on 11th June 1972. The reverberations of this explosion were picked-up by seismic stations all over the world.

On 16th February, 1972 a team from TNO representing the Dutch navy visited NCRE as part of the Anglo Dutch co-operation on Materials. The party included Dr. Van Lent, Dr. Van Elst, Mr. Keizer and Mr. Bouwman.

Discussions between the materials section and the Dutch group, covered all aspects of steel selection and manufacture together with fabrication problems.

Mr. S. J. Palmer, DDGS, Bath, visited NCRE on 17th April, 1972. NCRE set up a small discussion group so that Mr. Palmer could be acquainted with the current state of the work at NCRE.

On 22nd May, 1972 Messrs. D. Kallas, H. V. Nutt and Commander Barrie visited NCRE under the auspices of Anglo-U.S. collaboration of structural materials. The achievements of the collaboration were discussed as also were its shortcomings, and ideas were propounded as to how collaboration might be improved.

On the 6th June, 1972, NCRE were visited by Colonel Venturini, Lt. Col. Vitullo, Prof. G. Valdenayyi, Capt. Melly; the visit was arranged under the Anglo-Italian co-operation agreement. Discussions during the visit covered the areas of structures and materials.

‡ ‡ ‡

#### Naval Aircraft Materials Laboratory

Mr. E. J. Hammersley, Officer-in-Charge NAML, visited Bardufoss from 9 to 11 March during Exercise Clockwork, in connection with problems involved in low temperature operation of helicopters.

Mr. R. C. Clark, S.S.O., attended the 19th Meeting of A.S.C.C. Working Party 15, Aviation Fuels, Lubricants and Allied Products, in Wellington, New Zealand, from 25 April to 5 May 1972. This body, which meets annually, deals with interchangeability and standardisation of aviation fuels and lubricants and of the relevant test methods; besides this there was, as always, much interchange of information on R and D programmes, Service problems, etc. For the first time, New Zealand participated actively in the proceedings of this Working Party.



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## BOOK REVIEWS

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**Engineering Drawing and Communication.** By R. J. Webb and D. A. Ellis (Royal Military College of Science, Shrivenham). Pp. 32. London and Glasgow; Blackie. 1971. ISBN 0 216 87492 0. (Price not given).

Mainly intended for engineering craft apprentices taking the first year of the City and Guilds 500 course and hence of interest to those responsible for craft training, the claim on the back cover "This book explains the methods and conventions of drawing practice clearly and concisely" is, within the confines of 32 pages, reasonably met. Anyone who has the occasional need to communicate his ideas through the medium of sketches and drawings will find the information contained very useful as an aide-memoire. Wisely the authors have not attempted instruction in the matter of drawing itself, for in view of the amount of matter included it would have resulted in confusion. As it is, some of the sections intrude upon their close neighbours and care is occasionally necessary to avoid error. An example may be found on the two pages following page 20 (pages 21 and 22 not being numbered in the review copy) on page 21 one has to read the titles under the figures to find that Fig. 2 is the circuit diagram for the battery charger shown in practical form in Fig. 1. No mention is made in the preceding text regarding Fig. 1 although the comment on Fig. 2 demands such mention. On the same page reference is first made to the wiring diagrams (Fig. 4) shown overleaf on page 22, followed by the text for the Fig. 3 shown on the bottom of page 21 which gives the graphical symbols for electrical diagrams. It

would have been much more sensible to place the text for Fig. 4 on the same page as the figure. Fig. 4 on page 22 contains wiring diagrams with accompanying circuit diagrams and is entitled "Examples of electrical diagrams", no mention is made of the equivalence of the two sets of diagrams. It is left for the reader to assume and would not be clear to a tyro. Two of the inputs in these diagrams are marked  $\sim 50$  Hz, all the others merely  $\sim$  and could cause doubts to a complete beginner. Confusion is caused elsewhere by some diagrams not having titles, and one example at least, on page 7, has the title on the left hand side with the figure on the right hand side of the page.

A useful section on page 23 gives colour coding for pipelines but finishes on page 24 mixed up with the electrical wiring identification, which should have included the earlier mention on page 22, and geometric construction. The drawing examples shown are generally excellent although there is a slight lapse on page 19, where an idler pulley assembly appears slightly awry and its caption is missing, fortunately the text makes it clear that it should read Fig. 1.

Summing up, a potentially useful book that could be improved by a better layout in places, a little more elbow room to allow separation between different parts, and the placing of all page headings on the left hand side of the page. When writing an elementary book for students it is essential to avoid any possibility of confusion and it is a pity that the communication part of the book is occasionally suspect.

C. K. Aked

**Radio Direction Finding.** By D. W. Watson and H. F. Wright (Van Nostrand Reinhold, Marconi Series).

For many years now there has been a need for a book to replace Keen's classic "Wireless Direction Finding", which is both obsolete and out of print. Two potentially useful books have been published in Russian, but these are not readily available to Western readers, and the need for a definitive text book in English remains. It is inevitable, therefore, that any new book on Radio Direction Finding will be judged against this requirement.

It must be said at once that this book fulfils it in part only, having been directed to the needs of the user, rather than the designer, of DF equipment. It would perhaps have been better if this point, which emerges clearly from the text, had been brought out in the description on the dust-jacket, although it is adequately covered by the preface.

The first part of the book provides a review of the basic theory underlining DF equipment. This theory is clearly presented and provides a sound basis for understanding the operation of practical DF equipments. Such presentation has necessitated considerable simplification, but this has been done effectively by omitting a good deal of detail without distorting the essential facts. The reader who goes on to study the subject in greater depth will find he has much more to learn—but little to unlearn.

As noted, the emphasis is on practical DF equipment, and the theoretical treatment is limited to systems having current application. Unsuccessful ideas, for example the Compensated Loop, are not treated thus the reader is neither encouraged to re-examine them, nor cautioned against their inadvertent re-invention as would be the case with a more comprehensive treatment.

The second part of the book is concerned with the description of practical DF systems, mostly those available commercially, and also with their installation and operation. It should prove very helpful to anyone becoming involved in Radio Direction Findings for the first time. It includes a useful section on interpreting and plotting bearings.

The difference in approach between the two authors becomes rather apparent when the same subject is treated in both the theoretical and practical parts. Although cross-references

are given it would, in the reviewers opinion at least, have been better to seek a greater measure of synthesis. For example, the various types of errors likely to be encountered in Marine MF DF installations are described on pages 161 to 163, but a much better understanding of the basic causes would have been provided if these had been derived from an expansion of theoretical treatment of error sources given on page 35.

As the theory, although clear, is rather elementary anyone involved in Research or Development in the DF field will still be largely dependent on the periodical literature for treatment of particular problems in depth. The references are thus an important part of this book. The main list of References is to sources of information used, and, whilst this is valuable in following up any point of detail mentioned, it leaves considerable gaps where some specialised aspect has not been referred to in the text. The authors are clearly aware of this and have provided a subsidiary Bibliography which, although it has some surprising gaps, does give a useful introduction to a wider selection of literature. The shortcoming of this Bibliography, however, is that it is listed alphabetically by the author and only titles, not abstracts, of the items are given. Anyone seeking for guidance on a specific topic is, therefore, given only a minimum of help in finding a suitable reference.

The book should be of considerable value to anyone planning a DF system, or selecting, installing, calibrating or operating DF equipment, but for the potential designer of such equipment its value is limited to providing an introduction to the subject and a useful list of references for further reading.

In conclusion, two points of detail seem worth mentioning. Firstly, an item of praise; the review of the receiver characteristics required for use with a modulation DF system, which is given on pages 88-91 is excellent and this information is not generally available in such a convenient form elsewhere. Secondly, a criticism; the statement on page 164 that a loop sited on top of a resonant mast would be "useless" is most surprising. Theory, supported by practical experience of many war-time installations, has shown this to be by far the best site available anywhere in the vicinity of such a resonant object.

**P. G. Redgment**

**Guide to Science and Technology in the U.S.S.R.**, Edited by Sara White, published by Francis Hodgson Ltd., P.O. Box 74, Guernsey, British Isles, Pp. 300, price £16.

The main aim of the Guide is to provide basic information on science and technology in the U.S.S.R. for scientists, technicians and industrialists interested in studying or visiting the Soviet Union.

Anyone personally acquainted with the Soviet system will realise the difficulties in compiling a book of this nature. This is primarily because of the low level in the U.S.S.R. at which information is regarded as classified (the Moscow Directory of Telephone Subscribers' Names is a classified book!). Furthermore, Russians carry the "need-to-know" principle to the limit. It is, therefore, greatly to the credit of the Editor and Publishers that they have succeeded in obtaining the assistance of a number of Soviet individuals and organisations. Much information has been obtained also from members of British government and industrial organisations who have been associated with the U.S.S.R. in one way or another. The most important contributions, however, have been gleaned from recent publications such as "Science Policy and Organisation of Research in the U.S.S.R.", UNESCO, Paris 1967, and "Science Policy in the U.S.S.R.", O.E.C.D., Paris 1969. In general the information in the guide is well collated in a concise form with no padding. It is accurate and up-to-date; even the information extracted from older publications has been up-dated as far as possible.

Chapter 1 gives a brief historical background, bringing out the importance of the role of science and technology in the communist state. Mention is also made of political, social and economic aspects.

Chapter 2 covers the organisation and planning of science and technology. The basic structure of the whole organisation is illustrated and the various constituent bodies are described. A most significant point is brought forward, namely that the Communist Party controls research and development planning and policy *at all levels* through a hierarchy of Party Organisations of its Central Committee. (These organisations have branch representatives in all Soviet establishments; this probably, accounts for the fact that Soviet scientists and technicians appear to be lethargic in replying to foreign correspondence and in nominating representatives to attend conferences abroad).

Planning, finance and manpower are covered also but the figures for financing research are misleading. This is no fault of the Guide as the hierarchy deliberately conceals the true figures for the high expenditure on large items such as space, atomic and military research. (These items do not even come under the jurisdiction of the State Committee for Science and Technology, the single national body which co-ordinates research and development throughout the Soviet Union).

Chapter 3 deals with the structure of research bodies. A full account is given of the Academies of Sciences and useful outlines of the Ministerial and University systems.

The remaining chapters, 4 to 20, cover the following subjects and industries: Education; Natural Sciences; Space; Military Affairs; Computer Industry; Power Industry; Metallurgy and Engineering; Chemical Industry; Timber, Cellulose and Woodworking Industry; Food and Consumer Industries; Construction Industry; Agriculture; Medical Services; Transport; Communications Industry; Patents, Information, Libraries and Museums; and The Regions.

On the whole the material in these chapters is as comprehensive as possible. The chapters on such subjects as Education, Power, Agriculture and Transport are very informative, as they are non-sensitive subjects, whereas that on Military Affairs is largely conjectural. The chapter on Natural Sciences should be of particular interest to students wishing to study the U.S.S.R. and that on Computers gives a very useful summary of the present state of affairs in the Soviet Union. The final chapter on The Regions embraces, in short summary form, the main features such as natural resources, economy, industry, agriculture and sciences in each of the 15 Union Republics of the U.S.S.R.

Wherever possible the relevant research institutes are listed in each chapter and for good measure all the establishments mentioned in the text are given in an appendix. This is a useful sample—for a comprehensive list of non-Academy organisations is far beyond the scope of any of any one volume. (Throughout the U.S.S.R. there are roughly a couple of hundred organisations controlling some 5,000 institutes and around 100,000 associated industrial complexes, works, and factories). On the other hand, the appendix on the institutes of the Academies of Sciences of the U.S.S.R. and of the Union Republics is most comprehensive.

Again, in each chapter, relevant Soviet research journals are listed. There are also appendices giving lists of the "English Cover-to-Cover Translations of Soviet Journals" and "Publishers of English Cover-to-Cover Translations of Soviet Journals". These will be of assistance to those who do not read Russian and wish to keep abreast of progress in specialised fields.

In general the Guide is most interesting and informative and will be of value to students, scientists, technicians and industrialists concerned with Soviet science and technology. It will certainly provide a sound foundation on which to build.

**E. A. Alexander**

**Physics.** A. E. E. McKenzie, Cambridge University Press, Paperback; pp. 218; 1970. £1.68.

This book is concerned with general physics to about O/A level standard, and is divided into the four sections: Force, equilibrium and motion; Heat and molecules; Light and waves; and Electricity and electrons. Its general format is that of revision notes, being a digest

of subject matter far too excessive to be dealt with in any other way in a book of this size.

In view of its production in soft covers, it is obviously not intended as a standard school text-book, but rather is designed for the student with revision to do for impending examinations. However, as it is somewhat larger than usual revision notes length, it can (and does) combine the ease of reading of the standard textbook with the rather indigestible presentation of facts found in down-to-earth revision material, and consequently holds the attention and concentration of the reader for a longer period at one sitting.

Another important need for this clientele is the provision of questions (and answers) and this too is adequately met. SI units are used throughout, the volume is profusely scattered with drawings, graphs and photographs, and is very well laid out. It is, in fact, a pleasure to read, and that is an unusual statement to make about any textbook. It should find favour both with the student and tutor, the former for its ease of reading, and the latter for its presentation of much valuable information.

**J. R. Kirby**





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