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CONTROL CHARACTERISTICS OF DIESEL ENGINES

FOR ALTERNATOR DRIVES. Part 2

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Introduction The need for an investigation into the sampled-data properties of diesel engines and their control systems was shown in Part 1. A general discussion of the properties of the engine sub-systems; fuel-torque conversion process, injector and turbocharger dynamics was followed by a discussion on the special properties of sampled-data systems with regard to frequency response.

The analysis of such systems has been treated in this article by a "first principles" approach to z-transform theory with particular regard to the properties of diesel engine subsystems. The basis for the article is the concept of the pulse-transfer function adequately explained in the first chapter. For the more analytically inclined an excellent summary of the theory can be found in Lindorff⁽¹⁾. For the rest of the article an understanding of root-locus techniques is an advantage but not essential and where possible all important results have been summarised in graphical or tabulated form.

z transform properties of simple engine systems

The behaviour of a discrete control system can be expressed in terms of the amplitudes of the sampled error response as shown in Fig. 1. For a diesel engine speed control system, this will be analogous to the sequence of fuel masses injected into the engine, or alternatively the sampled fuel rack position. If the fuel rack position is given by $x(t)$, then the Laplace transform of the sampled rack movement is given by

$$X^*(s) = X(o) + X(T)e^{-sT} + \dots + X(nT)e^{-nsT} + \dots$$

In discrete control system theory the above expression is simplified by a change of variable $z = e^{sT}$

such that

$$X(z) = X^*(s) = X(o) + X(T)z^{-1} + \dots + \dots + X(nT)z^{-n} + \dots \quad (1)$$

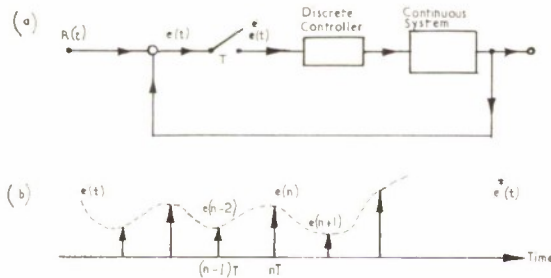


FIG. 1. General sampled-data control loop.
(a) block diagram,
(b) continuous and sampled waveforms.

Thus the rack position is expressed in the form of a polynomial in z^{-1} whose coefficients are related to the rack position at the sampling instants. This is known as the *z-transform* of the rack movement, $x(t)$, and is written $X(z)$.

The engine converts the sampled fuel rack position $X(z)$ into a continuous rotation of the engine by driving the engine inertia against drag torque with torque pulses. As described in Part 1, the torque pulses can be idealised to rectangular pulses of various types. For a four-cylinder engine the pulses approximate to the output of a zero-order hold circuit as shown in

Fig. 2. Since the feedback process only effects the control at the sampling instants it is necessary to know the response of the engine to the control pulses at these sampling instants.

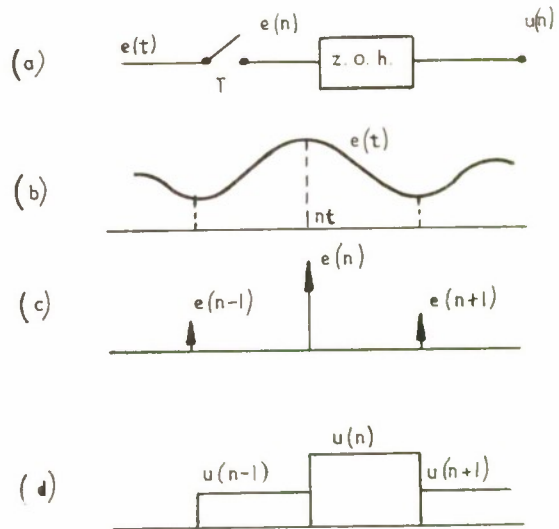


FIG. 2. Sampler and zero-order-hold circuit.
(a) block diagram; (b) input waveform;
(c) sampled input waveform; and
(d) output waveform.

The engine inertia and drag constitute a continuous first-order lag with time constant a^{-1} . Hence the response to a unit step at time $t = 0$ is of the form

$$1 - e^{-at}$$

and the impulse response is simply e^{-at} . The engine response at $t = nT$ can therefore be expressed in terms of the torque pulses applied prior to $t = nT$. If the continuous speed signal is $c(t)$ then $c(nT)$ is given by the difference equation

$$c(nT) = K_T \left[1 - e^{-aT} \right] \left[X(n-1T) + X(n-2T)e^{-aT} + \dots \right] \quad (2)$$

where the right hand side contains the decaying effects of previously applied torque pulses. By rewriting equation (2) for all sampling instants a whole series of difference equations for $c(nT)$ would be obtained. Substituting these into an equation of the form

$$C(z) = c(o) + c(T)z^{-1} + \dots + c(nT)z^{-n} + \dots$$

we would obtain the z -transform of the engine speed. This lengthy process can be omitted by the application of the general formulae

$$Z [c(nT)] = C(z) \quad (3)$$

$$Z (c(n-mT)) = z^{-m} C(z) \quad (4)$$

Thus equation (2) becomes

$$\begin{aligned} C(z) &= K_T \left[\frac{1 - e^{-aT}}{z - e^{-aT}} \right] \\ 1 + z^{-1} e^{-aT} + \dots + z^{-1} \cdot X(z) \\ \text{or } \frac{C}{X} &= - \frac{K_T \left[\frac{1 - e^{-aT}}{z - e^{-aT}} \right]}{z - e^{-aT}} \end{aligned} \quad (5)$$

This ratio is known as "the engine pulse-transfer function" and is written $GH(z)$. Similar expressions can be devised for engines with differing types of load.

The properties of the system are expressed by $GH(z)$. An expansion of $GH(z)$ as a polynomial in z^{-1} gives the impulse response of the engine. If the system is stable then the coefficients of the polynomial will converge to a limit. Expanding equation (5) it will be seen that the system is stable for

$$\left| e^{-aT} \right| < 1$$

i.e. the pole of the pulse transfer function must lie within the unit circle in the z -plane.

In a closed loop speed control system the poles of the closed loop pulse-transfer function are given by the pulse characteristic equation.

$$GH(z) = -1 \quad (6)$$

These poles must also lie within the stability boundary of the unit circle. Applying root-locus techniques to the study of equation (6) it is easy to establish response times and natural frequencies from the root-locus plot. The damping of the system is defined

$$\text{by } \left| \frac{C(k+1)}{C(k)} \right| = r$$

and the frequency is defined by

$$\omega = \frac{\theta}{2\pi} \omega_s$$

where (r, θ) are the polar co-ordinates of system poles in the z plane.

A set of typical response patterns is shown in Fig. 3. Obviously poles at the unit circle

$$GH(z) + 1 = 0$$

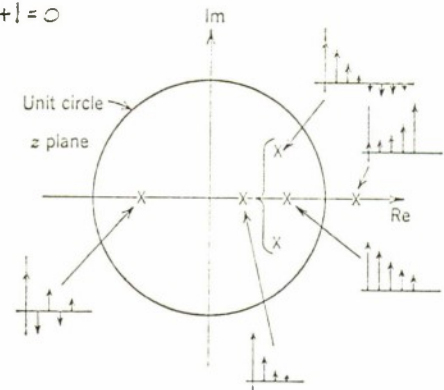


FIG. 3. Response characteristics corresponding to various root positions.

exhibit zero damping and poles at the origin exhibit maximum damping. It is therefore clear that systems should be designed with poles as close to the origin as possible. For such systems the minimum response time will be as many sampling periods as is the order of the system.

It should be noted that the maximum oscillatory frequency is limited to the half-sampling frequency. This is in accordance with the Nyquist sampling criterion statement that information cannot be passed at a higher frequency than one half of the sampling frequency. Frequency response therefore has a limited definition above this frequency for combined discrete-continuous systems.

Engine pulse transfer functions

The basic z -transform expressions derived for a z.o.h. circuit and a first order lag are extended here to cover the cases of six and eight cylinder engines. For engines with more than four cylinders the effect of torque overlap adds additional terms to the pulse-transfer function. Six- and eight-cylinder engines produce torque overlap with the same form of pulse transfer function.

The engine acts as a low pass filter depending only on the energy contained in the overlap, with the difference equation for torque output given by

$$T(k) = K_T \{ x(k) + \gamma x(k-1) \}$$

where $x(t)$ is the rack movement signal. In terms of the z -transform applying questions (3) and (4)

$$T(z) = K_T \frac{(z + \gamma)}{z} X(z)$$

If the speed transform is given by $C(z)$ then the pulse-transfer function between rack movement and speed is given by

$$\frac{C(z)}{X(z)} = K_T \frac{[1 - e^{-aT}]}{(z - e^{-aT})} \frac{(z + \gamma)}{z}$$

where $n = 4, \gamma = 0$

$n = 6, \gamma = 0.25$

$n = 8, \gamma = 1.0$

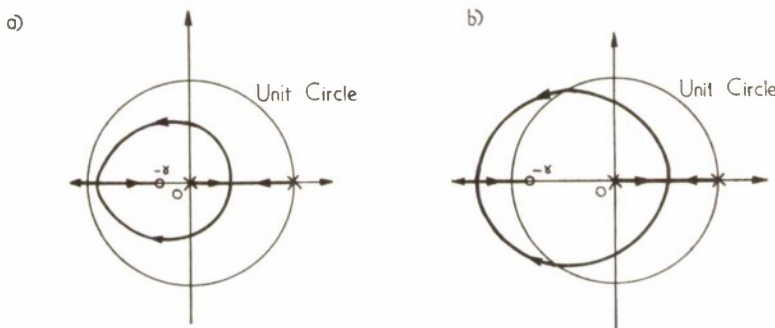


FIG. 4. Root-loci for (a) four and six-cylinder engines; (b) eight-cylinder engine.

Time domain properties of the basic engine

Before considering the effects of governor dynamics on a speed control system it is instructive to examine the behaviour of the engine when governed by a strictly proportional signal (*i.e.* neglecting governor dynamics).

The characteristic equation for this arrangement is

$$GH(z) = K_p \frac{[1 - e^{-aT}]}{z(z - e^{-aT})} \frac{[z + \gamma]}{z} = -1$$

The root-locus plot of this equation has two basic forms as shown in Fig. 4. If $\gamma < \frac{1}{2}$ the roots cross the unit circle at $z = -1$, and for $\gamma > \frac{1}{2}$ the roots cross the circle away from the real axis. This means that the critical frequency for the four and six cylinder engines is at half the sampling frequency but is lower than this for eight, or more, cylinders. Fig. 5 shows the variation of critical gain against the torque overlap parameter γ , where it can be seen that, in general, torque overlap tends to destabilize the system. This is not true for six cylinder engines where the small torque overlap compensates in such a way as to stabilize the engine.

Fig. 6 shows the critical frequency, expressed as a fraction of the sampling frequency, at which instability occurs.

The minimum response times for each engine are easily established using the root-locus concepts as illustrated. In the case of the four cylinder engine the root-locus plot passes through the origin and hence it is theoretically possible to produce a dead-beat response, *i.e.* any correction can be achieved in one sample time. This is not possible for engines with a greater number of cylinders. However the minimum response time occurs at minimum

root radius and Fig. 7 shows the curves of the minimum settling time and the corresponding gain plotted against torque overlap. The six cylinder and eight cylinder engines have minimum settling times of three and four sample periods respectively.

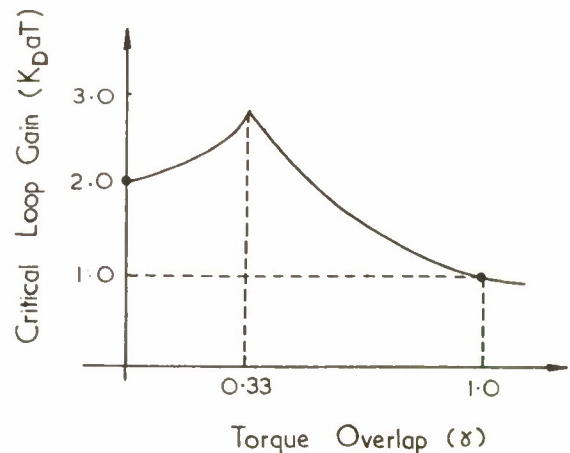


Fig. 5. Variation in critical loop gain K_c with torque overlap γ .

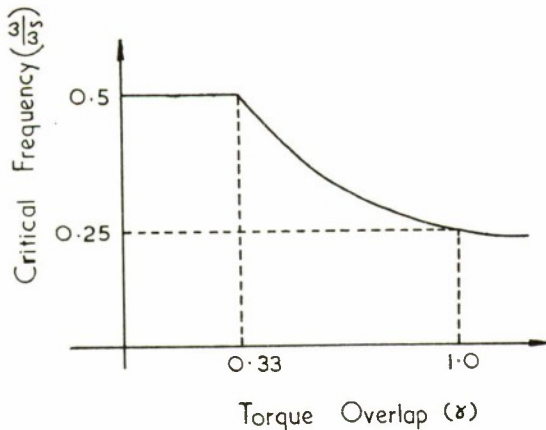


Fig. 6. Variation in critical frequency with torque overlap γ .

Limiting speed-droop conditions

Assuming a four cylinder engine is subjected to a constant load torque Q_0 then its behaviour, using a proportional control, is governed by the difference-differential equation.

$$K_T \left[\omega_0 - \omega(kT) \right] = J\omega + D'(\omega - \omega_0) + Q_0$$

where ω_0 represents the desired speed.

With the engine in the steady state the speed droop x may be expressed as

$$x = \frac{Q_0 \omega_0}{(K_T - D')\omega_0^2} \approx \frac{P_0}{K_T \omega_0^2} \text{ for high loop gains}$$

where P_0 is the desired output power. We see that x is expressed as a power ratio and can be decreased by raising the loop-gain. There are limits to the value that the gain can have before instability occurs and this implies a minimum speed droop constraint, i.e. K_T is limited by stability considerations.

Extending this analysis to include engines other than four cylinder types, we have for a basic engine

$$K_D = \frac{c'}{aT} \quad \text{and} \quad K_D a = \frac{K_T}{J}$$

where c' is dependent on the number of cylinders. Thus

$$x_{\min} = \frac{P_0 T}{c' J \omega_0^2} \text{ which relates the minimum}$$

speed droop to the basic engine properties. For a conventional four-stroke engine

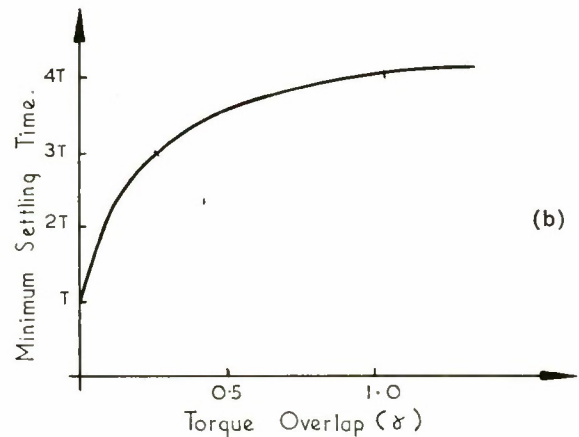
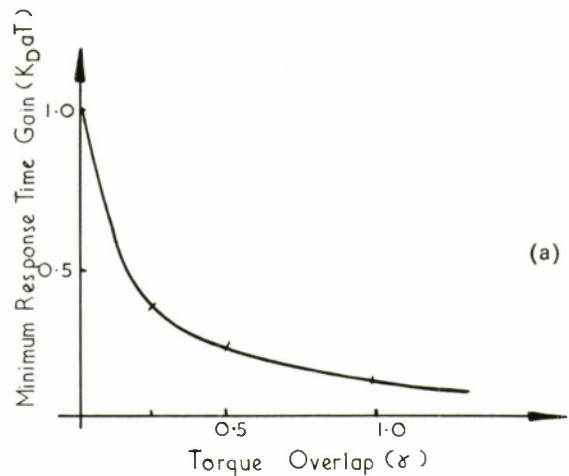


Fig. 7. Variation of minimum response time properties with torque overlap.

$$T = \frac{4\pi}{n \omega_0} \text{ and therefore } x_{\min} = \frac{4\pi}{c' \omega_0^3} \left[\frac{P_0}{nJ} \right]$$

We term $\left[\frac{P_0}{nJ} \right] = \lambda$, the *power inertia index* for the engine.

This denotes the power available per cylinder per unit of inertia for a given speed and droop specification. It can be used as a basis for comparing the merits of various engines and governing arrangements, such that governor performance is not bolstered by engine inertia.

Re-arranging the above equations we can write

$$\lambda = \frac{c' x_{\min} \omega_0^3}{4\pi} \text{ and Table 1 shows values of this}$$

parameter for various engines, speeds and for a 1% droop specification.

The inclusion of governor dynamics

A practical governor will have its own dynamic behaviour which for the type that we are interested in can be regarded as a simple lag term. The discrete characteristic equation now has the form

$$GH(z) = \frac{K_z(z + \gamma)(z + \beta)}{z(z - \alpha_1)(z - \alpha_2)} = -1$$

The corresponding root-locus plot is shown in Fig. 8. Certain features of the effect of governor dynamics are easily established. If, for example, the delay is much greater than the sample time then the root-locus crosses the unit circle at rather low frequencies implying a response over many power strokes. For effective control over a small number of power strokes the governor delay has to be of the same order as the sample time.

Let us examine the behaviour of a six cylinder diesel capable of driving a 350KW load at a speed of 720 r.p.m. with an inertia of 200 Kg.m². The time constant associated with a shaft damping and inertia is 22.7 s at no load. The governor actuator delay is 30 ms. and the control signal is proportional to speed error. We are to assess the properties of the system at no load.

$$\lambda = \frac{P_o}{nJ} = 0.292 \text{ KW/cylinder/Kg.m}^2$$

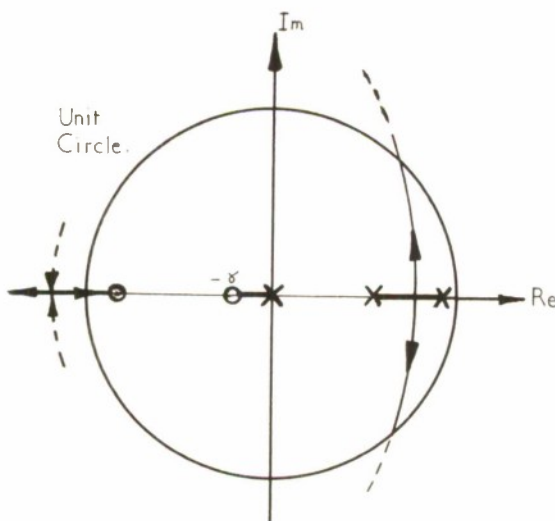


FIG. 8. Root-locus for engine and simple governor system.

TABLE I. Tables of power-inertia index (λ) for 1% droop (kW)/cylinder/Kg.m²

Alternator frequency 50 Hz					
Speed (r.p.m.)	1000	750	428	250	
No. of cylinders	4	1.8	0.77	0.14	0.027
	6	2.43	1.0	0.19	0.037
	8	0.9	0.38	0.07	0.013

Alternator frequency 60 Hz					
Speed (r.p.m.)	1200	900	514	300	
No. of cylinders	4	3.15	1.35	0.25	0.048
	6	4.25	1.84	0.34	0.056
	8	1.57	0.67	0.128	0.024

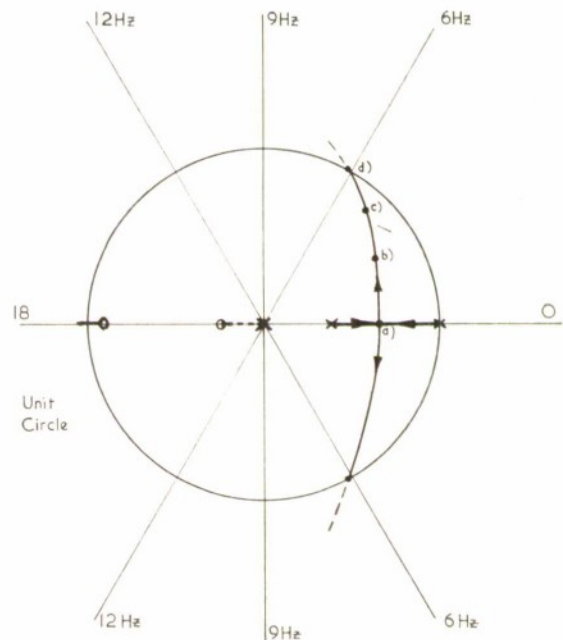


FIG. 9. Root-locus for example. Data; power output = 350 kW; inertia = 200 kgm²; $\tau = 22.7$ sec; $N = 720$ rpm; $n = 6$; $f_s = 36$ Hz; time constant of governor 30 m sec. (a) 5.6% droop; (b) 2.0% droop; (c) 0.56% droop.

Since $\lambda_{\max} = 0.92$ Kw/cylinder/Kg.m² then we see that 1% droop is possible for the basic engine. At 720 r.p.m. the sampling frequency of a six cylinder engine is 36 Hz with a corresponding sampling time of 28 ms.

This leads to an open loop pulse-transfer function

$$GH(z) = \frac{K_z (z + 0.25) (z + 0.85)}{z(z - 0.369) (z - 1.0)}$$

The resulting root-locus is shown in Fig. 9 which has been calibrated with respect to speed droop. At the critical condition the speed droop has a minimum value of 0.56% which implies that the proposed control achieving 1% droop may lead to difficulty at low power outputs. Notice also that the critical condition lies in the region of the frequency domain around 6 Hz, which is the basic pulse frequency of an individual cylinder. We would expect, therefore, that any effects of torque asymmetries of the cylinders would be considerably magnified and cyclic irregularity would increase. It is also likely that the natural frequency of the engine mounting would be near this 6Hz.

The settling time of the system is a minimum at 5.6% and it may be possible to improve the minimum response time by the use of derivative and proportional feedback which would have the effect of moving zero β in the positive real direction as shown in Fig. 10. This would inhibit the tendency for forced oscillation at the fundamental cylinder frequency.

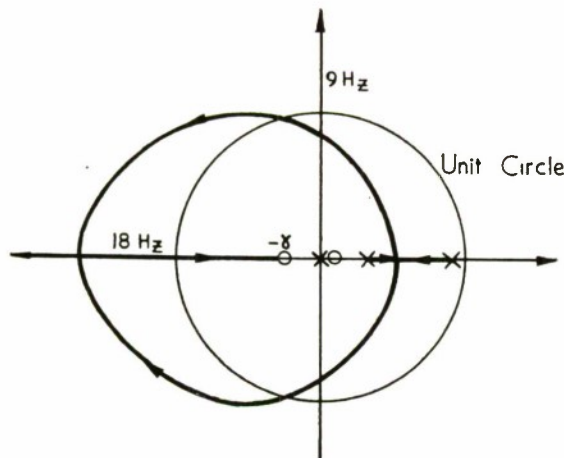


FIG. 10. Root-locus for governor and engine with proportional and derivative control.

The effects of the injection pump mechanism on stability

The injector pump mechanism was shown in Part 1 to be sensitive to the rate of change of rack position, such that the injected fuel mass at the n th sampling instant is given by

$$m_i(n) = K_m \left[\frac{y_d + y(n)}{V_c - \dot{y}(n)} \right]$$

where y_d is the mean value of translated rack position, V_c is injector cam velocity, and $y(n)$ is the translated rack position.

For a perturbational analysis the non-linear difference equation above can be approximated to

$$m_i(n) = \frac{K_m}{V_c} \left[y(n) + \dot{y}(n) \cdot \frac{y_d}{V_c} \right]$$

The z-transform of injected fuel masses are thus related to sampled fuel rack position transform by

$$m_i(s)^* = K_m^{-1} \left[(1 + s\tau) X(s) \right]^*$$

where $\tau = y_d/V_c$

Thus the injection mechanism acts as a derivative control with time constant τ equal to the length of the injection period, which of course varies with the mean power output level. The pulse transfer function $GH(z)$ is then given by

$$GH(z) = K_{Da}\tau \frac{(z + c) (z + \gamma)}{z(z - e^{-aT})}$$

$$\text{where } c \approx \frac{T}{\tau} - 1 \text{ for } aT \ll 1$$

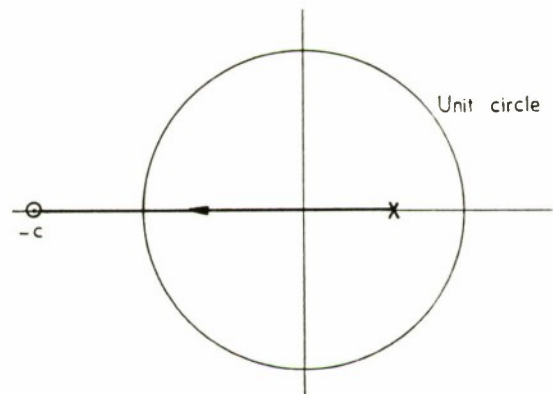


FIG. 11. Root-locus plot showing the addition of the zero.

The sensitivity of the system to the injector dynamics is thus dependent upon the ratio of sample time to injection period. With the range of injection period lying between 10°CA and 30°CA it is clear that injector effects will be quite significant for engines with more than six cylinders. A root-locus diagram is shown for an eight cylinder engine in Fig. 11 with root-loci shown for injection periods of 10°CA and 30°CA. The critical frequency is raised to one third of the sampling frequency and the power inertia index is raised to that of a six cylinder engine at high power output.

The Effect of the Turbocharger on the Engine Pulse-Transfer Function

In Part I of the article a discussion of the nature of turbocharger interaction was made. The combustion process results in an effective two input - two output system for which the inputs are trapped air mass and injected fuel mass; the outputs pulse torque to the shaft, and pulse torque to the turbo-charger. A linearised system is represented by the following equations:

$$T_e(k) = k_{11} m_i(k) + k_{12} m_a(k)$$

$$T_T(k) = k_{21} m_i(k) + k_{22} m_a(k)$$

By determining the dynamic nature of the conversion of the turbine torque pulses T_T to samples of trapped air masses it will be possible to form a pulse-transfer between these quantities such that

$$M_a(z) = D_T(z) T_T(z)$$

By substitution in the above equations an effective pulse-transfer function between injected fuel masses and shaft output torque pulses is obtained of the form

$$T_e(z) = \frac{[1 - k'D_T(z)]}{[1 - k_{22}D_T(z)]} \cdot k_{11} m_i(z)$$

$$\text{where } k' = k_{22} - \frac{k_{12}k_{21}}{k_{11}}$$

Hence the effect of the turbocharger loop will be dependent on the difference between the numerator and denominator polynomials represented generally by

$$(1 - KD_T(z))$$

The difference will be essentially due to the magnitude of the cross-coupling sensitivities, k_{12} and k_{21} and the ratio

$$\frac{k_{12} k_{21}}{k_{11}}$$

If the turbocharger loop has a fast response then there will be a significant coupling and hence a high performance turbocharged engine may be expected to contribute significantly to the stability properties of the engine.

In addition the equivalent pulse-transfer function will be of the form of discrete lead-lag components. As the number of engine cylinders is raised the number of these components will be raised due to the increasing significance of compression and exhaust delays within the loop. Under such conditions even loosely coupled turbochargers may contribute significantly to the frequency response.

Testing and Simulation of the Engine Subsystems

The development of a generalised control theory for diesel engines has highlighted a lack of detailed data for use with engine models. An experimental programme of tests on all the subsystems of turbocharged engines with up to possibly sixteen cylinders is highly desirable. Existing experimental evidence available to the authors is sparse but very promising indeed.

Most diesel engine testing has been based on the conventional method of frequency response measurement used for continuous control systems. As explained in Part I frequency response has a special meaning when applied to sampled data systems and measurements made by conventional transfer function analysers need careful interpretation. The experience of Bowns⁽⁸⁾ in investigating a low power naturally aspirated engine has highlighted these difficulties.

The most pressing need is therefore for equipment which will lead to accurate identification of the sampled-data properties of the system. At present this may be done by modifying conventional transfer function analysers to measure the 'pulse-transfer function' or by extending other techniques such as pseudo-random binary sequence (p.r.b.s.) testing. P.r.b.s. testing of diesels has been attempted unsuccessfully⁽²⁾ but modifications to this technique are being developed at Sussex which have been applied successfully on analogue computer studies. It is planned to build equipment whereby essentially engine data will be recorded 'on site' and processed 'off line' by digital computation. This promises to be an accurate method of parameter identification and capable of system identification at high frequency under closed loop conditions.

The identification of sufficient parameters to test the validity of the theory also depends upon the results of simulation studies planned for the future. The interaction of the engine-torque conversion process, fuel injector and turbocharger dynamics is probably too involved for an overall theoretical investigation and hybrid computer simulation studies will be necessary to study the whole system.

A preliminary simulation of the fuel-torque conversion process for various engine types has been completed and simulation of injector dynamics is in progress. However simulation of the turbocharger loop is less obvious and a study in depth of this loop is continuing before simulation is attempted. It is clear that if investigation of single and multiple diesel-alternator sets is to be made then a realistic simplification of the generalised diesel and alternator models must be made in order to perform system studies on a reasonable size computer.

The detailed models of diesel engine behaviour will however be valuable as they will act as a link between studies to be made of unconventional governor designs, such as the adaptation of load governors for turbocharger

recovery, and the use of signal stabilised governors to inhibit magnified cyclic irregularity under minimum speed droop conditions.

Conclusion The modelling and analysis of the diesel engine as a sampled-data system correlates extremely well with the limited experimental evidence available.

Some properties of the various engine models have been examined, and these have been generalised in terms of power output, sample-time and kinetic energy of rotation leading to the idea of the power-inertia index.

Subsequent exploitation of these sampled-data concepts in diesel alternator control will depend crucially on achieving a simple model of the turbocharger effects.

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THE APPLICATION OF OPERATIONAL RESEARCH TO MARINE ACCIDENTS

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Introduction Despite the wide application of Operational Research techniques in the many varied fields of human activity, both military and commercial, certain areas appear to have been either completely overlooked, or have evoked only a perfunctory interest. Such an area is the one concerned with marine accidents. This is not to say that the study of accidents at sea has been completely ignored, as a glance at Appendix A to this article will show, but the bulk of work to date has been done by a very small number of enthusiasts, forced to work in very limited fields of study due primarily to a lack of the right sort of data. Hitherto, it has been possible to postulate how the problem of OR in marine accidents should be tackled, but it has not been possible to implement ideas or methods, as the necessary data was either not readily available, or what was available was not in a palatable form. However, this particular difficulty has been overcome, to a certain degree, as explained in subsequent paragraphs.

The application of operational research methods to accidents at sea should not be just

an analytical and statistical exercise for the smug self-satisfaction of the OR analyst. Its implications reach to society itself, as was shown in a very dramatic way by the *TORREY CANYON* incident. Apart from the traumatic effect that this incident had on the marine insurance world and the questions it raised concerning marine navigation and handling of large ships at sea there was the cost to both Britain and France caused by counteracting the very large subsequent oil pollution (a bill that ran into millions of pounds), apart from the sheer inconvenience caused to the coastal communities and the effect on marine life.

General Accident Picture

In order to appreciate the following paragraphs, a study of Tables 1 and 2 would be well worthwhile in order to get some numerical feel of the magnitude of the problem. However, certain points about these figures should be borne in mind, viz: the figures relate only to ships over 500 GRT (Gross Registered Tons), to those incidents where a claim on insurance was evoked, and "total loss" includes those cases where certain old ships involved in accidents were considered to be beyond economical repair, and were "written off". The accident picture is not complete, but we may assume that the omissions are very small in comparison.

Apart from the obvious fact that 1966 was a bonanza year for accidents at sea, it is rather disquieting to see that the chance of a ship being involved in some sort of mishap at sea per year is one in three, and there is something

The typescript of this article was posted to the Editor of the *JRNSS* on 22nd October 1970. On the night of 23rd October a collision occurred between two oil tankers, the *ALLEGRO* and the *PACIFIC GLORY*, off the Isle of Wight; the tankers collided whilst endeavouring to avoid an oncoming vessel. The *PACIFIC GLORY* sustained damage, was holed, later subjected to a series of explosions and subsequently beached. Burning oil poured out for 36 hours, causing a pollution hazard!

TABLE 1. GLOBAL: MARINE CASUALTIES
(Ships over 500 GRT)

Year	Partial Losses		Total Losses		Grand Total of Casualties
	No.	% vs. World Fleet	No.	No. per thousand ships	
1959	7,259	32.2	100	4.44	7,359
1960	7,254	32.2	114	5.07	7,368
1961	7,740	33.6	78	3.39	7,818
1962	7,814	33.5	124	5.31	7,938
1963	7,860	33.2	148	6.25	8,008
1964	8,317	34.6	117	4.87	8,434
1965	8,884	36.3	154	6.29	9,038
1966	9,088	36.0	159	6.30	9,247
1967	8,333	32.2	163	6.30	8,496
1968	8,672	32.5	157	5.93	8,829
1969	8,024	29.2	147	5.35	8,164

in the order of one chance in 170 per annum of a ship being a total loss. These odds appear to be rather frightening, and it is not surprising that Lloyds pay out each year for marine claims (including cargo claims) sums of the order of £170,000,000 (A comparison with the cases for road and air accidents would be interesting). We need, of course, to look deeper than actual numbers of incidents, ratios, and gross-tonnage lost, when we realise that about 25% of the 819,740 GRT totally lost in 1969 was due to only three giant tankers, the *MARPESSA*, (104,373 GRT) and two other ships of similar size.

It would appear from the column of grand total of casualties given in Table 1, that the annual number of marine accidents steadily rose to a peak in 1966, with an improving trend over the final three years. We must be careful however in assuming that the apparent improvement will continue in the future, when we realise that if we select any three numbers at random, the chances that these numbers will be in either ascending or descending order will be one in

TABLE 2. GROSS TONNAGE OF WORLD TOTAL LOSSES (Ships over 500 GRT)

Year	Number of Ships Lost	G.R.T. Lost	Loss Ratio % of World Tonnage (Ships over 500 GRT only)
1960	114	418,195	0.33
1961	78	335,362	0.27
1962	124	507,530	0.37
1963	148	517,087	0.36
1964	117	477,208	0.32
1965	154	691,718	0.44
1966	159	836,659	0.50
1967	163	746,834	0.42
1968	157	675,054	0.36
1969	147	819,740	0.40

N.B.—The world fleet mentioned above includes only those ships over 500 GRT.

three. So there is one chance in three that the apparent improvement in marine accidents over the period 1967 to 1969 is illusory.

Marine Accidents

The operational research worker carries out his investigations by the use of "models", which are abstracts from or analogues about the real world, but are sufficiently representative to predict the effect of introducing changes into the real world. These models are based on observed data and physical laws and are validated by their ability to explain past events. Fig. 1 represents in block diagram form how an operational analysis of marine accidents could be carried out. On the assumption that all the desired data is available in the real world to begin with, we proceed to a statistical analysis of this data, at the same time taking into consideration what the future portends by way of transport changes, and with future possible R and D work in related marine fields. From this, an operational analysis (with possible cost-benefit analysis) is carried out, combined with what cost data is available and statistical prediction. This is then compared

with studies of any other alternatives available, and we "go round the loop," re-evaluating and converging towards an answer (or set of answers), on which decisions can be based.

A very wide range of studies could be involved, of which the following are a selection:

- Dynamics of collisions between vessels.
- Use of radar and radar displays.
- Simulation of collision encounters.
- Analysis of current collision regulations.
- Performance of navigation aids (and navigators!).
- Handling of larger tankers and bulk carriers.
- Traffic routing.
- Docking of super tankers (200,000 DWT or more).

This list alone illustrates the far reaching extent of any operational analysis of marine accidents, and helps to justify the need for such analysis to be performed.

It will be noticed that cost benefit analysis occurs in one of the boxes of Fig. 1. Whilst there is considerable literature on cost-benefit analysis as regards road, rail and air traffic, very little attention has been paid so far to sea transport. The principal cause for this omission is the lack of relevant cost data. Such data exists, but only behind the high unscalable walls of commercial secrecy. Neither the marine insurer or the ship operator is prepared to dis-

cuss costs with the analyst. In fact, any current estimate of direct costs, say to ship damage, are unavoidably crude. Nevertheless, in the absence of any other cost information, the OR analysts must make use of these, and any other relevant data he can find, despite its crudity.

Statistical Analysis

If we are provided with the requisite data on accidents, damage, ships' characteristics, etc., we can display the incidence of any definable class of accident or damage to any particular class of ship by type, age, size, flag, etc. in a form convenient for subsequent analysis. A procedure for such an analysis is shown in Fig. 2, and needs the following inputs:—

Incidents: accident and damage data in a given time, in such a form that any required group classification can be made; damage data should be suitable for estimating financial loss.

Population: classification of world ship population by characteristic, cargo and such equipment as navigation aids, for instance.

Environment: factors such as geographical location, weather, routing, operating rules and procedures, crew training, etc.

Traffic: the flow of traffic by route, distance and time in such a form that it can be related to events, population and environment.

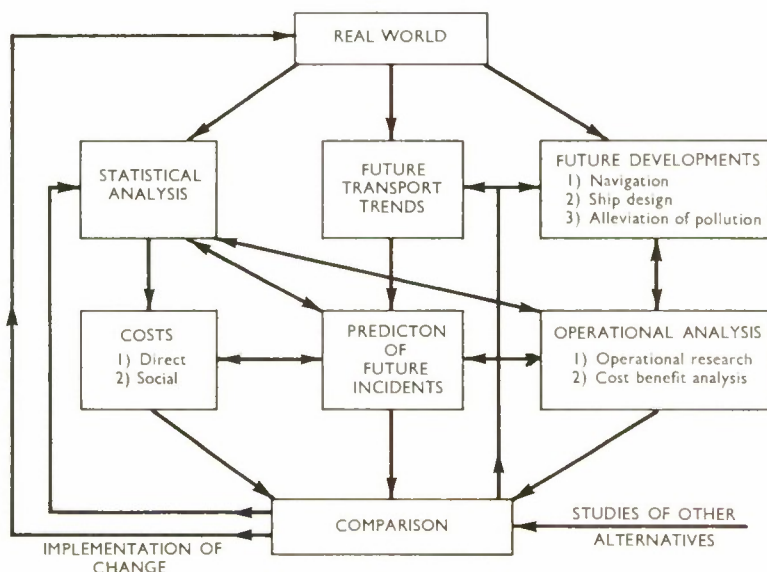


FIG. 1. Method of Conducting an Operational Analysis on Marine Accidents.

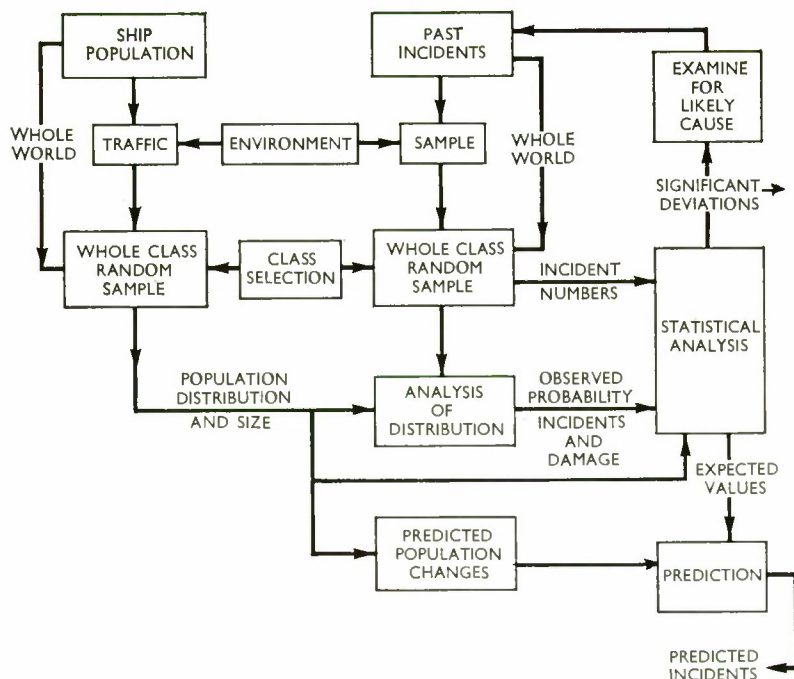


FIG. 2. Procedure for Statistical Analysis of Marine Accidents.

These are very extensive requirements, and the current "state of play" in this particular field will be dealt with later.

The main outputs from the statistical analysis would be:

- (a) indication of significant deviations, which would require further investigation, and
- (b) expected values of the various parameters, to be used for prediction purposes (on the assumption of no change in characteristics of the population but taking account of predicted changes in the size of the population).

The above suggested form of analysis may be considered ideal, and its degree of success depends largely on the size and range of the basic data bank. However illustrative examples will now be given where only limited data is available, culled mainly from Lloyd's Shipping Editors Department, the Liverpool Underwriters Association, with certain data extracted from Lloyds Register. [In the absence of quantitative cost data on damage, analysis has had to be restricted to very broad categories, such as 'total loss', 'major partial loss' and 'partial loss', which are marine insurance terms. Care is therefore needed in interpreting these examples, as a 'total loss' might not be a very heavy financial loss—for an old ship, salvage and repair costs may well exceed the

relatively low insured value—and a 'major partial loss' involves much subjective judgement.]

Accident Population

Fig. 3 illustrates the type of analysis that can be carried out *within* the accident population, without knowledge of the ship population. As can be seen, it is possible to show probability of cause of accident, not only in the general global sense, but also how probabilities may be affected by locality or type of ship. Fig. 3(a) shows how the relative ranking of accident cause changes from the all-classes of damage case to that where an accident can result in total loss. In the latter case, stranding and fires are the chief causes of an accident developing into a total loss, and are significantly different (statistically) from the indicated mean. Fig. 3(b) shows in a startling way how the probability pattern changes when moving from global considerations to a specific geographical area (N.W. European waters are defined to lie within a line due West from Ushant to Long. 12°W; due North to Long 12°W, Lat 60°N; due East to Bergen, with other boundaries the Kattegat and Continent of Europe). The significantly higher proportion of collisions of all ships leading to total loss (36%) and of tanker collisions leading to

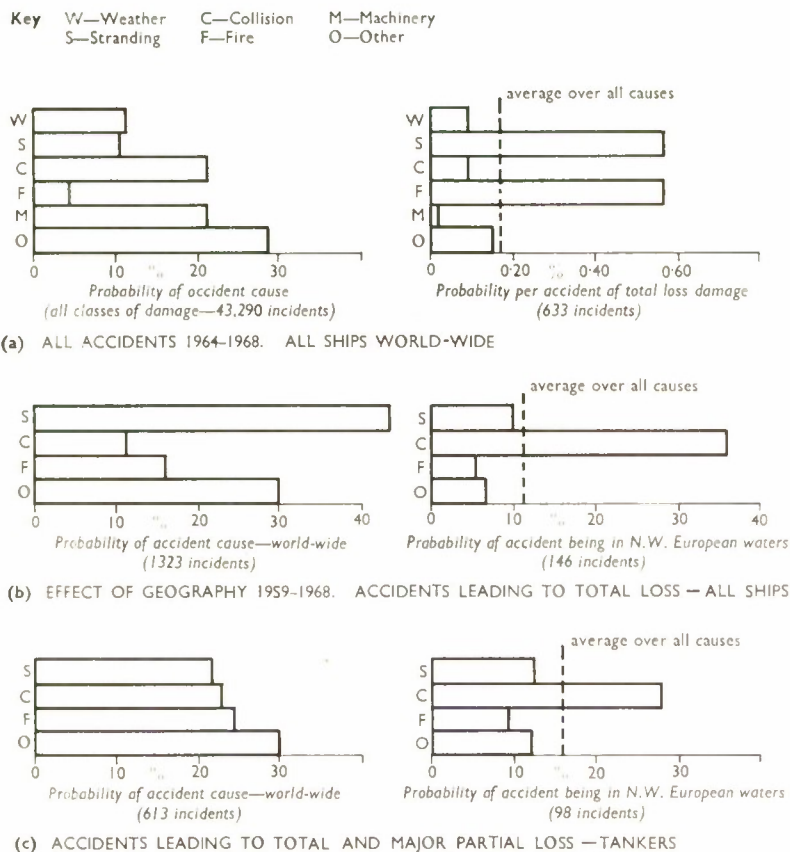


FIG. 3. Type of Analysis that can be made within the Accident Population without knowledge of the Ship Population.

Data Sources

To date (so far as the author of this article is aware) there is no central data bank for marine accidents on a global scale. The United States Coastguard however, maintain at their Headquarters in Washington D.C., a computer based data bank (fed by a punch card input) of accidents to all ships in the navigable inland waters and within territorial limits of the U.S.A., but only for U.S.A. owned ships on the high seas. Each investigation is examined in great depth, with as much concern for the damaged human being as for the damaged ship.

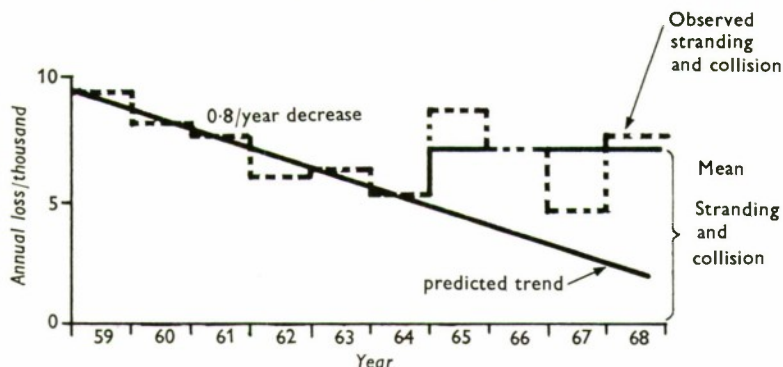
So far as statistics of marine accidents world-wide is concerned, the standard current method of publishing accident details is the monthly issue of a broadsheet by the Liverpool Underwriter Association, listing total and major partial losses for ships over 500 GRT, *i.e.* not the complete accident picture. This basic information is supplied to the L.U.A. by Lloyds of London, who compile their own lists of all reported marine accidents for all sizes of ships. These Lloyds lists are intended for internal use only, and the lists themselves are working sheets, which are finally put into bound volumes. No attempt appears to be made to store this vast amount of information in a convenient form so that it can be easily retrieved and neither is the raw data processed in any way to enable analysis to be carried out easily.

total and major partial loss (28%) compares with 54% for the same area for a much larger random sample of 2,748 collisions between 1959 and 1964 (Beattie 1966) and the differences are statistically significant.

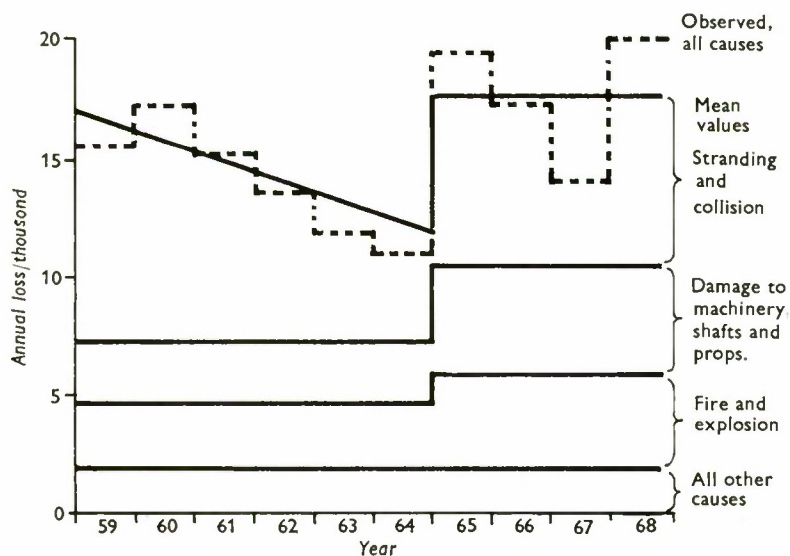
Tankers

Fig. 4 shows the type of analysis that can be made, knowing the population. In the bottom diagram of Fig. 4, it is clear that significant changes occurred in losses due to stranding and collisions, fire and explosions and damage to machinery in 1965 and after as opposed to the pre-1965 period. The change in pattern for stranding and collision is quite remarkable, 1959-1964 had shown a regular decrease of a rate of 0.8 per thousand ships per annum, but this happy state of affairs was rudely disrupted in 1965 and after, with a significant change in magnitude and trend. This type of discontinuity illustrates the limitations of predictions based on trends, underlining the point made on trends in the chapter, Accident Picture.

STRANDING AND COLLISION



ALL CAUSES



613 Incidents

FIG. 4. Tanker Accidents.
Total and Major partial losses
(over 500 GRT).

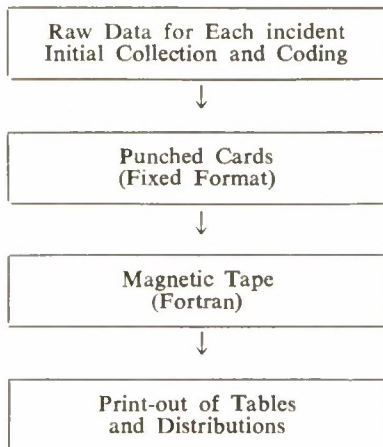
Data Bank of all Marine Accidents in N.W. European Waters and Tanker Accidents World-Wide

Some progress has however been made very recently towards the goal of a computer based data bank of marine accidents, although not yet on a global scale. The promotion of the idea of such a bank arose in the following manner. A recommendation was made in the Report of the Committee of Scientists on the Scientific aspects of the *TORREY CANYON* incident that an assessment should be made regarding the probable nature and frequency of future incidents of large scale oil pollution of

our coastline, so that the necessary scale of future effort to meet such threats could be more readily determined. The Board of Trade accepted responsibility for initiating action, but the task was carried out by the Defence Operational Analysis Establishment (Ministry of Defence) and a study was put out to extramural contract. The task was conceived as being in two stages, the first a data collection and statistical analysis of marine incidents with special reference to pollution. This first stage is now complete and a report issued entitled "Marine Accidents—Phase I, Volumes I and II". It was originally hoped for a twenty year

coverage of all marine accidents world-wide, but financial constraints limited the survey to a ten year period, to all marine accidents in N.W. European Water, and accidents to oil-tankers world-wide.

Lloyds of London supplied the contractor with the raw data, which was processed in the following manner:—



The report contains over 300 tables, and the coverage of the necessary basic parameters is as follows:—

(1) *Ship's Characteristics*

Size in GRT and DWT	Flag
Age	Speed
Type	Construction
Design	peculiarities

- (2) Type of cargo
- (3) Location of incident (full map reference)
- (4) Type of Location of incident
- (5) Distance from shore
- (6) Type and amount of any spillage
- (7) Oceanographic and meteorological conditions
- (8) Category of loss
- (9) Cause of accident
- (10) Major structural damage

The data bank covers 24,437 marine accidents for the period 1959 to 1968, each incident being covered (as far as the raw data allows) in accordance with the parameters listed above.

The 300 or more tables given in the published report are not exhaustive since all possible combinations of parameters have not been covered.

Concluding Remarks

Apart from the dramatic incident of the *TORREY CANYON*, and the great expense, damage to marine ecology and sheer inconvenience it caused, a rapid first assessment from Fig. 1 of the probability of a marine accident, is sufficient justification *per se* for a concerted attack to be made on the operational analysis problem. The self-interested purely national approach to the problem is quite inadequate.

All major seafaring nations are affected, so it needs some international body, such as the International Maritime Consultative Organisation to set up an OR division. The value of the work done by such a division would depend on what data was available, particularly so in the matter of costs, and in this respect there must be co-operation from all seafaring nations in persuading commercial and insurance concerns to provide what cost information they possess.

In the matter of data collection, a good start has been made. A computer based system has been established covering N.W. European Waters and tanker accidents on a global scale. The raw data for the rest of the world is available, and only nominal effort is now needed to complete the picture.

The pattern of merchant shipping is changing more rapidly than was thought a few years ago. Ships have become larger, faster and specialised, and the order books of shipbuilding yards confirm this. Already 300,000 DWT tankers are ploughing the seas, and a 477,000 DWT tanker is on order. Dry bulk carriers are approaching 120,000 DWT, container ships with speeds of 25 knots are on order, and general cargo ships are tending to be typed, like the SD-14 or Freedom ships. Commercial considerations alone would appear to warrant the establishment of a centralised OR organisation, if only to help reduce the 8,000 or more marine accidents a year.

[Further information is available in "Operational Research and Cost Benefit Analysis on Navigation with particular reference to Marine Accidents" by A. Stratton and W. E. Silver,

Vol. 23, July 1970—*Journal of the Institute of Navigation*. This paper was presented at the International Navigation Conference in Rome, May, 1970.]

APPENDIX A

Published Literature on Marine Accidents

A *Papers of the Journal of the Institute of Navigation*

- (1) Vol. 15, 49—1962.
The Safety of Navigation of Inland Waters in Europe—J. H. Beattie.
- (2) Vol. 16, 39—1963.
Locality of Collisions and Shipping Density.
- (3) Vol. 16, 49—1963.
The Statistics of Collisions at Sea, Part I—F. J. Wylie and D. Deacon.
- (4) Vol. 17, 243—1964.
North Sea MEMEDRI Routes, a Collision Problem—J. H. Beattie.
- (5) Vol. 17, 386—1964.
Routeing in the North Sea—F. Schonke.
- (6) Vol. 18, 163—1965.
Regional Nature of Collisions—Fricker.
- (7) Vol. 19, 262—1966.
The Statistics of Collisions at Sea, Part II—F. J. Wylie and D. Deacon.
- (8) Vol. 19, 436—1966.
Collisions in European Waters—J. H. Beattie.
- (9) Vol. 20, 12—1967.
Collisions in West European Rivers—A. Webster.
- (10) Vol. 20, 113—1967.
Speed and Size of Ships as Factors in Collisions—L. Oudet.
- (11) Vol. 20, 241—1967.
Analysis of Marine Casualties—W. C. Foster.
- (12) Vol. 21, 300—1968.
Groundings—Van de Ree.
- (13) Vol. 21, 448—1968.
Collisions in the River Scheldt.
- (14) Vol. 21, 490—1968.
Operational Research into Marine Traffic and Collisions—J. H. Beattie.

B *Other Publications*

- (1) Radar and Collision at Sea—Therolf Wikborg—paper presented at a meeting of the Institute of Navigation, London, November 1954.
- (2) Marine Casualties Reviewed—W. C. Foster—Proceedings of the Merchant Marine Council, November 1965.
- (3) Separation of Traffic at Sea Report of the Working Group of I.C.O.T.A.S.—Published in the *Journal of the Institute of Navigation* (London) for October, 1966.
- (4) Safety at Sea Problems—Arne Jensen, Vol. 1, July 1969—Accident Analysis and Prevention (Pergamon Press).



SIMULATED OXYGEN-HELIUM SATURATION DIVING TO 1500 Ft. AND THE HELIUM BARRIER

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Dr. Peter Bennett has been engaged on research into hyperbaric and underwater problems since he joined the RNPL in 1953. Graduating B.Sc. as an External Student of the University of London in 1951, he was awarded a University of Southampton Ph.D. (Physiology and Biochemistry) in 1964. He is an internationally acknowledged authority on the physiological problems of deep diving, having contributed over 60 papers and two books on the subject. From 1966 to 1968 he was on approved loan to the Canadian Defence Research Board, Toronto to supervise the installation of the first hyperbaric research chambers and initiate and head a new group to study hyperbaric physiology.

Introduction

In 1962 Hannes Keller carried out the first ocean dive to 1000 feet for a few minutes which ended, due to logistic problems, with the loss of two lives. In spite of this tragedy, Keller must be accorded the credit for showing that such great depths were within the scope of man's attainment and arousing interest as to the depth limits of man in the sea.

Early in 1965, experiments at the RNPL were carried out in which men were exposed to oxygen-helium at 600 ft for four hours and 800 ft for one hour during which tests were made of mental and manual efficiency (Bennett 1965). Decreases of 18% in the mental test of arithmetic ability and 25% in the ball bearing test of fine manual dexterity were found at 600 ft which were twice as severe at 800 ft. These decrements were accompanied by dizziness, nausea, vomiting and a marked tremor of the hands, arms and even whole body which came to be called 'helium tremors'. However, in about one and a half hours the subjects' condition had returned to normal. Subsequent experiments at depths between 300 to 500 ft for one hour (Bennett and Dossett 1967, Bennett 1967) confirmed the existence of the helium tremors. Much speculation arose as to the cause, including a hypercapnia, hypocapnia and the noise, heat and rate of compression. It was considered on the basis of these results that man would probably be severely incapacitated at 1000 ft.

However, in America, also in 1965, the first simulated saturation dive with oxygen-helium was made to 650 ft for 48 hours (Hamilton, McInnis, Noble and Schreiner 1966) which was followed by an increasing number of simulated dives which gradually extended the depth limit. Among the notable saturation dives were the exposure of two men to 800 ft for 100 hours by a German/French group (Cabarron, Hartmann, Weiner, Alinat and Fust, 1966), various dives between 700 and 800 ft by the Swiss (Waldvogel and Buhlmann 1968), a dive to 800 ft in 1968 by International Underwater Contractors and the US Naval Submarine Medical Center (Weybrew and Parker 1968, Parker 1969, Russolti and Duffy 1969, Dougherty and Schaefer 1969, Schaefer, Carey and Dougherty 1970), 48 hours at 825 ft and 30-60 hours at 600 ft at the Experimental Diving Unit, Washington (Kelly, Burch, Bradley and Campbell 1968, Biersner and Cameron 1970) and a further US Navy dive carried out at Duke University in December 1968 when the first saturation dive to 1000 ft was achieved (Salzano, Rausch and Saltzman 1970, Overfield, Saltzman, Kylstra and Salzano 1969).

Excursion dives from these saturation levels established further depth limits but the dives were of only short duration. Thus in February 1968 the two divers of the EDU experiment made an excursion to 1025 ft and on 12 March 1968, the Underwater Contractors Inc divers set new records with a five minute 'bounce' dive to 1100 ft and a 30 minute 'bounce' dive to 1050 ft.

The many detailed physiological, medical and psychological measurements made during these dives established that man could both live and work at these high pressures without significant disturbance. The problems of helium tremors, nausea, etc., did occur but were found to be markedly reduced by slowing the rate of compression. Thus, in the 1000 ft dive at Duke University, with a compression time of 24 hours, there were no tremors in any of the five subjects. This was considerably slower than the 100 ft/min of the early RNPL dives or even the 60 mins to 650 ft by Ocean Systems in which mild tremors and dizziness were reported.

However in June 1968 Brauer and Veyrunes carried out a record deep dive in a series by the COMEX organisation of Marseille which was aborted after only four minutes at 1189 ft. After a two hour compression the dive was abandoned due to the onset at depths greater

than 1000 ft of a marked increase in slow wave theta activity (4-8 c/s) in the electroencephalogram (EEG), helium tremors, and 'microsleep' involving an imperceptible transition between brief periods of somnolence and wakefulness, with right-left disorientation and difficulty in reading instrument dials (Brauer 1968). The decision to abort the dive was arrived at almost simultaneously by the divers and outside control staff. In earlier monkey experiments (Brauer, Johnson, Pessotti and Redding 1966), a similar but more serious sequence of events was seen during deep oxygen-helium diving, entailing tremors, a period of somnolence and finally convulsions, and it was inferred, on the basis of these studies and the June 1968 experiments, that convulsions could well be expected at about 1200 ft.

These signs and symptoms were labelled the 'High Pressure Nervous Syndrome' (HPNS) and it was inferred that this constituted a "Helium Barrier" at about 1200 ft. Yet MacInnis, Dickson and Lambertsen (1967) and Dossett and Hempleman (1970) were able to expose mice and rats to over 4000 ft with helium-oxygen without convulsions occurring and concluded that the trembling and hypersensitivity could be controlled by very slow compression. It is relevant that in the experiments of Dossett and Hempleman, the rise in temperature of the chamber was only 3-3.5° C. In an extensive series of experiments by Zaltsman *et al.* (1968) published in a Russian monograph on the neurophysiological action of nitrogen, argon, helium and hydrogen on rabbits, dogs, mice and man, it is noted that tremors appearing during compression are usually associated with temperature increases of 7-15° C and are reduced on return to ambient temperatures. Further, tremors are less prevalent in a 'wet' dive where the temperature is lower, whereas, the creation of hyperthermal conditions when compressing animals in helium causes general convulsions at 1000 ft. Thus use of a very slow rate of compression should permit man to dive deeper than 1200 ft without serious difficulty or risk of convulsions.

Of even greater significance to the theory that the 'Helium Barrier' may not prevent man from diving to very great depths was the human experiment in February 1969 carried out by a Swiss/British team in the Deep Trials Unit at the R.N. Physiological Laboratory which established, for three Swiss subjects, a world simulated 'wet' diving record of three

days at 1000 ft with five hours of underwater excursions to 1150 ft (Buhlmann, Matthys, Overrath, Bennett, Elliott and Gray, 1970). Intensive physiological and psychological investigations were made from which it was concluded there were no serious limitations to man performing effectively at this depth. Indeed the condition of the three subjects was excellent at 1150 ft and they were able to swim and work underwater with unexpected ease. It was difficult to believe that at only 40 ft deeper, these apparently normal men would be affected by the HPNS.

The present experiment was therefore planned in which two men would be exposed to 1500 ft under very carefully controlled conditions. With thorough physiological, psychological and medical monitoring and special emphasis being given to EEG and tremor measurements, it was hoped to determine the aetiology and importance of the HPNS when diving both very deep and at Continental Shelf depths in a saturated state.

Preliminary experiments were made involving the exposure of subjects in the closed chamber without pressurisation followed by exposure for three days to 40 ft and 24 hrs at 100 ft, 300 ft and 450 ft to test the many vital life support systems and to familiarise both the subjects and scientific staff with the various techniques, equipment and measurements to be made. Since the 300 ft and 450 ft dives were carried out by the same subjects as the 1500 ft dive this enabled comparison of the physiological and medical data over a wide range of depths.

Methods Two teams were responsible for the operation of the pressure chamber and the life support systems, each team working 24 hrs on and 24 hrs off. A team consisted of a chamber controller, a chemist and an engineer with some interchangeability and were under the direction of Mr. Jack Eaton the Chief Pressure Chamber Controller. Medical safety and the decompression were under the direction of Surgeon Commander Peter Barnard, R.N., with officers of the R.N. Medical Service, who also worked on a watch basis, and the scientific programme was co-ordinated by the author with virtually all departments and civilian scientific staff of the R.N. Physiological Laboratory.

The Pressure Chamber

The pressure chamber was 16 ft long by 5 ft 6 in diameter and consisted of two compart-

ments with a total volume of 360 cu ft of which 225 cu ft constituted the main compartment and the remainder the lock. A small hand lock of one cu ft was used to pass through food or small equipment, etc.

Each compartment was supplied with 31 either partially or fully screened electrical connections for the scientific measurements and it was possible to supply alternative breathing gases through an internal supply. Chamber temperature was controlled by electrically heated tapes around the vessel which was covered with 50 mm of fibreglass insulation.

The Chamber Atmosphere

The oxygen concentration was monitored by means of gas chromatographs, a paramagnetic analyser and polarographic oxygen electrodes and maintained by means of an oxygen injection system. The carbon dioxide concentration was monitored by gas chromatography and the level controlled by the use of two air driven impellers sucking the chamber air through standard size soda lime canisters used in submarines.

Water vapour, ammonia and hydrogen sulphide were removed with canisters of silica gel and carbon granules. The chamber atmosphere was maintained by Mr. Eaton and his staff within the following limits:—

Oxygen	0.45 ats abs
Carbon dioxide	less than 0.5% equivalent of 1 ats
Relative Humidity	70 - 90%
Helium	remainder
Temperature	30°C

Scientific Tests

A battery of psychological, neurophysiological and biochemical tests were devised to carefully examine any changes indicative of the HPNS.

- (a) *Electroencephalogram (EEG)* A technique was devised for secure application of scalp electrodes to the shaved scalp at the vertex, occipital and sphenoidal areas by means of Beckman stick-on electrodes and 3 M Brand Double Coated Plastic Medical Tape. Excellent noise free recordings were obtained throughout the 15 days of the dive using

a Galileo E8A Electroencephalograph. Spontaneous EEG with eyes open and shut was recorded together with on-line EEG frequency analysis for five bands *i.e.* delta (2-4 c/s), theta (4-8 c/s), alpha (8-13 c/s), beta 1 (13-20 c/s) and beta 2 (20-30 c/s) by means of a Nihon Kohden Frequency Analyser MAF 5. The EEG and frequency analysis were recorded continuously during compression and for periods of one min with eyes shut and open during application of the full test battery.

- (b) *Auditory Evoked Potentials* Averaged EEG potentials at the cortex evoked by 64 'clicks' to binaural earphones were recorded from a Datalab Biomac 1000 Computer and the height of the N₁P₂ potential measured as an indication of the central excitability of the brain (Bennett, Ackles and Cripps 1969). All EEG data was recorded both on tape and on a Philips ANALOG 7 FM instrumentation tape recorder.

In addition the EEG, ECG and respiration rate were continuously available on monitor screens.

(e) *Performance Efficiency*

- (1) Tremor Transducer. A Specialised Laboratory Equipment TREM 1 tremor transducer was attached to the middle finger of the right hand from which the frequency analyser provided on-line analysis of the amount of tremor present over one minute.
- (2) Ball Bearing Test. The subjects were required to pick up ball bearings one at a time with fine tweezers and place them in a tube. The score was the number in the tube in one min and is a measure of tremors and fine dexterity. (Bennett 1965, Bennett and Dossett 1967, Buhlmann *et al.* 1970).
- (3) Purdue Peg Board. Small pegs and washers must be assembled on a board in one minute. Each item consists of one peg, two flat washers and a small spacer threaded between the washers. The score is the number of units assembled.
- (4) Towse Touch Test. While blind-folded, the subject sorts two sizes and textures of ball bearing by hand.

The score is the sum of correct balls sorted minus the errors.

- (5) Visual Analogies Test. The Wechsler Bellevue Digit Symbol Test requires the subject to relate symbols to a set of numbers in a key. Time for test one min.
- (6) Arithmetic Test. Two figure by one figure multiplication. The sheets of sums were provided by a computer using random numbers. Score was the number correct and attempted in two mins.
- (d) *Pulse Rate* The pulse rate was measured from the electrocardiogram (ECG) recordings which were displayed on the electroencephalograph alongside the EEG recordings.
- (e) *Oral Temperature* The body temperature was measured by a thermo-couple under the tongue for one min using a Yellow Springs multi-channel recorder.
- (f) *Urine Analysis* All urine voided by each subject was collected at mid-day every 24 hours. The volume of fluid intake was noted as was the fluid output. The urine was analysed for cortico-steroids, calcium, sodium, potassium, magnesium, phosphorus, chloride and net renal acid by the Institute of Naval Medicine and Biochemistry Department Royal Naval Hospital, Haslar (RNHH).
- (g) *Blood* Venous blood samples (10 ml) were taken before and after the dive and analysed by RNHH for
 - (1) Haemoglobin, white cell count, differential, haematocrit and platelets.
 - (2) Lactate dehydrogenase, LDH/HBD ratio, total protein, urea, bilirubin, serum aspartate aminotransferase, alkaline phosphatase and serum electrolytes.
- (h) *Personal Comments* A personal comment check list (Weybrew and Parker 1968) was completed by each subject at each test period.

Excluding control data on the surface, over 22 hours of measurements were obtained in relation to the above test battery. Table 1 shows the depths and times for these test results shown in Figs. 5-12. A further 20 hours were devoted to measurement by Dr. Jim Morrison

of respiratory function of the two divers at rest and during moderate work on a bicycle ergometer (300 kg · m/min), the results of which are discussed elsewhere (Morrison and Florio 1970). In addition, Dr. Gill of the Admiralty Research Laboratory, Teddington used the dive to test and perfect a helium voice unscrambler. This proved excellent at 1500 ft, permitting not only internal/external communication but the subjects also to speak to each other.

Results The two subjects (Fig. 3) who volunteered for the experiment are both members of the civilian staff of the RNPL. John Bevan, is a 26-year-old Welshman and Assistant Experimental Officer, very experienced as a Sub Aqua Club diver, and his younger married colleague Peter Sharphouse, a Scientific Assistant, attained his 21st birthday during the dive.

The Dive Profile (Fig. 4)

During March 1970 the two subjects spent just over 15 days living in the pressure chamber. Compression initially was to 600 ft at 6 mins per 100 ft where 11 hours of scientific tests were made during almost 24 hours at this depth. After a further 24 hours at 1000 ft, with 11 hours of tests, an hour of tests were made at 1100 and 1200 ft. This was followed by compression to 1300 ft with nine hours of tests. On Friday, 6 March 1970, Bevan and Sharphouse were compressed to 1400 ft for an hour of tests before attaining 1500 ft for eight hours of measurements during a 10 hour stay at over 300 ft deeper than man had dived previously.

During decompression at 40 ft/hour, as a result of vestibular problems causing dizziness and vomiting with Sharphouse, there was a return from 1160 ft to 1535 ft followed by decompression at 10 ft/hour and slower so that five and a half days were spent deeper than 1000 ft and three and a half days deeper than 1189 ft the previous world record depth.

At 50 ft John Bevan developed decompression sickness in the form of a pain in his right leg which accounts for the changes in profile at this point (Fig. 4) due to the recompression therapy required.

Electroencephalogram

Analysis of the percentage change in the five common frequency bands of the EEG (delta,



FIG. 1. The pressure chamber at the R.N. Physiological Laboratory, Alverstoke, which is capable of simulating 2,250 ft, shown during the record dive to 1500 ft in March 1970.

theta, alpha, beta 1 and beta 2) showed significant changes in the two subjects (Fig. 2).

Sharphouse with eyes open or shut showed a dramatic increase in theta activity. At 600 ft, with eyes closed, there was in six hours a 25% peak increase in theta which returned gradually to normal (Fig 5). Compression to 1000 ft, again over six hours, increased the theta activity to 75% above controls. After 12 hours this had decreased to only 20-35%. Compression to 1300 ft resulted, in a further 5-6 hours, in a maximum theta increase of 90%. Again, after 12 hours this peak had returned to lower values. On compression to 1500 ft there was another increase in theta but the change was not as severe as seen at 1000 ft and 1300 ft. Among other changes were a decrement in the amount of delta activity (2-4 c/s) until, during decompression, a vestibular syndrome occurred with dizziness and vomiting which resulted on the third day in a marked increase in delta activity. No measurements are available during the first two days of decompression.

Other frequencies showed no change until at 1300 ft they were depressed. During the vestibular syndrome this decrement was even worse, but on return to the surface the delta activity had returned to normal and there was a significant recovery of all activity other than theta which remained high.

TABLE I. 1500 FEET DIVE 3-18 MARCH 1970
Compression Phase Test Sequence (see Figs. 5 - 12)
***Extra Length of EEG Recording after arrival at 1500.**

<i>Date</i>	<i>Time of Day</i>	<i>Depth in Feet</i>	<i>Test Sequence</i>	<i>Running Time</i>	
3.3.70	1100	0	—	000	50
	1200	50	A	001	
	1340	600	B	002:40	
	1440	600	C	003:40	600
	1750	600	D	006:50	
	2212	600	E	011:12	
4.3.70	0902	600	F	022:02	1000
	1200 → 1223	600 → 1000	CC1	025	
	1230	1000	G	025:30	1100
	1434	1000	H	027:34	
	1811	1000	I	031:11	
	2209	1000	J	035:09	
5.3.70	0905	1000	K	046:05	1200
	1200 → 1205	1000 → 1100	CC2	049	
	1208	1100	L	049:08	1300
	1300 → 1305	1100 → 1200	CC3	050	
	1312	1200	M	050:12	1400
	1400 → 1405	1200 → 1300	CC4	051	
	1409	1300	N	051:09	
	1604	1300	O	053:04	
	1704	1300	P	054:04	
	2205	1300	Q	059:05	
6.3.70	0817	1300	R	069:17	1500
	1200 → 1205	1300 → 1400	CC5	073	
	1211	1400	S	073:11	1500
	1300 → 1305	1400 → 1500	CC6	074	
	1310	1500*	T	074:11	1500
	1509	1500	U	076:09	
	1841	1500	V	079:41	
	2215	1500	W	083:15	

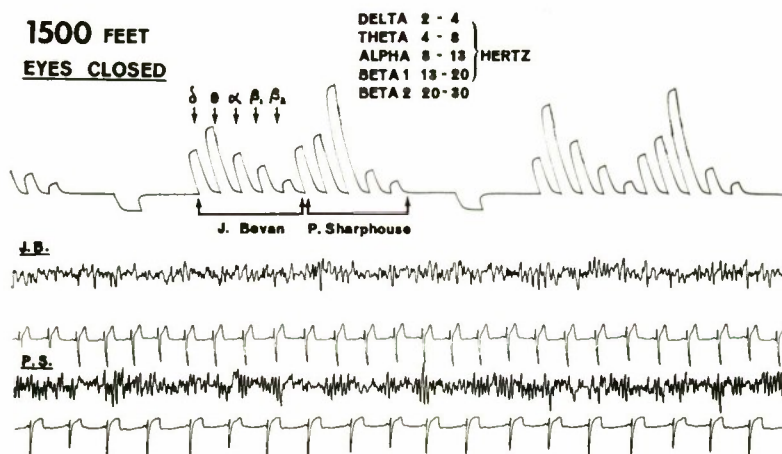


Fig. 2. Part of the electroencephalogram (EEG) and electrocardiogram (ECG) recordings made at 1500 ft. The first trace is the EEG frequency analysis of traces 2 and 4 beneath. Each frequency write-out sequence is 10 seconds for each subject.

TABLE I (Contd.) 1500 FEET DIVE 3 - 18 MARCH 1970
Decompression and Recompression Phase Test Sequence

Date	Time of Day	Depth in Feet	Test Sequence	Running Time (Total)	Running Time (decompression)
7.3.1970	1020	1170	D 1	094:20	011:20
	1050	1170	D 2	094:50	011:50
	1950	1530	RC 1 (a)	104:50	020:50
	1959	1535	RC 1 (b)	104:59	020:59
	2005	1500	RC 1 (c)	105:05	021:05
8.3.1970	2215	1220	D 3	131:15	047:15
9.3.1970	1124	1100	DA	144:24	060:24
	1611	1050	DB	149:11	065:11
10.3.1970	1105	858	DC	168:05	084:05
11.3.1970	1050	623	DD	191:50	107:50
	1605	565	DE	197:05	113:05
12.3.1970	1001	388	DF	215:01	131:01
13.3.1970	1026	226	DG	239:26	155:26
16.3.1970	1106	31	DH	312:06	288:06
17.3.1970	1424	24	DI	339:24	255:24

Similar changes were observed in Sharphouse with eyes open (Fig. 6), although the theta activity was even more markedly increased. At 600 ft the 4-8 c/s theta waves were increased over twice the eyes closed value to 75%. Again the peak occurred six hours after reaching depth and was followed by spontaneous recovery in 12 hours to control levels. At 1000 ft the peak was 120% in excess of control values before returning to just over 30%. Compression through one hour at 1100 ft and 1200 ft stimulated further increases in theta which did not start to recover until the 1300 ft saturation stage. On compression through 1400 ft to 1500 ft, theta activity reached a peak 110% greater than controls.

Other frequencies were not unduly affected except during the vestibular syndrome, when there was a marked increase in both delta and theta, and a depression of other frequencies. These recovered to normal limits on return to the surface.

Bevan on the surface already has a dominant theta activity and may be expected to less readily demonstrate large theta increases.

In fact at 600 ft with eyes closed the compression increase was only some 25% which soon returned to normal limits for most of the rest of the dive. However, as with Sharphouse, there was a tendency for increases to occur on compression followed by a slow recovery (Fig. 7).



FIG. 3. The two subjects perform tests of manual dexterity. Peter Sharphouse (left) is carrying out the Peg Board Test and John Bevan the Ball Bearing Test. EEG and ECG electrodes may be seen together with the umbilicals carrying the data to the recording apparatus.

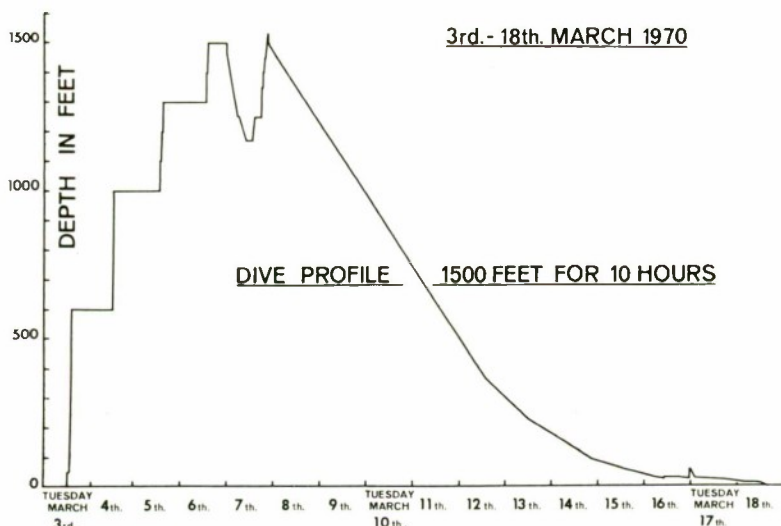


FIG. 4. The dive profile during the 15 days of the experiment illustrating the compression sequence, the recompression due to the vestibular bend and the small variations due to the leg bend during the last two or three days.

During decompression all frequencies returned to normal except for the beta 2 (20-30 c/s) activity which remained depressed by 20 to 30%. There was also a slight increase in all frequencies at 600 ft with a peak theta rise of 70% at about the time Bevan first complained of vague muscle aches leading to a bend at 30 ft.

At 600 ft with eyes open, theta frequencies increased by just over 50% (Fig. 8). This soon recovered to 10-20% for the rest of the time at depth. Again, however, all other

frequencies showed a 30-40% depressed activity which gradually recovered on decompression, except for the beta 2 frequencies which, as with eyes shut, remained depressed.

Thus, in general, on reaching 600 ft Bevan showed a decrease in all frequencies except theta, which reached a peak at 1000 ft and was no worse at 1500 ft. Sharphouse demonstrated a much more severe increase in theta activity which was stimulated by each new compression phase and reached its peak some six hours after each compression, followed by 12 hours to decrease to near control levels. Nevertheless, the theta shift at 1500 ft was no worse than at 1000 ft. It is of interest that similar theta shifts were noted in earlier 450 ft/24 hour dives which were also almost as great as those at 1000 ft or deeper, but the recovery seemed slower, the theta only reducing during decompression.

Auditory Evoked Response (Fig. 9)

The auditory cortical evoked response showed an average 15% decrement for Bevan and 25% for Sharphouse during most of the dive. At 1500 ft however, both men showed a progressive depression of the spike height of the N_1P_2 wave of the cortical evoked response. After 10 hours at 1500 ft this resulted in a decrement of 30% for Bevan and 50-55% for Sharphouse. At the first decompression measurement 2-3 days later at 1100 ft, the evoked response had returned to normal.

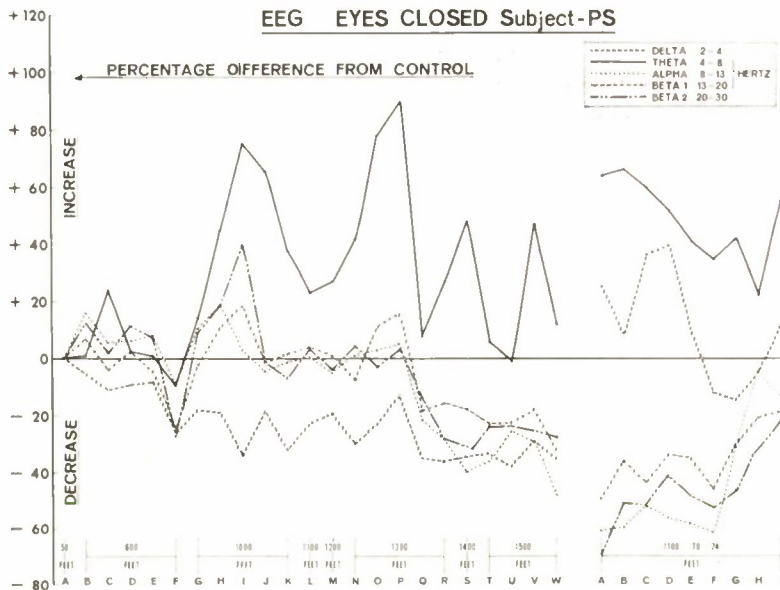


FIG. 5. Analysis of the EEG frequency shifts occurring during the time spent by Peter Sharphouse at the various stable stages of the dive. The recordings were made with the eyes shut. See Table 1 for additional details.

Performance Efficiency

Helium Tremors—The amount of helium tremors measured by the finger tremor transducer was quite different for each subject (Fig. 10). Bevan showed marked tremors whereas Sharphouse was affected only to a minor extent. The tremors were considerably enhanced by each of the compression phases and during the early morning on waking.

Bevan, at 600 ft, had a 100% increase in tremors over controls. This, initially at 1000 ft, increased to 400% but within two hours was reduced to 75% of normal. Compression through one hour at 1100 ft and 1200 ft to 1300 ft resulted in a further increase in tremors to 600% of controls. Again this returned in a few hours to a lower value of 125%. After one hour at 1400 ft compression to 1500 ft

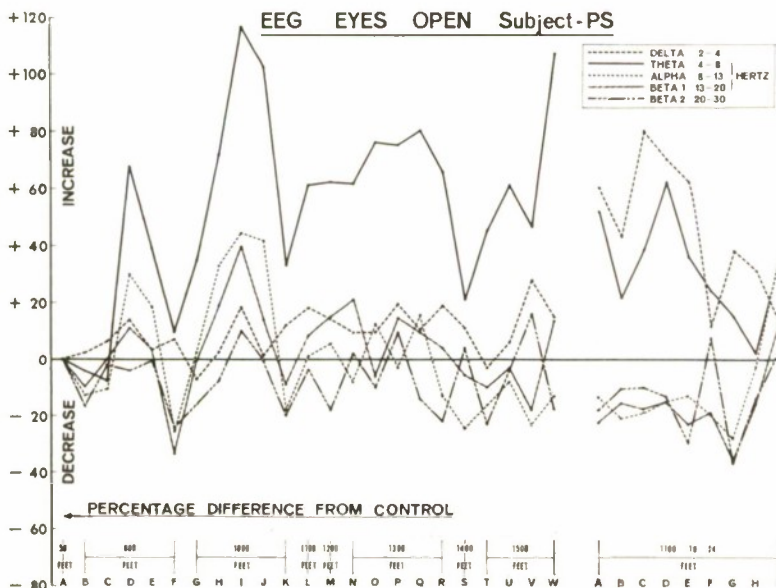


FIG. 6. As Fig. 5 but in this case the measurements were made with eyes open. See Table 1 for further information.

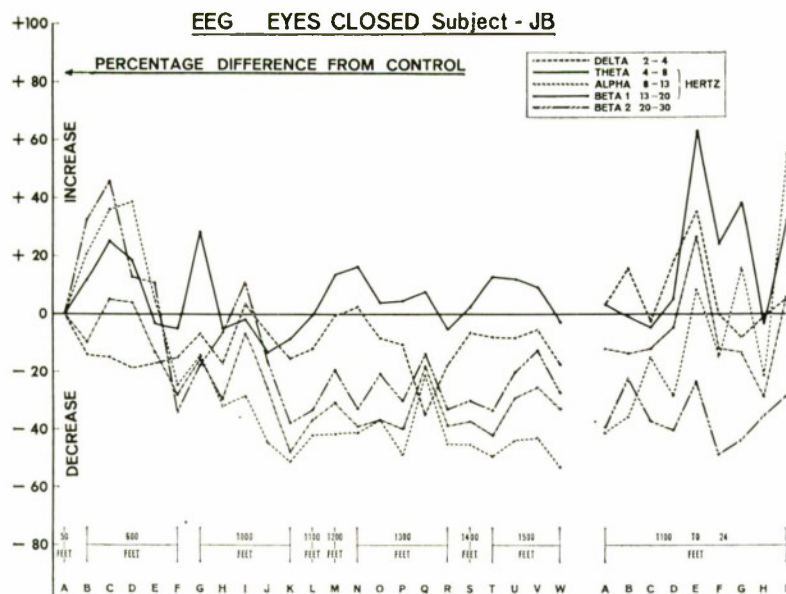


FIG. 7. Analysis of the EEG frequency shifts occurring during the time spent by John Bevan at the various stable stages of the dive. The recordings were made with the eyes shut. See Table 1 for additional details.

resulted in a less marked increase in tremors of some 275% with a reduction to a value somewhat greater than the stable value at 1300 ft.

Thus in general Bevan showed large increases in tremors on compression, which soon settled to lower values, but these more stable levels of tremors tended to become worse with increasing depth and were accompanied by an intention tremor. With Sharpshouse tremors

were never more than 100% greater than controls and the effect of compression was less obvious.

Performance Tests (Figs. 11 and 12)

The results of the tests of performance efficiency show that most of the decrement was in tests of fine manual dexterity such as in the ball bearing test, where ball bearings must be placed by tweezers in a tube; the peg board

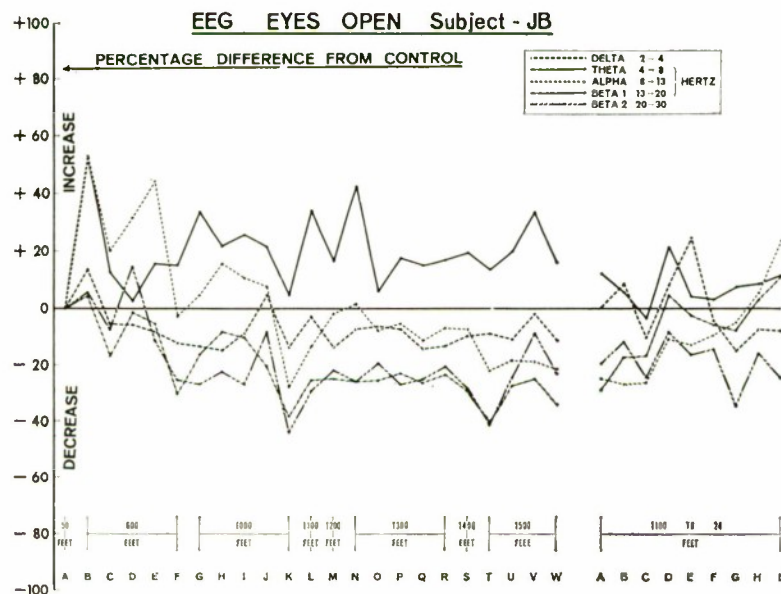


FIG. 8. As Fig. 7 but in this case the measurements were made with eyes open. See Table 1 for additional information.

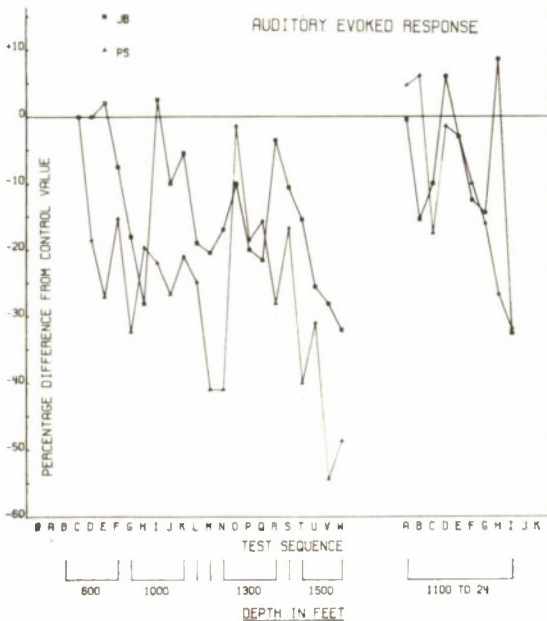


FIG. 9. The percentage difference in the N_1P_2 spike size of the auditory induced cortical evoked response at the stable stages of the dive. See Table I for further details as to the time sequence for each measurement A-W and A-K.

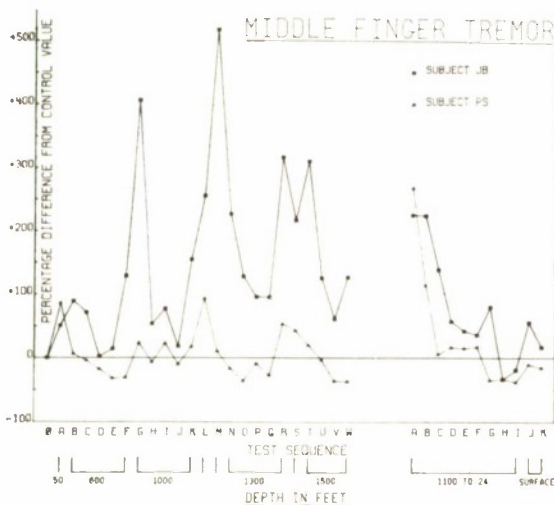


FIG. 10. The percentage change in the amount of tremor measured from the tremor transducer attached to the middle finger of the subject John Bevan shows evidence of a marked increase in tremor, especially after compression.

test, where pegs and washers are assembled on a wooden board and the touch test where, while blindfold, different sizes and textures of ball bearings must be sorted. The worst impairment was immediately after compression. Mental tests such as multiplication arithmetic (e.g. $68 \times 9 =$) and the visual analogies tests involving relating numbers to symbols virtually were unaffected.

Thus in the ball bearing test Sharpouse showed a compression peak decrement at 1000 ft of 50% which soon recovered to 20 - 25% less than normal. Thereafter, with minor peak depressions of efficiency on compression, a decrement averaging 30% was maintained. During decompression from 1100 ft to 800 ft there was a greater decrement of 45%, as a result of the vestibular syndrome, which returned to control values on return to the surface.

The touch, peg board and visual analogy tests were depressed by only some 10 - 15% below controls and except for an additional fall to 20% during the initial decompression, performance returned to control values on returning to the surface. No significant changes were observed in the arithmetic test, except during the initial decompression, when due to the vestibular syndrome, a 20% reduction occurred in both the number of sums correct and attempted.

Bevan was more seriously impaired in the performance tests. However, again the arithmetic test was unaffected and the visual analogies test was rarely depressed by more than 10%. Tests of manual dexterity were markedly depressed.

With the ball bearing test, on compression to 1000 ft the initial decrement of 45% soon recovered to only 20% but compression again to 1300 ft resulted in a 55% decrement which recovered to 25% less efficient than controls. On compression to 1500 ft the peak decrement was almost 70% recovering to a value 35% of normal.

Performance at the touch test gave a 25% decrement and peg board efficiency was reduced by 15 - 20%. However, efficiency as a whole at these tests was no worse at 1500 ft than between 600 ft to 1000 ft.

In general the decrement in performance mainly involved manual dexterity and was due primarily to the tremors. Tests of mental efficiency were virtually unaffected, which confirms that helium is not narcotic at 1500 ft.

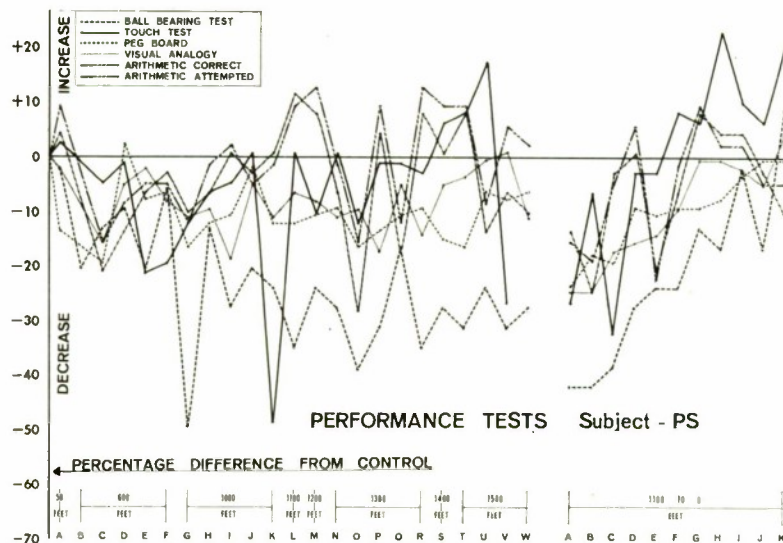


FIG. 11. The percentage change in efficiency of Peter Sharphouse to carry out tests of mental performance and manual dexterity throughout the experiment. The return to the base-line on decompression to the surface emphasises the lack of learning but clearly shows the high motivation of the subject.

Pulse Rate—In both men a bradycardia occurred at 600 ft which was more pronounced at 1000 ft with a pulse rate of 51 beats/min. Thereafter the pulse rate increased to a value of 55/60 beats/min.

Oral Temperature—The oral temperature showed no significant change in either subject.

Urine Analysis

The effect of the present experiment on urine electrolytes was similar to that found during the previous Swiss/British dive (Buhlmann *et al.* 1970). Both subjects between 600 ft and 1500 ft showed a retention of calcium, sodium, mag-

nesium and chloride and a diuresis of potassium and phosphorus.

The urine volumes did not change radically, except for a very low pre-dive control volume in the case of Peter Sharphouse, which was unfortunately accompanied by a high volume intake of almost 3400 cc. This resulted in a high urine volume on day two immediately prior to compression. By contrast, Bevan was more stable in his fluid intake, which varied between 1.5 to 2 litres.

On decompression, the majority of electrolytes showed a rebound effect, with, for example, a calcium diuresis as equilibrium was re-established.

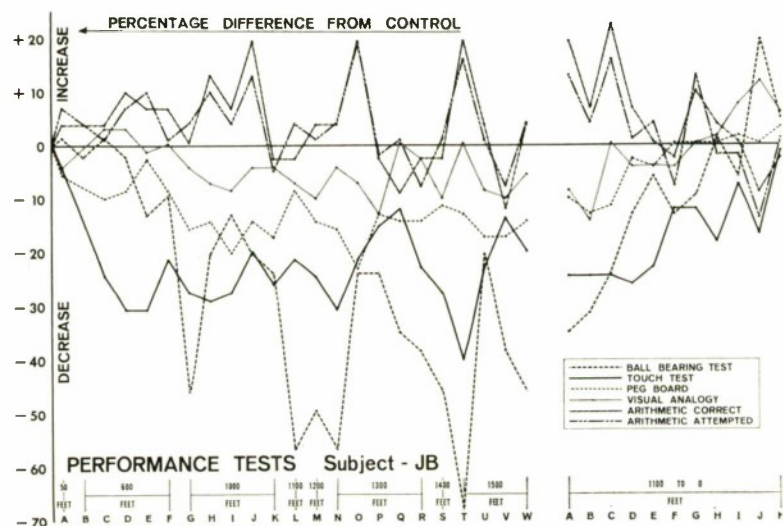


FIG. 12. The percentage change in efficiency of John Bevan to carry out tests of mental performance and manual dexterity throughout the experiment. The return of the base-line on decompression emphasises the lack of learning but clearly shows the high motivation of this subject. Due to his increased tremors he shows much more deterioration than Sharphouse at the tests of manual dexterity (Fig. 11) but like him there is no evidence of mental impairment or helium narcosis.

Corticosteroid measurements in Bevan indicated a lowering of stress during the compression and at depth phases. This also was maintained during the early decompression and was followed by a general fall to normal limits, until near the end of decompression the leg bend contracted by Bevan resulted in a sharp increase in corticosteroids.

Sharphouse, by contrast, showed no serious increase in corticosteroid excretion during the compression or time at depth. During the early phase of the decompression, however, when Sharphouse was suffering from a vestibular lesion resulting in vertigo, nausea, photophobia and vomiting, his corticosteroid excretion rose steadily each day to a maximum in excess of 35 mg/g creatinine and then gradually fell as he recovered to only 9 mg/g on reaching the surface. Net acid excretion also increased during the critical phase of the decompression when Sharphouse was affected by the vestibular syndrome. Bevan showed no significant change in net acid excreted.

Blood Measurements

Biochemical analysis of the venous blood samples taken before and after the dive showed no significant change. However, the white cell count was increased by some 3-4000 and the platelets showed a fall of 78,000/mm³ for Sharphouse and 135,000/mm³ for Bevan. This could be due to the fact that the pre-dive sample was taken at 0900 whereas the post-dive sample unavoidably had to be taken at 1630.

Personal Comments and Deep Diving Questionnaire

Analysis of the personal comment check lists show a high level of morale throughout the dive with, in both men, frequent comments of 'good' or 'happy'. No behavioural or psychological problems occurred during the 15 days.

Bevan at 600 ft mentions inefficiency due to tremors, clamminess of the hands and feeling too warm on compression (35°C). 'Clicks' were noted in the right knee joint during exercise on the ergometer. Some 5½ hours of good sleep were obtained and there was no respiratory difficulty. During the first two hours at 1000 ft tremors again are reported with light-headed sensations, dizziness and slight nausea. Clamminess is mentioned once more and 6½-7 hours of good, though interrupted sleep recorded. At 1200 ft, periodic muscle jerks of the limbs occurred and jerky voluntary move-

ments are noted. Appetite remained excellent and taste of food normal. At 1300 ft Bevan reported waking frequently during the night and having vivid dreams. As previously, he noted involuntary muscle jerks, feeling warm and inability to achieve adequate ventilation when breathing through the nose. Orientation was reported as excellent.

Sharphouse also reported dizziness, nausea and clamminess during the first two hours at 600 ft. Sleep was poor, with only four hours during the first night. On compression to 1000 ft the dizziness returned for the first hour but sleep improved to a fair six hours. Temperature regulation was difficult, as only slight variations around the chamber temperature of 29-30°C caused comments of feeling either too cold or too warm. At 1300 ft Sharphouse also reports feeling a need to breathe through the mouth, and a small amount of movement was found to quickly induce fatigue.

Discussion Further details of the many results and the conclusions from this dive are given in reports elsewhere (Bennett 1970a and 1970b). However within the limited space available for this article some of the more important points will be discussed briefly.

These experiments support the existence of a High Pressure Nervous Syndrome (Brauer 1968, Zaltsman *et al.* 1968) but indicate that it is possible to circumvent the so-called 'Helium Barrier' envisaged at 1200 ft by choice of a compression time which allows ample time for adaptation. This does not necessarily mean slowing the rate of compression which in the present dive at 16.7 ft/min was faster than the COMEX rate of 10 ft/min but does involve stages of some 24 hours at 1000 ft and 1300 ft, for example, which provides time for adaptation. On the basis of the present EEG and tremor results, continuous compression is considered inadvisable and may lead to a serious disturbance of function in the central nervous system.

The respiratory measurements (Morrison and Florio, 1970) indicate that ventilation at depth, during both rest and exercise, was increased slightly. This was probably due to the increased density of the breathing mixture and possibly to other factors such as the unavoidable temperature increases. For a given level of ventilation, the relation of respiratory rates and tidal volume were altered considerably. The rate decreased with depth while tidal volumes

showed a corresponding increase. At all depths alveolar carbon dioxide tensions were within normal limits at rest and during exercise, indicating adequate ventilation.

Although these results show that man can dive and work at a pressure equivalent to 1500 ft without incapacitating functional impairment, the changes in the EEG, the occurrence of tremors and the urine electrolyte disturbances do indicate some physiological problems primarily associated with compression and involving adaptive processes. Evidence is provided also of wide individual susceptibility and selection of divers could well help to decrease the incidence of some of these changes.

The EEG changes found in this experiment involving depression of alpha and beta frequencies and increases in theta and sometimes delta activity were detected due to the use of the sensitive frequency analyser. Visual appraisal of the records showed little change compared with the readily visible large amounts of slow wave activity seen during the COMEX dive with its compression to 1189 ft in only two hours.

It would seem that much of the EEG change is related to the compression phase but it is of interest that once initiated, theta shifts continued to increase for some six hours and required a further 12 hours to recover to within pre-compression levels. Hence the need at depths beyond 1000 ft for long stops of some 24 hours to permit this adaptation. Failure to institute these will result in a continuous increase in the slow wave activity. In support the studies of Zaltsman *et al.* (1968) indicate severe helium tremors, hyperexcitability, confusion and mental deterioration (or microsleep) and eventually convulsions if compression is too fast.

In this connection it is relevant that during decompression a recompression to 1535 ft was carried out due to the labyrinthine problems of Sharpshouse. The pressure was increased in a series of short compressions and stops over some 8½ hours from 1160 ft to 1535 ft. At 1500 - 1535 ft John Bevan began to feel drowsy and had difficulty in retaining consciousness in a manner very similar to the 'microsleep' described by Brauer.

Now Brauer and Veyrunes compressed from 1000 ft to 1189 ft in something over 37 minutes. A similar rate in the case of Bevan would have involved a compression time of 1 hour 15 minutes. Actually the time was 8½ hours but this did involve a further 350 feet and

once beyond 1000 ft the depth itself is probably also a relevant factor. Compared to the original compression phase to 1500 ft the 8½ hours is still relatively fast as compression from 1200 ft to 1500 ft, inclusive of the 24 hour stage at 1400 ft took some 26 hours and 18 minutes.

An important finding is that there is no helium narcosis in man at 1500 ft. This confirms earlier lipid adsorption and other studies (Bennett 1969) which suggest that unlike nitrogen and most other inert gases, helium does not possess narcotic properties. Such performance decrement as did occur was due to deterioration in manual dexterity as a result of helium tremors which are most severe during and immediately after compression.

The evidence of past experimental dives also supports the view that the incidence of helium tremors may be reduced by slow compression. Whether the tremors and EEG changes collectively called the HPNS are related in terms of the action of helium on the brain remains to be seen.

A further alternative, based on work by Brauer and also by Zaltsman *et al.* is to add small amounts of narcotic inert gas such as nitrogen or argon. Thus a mixture of 8.2% oxygen, 27% nitrogen and 64.8% helium at 17.5 ats resulted in no tremors, etc., but EEG and performance changes solely due to the 5 ats nitrogen present. Every effort should be made also to restrict temperature increases to the minimum as a sudden rise in temperature appears to exacerbate the signs and symptoms of the HPNS.

It is not possible at present adequately to explain the urine electrolyte changes or the possible long or short term effects of such shifts in subjects frequently exposed to very deep saturation diving. Possibilities such as a respiratory acidosis and lack of exercise have been suggested (Cabarro *et al.* 1966, Buhlmann *et al.* 1970) but these factors do not seem relevant to the present dive. Nor can the bradycardia be explained. Although it may in part be of vagal origin (Fagraeus 1970) the helium or pressure may also be involved. At least it appeared to be no worse than the slowing of heart rate induced by compressed air or hyperbaric oxygen (Salzano, Bell, Weglicki and Saltzman 1966).

Similarly, although an increase in leucocytes is reported in other deep dives (Hamilton *et al.* 1966, Waldvogel and Buhlmann, 1968) the reason is not known. It is possible that stress could be one of the factors responsible. The

elevated platelet counts may indicate 'silent bubbles' as Philip and Gowdey (1969) have indicated an association with such an elevation and aero-embolism. Much more basic research is required to solve these problems.

However, there is little doubt that Bcvan and Sharphouse could have stayed longer at 1500 ft. Indeed it may have been advantageous to do so, for decompression started before adaptation to the HPNS was complete. Although some of the results of this experiment do advise caution there is no doubt man also can dive deeper than 1500 ft provided that a suitable slow compression profile is used. The decompression from these great depths needs further study as the incidence of decompression sickness is large in such dives and involves a high incidence of vestibular problems as occurred with Sharphouse.

In conclusion, during the preparation of this article in late November 1970, a brief statement has been received that the COMEX organisation at Marsciles have exposed divers successfully to a simulated depth of 1700 ft this month using, as suggested here, the technique of slow compression with at least one long stop at 1150 ft thus confirming that it is possible to circumvent the helium barrier using the techniques described in this article.

Grateful appreciation is extended to Mr. J. Towse, Mr. A. N. Dossett and Mrs.

B. Andrews for their excellent technical support over the many hours and days of the 1500 ft and preliminary dives. The valuable help of Mr. S. Gray, Principal Biochemist, Royal Naval Hospital, Haslar and Surgeon Commander J. D. Walters, Institute of Naval Medicine is acknowledged in regard to the biochemical analyses.

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FULTON REPORT FOLLOW UP

Plessey/Civil Service Exchange Senior Engineers

The Fulton Report, published in 1968, examined the structure, recruitment and management of the Civil Service. Among its recommendations was an interchange of senior personnel between Industry and the Civil Service. Recently this far sighted report has begun to bear fruit and some exchanges have already been arranged.

From the onset the Report's recommendations were welcomed by British Industry and a number of major organisations began to negotiate personnel exchanges. One of the companies closely involved in the scheme is Plessey, who currently have several senior staff working in various Civil Service Departments, one of whom is Mr. E. H. Hammett, of the Marine Systems Division who recently joined the staff of the Admiralty Surface Weapons Establishment (ASWE) on a two-year exchange scheme. He changed places with Mr. N. E. Gubbey a Principal Scientific Officer at ASWE, who is now working in the Marine Systems Division at Ilford.

The scheme works on a one-for-one basis, lasting two years, and on joining the new organisation each man is absorbed exactly as any other member of the organisation's permanent staff.

The objectives of the exchange scheme are to appreciate each others problems—*i.e.* to learn how they are dealt with (actually taking part rather than merely observing)—to dispel any misconceptions, and to exchange ideas and experiences.

Before leaving Plessey to join ASWE, Mr. Hammett, a senior Engineer in the Naval Systems Unit of Plessey Marine Systems Division was involved in the development of small ships sonar. He has wide experience both in the development laboratory and in the field and has considerable knowledge of refitting and new installations in ships.

Mr. Gubbey, who joined the Royal Naval Scientific Service in 1951 has been concerned with R & D work on the design and development of naval equipment. At Plessey he will be working on similar aspects of marine electronics.

It will be 1973 before both men return to their original employers and the real worth of the exchanges can be assessed. However, judging by the knowledge and appreciation of each others organisations that has already been acquired, the value of the scheme has been proved and more exchanges are likely to be made in the future.



David Edward Weston was educated at Surbiton County Grammar School; and the Imperial College of Science and Technology; joining the RNSS in 1951. All his service has been at the ARL excepting the year 1964-1965 spent as an Exchange Scientist at the Hudson Laboratories of Columbia University. His principal interest has been in oceanographic acoustics; including sound propagation generally, underwater explosions as acoustic sources, signal processing, and recently the various low-frequency acoustic phenomena associated with fish having swim bladders.



John Revie joined the RNSS as an Asst. Sc. in 1948, becoming AEO in 1950 and EO in 1959. His service started at the Admiralty Research Laboratory Extension Coulpport, with a transfer to the ARL itself in 1950. He was at this stage involved in underwater television and took part in the Affray and Comet searches. He moved to the ARL Extension, Perranporth, as Officer-in-Charge in 1962, and has recently transferred to the National Institute of Oceanography on promotion to SEO.

FISH ECHOES ON A LONG-RANGE SONAR DISPLAY

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and J. Revie, R.N.S.S.**

Admiralty Research Laboratory

*The little fishes of the sea,
They sent an answer back to me.*

Lewis Carroll, 1871
Through the Looking-Glass, Ch. 6

Abstract

The display of a research echo-ranging equipment bottom-laid in shallow water has shown many echo traces. Returns from fish shoals and from areas of bottom roughness have both been seen out to ranges of a few tens of km. The fish tracks or "wrigglers" are more common in the summer, show a tidal motion, and usually disappear at night when the shoals disband. Although many different types of pattern have been seen, it is possible to estimate that the typical shoal is 10-15 metres across with about 3×10^4 pilehard in it. The work is useful in fish behaviour, geological and oceanographic studies.

Introduction In the summer of 1962 a special study was started on the reverberation in the shallow waters of the Bristol Channel. It used an experimental echo-ranging equipment to explore the reverberation structure with a high range resolution. At long ranges the structure consisted of wriggling traces due to large numbers of shoals of fish, plus some echoes at fixed range due to bottom features. Large numbers of fish echoes had first been seen in the summer of 1961, with smaller numbers apparent in some 1960 records, and somewhat similar effects in 1958 with an earlier equipment.

This article is mainly concerned with the "wrigglers", the name given to the moving targets before they were positively identified as fish shoals. The typical tracks due to fish present a meandering appearance, but there is really a whole spectrum of pattern types extending to the more purposeful porpoise tracks. We thus have here a valuable tool for behavioural investigations on fish. The work relates closely to some theoretical acoustic studies on fish⁽¹⁾ and to some experiments in the same area on fish effects in sound propagation⁽²⁾.

It is intended here to introduce the echo-ranging studies, without too much detail, and it is convenient to do this by describing results up to the spring of 1963.

Equipment and Records All the investigations have used experimental echo-ranging equipment laid on the sea bed in the shallow waters of the Bristol Channel, looking into water depths varying from about 35 to 90 m. The projector radiated a pulse of mean frequency 1 kHz into a beam of 15° horizontal width. The nearby receiving array had a horizontal beam width of 4°, arranged to lie within the projector beam. The vertical beam widths were unimportant since beyond a quite short range the whole water column is insonified. Virtually all the work employed correlation techniques, a single machine both generating the FM pulses and processing the echoes. The pulse bandwidth was 100 Hz, so that the output of the receiving array was compared every 10 msec with a replica of the transmitted pulse. The result was a travel-time or echo-range display with a travel-time gate of 10 msec or range gate of 7.5 metres. But since the correlator had an output bandwidth which was not quite matched, the effective range gate was degraded to 15 metres (about 50 feet). With regular transmission of pulses a range-time display could be built up, which showed the time history of all the important scatterers within a 4° receiver beam.

Figs. 1 to 5 show some selected range-recorder patterns, for periods during which the recording conditions were held constant. They are arranged in chronological order. Each facsimile or teledeltos record covers only 6 sec in time delay or about 4½ km (2½ nautical miles) in range. Some of the figures are photographic montages of records covering two or three neighbouring range intervals, and Fig. 2

is in fact a montage of a large number of records obtained by replaying magnetic tape recordings of the correlator output. On all figures the original range scale shown in miles has been retained, since the records bear 2.5 sec or roughly one mile markings. Note that one nautical mile = 1.853 km. Time is local, GMT or BST as appropriate.

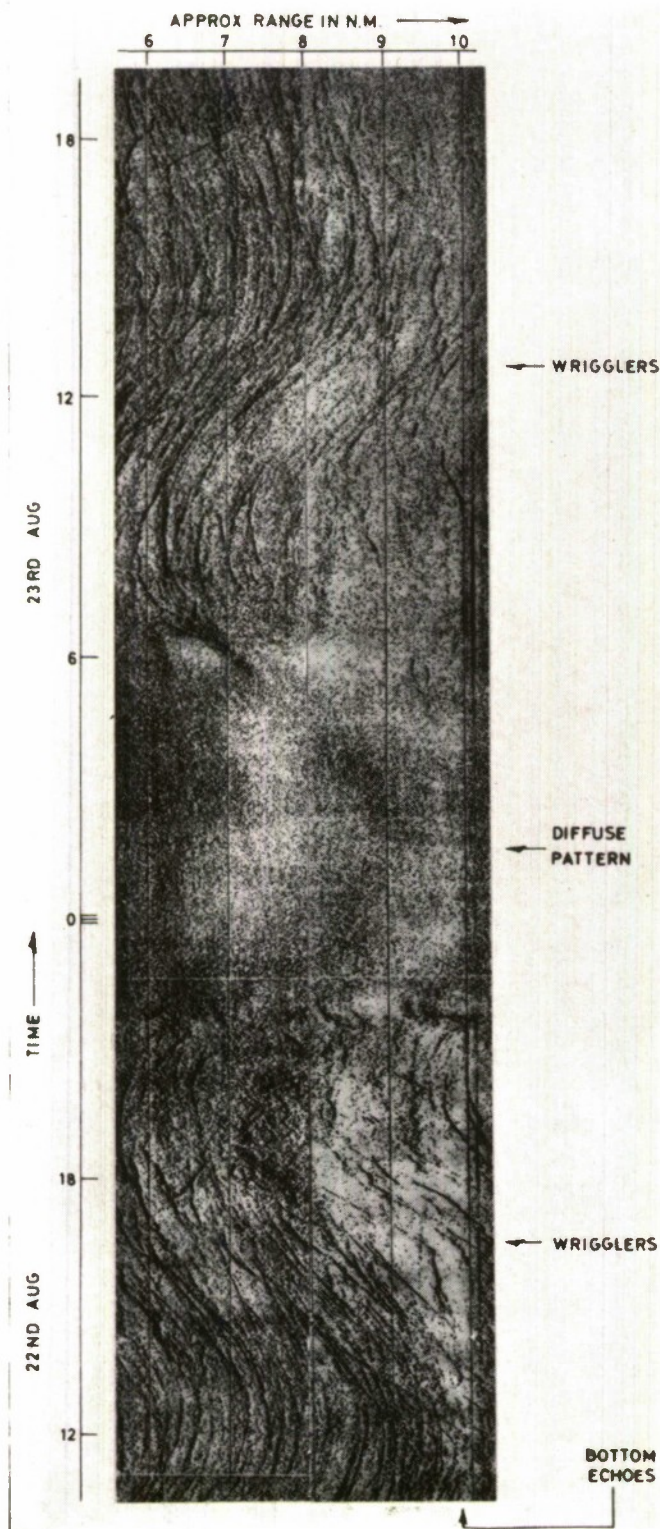
Fig. 6 shows a record obtained with an improved recorder display.

Each of Figs. 1 to 6 shows to at least some degree both fish traces and bottom echoes. The figures are intended to be self-contained and self-explanatory, but a general discussion is given in the succeeding sections of the text. Records of this type, each lasting up to 36 hours, were taken every few weeks and have proved extraordinarily rich in information. It is worth pointing out that such information could only be obtained because a *fixed* echo-ranging system was used, the rarity of such fixed systems explaining why similar results have not been reported previously. As a side comment, note that our experiments have constituted a stringent test of the reliability of the equipment, the breakdowns having been few in number and all minor in nature.

(a) *Numbers present*

Fish Traces Fish traces are more numerous during daytime in the summer months (compare Figs. 1 and 2). In a given pattern there is of course a variation in echo strength from track to track, and tracks occasionally cross or run into one another. However, it appears to be meaningful to count the number of tracks per km, and a typical number is 3 (or 6 per mile) although it can be about double this. At longer ranges the pattern may be less obvious, but usually the number of tracks per km does not change regularly. This is despite the increase in width of the acoustic beam, which is presumably compensated by the smaller fraction of wrigglers which can produce a detectable track. If one chooses quite arbitrarily a distance value of 20 km, the beam width is 1.4 km and the number of shoals per square km is about two (or eight per square mile).

Fish traces were observed in the late summer in this area by A.C.S. *St. Margarets*, using a conventional 12 kHz echo-sounder. Traces were seen at a variety of apparent depths, and averaged three per hour. Taking a ship speed of 1½ m/s (three knots) and assuming all fish within 40 metres horizontal range of the



sounder are detected, the number of scattering groups per square km comes out as seven. This is in order of magnitude agreement with the above figure of two, which is all that could be expected.

(b) *Seasonal variation*

Tracks due to fish are strongest in the summer months, and so far have always been observed when looked for. In the winter they may be seen occasionally, sometimes only in a limited part of the area. There is of course a gradual transition from summer abundance to winter rarity and back again, and this is accompanied by irregular changes in the characteristics of the patterns.

Fig. 1. Display for 22nd/23rd August 1962 (Montage).

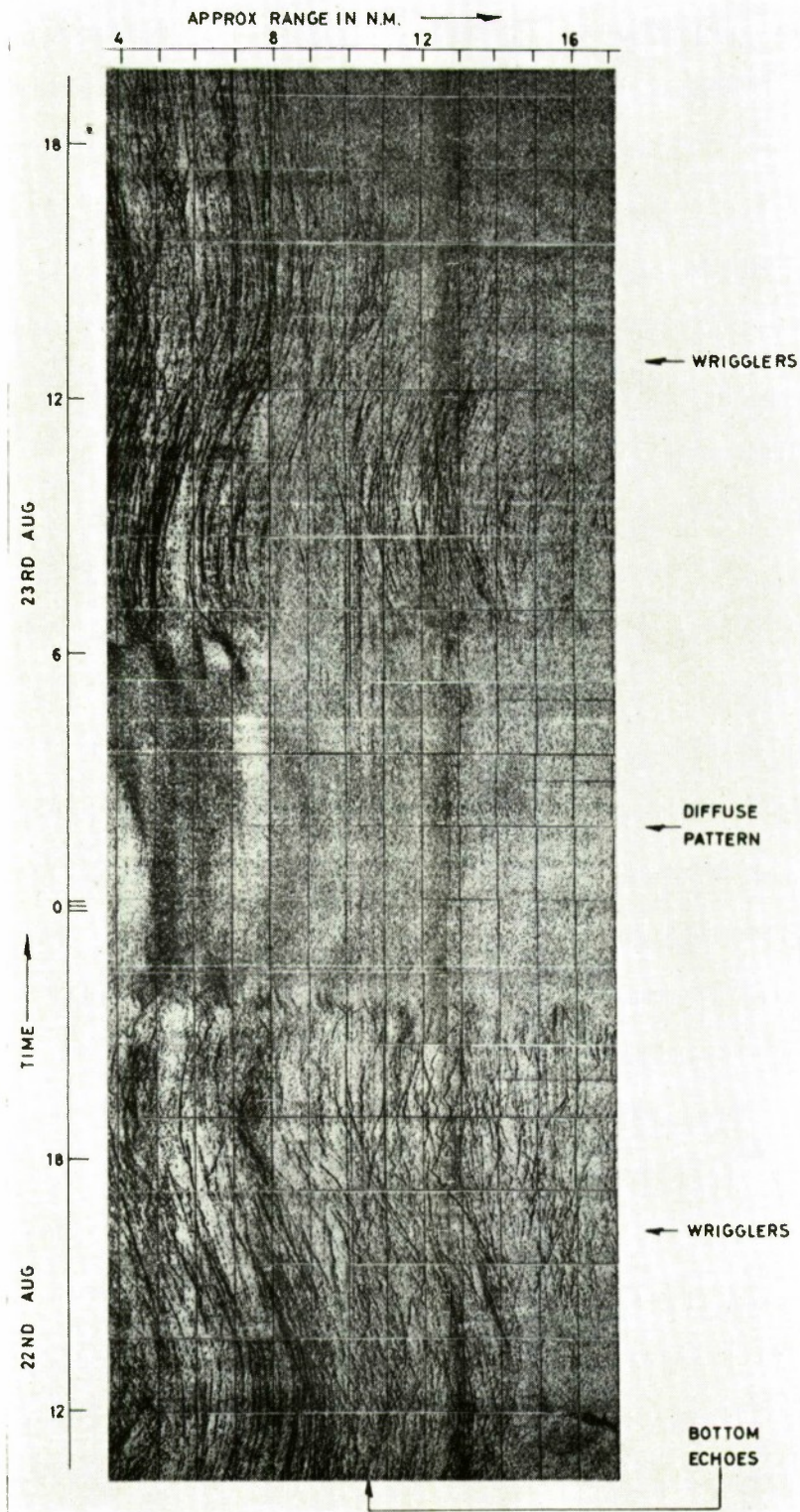


FIG. 2. Display for 22nd/23rd August 1962 (Replay Montage).

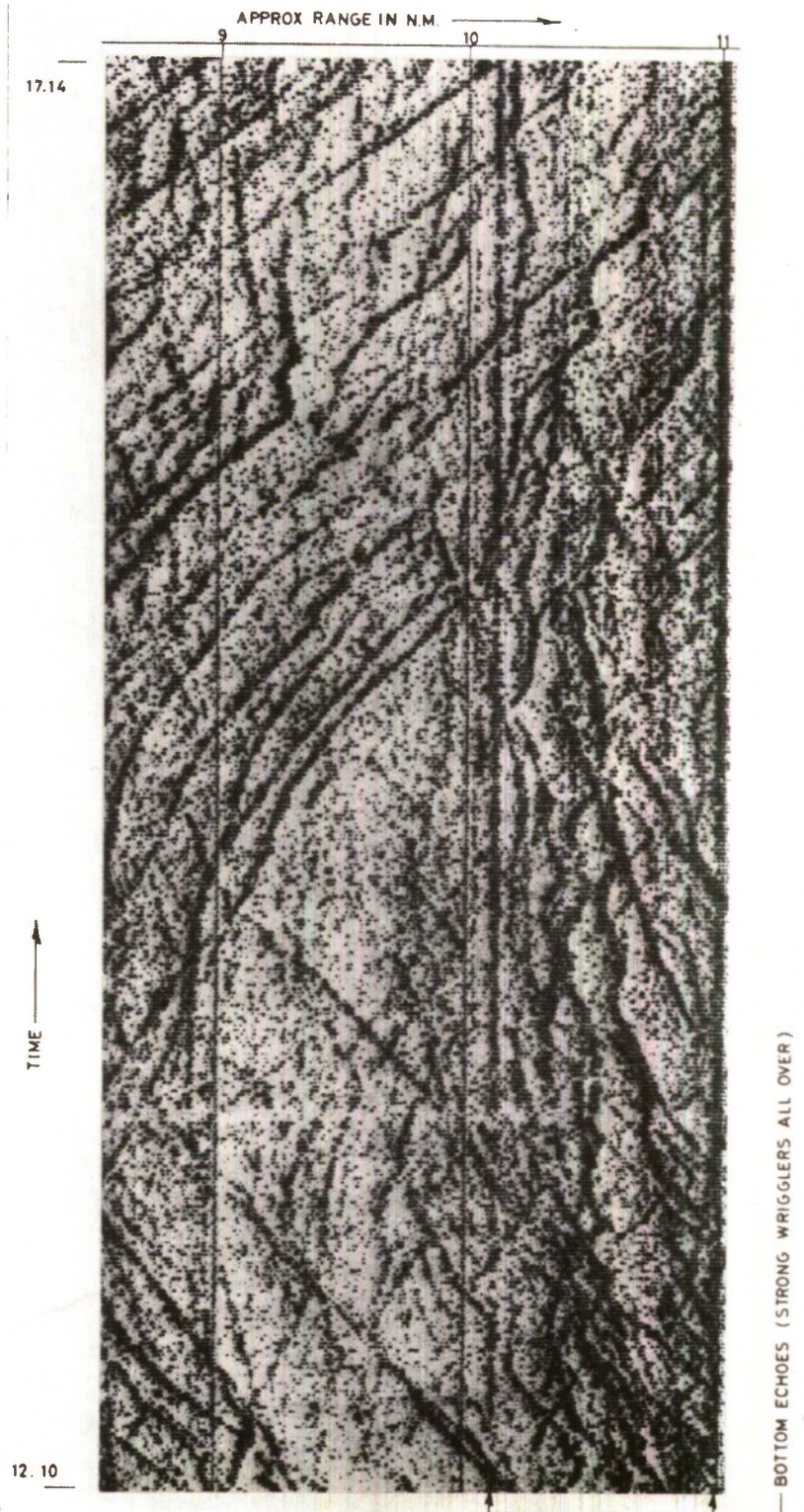
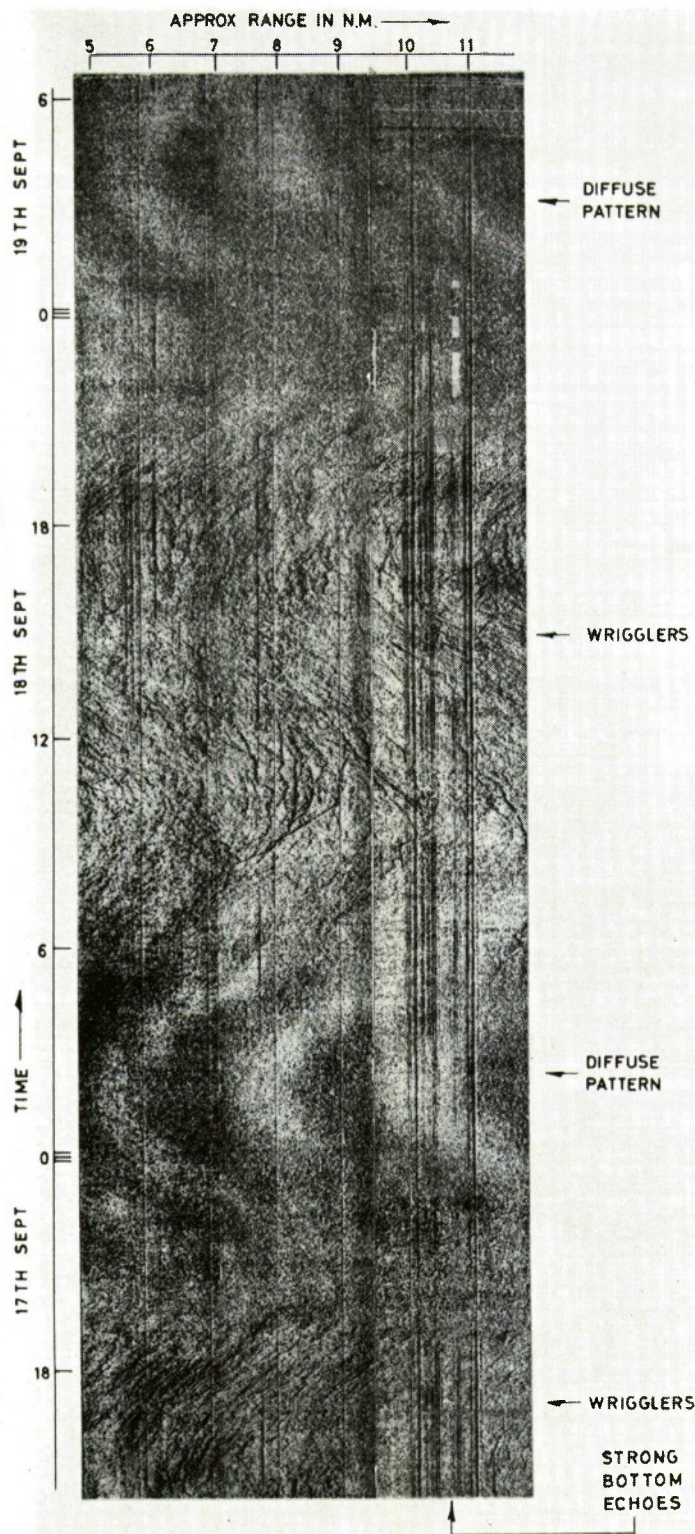


FIG. 3. Display for
30th August 1962.

(c) *Tidal variation*

(i) Timing of tidal stream patterns.

The patterns of tracks show a slow and large-scale variation in range which may be positively correlated with the tidal period. In some patterns the variation is smooth and nearly sinusoidal. In others there is much movement of shorter period on top of the tidal movement, so much so that tidal effects may not always be apparent. Occasionally some records seem to suggest that there are two or more intersecting patterns of different amplitude, which could be due to scatterers at different depths in the sea where the tidal flow is different.

There is some evidence (Fig. 2) for the range maxima in the sinusoidal patterns (*i.e.* the tidal flow changes) occurring later as the range is increased—there is the order of a half hour difference between 10 and 30 km range. This is in accord with the tidal information. The time of zero range-rate at 20 km range occurs just over two hours later than the time of local high or low water, in fair agreement with the latest direct measurements on the tidal streams.

FIG. 4. Display for 17th/19th September 1962 (Montage).

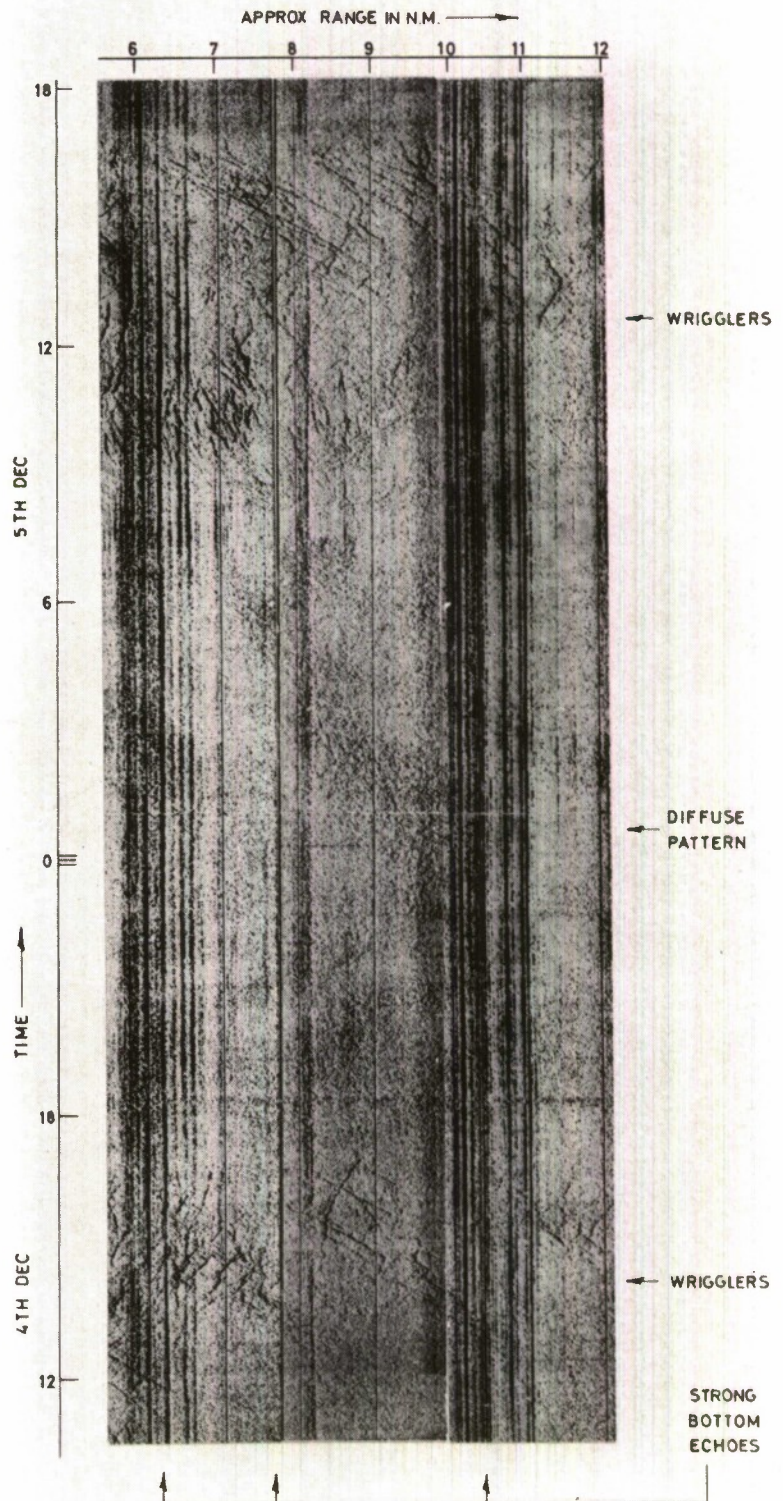


FIG. 5. Display for 4th/5th December 1962 (Montage).

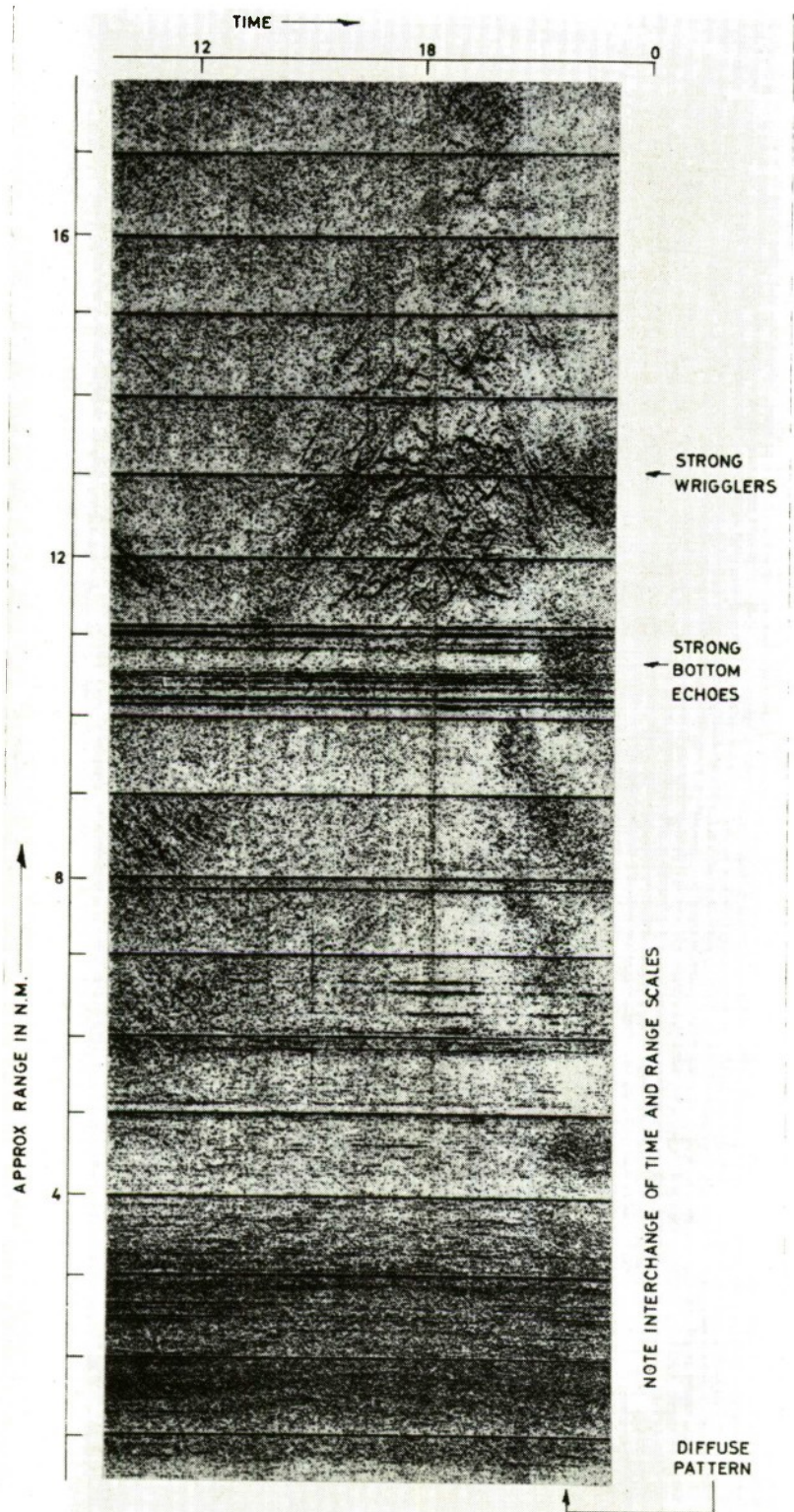


FIG. 6. Display for 6th April 1963 (New Recorder).

(ii) Amplitude of tidal stream patterns

Consider now the range amplitude of the sinusoidal pattern, and whether or not it varies with mean range. The two sample plots in Fig. 7 show that there is no very large effect, one sample remaining approximately constant and the other increasing with range. Note that a peak-to-peak amplitude of two miles corresponds to a maximum range-rate of 0.5 knots or 0.25 m/s. This is only the component of the flow measured along bearing 350° , and to obtain the total flow both values should be about doubled.

The flow should depend on whether it is a spring or neap tide, and the effect on range amplitude may indeed be seen in the results. However, when patterns are imperfect it is easier to measure maximum range rate, and Fig. 8 shows the expected linear dependence on tidal height. The measured components of flow go up to about 0.5 m/s at springs, so the total flow should go up to about 1 m/s, again in good agreement with published tidal information.

One experiment has been made to compare traces on different bearings, from which it was shown that maximum flow occurs along 43° - 223° . These are the directions expected, and confirm that the flow measured along 350° is about half (more accurately 0.6) the total.

The detailed agreements over the tidal flow tend to confirm that many of the scatterers are not very mobile, and are suitable markers for the water movement.

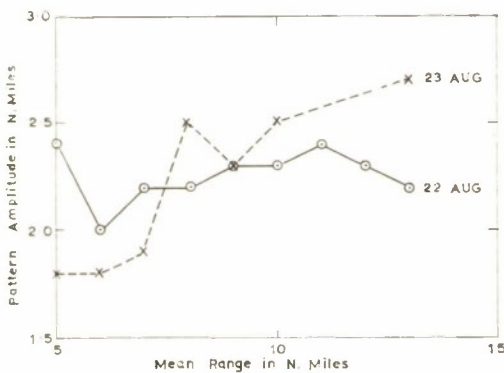


Fig. 7. Dependence of Tidal Flow Amplitude on Range.

(iii) Effect of tangential stream component

All the measurements above refer to movement resolved along the acoustic beam, but as discussed there is also a tangential component of tidal flow of rather greater magnitude. This causes the appearance and disappearance of particular scattering groups as they are swept into and out of the beam. For example at 20 km the beam is 1.4 km across, and whilst sweeping 1.4 km tangentially a scatterer should change range by 1.0 km. Fig. 3 shows that the effect exists, with a typical practical range interval very close to this figure. However, the range interval should be proportional to range, and although there is a trend this way the effect is masked by the reduction of echo strength with range.

(iv) Mode interference patterns

It may be noted that although the fish tracks disappear at night there is still a diffuse pattern of tidal period (Figs. 1 and 2). This is known to be a propagation effect due to the interference of the various propagation modes⁽²⁾, e.g. the first and second modes have an interaction spacing of about 4 km. The pattern is basically controlled by the tidal changes in the depth of water, whereas it is the tidal streams which affect the wrigglers. Thus changes in range or in bearing have been observed to affect the two types of pattern differently. Mode interactions also modulate the fixed bottom echoes (Fig. 6), and sometimes the wrigglers themselves.

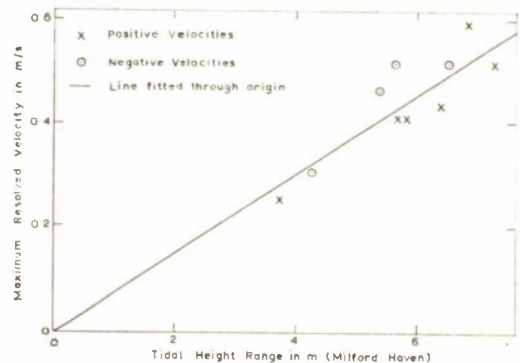


Fig. 8. Dependence of Tidal Velocity on Tidal Height.

(d) *Other characteristics of tracks*

As already noted in the section Fish Tracks (c) there is in addition to the sinusoidal tidal flow a smaller-scale shorter-period motion. It is difficult to generalise about it because its magnitude is so variable. For example it was very small on 22nd and 23rd August (Figs. 1 and 2), with velocities about 0.1 m/s and displacements about 0.2 km. However, even in this case there is a suspicion that only a fraction of the scatterers are taking part in it. Its causes are presumably a combination of turbulent water motion and the motion of the scatterers through the water, though its variability shows that the latter is the chief cause.

At the other extreme there are tracks showing no obvious tidal influence, and speeds along the beam of the order of 1 m/s. On at least three occasions (7th December 1960, 28th April 1961 and 30th August 1962 — Fig. 3) the behaviour was so extreme that porpoise or whales were thought to be the cause. In April 1961 this was confirmed by the sighting of porpoise, and by hearing their characteristic sounds on the hydrophone. It should be pointed out that these three sets of detections have resulted from a coverage of a very small area for only a small fraction of the total time.

(e) *Daily variation*

A major feature of the fish tracks is their disappearance at night, and replacement by a diffuse return of comparable mean level. Fig. 9 shows the dependence on the time of daylight for sample records spread over a few months. For some records (see Fig. 1 or 2 for 22nd and 23rd August) the appearance or disappearance is abrupt and occupies a total of about 15 min., allowing a transition time to be assessed to within 5 min. For the later samples the transition may take an hour or so, and the uncertainty in the best value for the transition time may be about 30 min. Weighted mean values for August to October are that disappearance follows local sunset by 41 min., and appearance precedes sunrise by 25 min.

Very occasionally discrete wrigglers have been seen at night.

The normal night-time disappearance of the traces provides strong evidence that they are affected by the light intensity and are of biological origin. There are two hypotheses, both of which suppose the scatterers are fish or shoals of fish. In one theory the shoals disband at night, perhaps because the fish cannot see

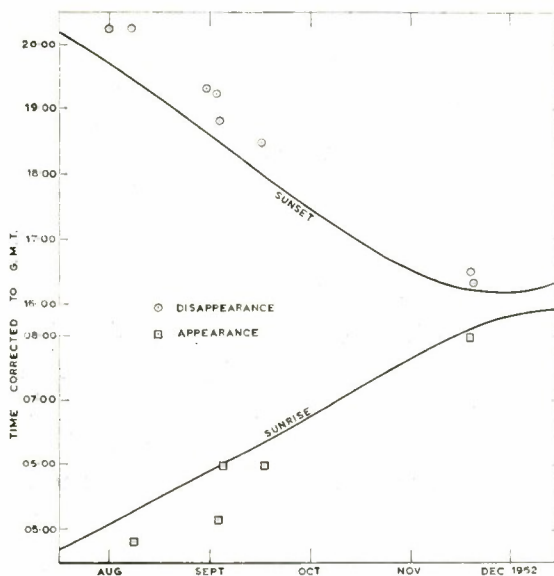


Fig. 9. Times of Appearance and Disappearance of Fish Traces.

their fellows well enough to keep in formation. In another theory they try to stay in a region of constant light intensity and therefore approach the surface at night, either because they are directly affected by light or because they are feeding on creatures (zooplankton) which are so affected. The diurnal vertical migration of the plankton scattering layer is well-known. Near the surface the sound intensity is reduced, and the echoes could become so weak as to be undetectable. It is also true that target strength depends on depth⁽¹⁾. There is no reason why both these mechanisms should not operate together, and this is supported by echo-sounder observations and by the related diurnal effects seen in one-way acoustic transmission⁽²⁾.

(f) *Fine structure*

Fine structure may best be studied on the cathode-ray oscillograms for separate sweeps. Because of its variability a separate study is really needed for each pattern type, but one example is shown in Fig. 10. Generally the echo shape is significantly prolonged compared to the ideal, and may show some structure. The horizontal extent of the scattering groups cannot be estimated reliably — but 3 range gates or 22 m is the apparent spread in a typical case, implying a real spread of the order of 15 m. The results with an ordinary vertical

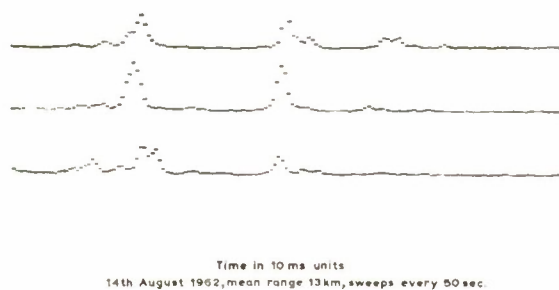


Fig. 10. Oscillograms of Correlator Output showing Fish Shoal Echoes.

echo-sounder, presuming they refer to the same types of group, suggest the figure should be 10 m or less. They also suggest the vertical extent is 2 m or less.

(g) Strength of echoes

The strength of the wriggler echoes in the summer may be enhanced because the fish shoals often lie below the layer, and both projector and receiver couple better into this region. But sound propagation is generally better in the winter⁽²⁾. The target strength of the scatterers obviously varies with the type of pattern being recorded, and also varies from group to group within any pattern. No systematic determinations have been made, but from various pointers the order of magnitude for the larger shoals is $+5$ dB re 1 m^2 .

(h) Nature of the wrigglers

It has been implied above that the wriggling patterns are due to fish. When the patterns were first seen many other possible causes were considered: *e.g.* entrained air bubbles, sea-weed broken free from inshore regions, focusing of sound—possibly by internal waves. Although some of these mechanisms might explain isolated parts of the patterns, to explain all the observations it seems essential to postulate marine animals, in particular fish shoals. The strongest arguments arise from their diurnal appearance, compare⁽²⁾, and the movement within the pattern.

Through the year many different pattern types have been observed on different occasions. Also on any given occasion the whole display often seems to consist of two or more different pattern types. It is suggested that each pattern type corresponds to a different type of fish, or

to fish at different stages of development. "Fish" may be divided into five groups, based partly on their way of life: bottom-living flat fish, pelagic but bottom-feeding round fish, pelagic fish, cetaceans and sharks. Wrigglers may be due to any of the last four groups: the drifting wrigglers perhaps mostly from the third group and the more purposeful kind from the fourth group. The wrigglers sometimes show an unusual behaviour near their times of appearance and disappearance (see Fig. 1), and this could be due to the presence at dawn and dusk of fish which are mainly active then—*e.g.*, many pelagic but bottom-feeding fish.

Another approach comes from the largeness of the target strength, which may be explained in three ways or combinations thereof. The shoals may contain vast numbers of fish, smaller numbers of fish having resonant air bladders, or small numbers of very large fish. It is in fact thought that some of the traces are due to large fish, or more precisely to porpoise. But most of the tracks are thought to be due to shoals of fish having resonant or near-resonant swim bladders. It may be shown that the gas-filled swim bladder resonates at a surprisingly low frequency, and at or near this frequency the target strength is very high. The high target strength helps to explain the strength of the night-time diffuse returns as well as the day-time discrete returns. A resonance precisely at the 1 kHz carrier frequency translates with certain assumptions⁽¹⁾ into a fish of length 17 cm. Taken together with the area this suggests the Cornish Pilchard may be responsible for many of the tracks. Later work with the Lowestoft Fisheries Laboratory, to be reported separately, has confirmed this and indicated a mean fish length of 23 cm.

Theoretical considerations⁽¹⁾ for a shoal of swim-bladder fish show that it is usually so densely packed with fish that over quite a wide frequency range nearly all the acoustic energy incident on the shoal will be scattered. The geometric cross-section will be approximately equal to the acoustic cross-section, and from the $+5$ dB target strength already quoted the latter is about 40 m^2 . Since the typical grazing angles of the sound rays are only a few degrees, the sound looks at the side of the shoal, and a shoal 13 metres across and 3 metres deep would have the right area. This size agrees reasonably with the independent estimates in the section Fish Traces (f).

Because of acoustic interaction effects it is very difficult from the acoustics to calculate anything about the number of fish within the shoal. But we can use instead the fact that the spacing of the fish is about the same as the fish length. For the 13 metre shoal, assumed circular, the volume is 400 m^3 corresponding to 3.3×10^4 fish at 23 cm spacing. At two shoals per km^2 this gives 6.6×10^4 fish/ km^2 ; in good agreement with a figure from the propagation experiments⁽²⁾ of 4.6×10^4 fish/ km^2 . It is interesting that these two distinct methods give comparable answers on population, and it is hoped to return to this subject later.

Fixed Bottom Echoes

The fixed bottom echoes always come from the same range, although given echoes are variable in level. Scattering from the bottom usually predominates out to about 7 km range, but beyond this the bottom returns are patchy. They are due to rocky outcroppings or bottom roughnesses or even perhaps wrecks, and there can also be a contribution from bottom-living fish swimming round the rocks. Some of the echoes are stronger than those from fish shoals, and this may be understood since rocky pinnacles up to about 20 metres high have been found in the area. If the pinnacle has a 100 metre length the subtended area will be $2 \times 10^3 \text{ m}^2$, and assuming complete and omnidirectional scattering (solid angle 4π) this corresponds to a target strength of +22 dB re 1 m^2 .

Much of the echo variability is due to mode interference and other propagation effects, including the diurnal variation due to fish effects in sound propagation. But the varying contribution of fish to the target strength will also affect the echo.

Propagation Effects

It may be asked on the one hand how the character of the sound propagation affects the present results, and on the other hand what may be learnt about propagation from this work. The effect of various types of propagation fluctuation on both wrigglers and fixed echoes has already been pointed out.

It is intended here to stress the significance of the change-over at about 7 km from predominantly bottom to predominantly volume

scattering. This arises because acoustic energy at the steeper angles is selectively attenuated with range, and by 7 km the effective grazing angles are limited to a few degrees, corresponding to just a few normal modes. Thus if one wishes to study shallow-water fish it is desirable to have a sonar powerful enough to reach well beyond 7 km, since in many ways things become easier at the longer ranges. As far as one-way propagation is concerned the observation adds weight to the argument^(1, 2) that at the longer ranges the volume scattering and absorption losses are more important than the boundary losses, and this point is vital to the understanding of all shallow-water acoustics.

Significance

It is apparent that the experimental echo-ranging equipment forms a valuable tool for the investigation of the population, distribution, movement and general behaviour of fish. It can be even more effective when used in conjunction with other more conventional methods of study. Another obvious thought is that it could help commercial fishing by extending the present use of echo-ranging. However, even in a simplified form, it is likely to be expensive. It is not known how the sound pulses may themselves affect the fish behaviour, but any effect is likely to be restricted to the very closest ranges.

Geological studies may be furthered by a long-range mapping of bottom features, similar to the shorter range cover given at present by side-scan sonars.

It is also possible to investigate water movements, and to estimate both speed and direction of the tidal flow. It would be difficult to achieve the same coverage in other ways. However, if one were starting from scratch it is likely that, due to expense, other simpler techniques would have to be employed.

Conclusions

- (a) The results presented show the great advantage in the research by having fixed bottom-laid echo-ranging equipment.
- (b) Wrigglers are more common in the summer months, with concentration typically 2 per km^2 .
- (c) Most wrigglers show a long-period motion, the timing and amplitude of which can be related to tidal flow.

- (d) Most wrigglers disappear at night.
- (e) Wrigglers have been seen out to a few tens of km, and their typical target strength is $+5$ dB re 1 m^2 .
- (f) Their night-time disappearance, their movement and other evidence show that the wriggling traces are due to fish shoals.
- (g) Many different types of fish trace have been seen. However, it is suggested that a typical one is due to a shoal about 13 metres across and 3 metres deep, containing about 3×10^4 pilchard, each 23 cm long and with a swim bladder near resonance.
- (h) The fixed echoes from bottom features predominate out to about 7 km, and may be seen in patches out to greater ranges.

Acknowledgements

It is a pleasure to acknowledge the benefit of early discussions with M. J. Tucker and R. Stubbs of the National Institute of Oceanography and P. Corbin of the Marine Biological Association at Plymouth. Many colleagues at the Admiralty Research Laboratory have contributed in the provision of equipment, records or ideas; notably E. J. W. Long, W. R. Stamp, J. G. Sheldon and G. Wearden.

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Appointments to Dockyard Policy Board

Mr. Peter Kirk, Parliamentary Under-Secretary of State for Defence for the Royal Navy, in reply to a question from Mr. Frank Judd, M.P., announced in the House of Commons that Sir Henry Benson, G.B.E., F.C.A., of Coopers Brothers and Company, chartered accountants and Mr. Richard O'Brien of Delta Metal Company Limited, have agreed to serve on a new Royal Dockyard Policy Board.

The Board will be chaired by Mr. Kirk; senior naval and civilian officers serving in the Ministry of Defence will be members. It will consider and advise on management policies for achieving the best use of the financial, material and human resources available to the Royal Dockyards for the performance of their task.

This Board is part of the new structure for the management of the Royal Dockyards. Two other boards were set up last year under the chairmanship of Mr. Leslie Norfolk, the Chief Executive Dockyards—Royal Dockyards Management Board and the Royal Dockyards Headquarters Board.

The Management Board considers major policy issues and provides a forum for discussion on matters of mutual concern and interest to C.E.D., H.Q. directors and the general managers of the dockyards. The Headquarters Board monitors performance of individual general managers and encourages greater involvement of everyone concerned with the dockyard task.

A substantial capital investment programme for the modernisation of the Navy's home ports, spreading over the next decade at a total cost of £80 million has previously been announced. One of the tasks of this new top management structure will be to oversee the implementation of those sectors of the programme which relate to the Royal Dockyards.

AN EMULSIFYING HYDRAULIC FLUID FOR SUBMARINE SYSTEMS

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Abstract

Hydraulic systems of submarines are inherently vulnerable to sea water contamination, which can cause damage by corroding critical components, and system materials, and, as a secondary effect, causing a significant increase in particulate contamination. Free water in contact with sliding surfaces forms a poor lubricant and seizure quickly follows thus further contaminating the system with metal particles. Conventional hydraulic fluids do little to prevent damage by these mechanisms since they readily separate from water leaving pools and 'slugs' of water in the system.

The article describes the problems experienced by the Royal Navy when using a conventional hydraulic fluid and the history of the introduction into service of an emulsifying fluid similar to that described by King and Glassman of the United States Navy. The emulsifying fluid has been used both for cleaning up contaminated systems and as the system hydraulic fluid in British submarines. Laboratory investigations into the characteristics of the emulsifying fluid and of solutions and emulsions containing varying percentages of sea water are presented, together with analysis data on oils returned from service.

It is concluded that the emulsifying oil is a satisfactory hydraulic fluid for applications where sea water contamination is a hazard.

Introduction

During the 1960's the R.N. has operated nuclear submarines of the Hunter Killer or Fleet type such as *Dreadnought* and *Valiant* and the Polaris type known as the *Resolution* class together with so called conventional submarines having diesel/electric propulsion.

The nuclear submarine is a highly sophisticated ship capable of travelling at high under-water speeds and at great depths and the hydraulic systems are complex and highly specialised. Some of the equipment such as the pumps, auto pilot and ram servo units are of

high precision and must be protected against contamination of the hydraulic fluid by dirt particles or water. It is usually the case that, if water finds its way into the system, the quantity of dirt present (or particles count) rises rapidly due to the direct entry of particles in the water and the secondary, and often more serious, effect of corrosion products caused by chemical interaction between the water and system materials. Most serious of all is the fact that equipment designed to operate on mineral oil will quickly fail due to the relatively poor lubricating properties of water.

Two conditions must be fulfilled before water can enter a submarine hydraulic system.

- (i) There must be a penetration of the pressure hull *i.e.* sea water must actually have access to the system.
- (ii) Sea water pressure must exceed fluid pressure for a long enough period to allow significant quantities of water to pass into the system.

Submarines use accumulator hydraulic systems in which fixed output pumps charge accumulators to 170 to 200 bar. Fluid passes to the various components such as rams and motors which, as they move, displace or divert fluid into the so called return lines which in turn take the low pressure fluid back to the tank. It follows that water will probably enter the system through a return line or perhaps through a drain from a component such as a hydraulic motor when the submarine is submerged.

The situation facing the R.N. is that, with many hull penetrations and high sea pressures during deep dives, hydraulic system integrity is becoming increasingly difficult to maintain. Several cases of gross contamination (more than 5% of sea water) have been recorded in the 10 or so years that the R.N. has been operating nuclear submarines and in 1967 a whole series of incidents of this kind called for urgent consideration of ways to combat the problem.

Situation Leading to the Use of the Emulsifying Fluid

In the past it had been standard practice to remove sea water from contaminated oil systems by means of a centrifuge; the residual salt being flushed out by distilled water. This operation, although successful in itself, had to be followed by partial stripping down of the system which was a time consuming operation. In hydraulic systems the pumps were generally found to be damaged and it was never clear whether this was a direct result of the entry of sea water or whether it was due to the cleaning up operation that followed.

Because of strict limitation on out of service time, stripping of the hydraulic system was considered to be very undesirable and the most effective way of eliminating the water was found to be by draining as far as possible the whole oil charge, which carried some of the water with it and flushing and recharging with new oil. This was time consuming, inefficient and

wasteful of oil and it became clear that, to flush efficiently, a kind of water seeking or water displacing fluid would be necessary.

It was known that the U.S.N. was using⁽¹⁾ as an experiment, a mineral oil hydraulic fluid which, apart from containing relatively large quantities of corrosion inhibitor, had the valuable property of emulsifying with water. It was therefore decided that supplies of this hydraulic oil should be used for flushing purposes after which it would be discarded in the wet state and the system refilled with new conventional hydraulic oil.

Late in 1967 one of the nuclear submarines suffered severe contamination of a hydraulic system, some 70 gallons of sea water gaining admittance to a 500 to 600 gallon system. Repeated flushing with the normal hydraulic fluid was believed to have removed about 90% of the water but did not appear to be getting the system dry. It was suspected that pockets of water were lying in "dead ends" and the quieter parts of the system and were not being disturbed by the flow of the flushing oil. Stripping the system to remove these pockets of sea water was not practicable in this case since the system was not confined to a single ship compartment and components were not readily accessible because of space limitations. Leaving the water *in situ* was considered unacceptable because of the danger of corrosion of components with possible delayed effects on system reliability.

Flushing With Emulsifying Fluid

After due consideration it was decided to flush with the emulsifying hydraulic fluid whilst appreciating that a magical improvement in the position could not be expected. The difficulties in drying out this system were compounded by (i) the need to use the system's own hydraulic pumps (ii) the piping runs, which are not arranged to ensure drainage to a low point to assist water removal (iii) the arrangement of the system which is not a closed loop from which all the oil could be circulated through clean-up devices and (iv) the fact that draining down removes only about 60% of an oil charge.

Three hundred gallons of the emulsifying fluid, rushed up to the Base by the supplier were filtered through strainers and fine filters into the circuit and pumped round for 24 hours: the water content rose to 0.15%. Pumping was continued for another day with operation of as much as possible of the equipment in order to

reduce to a minimum the number of pockets of sea water. The water content of oil from the ring main was 0.2% and the return bay of the replenishment tank contained a loose emulsion of about 8% water which was not being carried over into the ring main. The emulsifying oil was discharged and the system flushed a further four times with the normal hydraulic fluid to ensure that the operating charge was substantially the dry conventional hydraulic fluid. The water content was eventually reduced to 0.03 to 0.04% and the content of the emulsifying fluid to about 3%. These levels were considered acceptable. Sea water contains a considerable quantity of dissolved salts, the major constituents being approximately:—

Chloride ions	...	...	1.9%
Sodium	..	...	1.0%
Sulphate	..	...	0.25%
Magnesium	..	...	0.12%

The fate of these salts was of interest as well as that of the water and so during these extended flushing operations water, sodium and chloride contents were determined on samples of the fluid periodically removed from the system. The high concentrations of sodium and chlorine in the dry emulsifying fluid complicated the exercise but it was shown that salt was removed with the water and was not left behind in the oil.

This operation appeared to be successful in that several gallons of water were shaken out from the system. By the autumn of 1969 it had become standard practice to flush submarine hydraulic systems with the emulsifying fluid.

The Emulsifying Oil as a Hydraulic Fluid

Flushing with the emulsifying oil was seen to represent a step in the right direction but could only remove water from a system which had probably already been damaged. A major benefit would however accrue if the emulsifying oil could be used for the purpose for which it was originally intended *i.e.* as a hydraulic fluid capable of reducing the damaging effects of water as it entered the system. The fluid was already being used experimentally as a hydraulic fluid in the U.S. Navy, but even if these trials were concluded satisfactorily, there would be no guarantee that the oil would prove suitable for the slightly different R.N. systems. A separate R.N. trial was therefore thought desirable.

Many submarines have "Main and Vital" and "External" hydraulic systems with all equipment at risk from contamination by sea water on the External system. Others do not do so, the functions of both being served by a common system. The introduction of an experimental fluid into one of the latter submarines needed very careful consideration since the risk of widespread and damaging sea water contamination had to be weighed against the possibility that the oil might thicken or even gel under certain conditions thus putting the planes and rudders out of action. The first trial of the emulsifying fluid was therefore confined to the External system of a Fleet submarine.

The "experiment" was successful in that there were no problems with the hydraulic system attributable to the fluid during the 12 months of the trial. However no significant amount of water entered the system during this time so no information was obtained on the emulsifying characteristics of the oil or the behaviour of emulsions as hydraulic fluids. The water content of the oil did increase progressively but only to the 0.4% level, where the emulsifying oil still has a "clear and bright" appearance and physical characteristics virtually identical with those of the dry oil. The trial could therefore be considered to have confirmed the suitability of the dry oil as a hydraulic fluid but not the required water "neutralising" properties.

Meanwhile the operational problem had become more acute in that some of the submarines without separate External systems had become contaminated and the situation was aggravated by a particular design incorporating "dead legs" which could only be cleared by docking or by redesign. Certain spool valves had become corroded and had subsequently jammed, thus putting some of the weapon systems out of action. In these and other submarines, slugs of water had formed in the conventional mineral fluid and had passed through the hydraulic pumps causing extensive damage amounting in some cases to complete failure. In all cases where a pump had become contaminated there was rusting of steel parts and incipient failure of roller bearings.

It was agreed within the Navy Department that sea water leakages were most probably responsible for the troubles being experienced in service. A further short trial was run in a submarine without an External hydraulic system. This trial was very short and although some trouble had been experienced with stick-

ing valves, thought to be due to dirt remaining in the system from the previous oil charge, the results were sufficiently promising to warrant extending the use of the fluid. The other nuclear submarines were therefore changed over from the conventional fluid to the emulsifying hydraulic oil during the next few months. Possibly other changes introduced at the same time including perhaps some alteration to operating procedures reduced the incidence of sea water ingress. Despite the fact that the maximum water content detected since the change is only 1% it is gratifying that reliability has improved and in particular that there have been no pump failures since the introduction of the emulsifying fluid.

Samples of hydraulic fluid from submarines have been obtained for laboratory analysis because of the extremely limited previous experience on this oil. The results of this evaluation are discussed below.

Laboratory Investigations

General

King and Glassman⁽¹⁾ and Evans and Schneider⁽²⁾ have described the early work done for the U.S. Navy in developing the emulsifying hydraulic fluid. Samples of this fluid were obtained from the U.S.A. in 1966-67 and examined in the laboratory to get a feel for the product. Subsequently a somewhat thinner blend, adjusted to match the viscosity characteristics of the British Service Hydraulic Fluid OM 33, was obtained from the U.K. suppliers. Inspection data on this blend are given in Table 1.

Perhaps the first impression gained from the examination is of the similarity of the dry emulsifying fluid to the conventional product since both are based on mineral oils. Flash points, pour and cloud points, copper corrosion and foaming characteristics are all in close agreement with those for conventional hydraulic fluids.

The acidities and sulphated ashes are somewhat higher as might be expected from the increased additive content and chemical analysis reveals the presence of calcium, zinc, sodium and phosphorus as constituents of the various additives. The emulsifying characteristics prevent the fluid from separating from water, modifying the behaviour in demulsification, emulsification and corrosion tests. The emulsions produced are stable and better able

to prevent corrosion than are conventional hydraulic fluids.

Investigations of the emulsions showed that the emulsifying fluid formed reasonably stable emulsions when vigorously stirred or shaken with distilled or sea water. A definite energy input was required, emulsions would not form spontaneously or with only gentle agitation, and the stability of emulsions containing 40% or more of water was markedly less than that of those containing lower concentrations of water. Emulsions of either distilled or sea water had the water dispersed as droplets of around two microns in diameter.

Checks on emulsion viscosities with both kinematic viscometers and Ferranti constant rate of shear viscometers, the emulsions are of course non-Newtonian fluids, showed that emulsion formation was accompanied by increase in viscosity but not alarmingly for low water contents. An emulsion containing 30% of water had a viscosity about twice and a 50% emulsion three to four times that of the dry oil. Emulsions containing less than 20% of water have viscosities not more than 50% higher than that of the dry oil and thus those formed in service should not be so viscous that flow rates would be markedly affected and hydraulic systems should be able to continue to function on the emulsions although response rates might be slightly slower.

Concern was expressed, as has been mentioned above, about the possibility of semi-solid "mayonnaise type" emulsions being formed with the danger of blocking oil ways and preventing fluid flow. No such sludges could be generated in the laboratory so, although it cannot be stated categorically that in the presence of large amounts of rust or other solid contaminants this could never occur in service, it was felt to be a very unlikely occurrence.

The oxidation stability was evaluated using a modified form of the "Oxidation Characteristics of Inhibited Steam Turbine Oils" (TOST) test method⁽³⁾ at 65°C (150°F). The emulsifying fluid withstands about 750 hours oxygen blowing under these test conditions before the acidity reaches the commonly used limit of 2.0 mg KOH/g. This is a considerably poorer oxidation stability than is possessed by the Navy's conventional hydraulic fluid but it was felt to be adequate because of the relatively low operating temperatures involved. The TOST method is of course very time consuming and not really a practicable tool for studying either

TABLE 1. Typical Inspection Data on Emulsifying Hydraulic Fluid.

Characteristic	Emulsifying Fluid	Test Method
Appearance	Clear, light brown	
Colour	3.5	ASTM D 1500 — IP 196
Specific Gravity 60/60	0.892	ASTM D 1298 — IP 160
Flash Point °F	350	ASTM D 93 — IP 34
Viscosity—kinematic at 100°F (37.7°C) cSt	29	ASTM D 445 — IP 71
„ „ 210°F (90°C) cSt	4.7	„ „ „ — „ „
„ „ 0°F (−16.7°C) cSt	700	„ „ „ — „ „
Viscosity Index	+ 80	ASTM D 2270 — IP 226
Pour Point, °F	− 30	ASTM D 97 — IP 15
Cloud Point, °F	− 40	ASTM D 2500 — IP 219
Total Acidity mg/KOH/g	1.3	IP 1
Sulphated Ash % wt	0.75	ASTM D 874 — IP 163
Copper corrosion at 100°C	1A	ASTM D 130 — IP 154
Corrosion, salt water	Satisfactory	ASTM D 665 — IP 135
Corrosion, Static Water Drop	Satisfactory	Federal Test Standard No. 791A Method 5311
Demulsification No.	1200 +	IP 19
Emulsification test, salt water, separation after 30 minutes, ml.		DEF 2000 Method II
Oil	0	
Emulsion	80	
Water	0	
Foaming test, ml foam after 10 mins. of foam collapse		IP 146
Sequence 1	0	
„ 2	0	
„ 3	0	
Oxidation Stability		
TOST at 65.5°C (150°F) time hr. required to reach an acidity of 2.0 mg/KOH/g of oil,	750	ASTM D 943 — IP 157
Rotary Bomb, life in minutes	20	IP 229

quality of individual batches of oil or deterioration in service. The much quicker "Oxidation Stability of Steam Turbine Oils by Rotating Bomb" (I.P.229/68T)⁽³⁾ has been used instead for this purpose although it is realised that the test conditions, temperature 150°C and oxygen pressure 6.2 bar (90 psi), do not simulate practical conditions nor do test results necessarily

correlate with those of the less accelerated TOST method. The argument for use of this method is that it is quick and convenient to carry out, and that only comparative differences between oils are being looked for.

Lubrication studies have primarily been with the equipment for testing other petroleum products. Pump tests such as those reported by

Evans and Schneider⁽²⁾ on similar fluids and rolling-ball tests used by Scott⁽⁶⁾ and Schatzberg^(4,5) to investigate the effect of water in oils on fatigue failures have not yet been employed. Preliminary 4-ball tests under fairly high load conditions showed that the wear scars produced when using the emulsifying fluid or its emulsions were smaller than were obtained with conventional hydraulic fluids. Work at the University of Birmingham⁽⁷⁾ with another 4-ball machine has also shown that the emulsifying fluid gives a lower frictional force and prevents catastrophic wear up to higher loads than a plain oil of the same viscosity. Further confidence was generated by the high scuffing load 80 lb. in the I.A.E. machine operated at 4000 rpm with EN 34 gears.

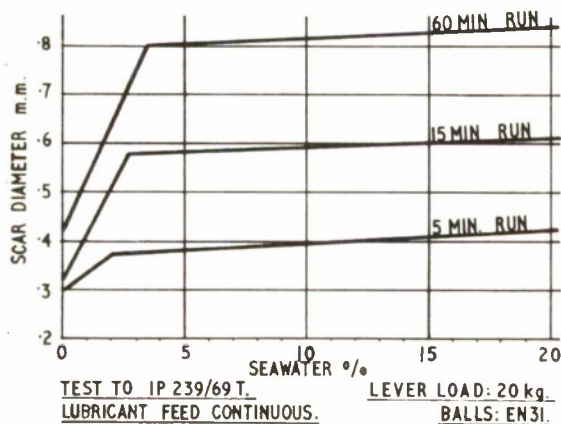


FIG. 1. 4-Ball Wear Tests.

Results of 4-ball tests on the emulsifying fluid and emulsions with varying quantities of sea water are shown in Fig. 1. So as to avoid changes in the composition of the lubricant during the test, due to evaporation of the water, fluid was fed continuously into the base of the test cup and the liquid level was maintained by drawing the liquid off at the top of the cup.

In the figure, scar diameters which give a measure of wear, are plotted against water content for runs of 5, 15 and 60 minutes duration at 20 Kg load. The wet oil permitted more wear, *i.e.* larger scars, than the dry oil but the differences are not large. The curve shows a sharp discontinuity at a water content of about 2% corresponding to the transition from clear oil to milky emulsion; above this inflexion there is

little change in the amount of wear as the water content increases. In general, wear of the emulsifying fluid and its sea water emulsions is of the same order or less than with the conventional fluid it replaces, which under the same test conditions gave scar diameters of .48, .68 and .76 mm respectively for the 5, 15 and 60 minute runs.

The solubility of water in the emulsifying fluid

Mineral oils dissolve only very small quantities of water, most will dissolve between 100 and 200 parts per million of water at normal temperatures, the amount increasing with increase in temperature. Larger amounts may be dispersed as separate drops which impart a cloudy appearance to the oil.

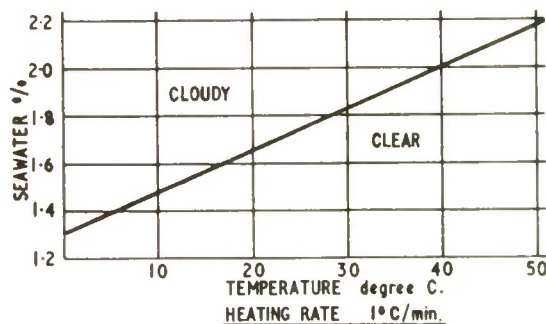


FIG. 2. Solubility/Temperature Relationships.

The emulsifying fluid will apparently dissolve more than 1.5% *i.e.* 15,000 parts per million of water and still have a clear and bright appearance. Fig. 2 shows the effect of temperature on the maximum amount that can be dissolved. All this water cannot be molecularly dispersed through the oil, and the majority must be solubilized by the surface active additives present. Solubilization^(8, 9, 10) is the process by which a disperse phase is dissolved in the interior of a micelle of surface active material formed in the dispersion medium. Here the water is dispersed in a finely divided state throughout the oil whilst being surrounded by polar additive molecules. In this colloidal state the individual particles are so small that they do not scatter light so a clear liquid results.

TABLE 2A. Inspection Data on Emulsifying Fluid from Submarine Systems.

Characteristic	Submarine A		Submarine B		Submarine C		Submarine D	
	AFT SYSTEM Nv.69 Fb.70 My.70 C&B C&B C&B	F'WD SYSTEM Nv.69 Fb.70 My.70 C&B C&B C&B	AFT SYSTEM Apr.70 May70 C&B C&B	F'WD SYSTEM Apr.70 May70 C&B C&B	AFT SYSTEM Mar.70 May70 C&B C&B	F'WD SYSTEM Mar.70 May70 C&B C&B	AFT SYSTEM Mar.70 July 70 C&B C&B	F'WD SYSTEM Mar.70 July 70 C&B C&B
Source & Date of Sample								
Appearance								
Colour ASTM D.1500	— 4.5 —	— 4.5/5.0 —	4.5 4.5/5.0 4.5	4.5 4.5/5.0 4.5	4.5 4.5	4.5/5.0 4.5	4.5 4.5/5.0 4.5/5.0	4.5/5.0 4.5/5.0
Specific Gravity 60/60	— 0.892 0.892	— 0.892 0.892	0.892 0.892	0.892 0.892	0.892 0.892	0.892 0.892	0.892 0.892	0.892 0.892
Viscosity at 100 °F cSt	— 30.0 —	— 29.9 —	30.0 30.0	30.2 30.0	29.8 29.3	29.9 29.2	29.4 28.9	29.6 28.8
Total acidity at mg KOH/g	— 1.3 1.4	— 1.3 1.4	1.2 1.2	1.3 1.3	1.3 1.6	1.2 1.6	1.2 1.5	1.2 1.5
Sulphated ash at % wt	— 0.65 —	— 0.65 —	0.65 —	0.65 —	— 0.7	0.55 0.7	0.7 0.7	— 0.7
Water content at %	0.2 0.15 0.15	0.25 0.15 0.2	0.05 0.07	0.05 0.1	0.05 0.1	0.05 0.05	0.15 0.05	0.3 0.1
Oxidation Life Rotary Bomb (min)	— 20 —	— 20 —	25 —	— —	— 20	15 25	20 —	20 —
Metals Content ppm								
Magnesium	2 1 1	4 2 3	1 1	2 1	1.0 1.0	2.0 1	1.0 2	4 2
Copper	20 20	25 20 20	20 30	35* 15	20 15	20 20	20 10	15 10
Nickel	2 1 1	3 1 1	ND ND	ND ND	0.5 ND	1.0 ND	1.0 ND	0.5 ND
Iron	2 1 1	2 1 1	ND 1	0.5 0.5	0.5 ND	0.5 ND	0.5 0.5	0.5 0.5

ND — Not detected

ppm — parts per million

C & B — Clear and Bright

* Second sample contained 6 ppm of Copper

TABLE 2B. Inspection Data on Emulsifying Fluid from Submarine Systems.

Characteristic	Submarine E	Submarine F		Submarine G
		Internal System April 70	External System April 70	
Source & Date of sample	External System March 70			External System June 70
Appearance	C & B	C & B	C & B	C & B
Colour ASTM D.1500	4.5/5.0	3.5	4.0/4.5	3.5
Specific Gravity 60/60	0.892	0.892	0.892	0.886
Viscosity at 100°F cSt	30.0	28.8	32.1	63.0
Total acidity, mg KOH/g	1.2	1.2	1.2	1.3
Sulphated ash, % wt	0.65	0.7	0.65	0.7
Water content, %	0.3	0.1	1.1	0.05
Oxidation Life (Rotary Bomb) min	15	-	-	-
Metals Content ppm				
Magnesium	5	0.5	11	1
Copper	25	25	15	5
Nickel	0.5	ND	ND	1
Iron	0.5	ND	ND	1

C & B — Clear and Bright

ppm — parts per million

ND — Not detected

Plots of physical characteristics such as refractive index, optical density and viscosity of the solutions and emulsions of water in the emulsifying fluid against water content are similar to the 4-ball wear test plot of Fig. 1 in showing a marked discontinuity at about 2% water content. The inflexions in the curves correspond to the limit of solubilization and the change in appearance from clear bright oil to a cloudy emulsion. The solubilization point for di-ionised water (ca 2.5%) is considerably higher than that for sea water (ca 2.0%)⁽¹¹⁾ presumably because the salts in the sea water causes a "salting out" effect.

Used Oil Analysis

In view of the extremely limited experience with the emulsifying fluid it was considered advisable to monitor the condition of the oil in different hydraulic systems. Tables 2A and B list inspection data obtained on samples received from service. They show little change from new oil values.

Water contents were low, 0.3% or less, except from the sample from submarine F's External system which contained 1.1%. Even this sample was clear and bright in appearance, and visually indistinguishable from the new oil. It was con-

TABLE 3. Proposed Specification Test Requirements.

<i>Characteristic</i>	<i>Test Limits</i>	<i>Test Method</i>
Specific Gravity 60°/60°F	Report	ASTM D 1298 — IP 160
Viscosity (kinematic) at 100°F (37·7°C) cSt	28 - 32	ASTM D 445 — IP 71
" " " 210°F (99°C) cSt min.	4·5	" " " — " "
Flash Point, °F (PMC) min.	330	ASTM D 93 — IP 34
Copper Corrosion at 100°C	1	ASTM D 130 — IP 154
Pour Point °F max.	+ 10	ASTM D 97 — IP 15
Total Acidity, mg KOH/g	Report	IP 1 Method A
Water Content, %	0·05	IP 74
Oxidation Stability (after 750 hr. oxygen blowing at 65°C (150°F))		
Total Acidity mg/KOH/g, max.	2·0	ASTM D 943 — IP 157
Sludge mg max.	100	
Corrosion Test	No corrosion	A dynamic corrosion test more severe than ASTM D 665 — IP 135 (Yet to be developed)
Rust Inhibiting Properties of Non-Aqueous Liquid (Static Water Drop Test)	No corrosion	Federal Test Standard No. 791 A Method 5311
Foaming, max. limit ml after 10 mins/foam collapse		
Sequence 1	300	
Sequence 2	25	
Sequence 3	300	
Emulsification test (synthetic sea water) ml emulsion after 30 minutes, min.	78	DEF 2000 Method II
4-Ball Wear Test on 10% sea water emulsion 5 min. run at 20 Kg load with continuous lubricant feed		IP 239
Scar diameter mm. max.	0·5	

firmed that this was sea water by determining magnesium contents and the very low figures obtained were in good agreement with the values expected from the water contents. Magnesium was more convenient for this purpose than sodium, in spite of the much higher concentration of sodium in sea water, because the fairly high sodium content of the emulsifying fluid makes detection of small changes difficult.

Other points of interest are the extent to which the previous oil charges had been removed and any evidence of deterioration in use. The close agreement of specific gravities, total acidities and sulphated ashes with the new

oil values showed that the oil changes had been reasonably satisfactory and that little deterioration had occurred. Further evidence on this last point was provided by the Rotary bomb oxidation test figures and the trace concentration, in the parts per million range, of the system metals copper, nickel and iron. All oxidation lives determined were as for new oil and the metal pick-up showed no tendency to increase. It is of interest that the emulsifying fluid picks up copper, presumably from pipe lines, almost immediately it is put into a system but the value appears to stabilise about 20 to 30 parts per million.

Future Laboratory Work

The evidence available to date, both from service and the laboratory indicates that the emulsifying oil is a promising hydraulic fluid particularly for use in systems liable to water contamination. The fluid's ability to solubilize and emulsify water is advantageous because it reduces the risk of corrosion and inadequate lubrication.

Additional work is necessary to elarify the chemistry of the solubilization proecess, the corrosion prevention properties and the effects on fatigue lives of machine components. Work in these areas is being put in hand.

The particular fluid in use is a proprietary product but if there is a continuing need in the Navy for an emulsifying oil it will be necessary, within a few years, to specify the desired properties and purchase by competitive tendering. Perhaps not enough is yet known about the desired characteristics for a specification to be prepared now but Table 3 lists the test requirements that might be proposed today. Some new test methods will be required and some work will be done on this development particularly to cover the corrosion prevention characteristics.

Summary and Conclusions

(a) An emulsifying hydraulic fluid has been found beneficial in submarine hydraulic systems

- (i) as a flushing agent to assist in removing sea water contamination and
- (ii) as the system hydraulic fluid.

(b) There has been a significant improvement in the reliability of submarine hydraulic systems since the introduction of the emulsifying oil into service use.

Acknowledgements

The assistance of many colleagues is gratefully acknowledged, notably C. J. Spilman and D. J. Pailthorpe of the Admiralty Oil Laboratory.

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N.C.R.E. PRODUCTIVITY AGREEMENT

Flexibility is the key word in the Productivity Agreement signed at the Naval Construction and Research Establishment, St. Leonard's and South Arm, on Monday, 7th December, 1970. Under the terms of the agreement craftsmen's take-home pay went up by 53 shillings a week as from 14th December and the non-craftsmen's pay packet was heavier by 40 shillings. In addition, craftsmen who had been in full-time continuous service for the 10 weeks prior to the signing of the document received a lump sum payment of £27 and non-craftsmen £20.

(The figures quoted relate to 40 conditioned hours per week. Payment will be reduced pro rata for shorter attendances and increased for longer attendances).

At the official signing ceremony Mr. K. G. Evans, N.C.R.E. Superintendent, said that the agreement was the result of some months of joint effort by both management and the Trade Unions. He emphasised that if it was going to work it would need the whole hearted co-operation of both management and the workforce.

The savings made by working the agreement will come from a greater "flexibility" of job demarcation lines with, it is hoped, a resulting drop in overtime working and increases in the DIBS indices and piece work returns.

Employees were told that contract times and bench marks would not be adjusted because of this but that it should be recognised that there must also be a corresponding increase in the rate of completing day-work.

By practising the flexibility aspects of the agreement, time lost through one type of craftsman or worker waiting for another type of craftsman to carry out a demarcated job will be

reduced to a minimum. In future a painter, for instance, will be within his rights to remove certain fittings which in the past could only have been removed by, say, a joiner. There will be a certain amount of overlapping of responsibilities.

Training programmes are to be instituted by which various craft and non-craft employees will learn how to carry out these overlapping jobs.

Although the terms of the agreement are aimed at cutting down the time factor, time in itself is not an issue in this particular agreement. However, a further phase in the campaign to increase productivity is expected to be resolved in the near future and this will lead to yet a further increase in the productivity bonus.

Mr. W. G. Watt, Chief Constructor, South Arm, said "The management look upon this agreement as a step towards closer liaison between the management and the Trade Unions. Our work is by no means finished and we will, both sides, have to work out a system whereby we can monitor the effects of the agreement".

Mr. Reg Sayers, Secretary of the N.C.R.E. Whitley Committee and T.G.W.U. representative on the negotiating committee, said "We are reasonably happy with the outcome but hope, of course, that further negotiations and agreements will bring more money to our members".

Some 226 employees will benefit from the new agreement.

Five Trade Unions were involved in the discussions: E.E.T.U., A.S.W. & P., A.S.B.S.B. & S.W., T. & G.W.U. and A.U.E. & F.W.



The Naval Construction Research Establishment's
Productivity Agreement is Signed

Seated left to right: Mr. R. Sayers, Mr. K. G. Evans
(Superintendent NCRE), Mr. J. McCusker, Mr. H. Gibson.
Standing left to right: Mr. J. Richardson, Mr. J. Cutland,
Mr. H. Walls, Mr. W. G. Watt (Chief Constructor, NCRE).



TECHNICAL NOTES

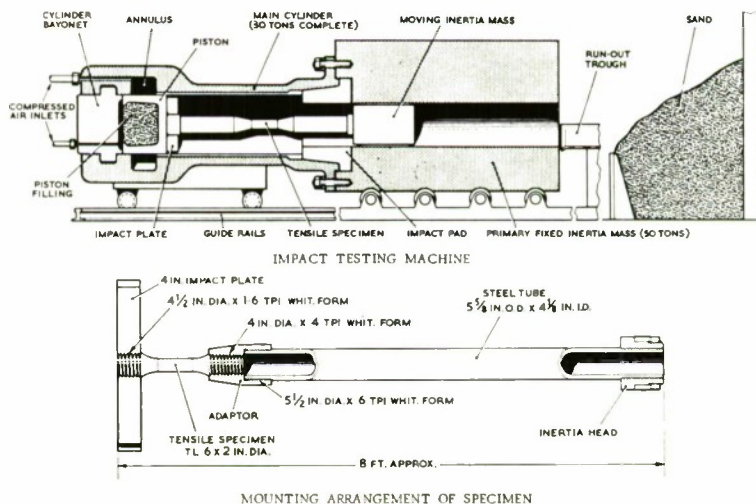
A High Energy Impact Testing Facility

An impact testing machine of 500,000 ft lbf (680,000 J) capacity and capable of impact velocities up to 200ft/s (60 m/s) is one of the facilities now offered as a service to industry by the Naval Construction Research Establishment. The machine is suitable for fracture testing specimens in tension, compression and bending and is equipped with the necessary recording devices to supply data from the test specimen.

The figure illustrates schematically the layout of the machine for tensile testing. A heavy cylinder of 30 in. (762 mm) bore, positioned horizontally and attached to a primary inertia mass of 50 ton (51 t), contains a compressed air driven piston acting as the driving force. For testing in tension an impact plate is attached to one end of the specimen and a

moving inertia mass to the other. As the piston is forced down the cylinder under air pressure of 4500 lbf/in² (31 MN/m²) it drives the assembly, including the specimen, before it until the impact plate at the rear of the assembly strikes the impact pad on the primary inertia mass. This arrest places the specimen in impact tension, the fracturing energy being supplied by the forward end of the specimen and the attached moving inertia mass.

For compressive and bending tests a suitable mass is accelerated by a push rod from the impact plate and allowed to run through the centre opening of the primary inertia mass and strike the specimen which is positioned against the secondary inertia mass. As an alternative to this method, suitably shaped specimens may themselves be projected to impact against the secondary inertia mass.



Electronic Governor for Diesel Generator Sets

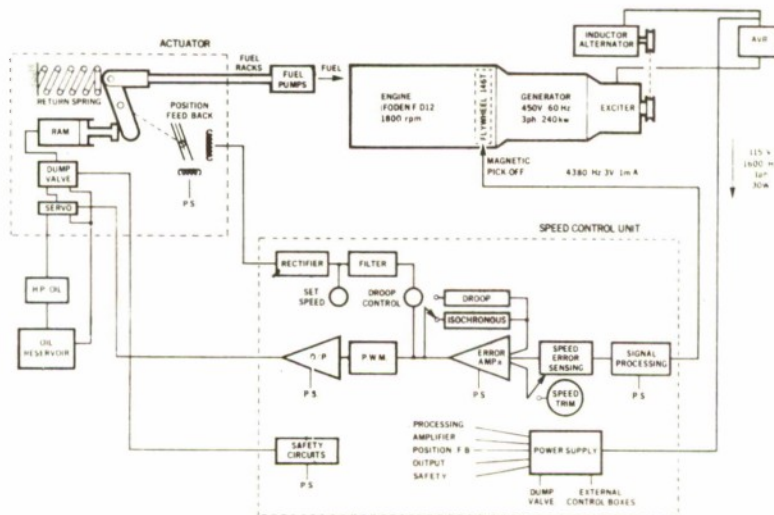
An electronic governor for a diesel generator set has been designed and developed at the Admiralty Engineering Laboratory to a pre-production stage which is capable of fast response to load change and has high stability at steady loads, giving an order better than current specification requirements. It overcomes the limitations of modern mechanical governors which are becoming more and more complex for smaller and smaller improvements in performance.

This governor derives its control signal from an electro-magnetic pick-off mounted adjacent to the engine flywheel, processes the signal electronically, and transmits the speed error signal to an electro-hydraulic actuator controlling injection of fuel to the engine. Advantages of the system include: rapid and accurate measurement of speed and speed error; easily incorporated control characteristics such as droop or isochronous modes; overspeed trip and speed trim only if required; remote control; accuracy and reliability of electronics, and the elimination of the effects of friction and mechanical wear.

The control loop consists of a single major loop, plus a minor loop for positional stability of the actuator shaft and fuel racks. In the droop mode (used when paralleling generators), the amplifier feedback is resistive, the speed/load characteristic drooping linearly from +2% at no load to -2% at full load. A facility for speed trimming is provided. In the isochronous mode—*i.e.* constant speed irrespective of load—the amplifier has an integrating feedback so that the output alters to compensate for drift and load changes, until the amplifier input resets to zero. Speed remains within $\pm 0.2\%$ nominal over a temperature range $0^{\circ}-100^{\circ}\text{C}$.

A dump valve is connected hydraulically between the servo and main ram. If its electrical supply is cut by the operation of any one of a number of safety circuits, the ram cannot oppose the return spring and the fuel racks move to no-fuel. One of the safety circuits is an overspeed trip: an additional facility permits it to be checked when the engine is stopped without actually overspeeding the set.

This invention is the subject of British Patent Application No. 53096/70.



Movable Thermocouple Probe for Surface Temperature Measurements

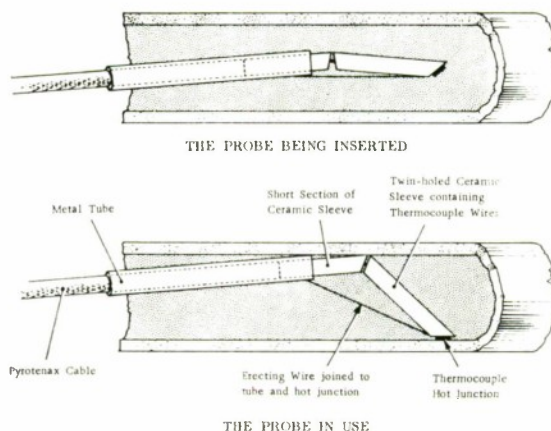
A simple design of movable thermocouple probe enables quick accurate temperature measurements to be made in inaccessible positions such as the internal walls of boiler tubes. The thermocouple is mounted at the end of a probe and is manoeuvred into contact with the surface to be measured by a device similar in action to a Bowden cable.

The probe consists of a metal tube of 0.25 in (5 mm) OD which encloses an inner core of standard metal sheathed 'Pyrotenax' thermocouple cable of 0.125 in (2.5 mm) OD. To operate on the inner surface of a tube the device is inserted as a straight probe. Once in position the outer sheath is held firmly while the inner core is pushed inwards to operate the erecting wire and force the thermocouple junction into contact with the hot surface.

The thermocouple junction has a very small mass whose surface area may be profiled to suit the shape of surface being measured. Its reverse side is provided with adequate heat

shielding by the ceramic sleeving on the 'Pyrotenax' cable and heat conduction paths away from the junction are minimal.

Accuracy achieved by this movable probe is comparable with fixed position, brazed thermocouples.



HIGH SPEED TOWING

Prior to entering the Mediterranean the *Scylla* was engaged in four weeks' trials with H.M.S. *Penelope* (Commander S. Idiens, R.N.) in the Gibraltar area. The trials involved towing the *Penelope* with her propellers removed, at various speeds past a R.A.F. launch equipped with a mobile noise range to enable the *Penelope's* hull noise through the water to be measured and analysed.

A long tow was necessary to avoid noise interference between the two ships and the towing hawser, an 11 inch braided nylon one, was one mile long and weighed one ton. The fastest speed recorded by the *Penelope's* log was 23 knots.

It is hoped to publish an article describing these unique trials in a forthcoming issue of *J.R.N.S.S.*

AWARDS TO NAVAL SCIENTISTS



Mr. S. B. Kendrick, O.B.E.



Dr. D. E. Weston



Dr. Ralph Benjamin

Three members of the Royal Naval Scientific Service have recently been honoured by awards for their part in significant advances in their respective fields.

Mr. S. B. Kendrick, O.B.E., B.Sc., Head of the Structures Group at the Naval Construction Research Establishment, has been awarded the Gold Medal for 1971 by the Council of the Royal Institution of Naval Architects for his paper entitled, "The Structural Design of Supertankers". The presentation is to be made by The President of R.I.N.A. on Tuesday, 27th April, 1971.

Dr. D. E. Weston, A.R.C.S., D.I.C., of the Admiralty Research Laboratory whose principal interests are in Oceanographic Acoustics, is to receive the 1970 British Acoustical Society's Annual Silver Medal. It is a condition of the award that the recipient should present a paper to the Society's Meeting on the 5th - 7th April, 1971 at the University of Birmingham.

Dr. R. Benjamin, B.Sc., A.C.G.I., C.Eng., F.I.E.E., Director of Admiralty Underwater Weapons Establishment, has been elected to the Council of the British Acoustical Society, and has also been awarded the degree of Doctor of Science (Eng.) by London University in recognition of his work in the field of general electronics.

NOTES AND NEWS

Admiralty Research Laboratory



The photograph shows **Mr. C. T. Wright**, B.Sc., F.I.Mech.E., before his retirement on the 30th November, 1970, by which date he had registered 44 years of work in the field of engineering.

Charles Thomas, or 'C.T.' as he was more popularly known, began his engineering career in 1926 as an apprentice with James Cruickshank Ltd. of Edinburgh. He attended the Heriot-Watt College and was awarded their Diploma in Mechanical Engineering with distinction. In 1931 he collected a Whitworth Prize and whilst holding an 1851 Industrial Bursary worked with C. & J. Weir Ltd. as well as Barr & Stroud Ltd. During this period he graduated in engineering at London University, and joined Mactaggart Scott Ltd. where he worked on the design and development of catapults for launching aircraft. 'C.T.' looks upon his work at this time as being one of the highlights of his career.

Mr. Wright's service in the Navy Department began in 1937—34 years ago—when he entered the Department of Scientific Research and Experiment, and was appointed to the Admiralty Research Laboratory. He worked in the Optics Group at a time when optical devices for range-finding, etc., were still important pieces of equipment to the Royal Navy. Such equipment was slowly superseded by radar devices until eventually optics work was aban-

doned at A.R.L. When the R.N.S.S. was inaugurated in 1946 'C.T.' was appointed an S.S.O.

After attending the R.N. Staff Course and the Joint Services Course he became, in 1949, a P.S.O. in the Hydrodynamics Group. His main responsibilities covered the provisioning of major hydrodynamic test facilities in the form of a rotating beam channel and a 30 inch water tunnel that were successfully installed within the Upper Lodge area of A.R.L.

In 1955 he was given the task of forming an Engineering Services Group and over the years welded the many diverse activities into an effective and efficient whole.

'C.T.' was promoted to S.P.S.O. in 1956 and for some years acted as Deputy to the Superintendent A.R.L. In 1966 he was made responsible for a Section specialising in the experimental aspects of vibration engineering. Under his control an efficient team was built up to undertake a wide range of work relevant to this field.

Mr. Wright became a member of the Institution of Mechanical Engineers in 1947 and was elected a Fellow in 1959.

Mr. Wright's retirement was unusual in that three presentations were made to him during his last two working days. The first was from Staff immediately responsible to him and materially took the form of a light-motor. The second was organised by the Workshop and took the form of a Dinner and Dance when Mr. and Mrs. Wright were the guests of honour. During the proceedings Mrs. 'C.T.' was presented with a bouquet of flowers and Mr. 'C.T.' a pipe. The third presentation arranged by the Joint Staffs Committee took the form of a silver tray and six crystal glasses and a supply of golf balls for luck, presented by Mr. W. L. Borrows the Director, A.R.L. Because of family connections Mr. and Mrs. Wright have decided to return to Scotland for their retirement and, to complete the cycle, settle in Edinburgh. As was evident from the presentations, Mr. and Mrs. Wright went forth to the North armed with the best wishes from all their friends at A.R.L.

Mr. J. Gibb, ARL's Administration Officer, retired at the end of February after 46 years' service.

He joined the Post Office in 1925, as a boy messenger, and after qualifying as a telecommunications engineer, joined the administrative field as a Clerical Officer, at the Hydrographic Department, in London. Serving both in Bath and later in Taunton, he returned to London as an H.E.O. and worked on behalf of the Royal Greenwich Observatory. In 1965, he was appointed to ARL as Administration Officer. John Gibb has had a life long interest in athletics, and even now as a member of the Belgrave Harrier Veterans, still regularly runs cross country every Saturday afternoon. Many happy years of retirement, John.

Admiralty Research Laboratory

A surprise visit was paid to ARL on 19th January by an old colleague of many RNSS members. Prof. Sir John Carroll motored in from his home in Wimbledon to borrow a rare table in Group M which had been discovered to be equivalent to an integral in which he was interested. It is quite clear that Sir John is still very active mathematically. He acts as consultant for various firms and has formed a friendship with a descendant of Evelyn the diarist and holds discussions on the theory of numbers.

Dr. I. M. Yuille attended a Symposium on Numerical Methods for Unconstrained Optimization organised jointly by the Institute for Mathematics and its Applications at the National Physical Laboratory on 7th and 8th January, 1971.

A paper entitled "A Method of Fitting Parametric Equations for Curves and Surfaces to Set of Points defining them Approximately" by Dr. I. M. Yuille and Mr. J. L. Earnshaw has been published in *Computer Aided Design*, Winter 1971.

A course in Computer Aided Ship Design, for Assistant Constructors attending the Post-M.Sc. course at University College, London, is being held at ARL, 18th-19th February, 1971.

In March 1967 a working party was set up to review the developments available to engineering by the use of numerical controlled technology. This has culminated in the setting up of a Numerical Control Section at ARL which has been in full working order since the beginning of 1971. The facility uses a Cincinnati CIM-X machining centre fitted with a ACRA-

MATIC IV control system and this is supported by manual and computer aided part programming using WANG desk-top electronic calculators and the N.E.L.-2CL processor and a re-written Cincinnati post processor run on the K.D.F.9 computer at ARL.

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A.R.L. Extension, Glen Fruin



Mr. Stevens (left) with
Mr. J. R. Littlefair

Mr. W. G. Stevens at ARL Extension Glen Fruin retired on 15th January, 1971 after a total of 35 years' service with the Admiralty.

A native of Greenock, he first entered R.N.T.F. in 1935 where he was employed as a fitter then as a progressman, spending most of the war years on night shift as a leading hand in the depth gear department. After a spell on recording he was transferred to the, then, A.H.B.R.E. Coulport as a fitter, where in 1953 he was awarded the Queen's Coronation medal.

In 1954 he was promoted to TG111 in charge of workshops and in 1959 he moved to Glen Fruin. He was promoted to TG11 in 1965 and since then has been in charge of workshops, both at ARLE, Glen Fruin and Coulport. The Officer in Charge, Mr. J. R. Littlefair presented Mr. Stevens with a wrist watch, suitably inscribed, on behalf of the staff. A keen golfer, he takes with him the best wishes of all his colleagues and friends for a long and happy retirement.

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Admiralty Materials Laboratory

Mr. J. J. Elphick visited the U.S.A. 16th - 20th November, 1970 to attend the annual conference on Biodeterioration of Military Material held at U.S. Army Natick Laboratories, Natick, Mass. Mr. J. McFadyen also visited the U.S.A. but from 11th - 19th September, 1970 to study developments in the use of logistic fuels to generate impure hydrogen for acid electrolyte fuel cells. Mr. A. A. Law went to the U.S.A. from 11th - 19th December, 1970 to discuss progress in fuel cell research under the Memorandum of Understanding between the Ministry of Defence and the U.S. Department of Defence and to visit firms and agencies working in this field.

Dr. C. H. Jones attended an international conference entitled "Clean Steels" at Balatonfüred, Hungary, in June 1970. The conference was organised jointly by the Iron and Steel Institute, London (ISI), Societe Française de Metallurgie (SFM), Institut de Recherches de la Siderurgie (IRSID), the Research Institute for Ferrous Metallurgy, Budapest (UKI), and the Hungarian Mining and Metallurgical Association (OMBKE). About 500 delegates, representing 26 countries, took part in the five day programme of lectures, discussions and visits.

In late September (22nd - 25th) Dr. D. J. Godfrey attended the International Conference on Copper and its Alloys to present a paper entitled "Present and Future Full-Scale Land-Based Corrosion/Erosion Studies of Ships Sea Water Piping Systems" by B. Angell, A. F. Taylor and D. J. Godfrey. Dr. Godfrey was an invited speaker on silicon nitride ceramics when he attended with U.S. Government sponsorship, a conference on Ceramics in Severe Environments at North Carolina State University, Raleigh, in early December (7th - 9th). Mr. Freegarde appeared on B.B.C. South Television on 14th January to describe the development at AML of the technique of fluorescence fingerprinting for use in characterising complex organic mixtures such as oils. The approach by the B.B.C. for the interview followed publication of an article in *Laboratory Practice*, 20 (1971), 35 on "Oil Spilt at Sea" by M. Freegarde, C. G. Hatchard and C. A. Parker.

A successful two day colloquium on "Hot Corrosion in Marine Gas Turbines" was held at AML on 22nd and 23rd September, 1970 and was attended by some 50 invited participants from Navy Departments, Government Defence and Civil Laboratories, Universities, CEEB and commercial companies.

A total of 15 papers were presented which promoted lively and wide ranging discussion. Virtually all organisations with an interest in corrosion in industrial and marine gas turbines were represented.

Mr. D. Birchon delivered the 43rd Thomas Lowe Gray Lecture, "The Use and Abuse of Materials in Ocean Engineering" at the Institute of Mechanical Engineers on 27th January, 1971. The lecture is to be repeated in Liverpool in February and Newcastle in March. Dr. R. Dukes and Mr. D. L. Griffiths presented a paper entitled "Marine Applications of Carbon Fibres" at the Carbon Fibre Conference organised by the Plastics Institute in London, 2nd - 4th February, 1971.

A note on "The Vulnerability of Wire Cable Armour to Impact Damage" by D. Healey was published in the October 1970 issue of *Metals and Materials*.

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Admiralty Surface Weapons Establishment

The Controller of the Navy, Vice-Admiral A. T. F. G. Griffin, C.B., visited the Establishment on 15th February accompanied by Rear-Admiral P. A. Watson, M.V.O., F.I.E.E., F.I.E.R.E., the Director-General Weapons. It is interesting to recall that the Controller used to be the Navigation and Direction Commander at the Establishment between September 1952 and January 1955 when he left to join H.M.S. *Eagle*. The photograph shows Admiral Griffin being welcomed to ASWE by the Director, Mr. H. W. Pout, O.B.E., B.Sc.(Eng.), A.C.G.I., C.Eng., F.I.E.E.



Dr. J. Croney, consultant to ASWE's Head of Research on Antenna Techniques, has been appointed Visiting Professor to the Department of Electronics at Southampton University.

On the 31st December, 1970 two well-known members of the Installation Engineering Division, **Mr. E. E. Goodall**, Senior Experimental Officer and **Mr. L. A. Lawrence**, Experimental Officer, retired after a combined service of 47 years on installation engineering. Mr. E. E. Goodall spent 45 years in Government service having entered Portsmouth Dockyard as an Electrical Fitter apprentice in 1925. In 1937 he joined H.M. Signal School in R.N.B. Portsmouth as a draughtsman in the Fitting-out Section of the drawing office, eventually being promoted to First Class Draughtsman in 1940. Following war damage to the Signal School building the section moved for a time to Commercial Chambers in Portsmouth and in May 1941 to Lythe Hill House in Haslemere. He was promoted to Assistant Grade II in 1944 and on the formation of the RNSS was assimilated as an Experimental Officer in 1946.

During the war and early post war years Ernie Goodall was concerned primarily with the installation aspects of Gunnery Fire Control Radars, Long Range Warning Radars and their associated aerial systems. The move back to ASRE at Portsdown came in May 1952 and in October of that year, following a re-organisation of the Installation Division, he was given control of a Ship Section with responsibility for all Communication and Radar installation matters appertaining to Aircraft Carriers and Aircraft Direction Frigates. This field was later expanded to include Commando Ships and Cruisers. Subsequently he was promoted to Senior Experimental Officer and took charge of a Ship Sections group in the Installation Division.

Mr. L. A. Lawrence retired after 49 years' continuous Admiralty service. In 1922 at the age of 16 years he joined the Royal Navy as an Electrical Artificer apprentice and saw sea service in many classes of ships. Promoted to Lt. Cdr. (L) he served as Electrical Officer in the Naval Air Stations at Lossiemouth, Lee-on-Solent and Yeovilton. Whilst serving in these air stations he made his first contacts with Messrs. Ted Lee and "Bish" Grocott of the ASRE Installation Division. These two officers, now retired but both well known to older colleagues, were then planning the radio modernisation of the air stations. In 1956 Les Lawrence retired from the Navy and joined ASWE as an Experimental Officer in the Installation Engineering Division where he worked for 14 years in the Carrier and Cruiser Ship Section.



Mr. Budden (right) with
Mr. H. W. Pout, O.B.E.

Mr. R. Budden retired in December 1970 after 44 years of service with the Admiralty.

He was initially employed in MED in Portsmouth in 1926 and 10 years later transferred to the Director of Naval Ordnance. He joined the Admiralty Gunnery Establishment as a Technical Officer in 1943. In his early days at AGE, naval gunnery depended very much on complex optical instruments for sighting and ranging. Ray Budden was an expert in these matters and was in fact one of a very small group of people in the Admiralty who could design optical instruments.

During the war and subsequently, the Admiralty Gunnery Establishment was responsible for army fire control including the sighting used in tanks and Ray designed a number of sighting and rangefinding instruments for this purpose.

Apart from his special skill in optics he was a very competent mechanical engineer and enjoyed the work entailed in designing the mechanical parts of such optical instruments as rangefinders and complex gunnery sights as well as the purely optical systems.

He will be remembered for his enthusiastic leadership of the "Optical Group" accompanied by a patience and good temper not always apparent in such talented engineers. He transferred to ASWE with his optical group in 1959 as part of the AGE/ASRE merger.

The emergence of automation in ASWE, firstly in Action Information Organisations, subsequently in Weapon Systems found Ray in a new role. He was appointed head of the division dealing with new systems for escorts designed to accompany the then New Carrier Fleet. When the Carrier Fleet programme was cancelled, Ray's division carried on with the systems for

the ship which was subsequently named H.M.S. *Bristol*—the forerunner of three new classes of ships, viz., Ikara guided missile and anti-submarine, Sea Dart guided missile ship and the proposed Helicopter Cruisers. Later, the systems for the second batch of County Class destroyers were added to his load.

The systems and techniques involved were mostly alien to anything he had previously done, but the speed at which he familiarised himself with the problems and assisted in their solution was a tribute to his innate ability. In this new field he proved a tower of strength, particularly in philosophical discussion inside and outside ASWE, with personnel at all levels both Admiralty and contractor.

He managed to combine a tough almost uncompromising exterior with a basic kindness and consideration towards any of his staff who were in personal trouble. This combination will be missed by the recipients of both talents.

As a token of the affection and respect in which his colleagues hold him the Director presented him with a silver tea-service and plaque indicating all the departments in which he has served.

Another recent retirement has been that of **Mr. R. C. Hawkes** who joined SEE Portsmouth in 1926 as an Electrical Fitter apprentice. He became an Electrical Fitter in 1931 and gained a variety of experience in AEL, H.M.S. *Vernon*, and ASRE.

He gained a second class honours B.Sc. in Engineering in 1935 and returned to ASRE in 1939 becoming a Technical Officer in 1945. In 1946 he became an Experimental Officer, being promoted to S.E.O. in 1947.

Among his contributions in the mechanical engineering field, he is best known for the water-cooling of electronic cabinets in a guided missile radar. This was a novel approach to cooling problems at the time, it was carefully investigated and has proved to be a successful design now in service in a number of ships. Mr. Hawkes retired on 12th February, 1971.

Central Dockyard Laboratory

Dr. E. N. Dodd retired as Superintending Scientist on 30.11.70. He is continuing in the Laboratory until December 1971 to complete his work on oil pollution of the sea.

Mr. D. L. Griffiths became Superintending Scientist on 1.12.70. He was formerly Deputy Head of the Polymers Division at AML.

A paper entitled "A Simple Laboratory Potentiostat" by M. N. Bentley and A. G. Denham was published in *British Corrosion Journal* 1970, 5, 227-229. A synopsis of a lecture "Corrosion in Non-Ferrous Seawater Systems" given by J. C. Rowlands at a Marine Corrosion Symposium was published in the Institution of Corrosion Technology News Letter, September 1970.

Mr. J. Smith and Mr. W. R. Weaver visited Paris on 18-20 November for a meeting of an ISO Task Group TC35/SC9/TGA on artificial weathering of paints. Mr. Smith is the Task Group Leader and Mr. Weaver Chairman of the British Standard committee responsible for the U.K. contribution to the work.

Mr. G. Newcombe visited Amsterdam, September 21-25, 1970 to attend the Institute of Metals, International Conference on "Copper and its Alloys" at which a paper by J. N. Bradley and G. Newcombe entitled "Copper Alloy Cladding as an Approach to the Future Requirement for Corrosion-Resistant Components" was presented. The paper was subsequently published in the *Journal Institute of Metals*, November 1970.

At the Naval Materials Week Symposium held in the Commonwealth Hall, London on the 24th November, 1970 a paper entitled "The Naval Approach to Cladding" was presented by G. Newcombe. At the Exhibition the following day the CDL stand showed the weld cladding of components with copper-base alloys together with corrosion monitoring and eddy current non-destructive testing developments.

A new filler wire has been developed in the non-ferrous welding laboratory at CDL for inert-gas welding of gunmetal and dissimilar metals.



Admiralty Underwater Weapons Establishment

Somewhat belatedly we report the retirement in 1969 of three members of the Engineering Services Division Trials Group.

Mr. H. M. Taylor, who worked throughout the war years on projects connected with midget submarines used by the "Cockleshell Heroes," and beach clearance devices of a unique nature, notable amongst these were "Tureen" and "Bookrest".

Mr. L. R. Bailey, who after an apprenticeship in Portsmouth Dockyard as an Electrical Fitter worked on the development of the Mk 10 A.S. Mortar. He is one of the few, who in 30 years, has seen the title of his establishment change from M.D.D., A.M.E., U.C.W.E., U.W.E., to its present designation A.U.W.E.

Mr. W. J. Mason, joined the Royal Navy in 1930 and was invalided in 1944 as a result of enemy action. He joined A.R.L. in 1944 working on gyro sights, predictors, constant speed mechanisms and torque amplifiers. In the Way-Ahead amalgamations in 1959 he remained at Portland with the Trials Group where his skills and flare for devising simple but effective machines were put to excellent use.

Dr. R. Benjamin has been appointed Chief Scientist at the Government Communications Headquarters in succession to Dr. G. A. Touch, who is retiring from the Service in July 1971.

Dr. Benjamin's place at Portland will be taken by Dr. G. L. Hutchinson, Head of the Military and Civil Systems Department at the Royal Radar Establishment at Malvern. From March until June, when he will start to take over from Dr. Touch, Dr. Benjamin will be working with the Chief Scientist (Royal Navy) of the Ministry of Defence.

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Naval Aircraft Materials Laboratory

Admiral Sir Michael Pollock, as Controller of the Navy, visited NAML on 30th November 1970 during a farewell visit to the Naval Aircraft Yard Fleetlands. He saw some of the general work of the laboratory, particularly SOAP (Spectrometric Oil Analysis Programme), the current aircraft hydraulic fluid hygiene studies and some current helicopter engineering and materials problems presently under evaluation.

Messrs. P. Gadd and R. C. Clark attended the second meeting of the NATO Panel of Experts on SOAP in Brussels from 18th - 22nd

January 1971. Nations represented were U.S.A., Germany, Denmark, France, Italy, Belgium, Norway, Canada, Netherlands and U.K. There was much useful exchange of information in this important field and some progress was made towards standardisation of analytical and documentation procedures.

Mr. R. F. Tollervey sailed in H.M.S. *Albion* from 28th January to 18th February, 1971 to participate in cold weather trials of helicopter operation, to study and advise upon means of keeping the flight deck clear of ice. Much useful information was gathered, but owing to the mildness of the weather, ambient conditions were less severe than had been anticipated.

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Corrosion Costs £1,365M A Year

The Committee on Corrosion and Protection whose report to the Secretary of State for Trade and Industry was published on 4th March, 1971 estimates the annual national cost of corrosion at not less than £1,365 million and considers that £310 million could be saved by making more effective use of existing knowledge.

The Committee was set up under the chairmanship of Dr. T. P. Hoar, Department of Metallurgy, University of Cambridge, by the former Ministry of Technology in March, 1969. Two examples are cited where a relatively small investment would lead to large overall savings.

Apart from the national cost and the possible savings, the Committee noted three findings which stand out above all others (i) the need for better dissemination of information (ii) the need for more education and (iii) the need for an increasing awareness of the hazards of corrosion.

The Committee recommended that:—

- (a) a National Corrosion and Protection Centre should be established which should encourage the practical application of new and existing knowledge. In addition to giving advice and information the centre should co-operate with appropriate existing organisations to improve education and should undertake test work.
- (b) Undergraduate and professional courses for engineers, designers and architects should contain specific reference to the subject. Short specialised courses should be provided for those in industry and there should be wider acceptance of technicians qualifications.

- (c) There should be more research on protection (rather than corrosion) and co-operation and exchange of information between various research bodies should be encouraged.
- (d) Co-operation between the learned societies should be encouraged.

A public discussion of the Report was held on 20th-21st April, 1971 by the Institution of Mechanical Engineers in conjunction with 12 other bodies most immediately affected by the findings and recommendations of the Report.

The Ministry of Defence, Navy Department was represented on this Committee by Mr. N. L. Parr, Director of Materials Research (Navy) and Dr. H. K. Farmery.



Plaque Unveiled to a Famous Scientist



The plaque to Dr. Wood is unveiled by Sir Charles Goodeve. Left to right: Lord Rhodes, Mrs. Wood, Mr. Eric Smith and Councillor J. D. Thompson.

(Photograph courtesy of "Oldham Evening Chronicle")

Glowing tributes to Dr. Albert Beaumont Wood, an Uppermill man who became a world-famous Naval scientist, were paid on Saturday, 12th December, 1970, when a memorial plaque was unveiled in the foyer of Saddleworth Secondary School by a war-time colleague, Sir Charles Goodeve, a former Controller of Research of the Admiralty. Saddleworth Council who arranged the ceremony, also founded a school science prize to his memory. About 200 people attended the ceremony, including Dr. Wood's widow. As readers will know, Dr. Wood died in 1964 at the age of 74 and was renowned for his work in underwater sound.

Councillor J. D. Thompson, chairman of the Council, who presided at the ceremony, referred to the gold medal awarded to Dr. Wood

by the Acoustical Society of America, and remarked that, judging by the correspondence he had received from that continent, Dr. Wood had proved to be not only a great scientist but also a great ambassador.

When the First World War came Dr. Wood joined the Navy, where he entered his pet field of sound. He became in 1915 one of the first two paid scientists in what was to become the Royal Naval Scientific Service.

His skill was probably best illustrated by the fact that the textbook on sound which he wrote in 1930 was still a classic, having been reprinted 11 times and twice revised by Wood himself.

Dr. Wood examined and prepared the first report on the German magnetic mine. This had been greatly feared, but Wood's work had rendered it ineffective. It had earned him the O.B.E. He spent a year in the United States, where a research vessel had been named after him.

Led by Sir Charles Goodeve and Lord Rhodes, a number of AB's other colleagues, relations and friends of his early school days, reminisced in a laudatory manner upon the life and work of a man who, whilst achieving such eminence in his chosen field, had at all times remained a very human person.

Finally, Mr. W. L. Borrows, Director of the Admiralty Research Laboratory, presented the school with two bound copies of the memorial number of the *Journal of the Royal Naval Scientific Service*.

Guests included Dr. E. Lee, Deputy Controller of Research, Ministry of Technology; Sir George Deacon, National Institute of Oceanography; Mr. H. L. R. Hinkley, Head of the Naval Scientific and Technical Information Centre, Ministry of Defence; Mr. J. R. Gossage, Deputy Director, Admiralty Research Laboratory; Mr. L. Walden, Imperial College of Science and Technology; Professor Edwards, vice-president of the Institute of Physics and the Physical Society, and Dr. Wood's godson, Mr. J. Bower.



BOOK REVIEWS

Digital Computers (a practical approach). By J. P. Marchant and D. Pegg. Pp. xiv+199; London; Blackie & Son Ltd., 30s.

The first chapter introduces basic ideas related to digital computers and the binary system. A brief description of bits, words, parity and signs is followed by a simple introduction to binary arithmetic with ideas of complements in subtraction and shifting in multiplication and division being briefly explained.

The component parts of the computer and logic circuits are discussed in the next two chapters although perhaps half of the logic function implementation is described using relay logic which seems to be somewhat dated and does not aid clarification of the arguments presented.

Storage, the theme of the next chapter, adequately covers types of storage including magnetic core, drum and tape, the inevitable relay, and electronic (shift registers and counters). There is a conspicuous absence here of any mention of addressing, or reading and writing into, stores except in the broadest of terms.

Chapter 5 describes, in unnecessary detail, two complete relay computers which have been built and apparently successfully programmed by boys at Bedford School although it would appear that the aims could be more successfully, realistically, and economically be achieved if semiconductor logic was used instead of relays. The chapter is concluded with a brief mention of the electronic digital computer described by B. Crank in *Wireless World* from August to December, 1967, in

which the authors appear to substantiate my earlier observation.

Programming with brief descriptions of autocoordinates and languages is dealt with in Chapter 6 but again in too little detail to be very instructive.

Further electronic circuits are described in Chapter 7. The astable multivibrator is shown in its basic form for use as a master clock and an asynchronously gated version with no mention of the importance of timing is described to illustrate inhibit gating with application to forming a digital complement (inversion) and true complement.

Monostable multivibrators are shown with application to half digit delays followed by brief description of shift registers with application to serial addition.

Printed circuits are given a two page treatment before a commercial patch panel is described at length.

There then follows the final three chapters concerning a survey of computer application, computers and automation and integrated systems respectively which are worth one read through although little information is contained in those 40 pages.

The appendices are not at all enlightening and the appendix to Chapter 3 infers that a ternary output may be available from a binary circuit.

There is a useful glossary and bibliography at the end of the book but the overall impression of the book is that it has little value today although recently published. I feel certain that it will not displace the introductory texts on this subject already in existence.

D. Robson

Navy Department Advisory Committee on Structural Steel. Edited by G. M. Boyd. Pp xiii + 122. Butterworth and Co. (Publishers) Ltd.; 1970. Price £4.25.

During the past 20 years or so there have been many serious and disturbing failures in steel structures in many countries throughout the world. Ships have broken in two, bridges collapsed, oil storage tanks, pressure vessels and pipe lines have burst, and there have been many other serious fractures in many types of structure.

These failures have been traced to an illusive phenomenon known as brittle fracture and have given rise to an enormous world wide research effort, with a correspondingly vast accumulation of literature. In the United Kingdom this research has been carried out mainly under the auspices of the Navy Department Advisory Committee on Structural Steel. This committee is a continuation of the Admiralty Ship Welding Committee, which was set up in 1943 to study the brittle fracture failures, which at that time were occurring in welded ships. In the early years much of the work was concerned with improvements in welding procedures and equipment used in shipbuilding, but in the course of the work it became clear that the incidents of brittle fracture was as much affected by the properties of the steel as by welding factors, and that improvements were needed in the notch toughness of standard shipbuilding and structural steels in general use at that time. In recent years the committee has continued to study brittle fracture phenomena and is at present the main British repository of expert knowledge in this subject. Because the committee feel the salient aspects of the problem and methods for dealing with it should be more widely available to practising engineers it has, therefore, produced this book which describes many known cases, details the characteristics of the phenomenon and gives recommendations aimed at reducing the risk.

The book is mainly concerned with mild steel structures fabricated by welding from rolled steel plates and sections, and does not cover forgings, castings or special steels. These and also cases involving extremes of temperature, severe impact loading, or in which the consequences of a fracture would be very serious, require special investigation, which is not attempted in this book. The first chapter gives the historical background and summarises numerous cases of brittle fracture that have occurred in service with a review of the lessons learnt from them. Chapters 2, 3 and 4 describe the nature of the phenomena and the factors which influence its incidence, as well as the various methods of testing that have been developed to determine the notch ductilities of different steels. Chapter 6 reviews the main methods in current use for assessing the degree of notch ductility needed for different applications, whilst Chapter 7 gives practical procedures recommended by the Navy Department Advisory Committee on Structural Steels, for assessing the suitability of different steels for particular applications. Some golden rules are given in the appendix, which designers, engineers, and management are enjoined to observe in order to minimise the risk at catastrophic failure of the structures for which they are responsible.

The NDACSS represents many shades of opinion concerned with many differing applications. The book cannot therefore reflect exactly the views of all members but is rather a consensus of their views. It is intended to review the book as further knowledge is gained and a plea is made for comments from readers to assist in this objective.

The book should be essential reading for design engineers as well as for managements, fabricators and all concerned with the safety of steel structures. It is well documented and should be found valuable also as a text for engineering courses at universities and technical colleges as well as an introduction to a fertile field for further research.

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