Paper No. 2

A Statistical Model of Ship Performance in Service Conditions

D. J. DOUST, M.Sc., Dr. Techn. (Member, R.I.N.A.)*

In 1962 Shell International Marine Ltd. approached Ship Division, National Physical Laboratory, to assist in the study of the general problem of formulating a mathematical model of ship performance in service conditions(1).

The objects of this paper are to give details of the background philosophy underlying such investigations of ship performance, to refer to the appropriate literature which is considered to be of assistance in formulating such a model and to describe in some detail the form of the equation proposed by N.P.L.

Using ship data supplied by Shell International Marine Ltd. for one of fifteen vessels participating in their investigations of service performance, an example of the application of the proposed method is given for one 15-day period in the loaded condition.

It is concluded that the quality of ship instrumentation is now reaching the stage when much greater reliability can be placed on full scale data and such indices of performance can be evaluated to detect real changes in operational efficiency. New possibilities for verifying many of the assumptions made in translating model experiment results to full scale should become available as a result of such investigations.

INTRODUCTION

A ship in service will generally experience, over time, a deterioration of both hull and propeller surfaces which is reflected directly in the recorded values of delivered horsepower (propeller torque and revolutions), propeller thrust and ship speed. As is well known, these hull and propeller deteriorations mainly arise due to fouling by marine growths, corrosion, and general wear and tear, including, on occasion, mechanical damage. It is, therefore, of prime importance to shipowners to be able to assess quickly any fall-off in operating efficiency of a vessel, so that remedial action may be taken to restore the ship as closely as possible to its original condition. One of the main problems which arises in detecting loss of performance of a vessel in service, is to distinguish between the individual effects of hull and propeller on thrust, torque, revolutions and ship speed. In addition, due to the variability of the wind and wave actions which affect the ship performance, genuine deteriorative effects tend to be masked, in the short term, unless special provisions are made to cater for their detection. Statistical methods of analysis of the ship data are therefore indicated, using a regression model which conforms with the known or empirically deduced physical laws governing the individual components of ship resistance. It is also envisaged that direct access to a high-speed digital electronic computer is available, and that the shipboard measurements can be quickly transmitted to the data processing centre.

THE REGRESSION MODEL BASED ON SHIP THRUST MEASUREMENTS

The author will consider the components of ship resistance to be viscous and non-viscous hydrodynamic forces for the ship in calm water in prime condition, forces induced on the hull by wave action, wind forces on the above-water hull and superstructure and those hydrodynamic forces due to combined hull and propeller deterioration of surface from the prime condition. Recent work by Hughes(2) suggests that for the present purpose the viscous forces on a hydrodynamically smooth hull may be regarded to be expressed by the equation,

$$C_v = 0{\cdot}067r[\log R_n - 2]^{-2} \tag{1}$$

(see nomenclature and Fig. 1)

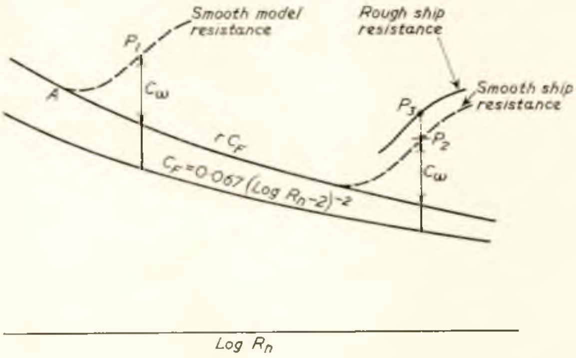

FIG. 1—*Extrapolation from model to ship resistance*

or in the form now preferred by Hughes as

$$\copyright_v = x[(\log R_n - 2)]^{-2} \tag{2}$$

The value of the form factor r or of the viscous resistance coefficient x can now be estimated with sufficient accuracy from model experiment data. Associated with this work is the

---

*Ship Division, National Physical Laboratory.

assumption that the mean wave resistance coefficient (ignoring humps and hollows) may be taken to vary as $(F_n)^4$ over the normal ship operational speed range. Details of this later work are published in a new paper by Hughes to the Royal Institution of Naval Architects(16).

It can be seen, therefore, that in the case of tankers, where the humps and hollows are either completely suppressed up to the operating speed or very minor in magnitude, the subdivision of total resistance of the smooth ship into viscous and non-viscous components depends mainly on functions of Reynolds number and Froude number at particular values of draught and trim. By deducting from the measured model values of total resistance coefficient, $C_T = \frac{R_T}{\frac{1}{2}\rho V^2 S}$, the appropriate values of C_v at a series of constant values of Froude number, the non-viscous resistance coefficient C_w can be obtained (see Appendix) over the full practical speed range. The results of an analysis for a typical model of 0·80 Block coefficient at three draught conditions, including the effect of trim in the ballast condition, indicate that r is draught and trim-dependent, and that C_w varies with F_n in a manner which is largely independent of draught (see Fig. 2). Model experiments to determine r and the variations of C_w with ship speed can therefore be conducted in specific cases, over the practical ranges of draught and trim which occur in service conditions.

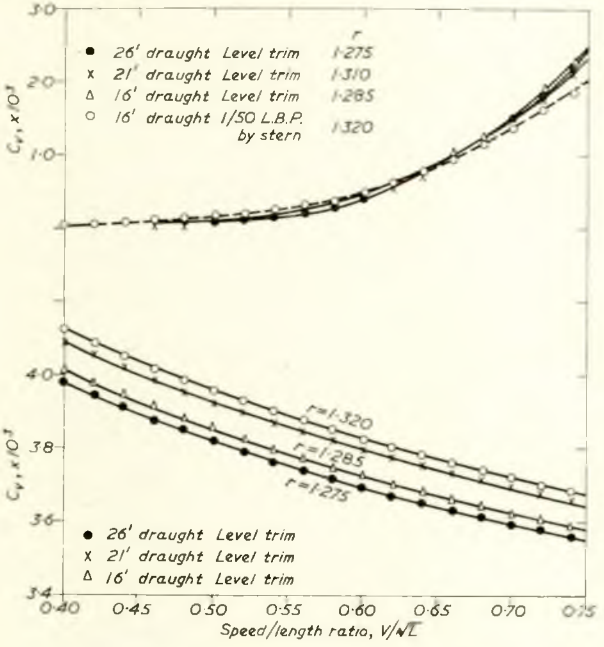

FIG. 2—*N.P.L. Model 3861 0·85 Block coefficient analysis of typical viscous and non-viscous resistance components*

The forces induced on the ship hull due to wave action are extensively dealt with in the literature on this subject, the most useful applications for the present purpose being those contained in references (3, 4 and 5). It is generally accepted that the increase in thrust due to wave action is proportional to the square of the wave height, and dependent on the frequency of encounter and ship speed. Using the thrust coefficient(3):

$$\delta(T)_K = \left(\frac{\delta T.L}{gB^2h^2_w}\right) \tag{3}$$

where $\delta(T)_K$ is the incremental thrust coefficient due to wave action:

$$\delta.T \text{ (due to wave action)} = \delta(T)_K \times \left(\frac{\rho g B^2 h^2_w}{L}\right) \tag{4}$$

The coefficient $\delta(T)_K$ depends on frequency of encounter and to a lesser extent on the ship speed. The values of $\delta(T)_K$ are uniquely determined for a given vessel by conducting model experiments in a series of regular waves at a number of constant speeds covering the practical operating conditions. By evaluating the thrust increment at a given speed, over and above that required to tow the model at the same speed in calm water, curves such as those shown in Fig. 3 may be derived. The net increase of ship thrust in irregular waves can be obtained by integration of the products of the energy spectrum ordinates and the values of $\delta(T)_K$ at each component frequency.

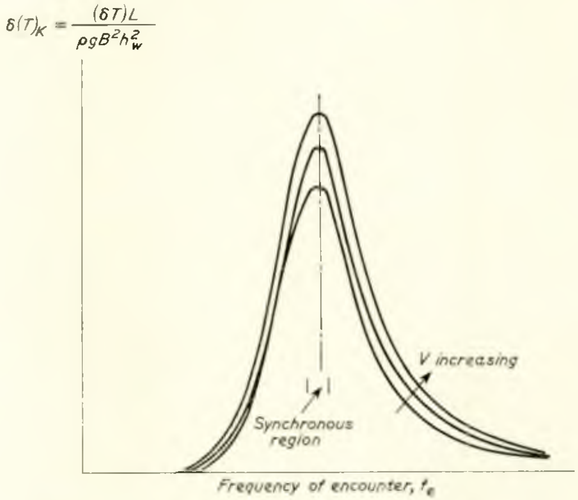

FIG. 3—*Mean increase of thrust in regular waves*

Unless special instrumentation can be provided on the ship to record the wave data in this form, however, it is suggested that the mean estimated values of wave height and frequency of encounter be used in equation (4) to evaluate the increase in ship thrust due to wave action. A scheme of recording the wave conditions encountered by the ship in service, similar to that described in references (6 and 7) is recommended in these circumstances.

Experiments to determine the wind forces on the hull and superstructure of several vessels have been conducted by the British Ship Research Association and the basic information required to estimate the ahead resistance is contained in reference (8). It is usual to express the ahead resistance coefficient due to windage in the form:

$$C_{wa} = \left[\frac{R_{wa}}{\frac{1}{2}\rho_a . V^2_R . A_T}\right] \tag{5}$$

which is dependent on the direction of the relative wind off the bow of the vessel, the draught and trim. In addition to these quantities therefore, it is necessary to record the magnitude of the relative wind force (V_R) and the transverse projected area of the ship above water (A_T) to deduce the total wind force R_{wa}.

The roughness of a new ship's hull may be considered as a combination of structural roughness and paint roughness. Allan and Cutland(9) have shown that even in the case of a modern flush-welded ship with a good paint finish on top of clean bare steel, the resistance is considerably above that of a perfectly smooth surface. In the case of a riveted vessel with projections along and transverse to the lines of flow, the structural roughness increases by as much as 15-20 per cent above that of a flush-welded hull surface. The most significant conclusion arising from the work described by Allan and Cutland is that incremented structural roughness for a given vessel is practically independent of Reynolds number. Therefore the increase in resistance coefficient C_T, due to structural roughness, over and above that of the hydrodynamically smooth ship, may be regarded as a constant quantity for all ship speeds in the operating range. In a similar fashion, Todd has shown that combined structural and paint roughness on different types of ship including tankers, generally increases C_v by a constant quantity at all ship speeds$^{(10)}$. Differing degrees of paint roughness therefore, in general, only determine the increments of C_v above the basic viscous formulation.

Having now accounted for the major components of ship resistance, the effects of propeller and hull surface deteriorations from the new ship condition may be regarded to be the difference between the measured values of total resistance and these combined effects already enumerated. Therefore, in coefficient form:

$$\alpha_1 = C_T - \Big[0{\cdot}067r\,[\,\log R_n - 2]^{-2} + C_w + \delta(T)_K.\left(\frac{g.B^2.h^2{}_w}{\frac{1}{2}.S.L.V^2}\right) + C_{wa}\left(\frac{\rho_a.V^2{}_R.A_T}{\rho S V^2}\right)\Big] \tag{6}$$

Now $C_{Ts} = \dfrac{R_{Ts}}{\frac{1}{2}\rho V^2 S}$, and the values of total resistance of the ship in service R_{Ts} need to be estimated at any time during the voyage. Since only propeller thrust readings are assumed to be available, the estimation of resistance has to be relied on from the identity:

$$R_T = T(1 - t) \tag{7}$$

Values of the thrust deduction fraction t have been analysed for several tanker models, to ascertain the dependence of this quantity on draught and trim. It is apparent from this preliminary analysis that no consistent trend exists, the general level of t being of the order of 0·250, sometimes increasing and sometimes decreasing with decreasing draught at constant values of Froude number. For a particular model however, it was expected that the variation of t with draught and trim could be established in equational form in the working range of ship speed, by conducting model experiments specially for this purpose. As can be seen in Fig. 4, the results for the model of the *Hemifusus* indicate that there is a large change of thrust deduction fraction (t) with variation of draught and trim, although it should be noted that these variations are rather severe and cover the most extreme values of draught and trim ever likely to be experienced with this vessel in service. Even so, a cross-plotting of t at constant trim of 6ft./stern and varying draught suggests that the equation:

$$t = 0{\cdot}254 - 0{\cdot}0003T_s + 0{\cdot}000089\ T_s^2$$

is a reasonable approximation for all values of speed/length ratio between $\dfrac{V}{\sqrt{L}} = 0{\cdot}45$ to $\dfrac{V}{\sqrt{L}} = 0{\cdot}52$. Since the cross-plotting of t with trim varying at constant draught also suggests some form of second degree curve, it may be assumed that in general the equation connecting t with draught and trim has the form:

$$t = B_0 + (B_1T_s + B_2\tau) + (B_3T_s^2 + B_4\tau^2 + B_5T_s.\tau)$$

where the symbol τ is used for trim in the absence of any agreed nomenclature. It can be seen therefore that from six experiments involving changes in draught and trim the values of $B_0B_1 \ldots B_5$ can be calculated exactly and that by running extra experiments, estimates of the accuracy of the fitted relationship connecting t with T_s and τ can be made, using the principle of least squares. Using such an expression for t thereby enables estimates of ship resistance R to be made from the measured ship values of propeller thrust T, from the identity $R = T\ (1 - t)$. As far as the effect of hull roughness on thrust deduction fraction is concerned, there is reason to suppose that this is of secondary importance in relation to the effect on wake fraction$^{(11)}$. Gawn's experiments indicate that various degrees of roughening of the surface of a 20ft. warship model only produce minor increases in t for quite substantial increases in wake fraction. Similar results have been obtained at the David Taylor Model Basin for a model of a single-screw cargo ship. In the absence of any conclusive evidence regarding the specific effect of scale between model and ship values of thrust deduction fraction, it will therefore be assumed that values of t deduced from the model experiments are not markedly dependent on hull surface deterioration, although the level between the ship and model values may differ in magnitude by a constant amount for a given ship.

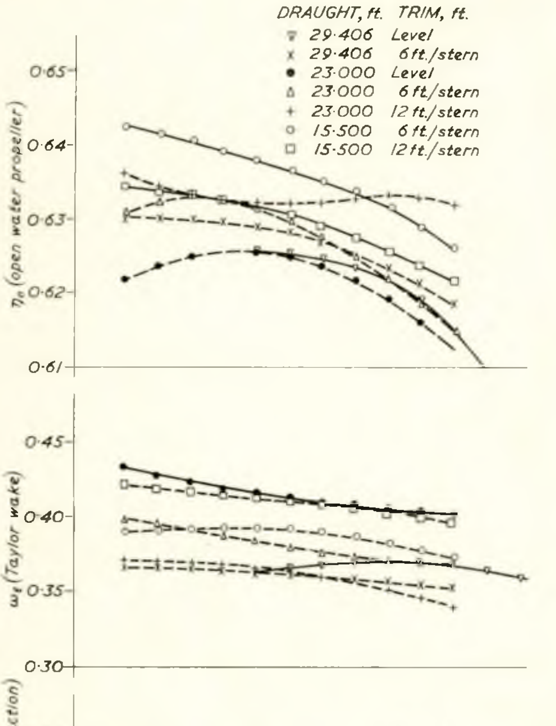

FIG. 4—*Model 4490* Hemifusus *results from computer analysis*

The specific effects of propeller surface roughness have been studied theoretically by Lerbs$^{(12)}$ and some experimental work by Emerson$^{(13)}$ supports the view that at high Reynolds numbers significant reductions in thrust and increases in torque coefficients (K_T and K_Q) occur with increasing roughness. These changes in thrust and torque coefficient inevitably result in a reduction of propeller efficiency with increasing surface deterioration. When plotted to the conventional J_0 base, the thrust coefficient K_T is substantially linear over the usual operating range for all values of constant roughness, whilst their slopes are substantially the same. For the ship advancing at speed V, therefore, on voyage in a particular condition, the progressive effect of increasing propeller roughness would be to necessitate increasing r.p.m. from the propeller to derive the same thrust T, as it is evident that no major change in wake fraction or thrust deduction fraction should be involved. The effect of propeller deterioration by roughening of its boss and blade surfaces will therefore be considered as a thrust change in equation (6), in a similar manner to the effect of hull roughness.

DISCUSSION OF EQUATION (6)

If all the quantities referred to are accurately measured, estimates of α_1 in equation (6) can be obtained for each simultaneous set of observations made on the ship in service. If such a series of observations are made every four hours, the derived values of α_1 should remain sensibly constant during any two days' observations of 12 readings, provided that the individual components of total resistance adequately account for changes in ship speed, wind and wave action. This can be checked using regression techniques. The results obtained for any one vessel in service can therefore be assessed on this basis to verify the adequacy of the equation proposed.

If equation (6) is re-written in linear form and is used as a regression model to estimate the variation of α_1 with time, the significance of the individual resistance components can then be assessed, viz.:

$$\alpha_1 = \left(\frac{T}{\frac{1}{2}\rho V^2 S}\right) - \left(\frac{t.T}{\frac{1}{2}\rho V^2 S}\right) - \alpha'_2\left(r.[\log(R_n - 2)]^{-2}\right) - \alpha'_3(C_w) - \alpha'_4\delta(T)_K\left(\frac{gB^2h^2{}_w}{\frac{1}{2}\rho SLV^2}\right) - \alpha'_5(C_{wa})\left(\frac{\rho_a.V^2{}_R.AT}{\rho SV^2}\right) \qquad (8)$$

To avoid possible correlation between variables, it is probably better to make the independent variable equal to:

$$y = \left[\frac{T(1 - t)}{\frac{1}{2}\rho V^2 S} - \delta(T)_K\left(\frac{gB^2h^2{}_w}{\frac{1}{2}\rho SLV^2}\right) - C_{wa}\left(\frac{\rho_a V^2{}_R.A_T}{\rho SV^2}\right)\right] \qquad (9)$$

and to regress on $\alpha_1 + \alpha_2 \log(R_n - 2)^{-2} + \alpha_3(C_w)$. In this case α_1 will mainly be expected to reflect the increase in resistance coefficient due to hull and propeller deterioration for successive samples, α_2 will mainly reflect the variation of r with draught and trim for successive samples, whilst α_3 should remain very nearly constant for all samples. The difficulties likely to be experienced in deriving statistical estimates of the coefficients α_1, α_2 and α_3 are that over a relatively short period, the changes in ship speed are not likely to be large, so that estimates of α_2 and α_3 in particular may be unreliable. Some of the uncertainty of α_2 and α_3 will therefore be reflected in α_1 which the author wished to use as a measure of hull and propeller deterioration. It may be desirable therefore to extend the sample size of each batch of data, by analysing the ship performance on a weekly basis when the speed variations should be greater. In this case it might be expected that the estimates of α_2 and α_3 should improve, and the correspondingly improved value of α_1 will then become a mean measure of performance deterioration per week. As the data are accumulated therefore, for specific vessels it should be possible to determine the best sample size which gives maximum significance to the term α_1.

THE REGRESSION MODEL BASED ON THRUST AND TORQUE MEASUREMENTS

It has been argued that the regression analysis of ship performance data based only on thrust measurements generally determines a fall-off in quality of surface of both hull and propeller, when both occur simultaneously. To distinguish between the effects of hull and propeller deteriorations, it is therefore considered necessary to analyse the behaviour of the propeller independently. Referring to Fig. 5, in which the ratio $\left(\frac{K_T}{K_Q}\right)$ of the propeller is plotted against K_Q, we obtain the curve *ABCE* for the smooth model propeller which can be used as the basic interpolator of performance[14]. The point *A* is taken as the intercept of the measured trial value of K_Q in the region of the average service speed, designated K_{Qo}, with the $\left(\frac{K_T}{K_Q}\right)$ curve for the smooth model propeller. Clements has shown from an analysis of service performance data that changes in weather from the ideal measured mile trial condition and the effect of hull roughness merely shift the observed values of $\left(\frac{K_T}{K_Q}\right)$ along the model propeller curve (Fig. 5). It will be assumed therefore that *AB* represents the effect of weather changes from the trial condition in a particular case, *BC* the effects of hull roughness deterioration from the prime condition, whilst the observed value of $\left(\frac{K_T}{K_Q}\right)$ plots in Fig. 5 at the point *D*. The effect of propeller roughness as already noted[12, 13] is to increase the value of K_Q and reduce the value of K_T, so that the vector *CD* represents this effect.

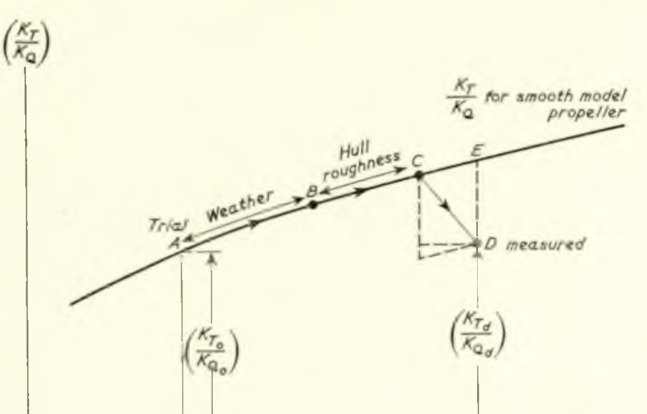

FIG. 5—*Determination of propeller deterioration*

If therefore the smooth propeller curve of $\frac{K_T}{K_Q}$ is expressed as a quadratic in K_Q:

$$\left(\frac{K_T}{K_Q}\right) = A_o + B_o(K_Q) + C_o(K_Q)^2 \qquad (10)$$

and denoting the values of K_T and K_Q at the point *D*, by the suffix *d*, therefore:

$$DE = A_o + B_o(K_{Qd}) + C_o(K_{Qd})^2 - \left(\frac{K_{Td}}{K_{Qd}}\right) \qquad (11)$$

The coefficients $A_oB_oC_o$ can be derived from the results of open water experiments, or preferably from experiments conducted in a water tunnel at high Reynolds numbers[13] using the least-squares technique and equation (10). *DE* in equation (11) is assumed to be a measure of propeller deterioration from the prime condition in the absence of precise definition of the point *C*. Since it can be assumed further that the condition of the propeller will generally remain constant in any two-day period, the twelve estimates of *DE* can be used to provide values of the standard deviation. Successive deterioration of propeller surface with time should therefore be reflected in the values of *DE* for successive samples.

CONCLUSIONS

A method of assessing deteriorations of hull and propeller surfaces of a ship in service conditions has been proposed using equations (9) and (11). If equation (9) is re-written, viz.:

$$\left[\frac{T(1 - t)}{\frac{1}{2}\rho V^2 S} - \delta(T)_K\left(\frac{g.B^2h^2{}_w}{\frac{1}{2}\rho SLV^2}\right) - C_{wa}\left(\frac{\rho_a.V^2{}_R A_T}{\rho SV^2}\right)\right] = \left[\alpha_1 + \alpha_2[\log(R_n - 2)]^{-2}\right] + \alpha_3(C_w)$$

each term can now be studied to assess what measurements are involved on the ship and corresponding model.

(a) *The first term*:

$\left[\frac{T(1 - t)}{\frac{1}{2}\rho V^2 S}\right]$ involves measurements on the ship of the thrust of the propeller T, the specific density of the water in which the vessel is working ρ which is dependent on temperature, the ship speed V and the wetted hull surface area S. The only quantity not directly measured is therefore S which is dependent on the draught and trim of the vessel. Curves of wetted surface area S can be calculated over a range of draughts and corresponding trims, so that this information can be stored in the computer, and a second order interpolation scheme will yield the value of S at specific values of draught and trim. Values of thrust deduction fraction t derived from model experiments and dependent on ship speed, draught and trim are assumed to be available.

TABLE I—TYPICAL SAMPLE OF DATA TRANSMITTED BY RADIO TELEPRINTER

00031 *Serenia*	English units							Line total
Reference	No.	31	31	31	31	31	31	186
Year day	Days	3,279	3,279	3,279	3,280	3,280	3,280	19,677
Time	Hrs., mins.	1,400	1,905	2,230	200	715	1,030	7,480
Wind V.	1/10 Knots	26	22	24	18	15	5	110
Wind drn.	Degrees	330	330	330	290	290	290	1,860
Swell ht.	Ft.	4	4	4	3	1	1	17
Swell frq.	1/10 e/min.	10	8	8	8	15	12	61
Swell drn.	Degrees	280	290	290	290	240	190	1,580
Ship V.	1/10 knots	170	170	171	174	175	175	1,035
Draught fwd.	1/10 ft.	434	434	434	434	434	434	2,604
Draught aft	1/10 ft.	428	428	428	428	428	428	2,568
Rudder	Degrees	5	5	5	5	2	3	25
Prop.	1/10 r.p.m.	1,040	1,040	1,040	1,042	1,036	1,040	6,238
S.h.p.	10 s.h.p.	1,953	1,953	1,953	1,956	1,945	1,953	11,713
Card ident.		1	1	1	1	1	1	6
Thrust	1/10 ton	1,473	1,520	1,496	1,473	1,473	1,473	8,908
Sea T.	deg. F.	77	77	76	76	75	75	456
Fuel consp.	gal./hr.							
Fuel s.p.g.	1/1,000	9,606	9,606	9,606	9,606	9,606	9,606	57,636
Fuel T.	deg. F.	237	237	237	237	236	237	1,421
Mst pres.	lb./sq. in.	600	600	600	600	600	600	3,600
Mst T. P	deg. F.	900	900	900	905	900	900	5,405
Mst T. S	deg. F.	898	900	901	904	899	900	5,402
Flugas P	1/10 % CO_2	132	130	131	133	132	133	791
Flugas S	1/10 % CO_2	129	128	129	130	129	130	775
Fnlgas P	deg. F.	354	355	357	357	348	352	2,123
Card Ident.		2	2	2	2	2	2	12
Fnlgas S	deg. F.	362	363	368	370	354	361	2,178
Air T. P	deg. F.	224	223	223	222	223	224	1,339
Air T. S	deg. F.	221	221	222	221	222	222	1,329
Alt. output	kW	465	440	430	440	465	500	2,740
Carst. flow	10 lb./hr.							
Carst. pres.	lb./sq. in.							
Carst. T.	deg. F.							
TC ballast	yes/no*							
Hull foul								
Card ident.		3	3	3	3	3	3	18
Watch tot.		25,074	25,605	25,909	23,839	24,275	24,591	49,293

*Yes = 1,111 No = blank

(b) *The second term:*

$\left[\delta(T)_K\left(\frac{g.B.^2h^2_w}{\frac{1}{2}\rho SLV^2}\right)\right]$ involves the known quantities of breadth B and length between perpendiculars L for a given vessel, V, ρ, and S already dealt with in the first term, and the additional quantities $\delta(T)_K$ and h_w. The coefficient $\delta(T)_K$ can be derived from special model experiments conducted in waves to assess the increase in thrust due to wave action, over and above that required to propel the model in calm water. As already noted under "The Regression Model Based on Ship Thrust Measurements", this coefficient for a given vessel is dependent on the frequency of encounter and to a lesser extent on ship speed. Measurements of the frequency of encounter and the mean wave height are therefore required on the ship.

(c) *The third term:*

$\left[C_{wa}.\left(\frac{\rho_a.V^2_R.A_T}{\rho SV^2}\right)\right]$ involves the additional quantities ρ_a, the specific density of air which is dependent on temperature, the velocity of the wind relative to the ship V_R and the area of the transverse projected area of the ship above water A_T. Values of A_T can be stored in the computer for various values of mean draught of the vessel, and interpolations made for any required value of draught recorded during the voyage. The coefficient C_{wa} is dependent on the direction of the relative wind off the bow of the vessel, the draught and trim and these quantities are therefore required before interpolation can be made using the diagrams contained in reference (8).

(d) *The coefficient* α_1:

As already noted, changes in this coefficient are taken to represent the variation of hull and propeller surface deteriorations. Being in coefficient form, it may be regarded as a change in C_T, so that if successive values of C_T by C_{T1}, C_{T2}, C_{T3} etc., are denoted then differences in C_T such as $(C_{T2} - C_{T1})$, $(C_{T3} - C_{T2})$ etc. can be transformed into changes in propulsive efficiency, if it is recalled that

$$C_T = \frac{R_T}{\frac{1}{2}\rho V^2 S} = \frac{T(1-t)}{\frac{1}{2}\rho V^2 S} = K_T\left(\frac{2D^2(1-t)}{S.J^2_B}\right) \tag{12}$$

and since $\eta_D = \eta_H.\eta_B$ we have:

$$\eta_D = \frac{C_T}{4\pi K_Q}.\left(\frac{S}{D^2}\right).J^3_B \tag{13}$$

Hence the change in propulsive efficiency is given by,

$$\eta_{D2} - \eta_{D1} = \frac{S}{4\pi D^2}\left[\frac{C_{T2}.J_{B2}^3}{K_{Q2}} - \frac{C_{T1}J_{B1}^3}{K_{Q1}}\right] \tag{14}$$

(e) *The coefficient* α_2:

This coefficient is a measure of the Hughes form factor r, which as has already been noted depends on draught and trim for a particular vessel. There would be some advantages therefore in assessing α_2 by the least-squares technique, rather than making a large number of calculations of the Hughes form factor for each draught and trim of the vessel in service, especially when the number of vessels involved is large. As is seen, the reliance which can be placed on these estimates of α_2 will depend on the size of sample during which it must be assumed that draught and trim do not materially change.

(f) *The coefficient* α_3:

Even if the Hughes form factor r is only approximately estimated, the analysis of Model No. 3861 given in the Appendix indicates that the $C_w - F_n$ relationship does not vary appreciably in character. The coefficient α_3 should therefore remain more or less constant for all samples of the data, irrespective of whether the ship is in prime condition or not. The derivation of C_w is still dependent however on a knowledge of the form factor and its behaviour with draught and trim.

(g) *The coefficients* $A_0B_0C_0$:

These will be determined by the method of least squares from the model data values of K_T and K_Q. As can be seen from equation (11), individual readings of thrust and torque coefficients K_{Td} and K_{Qd} taken on the ship are then sufficient to estimate the effect of propeller deteriorations DE.

AN EXAMPLE SHOWING AN APPLICATION OF THE MATHEMATICAL MODEL TO THE TANKER *Serenia*

Some service performance records for the tanker *Serenia* were made available by Shell International Marine Ltd. and the vessel's performance was analysed for one period of 15 days in the loaded condition. A sample of data for one day is given in Table I.

Using equation (9) viz.:

$$y = \alpha_1 + \alpha_2 [\log (R_n - 2)]^{-2} + \alpha_3 F_n^4 \qquad (C_w \propto F_n^4)$$

each three-day sample of data within this period of 15 days was scanned to determine if any significant correlation existed between the variables $[\log (R_n - 2)]^{-2}$ and F_n^4. Due to the high ranges of sea temperature recorded within these periods it was found that a strong linear relationship existed between the variables in some of the three-day samples of 18 observations. It was therefore unwise to expect any stability of the coefficients α_2 and α_3 since in these circumstances both statistical and computational difficulties arise in their determination. In an attempt to overcome the high correlation which existed between these two variables for some of the three-day samples, the sample size was increased to nine days. It was then found that the derived values of α_2 and α_3, using the least-squares techniques, were much more in keeping with the values expected on other experimental evidence.

By adding a new batch of data for the next three days and removing the data for the first three days for each nine-day sample, it was possible to estimate the values of the coefficients α_2 and α_3 without introducing any strong correlation between the two variables $[\log (R_n - 2)]^{-2}$ and F_n^4. In this way the values of α_1, α_2 and α_3 were derived for three successive nine-day periods within this period of 15 days, and these are shown in Tables II and III.

TABLE II

Coefficient	α_1
First 9 days	−0·256
Middle 9 days	−0·211
Last 9 days	−0·205
Average	−0·224

TABLE III

Coefficient	α_2	α_3
First 9 days	+0·0623	−0·910
Middle 9 days	+0·1700	−0·990
Last 9 days	+0·2100	−0·931
Average	+0·1474	−0·944

It can be seen that the coefficient α_1 representing the general roughness level is substantially constant for this 15-day period, although there is a slight tendency for α_1 to increase with increase of time.

As anticipated there is a high degree of stability in the coefficient α_3 whilst α_2 reflects the variation in form factor.

CONCLUDING REMARKS

A statistical model of ship performance is suggested for detailed analysis of service performance data for tankers and similarly full ships.

The quality of ship instrumentation is now reaching the stage when greater reliability can be placed on full scale data, and indices of performance can be evaluated to detect real changes in operational efficiency.

Further experience of using the present model is required however and it will no doubt need to be refined in the light of new developments.

With the improvements in quality of the ship data for service conditions and the speedy transmission of these data to the computer, new possibilities for verifying many of the assumptions made in translating model experiment results to full scale are available.

ACKNOWLEDGEMENTS

The work described in the foregoing paragraphs has been carried out as part of the research programme of the National Physical Laboratory and this paper is published by permission of the Director of the Laboratory.

NOMENCLATURE

(Based as far as possible on the recommendations of the 1960 I.T.T.C. committee meeting recommendations in Paris.)

Symbol *Quantity and Definition*

A_T = The transverse projected area of the ship above the waterline
B = Beam or breadth of ship
C_T = Coefficient of total specific resistance $= \frac{R_T}{\frac{1}{2}\rho V^2 S}$
C_v = Coefficient of viscous specific resistance $= \frac{R_v}{\frac{1}{2}\rho V^2 S}$
C_w = Coefficient of non-viscous specific resistance $= \frac{R_w}{\frac{1}{2}\rho V^2 S}$
C_{wa} = Coefficient of total wind specific resistance $= \frac{R_{wa}}{\frac{1}{2}\rho_a V_R^2 A_T}$
D = Diameter of propeller
F_n = Froude number $= \frac{V}{\sqrt{gL}}$
f_e = Frequency of encounter of ship to waves
g = Acceleration due to gravity
h_w = Height of wave from trough to crest
J_B = Advance number or ratio based on ship speed $= \frac{V}{nD}$
J_o = Advance number or ratio based on propeller speed of advance $= \frac{V_A}{nD}$
K = Coefficient of speed $= \frac{C_w}{F_n^4}$
K_Q = Torque coefficient $= \frac{Q}{\rho n^2 D^5}$
K_T = Thrust coefficient $= \frac{T}{\rho n^2 D^4}$
L = Ship length between perpendiculars
n = Rate of rotation of propeller
R_n = Reynolds number $= \frac{VL}{\nu}$
R_{Ts} = Total ship resistance
R_{vs} = Total viscous resistance of smooth ship
R_{ws} = Total non-viscous resistance of smooth ship
r = Hughes form factor
S = Wetted surface area
T = Thrust of propeller
T_S = Draught of ship
t = Thrust deduction fraction $= \left(1 - \frac{R_T}{T}\right)$
V = Speed of ship
V_A = Speed of advance of propeller
V_R = Relative wind speed to the ship
w = Taylor wake fraction in general $= \left(1 - \frac{V_A}{V}\right)$
α = Coefficient of regression equation in general
Δ = Displacement weight
η = Efficiency in general
η_B = Propeller efficiency behind ship
η_H = Hull efficiency $= \frac{(1-t)}{(1-w)}$
η_o = Propeller efficiency in open water
η_D = Quasi-propulsive coefficient
ν = Coefficient of kinematic viscosity
ρ = Mass density of sea water
ρ_a = Mass density of air

REFERENCES

1) DUGGAN, R. M., and FIELD, R. S. "A Statistical Approach to Ship Performance". Paper read at a joint meeting of the Institute of Marine Engineers and the Royal Institution of Naval Architects on Tuesday, 22nd February 1966.

2) HUGHES, G. 1963. "Correlation of Model Resistance and Application to Ship". *Trans. R.I.N.A.*, Vol. 105, p. 177.

3) CANHAM, H. J. S., CARTWRIGHT, D. E., GOODRICH, G. J., and HOGBEN, N. 1962. "Seakeeping Trials on O.W.S. *Weather Reporter*". *Trans. R.I.N.A.*, Vol. 104, p. 447.

4) ST. DENIS, M. 1951. "On Sustained Sea Speed". *Trans. S.N.A.M.E.*, Vol. 59, p. 745.

5) GERRITSMA, J., VAN DEN BOSCH, J. J., and BEUKELMAN, W. 1961. "Propulsion in Regular and Irregular Waves". *International Shipbuilding Progress,* Vol. 8, No. 82, p. 235.

6) HOGBEN, N. "A Study of Voluntary Observer Ship Data for the North Atlantic". National Physical Laboratory, Ship Division Report No. 33.

7) HOGBEN, N. "Sea State Observation Studies on the s.s. *Cairndhu* and r.v. *Ernest Holt*". National Physical Laboratory, Ship Division Report No. 32.

8) "Revised Code of Procedure for Measured Mile Trials". B.S.R.A. Report No. 145.

9) ALLAN, J. F., and CUTLAND, R. S. 1956. "The Effect of Roughness on Ship Resistance". *Trans. N.E.C.I.E.S.*, Vol. 72, p. 257.

10) TODD, F. M. 1951. "Skin Friction Resistance and the Effects of Surface Roughness". *Trans. S.N.A.M.E.*, Vol. 59, p. 315.

11) GAWN, R. W. L. 1942. "Roughened Hull Surface". *Trans. N.E.C.I.E.S.*, Vol. 58, p. 245.

12) LERBS, H. W. 1951. "On the Effects of Scale and Roughness on Free Running Propellers". *Journal of the American Society of Naval Engineers,* Vol. 63, p. 58.

13) EMERSON, E. 1958. "Roughness and Scale Effect on Propellers". *International Shipbuilding Progress,* Vol. 5, No. 43, p. 136.

14) CLEMENTS, R. E. 1957. "A Method of Analysing Voyage Data". *Trans. N.E.C.I.E.S.*, Vol. 73, p. 197.

15) HUGHES, G. 1965. "Ship Model Viscous Resistance Coefficients". National Physical Laboratory, Ship Division T.M. 80.

16) HUGHES, G. "An Analysis of Ship Model Resistance into Viscous and Wave Components" Parts 1 and 2. Paper read before the Royal Institution of Naval Architects on 10th February 1966.

APPENDIX

Analysis of Model No. 3861 (load draught)—level trim.

Ship dimensions:	400ft. b.p. × 55ft. breadth moulded × 26ft. draught moulded × 0·80 Block coefficient.
Scale of model:	1/22, Ⓢ = 5·994 (calculated) $\nu = 1{\cdot}2285 \times 10^{-5}$ at 59 deg. F.
Equivalent model dimensions:	18·2ft. b.p. × 2·5ft. breadth moulded × 1·181ft. draught moulded
Conversion factors:	Displacement Δ = 13,055 tons (SW)

1) $C_T \times 10^3 = \frac{8\pi}{\circledS} \times \copyright$ ($\copyright$ = measured model value)

2) $\circledS = \frac{0{\cdot}0935S}{\Delta^{\frac{2}{3}}}$ (S = wetted surface area of ship, sq. ft.)
(Δ = moulded displacement of ship, tons)

3) Froude number, (V = ship speed in knots)
$F_n = 0{\cdot}2977 \frac{V}{\sqrt{L}}$ (L = LBP ship in ft.)

4) Reynolds number $R_n = \frac{V.L}{\nu} = 10{\cdot}7 \times 10^6 \times \frac{V}{\sqrt{L}}$
(for model).

Hence

$$\frac{\nabla_m}{L_m.A} = \frac{42{\cdot}9}{18{\cdot}2 \times 324} = 0{\cdot}73 \text{ per cent}$$

the corresponding reduction in $C_T \times 10^3$ measured in the model resistance experiments is given by:

$$\delta C_T \times 10^3 = \frac{2\left(\frac{\delta V}{V}\right)_a}{1 + 2\left(\frac{\delta V}{V}\right)_a} \times C_T \times 10^3$$

and the following values therefore apply:

TABLE VI

$\frac{V}{\sqrt{L}}$	K	$\left(\frac{\delta V}{V}\right)_a$ %	$\delta C_T \times 10^3$	$\delta\left(\frac{V}{\sqrt{L}}\right)$
0·38	2·30	1·68	0·1350	0·0064
0·48	2·10	1·53	0·1195	0·0074
0·58	1·80	1·31	0·1051	0·0076
0·68	1·65	1·21	0·1195	0·0081
0·78	1·70	1·24	0·1732	0·0097

TABLE IV—LOAD DRAUGHT

$\frac{V}{\sqrt{L}}$	F_n	$R_n \div 10^6$	© (measured)	$C_T \times 10^3$ (measured)	$\overset{*}{C_T \times 10^3}$ (corrected for blockage)	$C_w \times 10^3$	+(r = 1·275) $C_v = 0{\cdot}067r\,[\log R_n - 2]^{-2} \times 10^3$
0·40	0·1191	4·280	0·986	4·131	4·015	0·035	3·980
0·42	0·1250	4·494	0·977	4·094	3·980	0·030	3·950
0·44	0·1310	4·708	0·970	4·064	3·950	0·040	3·910
0·46	0·1369	4·922	0·963	4·035	3·928	0·048	3·880
0·48	0·1429	5·136	0·960	4·022	3·910	0·060	3·850
0·50	0·1489	5·350	0·960	4·022	3·895	0·075	3·820
0·52	0·1548	5·564	0·960	4·022	3·890	0·100	3·790
0·54	0·1608	5·778	0·961	4·027	3·900	0·140	3·760
0·56	0·1667	5·992	0·970	4·064	3·930	0·190	3·740
0·58	0·1727	6·206	0·985	4·127	3·995	0·280	3·715
0·60	0·1786	6·420	1·020	4·274	4·100	0·408	3·692
0·62	0·1846	6·634	1·062	4·450	4·250	0·580	3·670
0·64	0·1905	6·848	1·103	4·622	4·432	0·782	3·650
0·66	0·1965	7·062	1·153	4·831	4·640	1·010	3·630
0·68	0·2024	7·276	1·211	5·074	4·860	1·250	3·610
0·70	0·2084	7·490	1·275	5·342	5·100	1·510	3·590
0·72	0·2143	7·704	1·352	5·665	5·390	1·815	3·575
0·74	0·2203	7·918	1·440	6·034	5·740	2·180	3·560
0·76	0·2263	8·132	1·551	6·499	6·180	2·640	3·540
0·78	0·2322	8·346	1·710	7·165	6·710	3·185	3·525

* *Blockage corrections*

This has been based on Dr. Hughes' paper (Tank Boundary Effects on Model Resistance, Trans. R.I.N.A., p. 421, 1961).

In this method the increase in speed of the model at speed V, to account for the tank boundary effect is given by $K.\left(\frac{\delta V}{V}\right)$ %, where $\left(\frac{\delta V}{V}\right)_b = \frac{\nabla_m}{L_m.A}$ and the following values of K are applicable to models tested at N.P.L.

TABLE V

$\frac{V}{\sqrt{L}}$	0·38	0·48	0·58	0·68	0·78
K	2·30	2·10	1·80	1·65	1·70

and: ∇_m = volume of displacement of model (cu. ft.)
$= \frac{2184.\Delta}{22^3} \times \frac{1}{62{\cdot}4} = 0{\cdot}003295\ \Delta$
L_m = length of model b.p. (ft.) = 18·2ft.
A = tank section area (sq. ft.) = 324 sq. ft.

Analysis of Model No. 3861 (medium draught)—level trim.

Ship dimensions:	400ft. b.p. × 55ft. breadth moulded × 21ft. draught moulded × 0·783 Block coefficient
Scale of model:	1/22, Ⓢ = 6·168 (calculated) $\nu = 1{\cdot}2285 \times 10^{-5}$ at 59 deg. F.
Equivalent model dimensions:	18·2ft. b.p. × 2ft. breadth moulded × 0·955ft. draught moulded
Conversion factors:	Displacement Δ = 10,342 tons (SW)

1) $C_T \times 10^3 = \frac{8\pi}{\circledS} \times \copyright = \frac{8\pi}{6{\cdot}168} \times \copyright = 4{\cdot}075\ \copyright$

2) $\circledS = \frac{0{\cdot}0935S}{\Delta^{\frac{2}{3}}}$

3) Froude number, $F_n = 0{\cdot}2977 \frac{V}{\sqrt{L}}$

4) Reynolds number, $R_n = \frac{VL}{\delta} = 10{\cdot}7 \times 10^6 \times \frac{V}{\sqrt{L}}$
(for model).

TABLE VII—MEDIUM DRAUGHT

$\frac{V}{\sqrt{L}}$	F_n	$R_n \div 10^6$	© (measured)	$C_T \times 10^3$ (measured)	$C_T \overset{*}{\times} 10^3$ (corrected for blockage)	$C_w \times 10^3$	$C_v \times 10^3$ ($r = 1{\cdot}310$)
0·40	0·1191	4·280	1·025	4·177	4·100	0·010	4·090
0·42	0·1250	4·494	1·016	4·140	4·070	0·015	4·055
0·44	0·1310	4·708	1·011	4·120	4·040	0·020	4·020
0·46	0·1369	4·922	1·006	4·099	4·015	0·030	3·985
0·48	0·1429	5·136	1·003	4·087	3·995	0·045	3·950
0·50	0·1489	5·350	1·001	4·079	3·982	0·062	3·920
0·52	0·1548	5·564	1·002	4·083	3·982	0·087	3·895
0·54	0·1608	5·778	1·006	4·099	4·000	0·135	3·865
0·56	0·1667	5·992	1·015	4·136	4·035	0·193	3·842
0·58	0·1727	6·206	1·033	4·209	4·100	0·280	3·820
0·60	0·1786	6·420	1·063	4·332	4·197	0·402	3·795
0·62	0·1846	6·634	1·095	4·465	4·325	0·552	3·773
0·64	0·1905	6·848	1·135	4·625	4·475	0·720	3·755
0·66	0·1965	7·062	1·182	4·817	4·657	0·922	3·735
0·68	0·2024	7·276	1·245	5·073	4·880	1·165	3·715
0·70	0·2084	7·490	1·318	5·371	5·142	1·447	3·695
0·72	0·2143	7·704	1·400	5·705	5·452	1·777	3·675
0·74	0·2203	7·918	1·496	6·096	5·810	2·155	3·655
0·76	0·2263	8·132	1·621	6·606	6·220	2·585	3·635
0·78	0·2322	8·346	1·773	7·225	6·690	3·075	3·815

**Blockage correction:*

$$\left(\frac{\delta V}{V}\right)_b \% = \frac{\nabla_m}{L_m \cdot A} = \frac{0{\cdot}003295\,\Delta}{18{\cdot}2 \times 324} = 0{\cdot}58 \text{ per cent.}$$

TABLE VIII

Blockage Correction:

$\frac{V}{\sqrt{L}}$	K	$\left(\frac{\delta V}{V}\right)_a$ %	$\delta C_T \times 10^3$	$\delta\left(\frac{V}{\sqrt{L}}\right)$
0·38	2·30	1·33	0·109	0·0051
0·48	2·10	1·22	0·098	0·0059
0·58	1·80	1·04	0·086	0·0060
0·68	1·65	0·96	0·096	0·0065
0·78	1·70	0·99	0·140	0·0077

Analysis of Model No. 3861 (ballast draught)—level trim.

Ship dimensions:	400ft. b.p. × 55ft. breadth moulded × 16ft. draught moulded × 0·766 Block coefficient.
Scale of model:	1/22 Ⓢ = 6·543 (calculated) $\nu = 1{\cdot}2285 \times 10^{-5}$ at 59 deg. F.
Equivalent model dimensions:	18·2ft. b.p. × 2·5ft. breadth moulded × 0·728ft. draught moulded
Conversion factors:	Displacement Δ = 7,706 tons (SW)

1) $C_T \times 10^3 = \frac{8\pi}{Ⓢ} \times © = \frac{8\pi}{6{\cdot}543} \times © = 3{\cdot}841\, ©$

2) $Ⓢ = \frac{0{\cdot}0935 S}{\Delta^{\frac{2}{3}}}$

3) Froude number, $F_n = 0{\cdot}2977 \frac{V}{\sqrt{L}}$

4) Reynolds number, $R_n = \frac{VL}{\delta} = 10{\cdot}7 \times 10^6 \times \frac{V}{\sqrt{L}}$

(for model).

TABLE IX

			Level trim		Trimmed l.b.p./50 by stern	
$\frac{V}{\sqrt{L}}$	K	$\left(\frac{\delta V}{V}\right)_a$ %	$\delta C_T \times 10^3$	$\delta\left(\frac{V}{\sqrt{L}}\right)$	$\delta C_T \times 10^3$	$\delta\left(\frac{V}{\sqrt{L}}\right)$
0·38	2·30	0·99	0·0804	0·0038	0·0829	0·0038
0·48	2·10	0·90	0·0715	0·0043	0·0745	0·0043
0·58	1·80	0·78	0·0645	0·0045	0·0666	0·0045
0·68	1·65	0·71	0·0705	0·0048	0·0701	0·0048
0·78	1·70	0·73	0·1000	0·0057	0·0955	0·0057

TABLE X—BALLAST DRAUGHT LEVEL TRIM

$\frac{V}{\sqrt{L}}$	F_n	$R_n \div 10^6$	© (measured)	$C_T \times 10^3$ (measured)	$C_T \overset{*}{\times} 10^3$ (corrected for blockage)	$C_W \times 10^3$	$C_V \times 10^3$ ($r = 1{\cdot}285$)
0·38	0·1139	4·066	1·075	4·129	4·050		
0·40	0·1191	4·280	1·066	4·095	4·030	0·020	4·010
0·42	0·1250	4·494	1·060	4·071	4·010	0·035	3·975
0·44	0·1310	4·708	1·056	4·056	3·990	0·048	3·942
0·46	0·1369	4·922	1·054	4·048	3·975	0·065	3·910
0·48	0·1429	5·136	1·052	4·041	3·970	0·090	3·880
0·50	0·1489	5·350	1·053	4·045	3·970	0·120	3·850
0·52	0·1548	5·564	1·055	4·052	3·980	0·160	3·820
0·54	0·1608	5·778	1·063	4·083	4·005	0·213	3·792
0·56	0·1667	5·982	1·072	4·118	4·050	0·280	3·770
0·58	0·1727	6·206	1·092	4·194	4·120	0·374	3·746
0·60	0·1786	6·420	1·121	4·306	4·215	0·487	3·728
0·62	0·1846	6·634	1·157	4·444	4·340	0·640	3·700
0·64	0·1905	6·848	1·197	4·598	4·490	0·808	3·682
0·66	0·1965	7·062	1·242	4·771	4·673	1·013	3·660
0·68	0·2024	7·276	1·310	5·032	4·900	1·260	3·640
0·70	0·2084	7·490	1·394	5·354	5·190	1·565	3·625
0·72	0·2143	7·704	1·484	5·700	5·520	1·917	3·603
0·74	0·2203	7·918	1·573	6·042	5·860	2·270	3·590
0·76	0·2263	8·132	1·676	6·438	6·230	2·660	3·570
0·78	0·2322	8·346	1·806	6·937	6·670	3·115	3·555

**Blockage correction:*

$$\left(\frac{\delta V}{V}\right)_b \% = \frac{\nabla_m}{L_m \cdot A} = \frac{0{\cdot}003295\triangle}{18{\cdot}2 \times 324} = 0{\cdot}43 \text{ per cent}$$

TABLE XI—BALLAST DRAUGHT—TRIMMED 1/50 LENGTH B.P. BY STERN

$\frac{V}{\sqrt{L}}$	F_n	$R_n \div 10^6$	© (measured)	$C_T \times 10^3$	$C_T \overset{*}{\times} 10^3$ (corrected for blockage)	$C_W \times 10^3$	$C_V \times 10^3$ ($r = 1{\cdot}320$)
0·38	0·1139	4·066	1·110	4·264	4·183	0·021	4·162
0·40	0·1191	4·280	1·103	4·237	4·160	0·035	4·125
0·42	0·1250	4·494	1·098	4·217	4·142	0·055	4·087
0·44	0·1310	4·708	1·095	4·206	4·135	0·085	4·050
0·46	0·1369	4·922	1·094	4·202	4·130	0·115	4·015
0·48	0·1429	5·136	1·095	4·206	4·130	0·145	3·985
0·50	0·1489	5·350	1·096	4·210	4·135	0·180	3·955
0·52	0·1548	5·564	1·099	4·221	4·145	0·217	3·928
0·54	0·1608	5·778	1·105	4·244	4·160	0·260	3·900
0·56	0·1667	5·982	1·114	4·279	4·192	0·317	3·875
0·58	0·1727	6·206	1·128	4·333	4·248	0·398	3·850
0·60	0·1786	6·420	1·151	4·421	4·325	0·500	3·825
0·62	0·1846	6·634	1·182	4·540	4·425	0·620	3·805
0·64	0·1905	6·848	1·212	4·655	4·550	0·770	3·780
0·66	0·1965	7·062	1·252	4·809	4·700	0·940	3·760
0·68	0·2024	7·276	1·305	5·013	4·880	1·140	3·740
0·70	0·2084	7·490	1·365	5·243	5·095	1·375	3·720
0·72	0·2143	7·704	1·425	5·473	5·325	1·625	3·700
0·74	0·2203	7·918	1·492	5·731	5·560	1·875	3·685
0·76	0·2263	8·132	1·592	6·115	5·865	2·195	3·670
0·78	0·2322	8·346	1·728	6·637	6·350	2·698	3·652

Discussion

Mr. D. R. Kaye congratulated the authors of the two papers on their contributions to the analysis of the performance of tankers in service conditions. They had given a vivid picture of practical and theoretical difficulties. One could only admire the way in which their own interest and humour and the resources of Shell International Marine had supported them through their difficulties. The extent of their achievement would provide encouragement for the work which still had to be done. The scope of the project covered so many particular areas of interest that he hoped he would be forgiven if he only touched on those with which he was familiar, but he trusted that they would be of general interest.

When he started to work on this subject in the Operational Research Division of Shell International Petroleum, he felt that they had to be very clear as to what they were trying to achieve. How might the results of the analysis improve tanker economics? How sensitive were these economics to the promptness and accuracy of the analysis? Just how prompt in their analysis and how accurate in their measurements and formulations did they need to be to produce planning and operating guide lines which would make a worthwhile difference to traditional procedures?

For any particular ships, the answers to those questions determined the scope and depth of the study which is required. This study will probably be different for different tanker fleets; it is even more different for different classes of ship. The feeling that ends must determine means had been reinforced during his recent work as a consultant with Mr. Canham of the British Ship Research Association. This work was concerned with the analysis of a more general class of ships, but which had so far concentrated on certain aspects of 10,000-ton cargo ships.

The question has to be asked, what is the purpose of making detailed analyses of service performance? Is it basic research into what causes the performance characteristics of ships, and so into how those characteristics can be changed? Such research seems to have two main aspects.

The first includes the questions: what are the performance characteristics of a ship at any one time? How do these compare with the characteristics of a model? How are they affected by various weather conditions which cannot be properly simulated in a tank? One attempts to investigate these questions in measured mile trials, but U.K. shipbuilders do not seem to have found it practical to do these trials for a given ship in a wide variety of conditions. Maybe this has led to over-generous performance allowances and to the required performance of a ship on its acceptance trials being not too stringent. Hence, if there is a competitive advantage to be found in offering ships with very little performance tolerance, one needs to find how they actually behave in the variety of conditions met in practice. This leads to the need for a very comprehensive and expensive programme of trials or to an effective way of finding what really happens to a ship in service conditions by monitoring its performance.

The second research aspect is to find how the characteristics change over time. There is clearly considerable potential value in this if it leads to proper discrimination between ways of inhibiting deterioration and fouling, and this would probably be of considerable value for Shell.

On the other hand, the answer to what is the purpose of the analysis may be to provide current operating criteria to give better management control of ships, to take best account of the changing costs of running the ship and of the changing value of its time, and to find the best economic balance between speed and route and running costs in current weather conditions and with current performance characteristics.

The definition of the purpose influences when the analysis had to be done, what has to be included in it, and the accuracy required. How current does the analysis have to be? If the purpose is research, as it seemed to have been in Shell work which had been reported, then he did not understand why radio with its complications was preferred to the post. It might lead to the ship's engineers following a discipline in maintaining their instruments, but it seemed to be an expensive way of achieving this discipline—if the study provided the only justification for telemetering. On the other hand, if the purpose was to lead to better management control, then little would have been lost by having the analysis delayed until the ship reached a port with a postal service.

What has to be included in the analysis? What are the relationships which have to be estimated? These questions are difficult, and they seem to have caused, originally, some disagreement between the authors of the two papers. The difficulty seems to be threefold.

Firstly, the problem is to translate naval architectural knowledge into equations having a form in which the particular physical characteristics in which one is interested can be fully identified with the parameters being estimated, and of course the physical characteristics have to be appropriate to the rough ship which is used in practice rather than the idealized smooth model met in tanks. Furthermore, the forms of the equations have to be such that changes in the dependent variables are caused by changes set into the independent variables by the ship's officers or by natural elements. Otherwise, the physical meaning of the regression estimates may be obscure.

Secondly, existing knowledge may not be adequate to represent properly the form in which the variables should enter the equations; this seems to be particularly true in regard to the propeller and in regard to weather and swell. He was surprised that the Shell authors had not taken greater account of waves and swell. He himself had found their effect highly significant for the two 10,000-ton cargo ships with which he had been concerned. However, he left to others the discussion of the naval architecture aspects of the two papers.

Thirdly, the relationships have to be written in such a way that their parameters can be estimated in spite of the correlations which arise between the various types of data generated in non-experimental conditions. Such correlations can have a severe effect on the estimation, so that while the fit of a relationship to a set of data may be good, the estimates of the parameters may be quite different for different sets of data. In so far as deterioration is of interest, it then becomes important to estimate separately those coefficients which are time-dependent and independent. It was a pity that it had not been possible to report the application of Dr. Doust's model to much more data in order to see whether, under a variety of conditions, he could get round the serious confounding between the regression coefficients. Mr. Kaye himself had found that over a greater amount of data, models which at times looked promising began to break down in particular combinations of circumstances.

In this type of work, what accuracy is required from the data? Firstly, if the interest is in learning how performance changes over time, then continued records are required, and it is clearly imperative that the instruments are robust enough to be kept in working order. The authors' observations on instrument reliability were most interesting, and somewhat depressing.

Secondly, what are the effects of the various types of error to which the readings are subject? Scatter of the measurements about their true value does not seem to be so serious because a sufficient amount of data is generated for the statistical analysis to take care of this. However, there is some bias in the regression estimates due to measurement scatter, but Mr. Kaye had found this to be negligible in his analysis. It would be interesting to know if the same had been found for tankers. Gross errors due to occasional misrecording can be picked up in the analysis so that these were not serious either, even though some ingenuity was required to devise effective computer programmes for picking up these errors. However, errors due to instruments going out of adjustment or starting to measure a different physical quantity are more troublesome, as the effect is not averaged out in the analysis. One can do a certain amount of consistency testing after the event to find when such changes had happened, and a correction can sometimes be applied. However, in spite of this, there were indications in the analysis with which he had been concerned that zero errors in the thrustmeter could cause up to a 2½ per cent error in the skin friction estimate. Errors or drift in the Pitometer can sometimes be picked up by analysing the cumulative sum of the differences between apparent water speed and land speed when the effects of current cancel out after a time. However, during the period when these effects are cancelling out, there could be as much as an eight per cent error in the skin friction estimate.

Mr. Kaye said that whilst he did not want in any way to disparage the work which had been reported, because it was a remarkable contribution and represented considerable faith on the part of Shell, he thought there was a danger that other shipowners might be put off, by the sheer scale of the Shell effort, from seeking the rewards of detailed analysis of the service performance of their own ships. With much more limited resources, using ordinary well kept log book data and some careful statistical analysis on a computer, programmers and operators of which did what one wanted, rather than what they wanted, one could look for estimates of skin friction to be accurate to within two per cent based on one week's fine weather data or four week's rough weather data. This was good enough for many purposes. However, this, of course, assumed that the instruments were functioning.

It was now becoming possible for most shipowners to have this type of analysis done. The insight gained from the programme, of which these two reports were probably only the first of many, would be of great use to such owners.

Mr. D. J. van Doorninck commented on the subject "Data Transmission" in the paper "A Statistical Approach to Ship Performance".

Two systems were mentioned, "Editor" and "Philips". He stressed that, although he was a representative of the Netherlands P.T.T., it was not his intention to push the Netherlands system. However, he wanted to remove a wrong impression which might have been created by the manner in which some data had been entered in the paper. The Netherlands P.T.T. were very grateful to the Institute of Marine Engineers and the Royal Institution of Naval Architects for enabling him to express the opinion of his Administration.

The starting viewpoint was the same: that the data collected on board should be fed into the computer with a minimum delay, without errors, and with the smallest possible number of intermediate processes. For that purpose some systems were studied in which a comparison was made between a British and a Netherlands system for the data transmission by means of radio-telegraphy. He would refer to the systems in that way.

It appeared that both systems were capable of data transmission in the desired manner. Finally the British apparatus was chosen "because delivery could be promised six months earlier". That was based on a misunderstanding, because the Netherlands industry, if necessary assisted by the Netherlands P.T.T., was undoubtedly able to deliver the required numbers at the right time.

For a good understanding of the fundamental difference between the two systems, he pointed out that the British system was an error-detecting and indicating and partly correcting system; the Netherlands system was an error-detecting and correcting system, the so-called A.R.Q. system (A.R.Q. standing for Automatic Request for Repetition), meaning that the Netherlands system printed a letter or figure only if it was correct. If the apparatus found a sign incorrect, nothing was printed on the tape or page. After an operator had received a message in the British system he would sometimes notice that the text was interrupted by asterisks, indicating that signs received there had been found incorrect. A tape received in the Netherlands system was always quite smooth, without any interruptions. But in good conditions both systems produced an error-free tape.

It was no doubt correct that in good conditions both worked without error; in bad conditions neither could manage. In regard to the statement: "The borderline at which the Editor started generating large numbers of error symbols and the Philips equipment started vainly cycling for error-free data was much the same", that was also correct in so far as the British system, apart from error symbols, also printed normal symbols of possibly non-detected errors. Within those limits, both sets of apparatus operated. The difference was that what the Netherlands apparatus produced was error free, whereas the British apparatus produced tapes with errors, at least symbols for errors which could not be corrected. The worse the connexion became, the more repetitions the Netherlands apparatus had to ask for, but the result remained an error-free tape, and hence a tape which could be used directly. In worsening conditions the British system produced more error symbols, hence a tape which could not be used, and repetition of the message had to be asked for.

In the paper, mention was made of the power of the transmitter to be used. There was a difference in the approach to the required transmitting power.

Starting from a geographically given transmission path at a certain time on a certain day in a certain year, in order to get an error-free tape in the British system it would be necessary to have a transmitter with a certain minimum power. For the same transmission path in the same conditions the minimum power for the Netherlands apparatus was determined by the number of repetitions accepted; in other words, a longer time required for transmission compared with a transmission without repetitions; in any case, an error-free tape would be obtained.

Mr. van Doorninck commented on the statement: "The level of errors is critical to the success of the system". He supposed that his requirements and those of the authors were the same, namely, data transmission which was quick, error-free and in directly processable form. It was not clear to him why a system should be accepted in which ten per cent of the tapes should be repeated, so that ten per cent more work would have to be done, with loss of time, and manipulations would have to be made with two versions of the same message to enable processable data to be fed into the computer. The procedure described in the last paragraph but one of "Data Transmission" and in the first, second and third paragraphs of "Data Processing" could be eliminated for the greater part if use could be made of error-free tapes immediately, at the first reception.

With regard to the expression "error-free", the British system was not fully error-free, but no more was the Netherlands system. It was possible, although the chance was very small, that in the Netherlands system an undetected error could creep in during transmission, that two elements of the seven-unit sign could change to such an extent that the ratio 3:4 was maintained, but that nevertheless a faulty sign was printed. The question might rightly be put, "How great is this chance?" His answer would be to the order of 1:1,000,000, dependent on the signal/noise ratio and fading.

Some time ago the Netherlands Administration had started collecting data with the aid of three Shell tankers which, every day, in very different conditions, transmitted and received standard data. After a sufficient amount of practical experience had been gained, data would be established for the efficiency and the chance of undetected errors.

The chance of the transposition error increased accordingly as the number of repetitions increased.

He hoped that he had succeeded in putting forward some aspects which might be of importance when other people were deciding on the data transmission system to be applied.

He was deeply impressed by the results of the measurements made by the authors, but it was rightly remarked in the Conclusions: "The principal weakness at present is the erratic reporting of information, and this is largely attributable to the high incidence of instrument failure that has been experienced. This has supported the early decision to use sophisticated data-transmission and data-processing techniques to ensure prompt discovery of faults in the recorded data."

However, he advocated, not a sophisticated data-transmission system, but an efficient, rapid, reliable system, compatible not only with the data-processing systems of today, but also with those of the future. The more profoundly this subject matter was studied, the higher would be the demands made. They must be fully aware of the chance that communication could become a weak link in the chain of the whole process.

MR. J. R. SCOTT said that the attack by Mr. Duggan and Mr. Field on the data embodied much sound statistical method, and their efforts to obtain or develop reliable instruments seemed certain to lead, at least, to noise-only (unbiased) measurements, the importance of which appeared to be clearly appreciated by them.

There were two points of analytical method with which he did not agree. Firstly, he was not happy about the use of the coefficient C_P, and would have some further remarks to make about such coefficients shortly. Secondly, on the matter of propeller deterioration there was no need to assume fixed wake conditions, to use the ratio K_T/K_Q or introduce the advance coefficient to obtain a measure of such deterioration. He would have some further remarks to make on this matter also.

Dr. Doust in his paper offered a mathematical portrait for use with voyage data which, according to him, was likely to be less reliable the more constant the ship speed (the latter part of the third section), or the larger the correlation between $(\log R_n - 2)^{-2}$ and $F_n{}^4$ (early part of sixth section). Now, if sea temperature was constant, R_n and F_n were linearly related since L was constant, and there was automatically a very high correlation between $(\log R_n - 2)^{-2}$ and $F_n{}^4$ over a large range of ship speed. Hence the author was effectively demanding large variations of both ship speed and sea temperature to obtain a reliable estimate of ship and propeller deterioration from voyage data. This demand was one which common sense rejected; speed and temperature were variables in this complex problem, and their constancy in voyage data would reduce, not increase, the complexity of the solution.

Hughes, in reference (16), was not concerned by the correlation between $(\log R_n - 2)^{-2}$ and $F_n{}^4$; indeed he did not even notice it. Dr. Doust would have done better to have followed that example, because the correlation and the splitting of resistance into viscous and wave-making components were both totally irrelevant to the problem. Assuming, to simplify the discussion, calm weather, the dependent variable y of equation (9) was an estimate, from a number of sources including the ship on voyage, of the current ship resistance coefficient. This quantity varied with speed in a non-linear fashion as well as with hull condition. If it was subtracted from any estimate of ship total resistance coefficient which did not depend upon the current voyage (e.g. estimates based on acceptance trials data or, if they were not available, any ship estimates based on model results), the variation due to speed was largely removed. The new dependent variable was a deviation from a reference curve which estimated new ship resistance, and as such would reflect the hull deterioration without the complicating influence of speed variations.

Apart from tidying up the variable y—the need for which he would shortly show—there was, in view of error of the measurements concerned, little more which could justifiably be done towards the estimation of ship deterioration. Dr. Doust had, however, done quite a lot more. He had almost completely fogged the measure of hull deterioration by expressing the estimate of ship total resistance in the approximate component form described in reference (16) (thereby imposing additional error due to not taking account of hollows and humps in the resistance curve), discarded the coefficients derived from the model, and replaced them by others which, by placing the resistance components into regression instead of using them as a pre-correction, he left the error-prone voyage data to estimate. This latter action was effectively using the voyage data as a very coarse (and irrelevant) test of a type of total resistance breakdown which should not have been introduced at all. It also had the effect of causing the values of α_1, derived from samples to be much more sensitive to measurement error than simple deviations from some independent reference resistance curve. It was not surprising that he found himself wanting large variations of ship speed and sea temperature.

Such were the dangers and penalties of unjustifiable over complication. This was the type of statistical method which led, in a recent ship model correlation study, to the discovery of an automatic ship cleaning property of warm sea water, to the interpretation of a systematic block coefficient difference as being due to some mysterious difference between Arran and Newbiggin and to other absurdities. It could be more dangerous when applied to the economics of ship design and operation, for it might well allow some mechanical or physical variation to emerge convincingly in the form of ship's captain inefficiency or even negligence.

The use of the voyage thrust measurement in the first term of equation (9) seemed a strange choice. This term, when properly referred to a standard, reflected mainly the hull deterioration, but presumably had an element of reflection of propeller deterioration, because it was modified by a thrust deduction deduced from model results rather than actual current ship thrust deductions. In other words, it neither measured the hull deterioration nor the full hull and propeller deterioration, and it was very difficult to decide precisely what it did measure. Full hull and propeller deterioration was measurable by observing the variation of ship input (d.h.p.) with ship output (speed). One wondered why Dr. Doust had again departed from the wiser precedents of previous voyage analysts, when the result of such departure was merely additional confusion. Mr. Scott had succeeded in performing an unbiased voyage analysis on these lines for a well-known passenger liner, using the usually much maligned routine ship's logs; such logs in the past had often been the scapegoat of the analyst's deficiencies.

The first term of equation (9) could be criticized on two more grounds which did not exist for other choices. First, it embodied a displacement correction which assumed that the variation of resistance with displacement was exactly linear in wetted area. This was certainly not true for models (the results of which could be used for a superior displacement correction) and seemed most unlikely to be true for ships.

The second reason for criticism was that the choice of the term had evidently been heavily influenced by naval architects' algebra, without the necessary detailed error consideration which was vital for obtaining efficient and unbiased results from regression. Ratios of any kind which involved important random error in both numerator and denominator required particularly careful "statistical" attention. This term had not been so considered by Dr. Doust for, had he done so, he would have used another much simpler and potentially more reliable dependent variable. Here again unnecessary complication had been injected.

Turning next to the wind and wave terms of equation (9), these too could be criticized on similar grounds plus another one. Both these terms were subject to both systematic (scale effect) and random error. His own experience of voyage analysis had shown that the random error of any representation of wave effect was large enough to cause very important systematic biases if such a term was used as a pre-corrector instead of being put into regression. This systematic effect of random error was a case of a general "statistical" phenomenon usually called spurious correlation. Here the effect of pre-correction by the wave term would be to make the residuals indicate a systematically better ship performance in bad weather than really existed, and a worse one in good weather. The author had, in his paper, pre-corrected where he should not have done, and not pre-corrected where he should have done.

Given unbiased sets of Q, T, N for trial and a short period during any voyage, he could desk-calculate, in a very short time, a reliable and easily interpretable measure of propeller deterioration. He was therefore surprised to see the complexity and indeterminacies of the fourth section. The method ran the risk of several kinds of scale effect, and Dr. Doust would be fortunate to find a trial point (A in Fig. 5) which lay on the model curve even if all measurements were error-free; ship wake was not uniform.

Those people who believed that a knowledge of the mere mechanics of multiple regression plus a computer were the only analytical requirements for solving such complex problems as voyage analysis and ship economics would, after needless expenditure of large sums of money and time, discover that they were wrong.

MR. G. H. M. GLEADLE said he was a member of the Post Office which had been concerned with helping to provide radio communications between ship and shore. It would be invidious for him to comment on some of the unkind things which had been said about the Post Office, but suffice it to say that not all the difficulties due to equipment faults and operating difficulties resided in that part of the communications carried out by the Post Office. The difficulties in transmitting data from a ship to the shore, if possible without any errors at all, stemmed from the vagaries of the medium involved, radio communication via the ionosphere. There were certain things which could be done, such as devising a system which attempted to compensate for those errors, such as that described by Mr. van Doorninck and the Marconi system used in the Shell experiment.

To get the difficulties into perspective, one should look at them against the background that there was no existing radio communication system available for the purpose. What had been done was to pioneer a system suitable for use by ships at sea, with all their limitations. For instance, ships had limitations in the size of the transmitter which could be used, and there were difficulties of frequency stability, diversity reception, the possibility of using single side band emission, and so on.

The Post Office had future plans for this kind of work. It was in the process of setting up a permanent service at the long distance radio station at Burnham to enable data from ships to be received and connected directly to the offices of the subscriber on shore by Telex, or if preferred, the messages could be received at Burnham and transmitted later to the offices of the subscriber. This latter point was rather subtle. For instance, when the ship was in the Far East, the times of the day when reliable radio propagation was possible were limited, and when it was possible for propagation, it was very likely that the offices of the shipping organization on shore were not open.

This radio system could be used not only for transmitting data such as had been described in the papers, but for all kinds of messages, such as sending radio teleprinter messages, radio telegrams, and for dealing with such things as wages sheets, stores lists, and so on, which were difficult to transmit at the present time.

On the international plane, the International Radio Consultative Committee of the International Telecommunications Union was now studying systems suitable for transmitting radio teleprinter messages and data, with the object eventually of trying to reach agreement internationally on a preferred system, so that once a ship was equipped it would be able to work into any country which operated the service.

In Britain, the Marconi system was being used not only by the Shell Centre. It was also being used on the oil rigs operating in the North Sea; it was used on the *Mauretania,* on her last voyage, for receiving press broadcasts from New York and Tangier. At the present time the Post Office had a number of requests from shipping organizations for similar services to be provided on a commercial basis.

At the moment, the performance of the system for the Shell service was working out as follows, on an average over the last 18 months: about 60 tapes per week were transmitted from Shell tankers, and each tape contained about 1,800 characters. The detected, but uncorrected, error rate was averaging out at one error in 1,200 characters. This was sufficiently good for all practical purposes. On certain shipping routes, such as the North and South Atlantic, the error rate was practically nil. The error rate was increased when transmissions to ships in the Far East were concerned.

The United Kingdom could be justifiably proud in pioneering this work, and in providing a new kind of service for shipping. It was not claimed that we were the first, but we were among the first countries in the world to develop such a system and put it to commercial use.

CAPTAIN W. S. C. JENKS, O.B.E., R.N. (Member of Council, I.Mar.E.) said he was impressed by the wealth of technical information which was contained in the papers. The key to the first paper was the objective given in the first few pages, that this was a research exercise for investigating performance deterioration and not a management tool. When he had first heard that this was happening, his first reaction was one of frank disbelief and his second reaction was that certain people needed their heads examining, but that was based on the misconception that this was an attempt to be a tool of management.

Here was an example of the very considerable resources of a large organization being used in an extremely sophisticated way to obtain precise scientific data under seagoing conditions. The authors had been frank in indicating that they found this a very difficult thing to do. This, for any marine engineer, was a quite predictable conclusion to come to. His impression was that this was a very large sledge hammer attacking what was admittedly a very large nut. At the end, it seemed that no claim had been made to do more than to put one or two dents in the nut. The nut was not really cracked, and it appeared that it would be a long time before it would be. This was no disrespect to the authors, for the problem they had tackled was very formidable.

Like so many statistical exercises, whatever came out of this exercise could not be better than that which was put into it. The authors had stressed the instrument errors. He suggested it might have been a more economic procedure to list the basic things which were really essential to the object of the exercise, which was hull performance deterioration, and to see whether the accuracy of the instruments available for measuring the basic parameters was likely to be sufficient to give a useful result. These parameters were the r.p.m. of the shaft, the torque, the thrust, the speed of the ship relative to the water outside the boundary layer, the wind relative direction and speed, the sea state as regards the relative direction, height of sea and frequency of encounter (this had only been estimated), the trim of the ship related to still water, and, something which was very important, the course record and rudder angle record; bad steering could make a very great deal of difference to the speed of the ship in relation to the power input; also a record of the ship's motion in respect of roll angle, pitch angle and heave would be desirable.

Machinery data did not appear to be directly related to the main purpose of the exercise, but when one had set up all the elaborate equipment, there was an obvious temptation to use it for other purposes.

The factors of torque, thrust and speed were so fundamental that he did not believe useful results could be obtained unless those figures were reliable. He deduced from the paper that only now was the authors' company beginning to obtain measurements of sufficient accuracy for the purpose required. Particularly, speed was still apparently not being measured with the relative degree of accuracy and this must throw doubt on the reliability of results so far obtained.

The other basic parameter which was exceptionally difficult to measure was the sea state. At present it was estimated, but was the effect not really very large indeed in relation to the results being analysed? He realized that these were very large ships, and the effect was much less than it would be on some of the smaller ships to which he was more accustomed; but certainly with smaller ships, the effect of adverse sea conditions could be devastating.

He expressed the view that, given accurate instrumentation of the really effective parameters, and using manual recording—which was not all that difficult—and by using the mail, and then feeding the information into the most suitable kind of processing equipment back at base, it would be possible to get just as reliable a result with a great deal less effort. A great deal of the equipment described was concerned with trying to deal with errors which it itself had produced, and a large part of the discussion so far had been concerned solely with the question of transmitting the information by radio from the ship to the head office. This was a difficulty which had been imposed by the authors themselves, and it was completely irrelevant to the basic research, which was trying to find out why the ship went more slowly after a certain time.

Most marine engineers would not be tempted, after reading the papers and certainly not after listening to the discussion, to rush into these kinds of techniques for the day to day management of their ships. In fact, the papers provided a very worthwhile warning of the difficulties into which one could run and the order of cost which would be required.

He stressed the human element. If one was going to try and manage ships remotely, it was going to reduce the marine engineers, and captains and ships' officers to the level of automata. Human beings were not very good at being automata. Ship's officers had others things to do besides trying to evaluate the performance of the ship or getting the last ounce of efficiency from fuel consumption. They had to keep the ship running, and they were only going to keep it running if they were self-reliant, practical men who had been brought up to exercise their own judgement and their own discretion, and if they had the authority and trust of their management. So far as ordinary management was concerned we should beware of rushing into these modern, sophisticated techniques and ignoring the human factor, however valuable such techniques might prove for research purposes as described in this paper.

Mr. A. Silverleaf, B.Sc. (Member of Council, R.I.N.A.) said that there was no more important subject for the naval architect, the ship designer and the marine engineer than that of knowing more than they did at present about performance of ships in service. Unless more was known, they would not be able to design ships to achieve the best performance over their whole service lives. The work described, particularly in the first of the two papers, was an extremely valuable and bold step in that direction.

It was necessary to know a number of things. Firstly, if more was to be learned about the behaviour of ships at sea, it was necessary to know what information one needed to have at one's disposal. Secondly, it was necessary to know how to get it. Thirdly, one had to be prepared to make the effort to get it. Fourthly, and perhaps just as important as any of the others, one had to know how to interpret it and make use of it as, among other things, a tool of management.

The National Physical Laboratory had been delighted four years ago to find that Shell were prepared to make the very substantial effort to take the real first step along this largely untrodden road, and it was deemed an honour to have been asked to help in breaking the new ground. It was also gratifying that Shell had found it possible to publish so much, and so frankly, about what had been achieved and the difficulties that had been encountered; some of the difficulties had probably been anticipated—though not in detail—and complete success had not been expected.

The first comment to be made on the paper by Mr. Duggan and Mr. Field was gratitude for the way in which they had so thoroughly and feelingly described the difficulties involved in the first three stages. There was a major difficulty in dealing with the first stage, that of knowing what information was essential. It was stressed that in a first approach of this kind, the target was deliberately limited, in the knowledge that what one felt ought to be obtained was far too difficult to achieve at first shot. For instance, there was the point which had been made about the quantitative measurements of sea states and ship responses, which were vital if the job was to be done thoroughly; that would be done in the next phase.

It was striking that what had been tackled would have been impossible 20 years ago; the tools were not there. Even with the most modern tools, the most substantial resources, and the most intensive effort, there had been considerable difficulties. But we were not going to be daunted by those; there was a point of no return, and Mr. Silverleaf suspected that that had been passed. Many other shipowners, if they were going to stay in profitable business in the next 20 years, would have to adopt techniques of the same kind in principle, if not in detail.

The attitude of progressive shipowners was a tremendous challenge to those who worked in ship model laboratories. It was clear that we did not yet have much of the information which the laboratories ought to be able to provide. Some first steps had been taken towards supplying this information and the papers provided a very useful opportunity to assess the present position. One could look back and see how far one had come, on the ship model side, knowing clearly that there was a long way further to go.

Although he had spoken in general, there was one point of detail he wished to mention. When he had read the first paper, he had been rather surprised and puzzled at some of the comments in that part of it dealing with the analysis of data. However, Mr. Field had cleared up many of those doubts in his presentation of the paper. For the sake of the record, he hoped Mr. Field would repeat them. One particularly puzzling phrase was: "It was a serious setback when some of the assumptions required by the mathematical model proved to be invalid". That was not the kind of sentence he would have expected from a mathematician. He saw no evidence in the paper, as written, to substantiate such a criticism. It appeared, from what Mr. Field had said, that it was the way they set out to use the model that was in question, and that nothing in the first paper invalidated the basic approach proposed in the second paper.

The simplified system of analysis which had been adopted in the first paper was open to criticism, more so than the rather more complicated version which the National Physical Laboratory had attempted to produce. However, it was important to recognize that it had been adopted before the information, which Mr. Field had mentioned, in particular the variation of thrust deduction fraction with ship loading and trim, had become available. Mr. Silverleaf's confidence in the N.P.L. analysis method was not damaged by the results of the first tentative analyses which Dr. Doust had carried out on the samples of data which Mr. Silverleaf had so far been able to examine.

He was not clear how the accuracy of the values which had been derived from the simplified approach which was used in the paper could be assessed, and this seemed to be important in such a statistical approach.

How would Mr. Duggan and Mr. Field have modified the plans they had made three or four years ago if they were now to make a fresh start, using all the experience they had gained?

Mr. H. J. S. Canham (Member, R.I.N.A.) said that he found the paper by Mr. Duggan and Mr. Field a mixture of the admirable and the curious. It started by a brief review of the problem of performance deterioration in service, and in this context mentioned some 50 trials on Shell tankers. It mentioned Mr. Kaye's ideas about using log-book data as an alternative to trials, but rejected these ideas because a very high proportion of data from Shell tankers was found to be missing or inaccurate. Having discussed the subject of voyage analysis in a few terse sentences, it then gave a detailed description of a most comprehensive system for recording, transmitting and editing voyage data. It then described very briefly a method of analysing the data, which the authors apparently regarded as somewhat primitive, but apparently also successful.

Primitive was the last word he would use to describe the Shell system for collecting data and censoring it for analysis. It was obviously rather an expensive system; he guessed the annual cost of running the system was about £30,000, and in addition there was the cost of the capital equipment. It was spoken of as a research tool rather than a management tool, but presumably, as a result of the investigations, the company must in due course extend the system to other ships. The running costs would fall as the number of ships involved increased; but what was the position of a shipowner who had a much smaller fleet than Shell? The expected return on the investment must therefore be quite considerable; could the authors say something more about the economics of the exercise?

Accepting for the present the necessity for having such an advanced system—and the studies which had been made by Arthur Andersen and Co. for B.S.R.A. seemed to come to a contrary conclusion—then without a doubt the recording, transmitting and editing system had been developed in a thoroughly professional way.

The choice of sampling once per watch was wise; it accorded with shipboard routine. Time would tell, but he believed the choice of a five-minute sampling period to be unwise. It would be adequate under steady steaming and favourable weather conditions, when precise synchronization of deck and engine room readings did not matter. It was a different situation when the ship encountered waves. Due to their irregular nature, particularly ocean swells, waves encountered could vary considerably within a period of minutes; even when the waves constituted a stationary random process. A widely accepted criterion was the need to meet 100 waves to secure an adequate statistical sample. This could not usually be done in quartering or following seas, but their effect was probably small anyway. At least 15 minutes was usually required, even in head seas. A shorter sampling period might not matter if the propulsion data conformed to the wave conditions actually encountered, but the speed of the ship would tend to lag behind the waves, and the lag became less important as the sampling period lengthened. With a sampling period of 15 to 20 minutes it was more likely that the recorded speed would conform to the average wave conditions. Automatic data-logging was the best way to ensure that adequate records were taken and that they were properly synchronized. Records, taken by B.S.R.A. during seakeeping trials, had shown that the coefficient of variation of thrustmeter readings was about one per cent of normal service thrust in winds up to Force 7, so that it should be practicable to get an accurate thrustmeter reading quite quickly when steaming at constant power, and five minutes was more than enough for that purpose.

He questioned whether it was realistic to aim at speed measurement within ⅓ per cent. In the work carried out by Arthur Andersen and Co. for B.S.R.A., an error of one per cent in the measured thrust was found to lead to an error of 1½ per cent in the estimate of a frictional resistance coefficient, obtained from data logged in fine weather by the particular 10,000-ton cargo ship under investigation. The figure corresponding to an error of ⅓ per cent in measured speed was one per cent in the coefficient. He doubted if they would ever get below ½ per cent even with the electromagnetic log which the Royal Navy regarded so highly, but that should be quite adequate for voyage data purposes. The major part of the inaccuracy in speed measurement would arise because of the turbulent nature of ocean waters, because of the various interactions between ship and surrounding water, because of the limitations of any log calibration technique and because, in waves, the speed of the ship was unsteady, anyway.

Some explanation was required as to why Dr. Doust's analysis method was found unsatisfactory. Mr. Field had given some of the information in his presentation, and it should be on record.

In the second paper, Dr. Doust had proposed a method of analysis which was a considerable advance on anything yet published and which, on the face of it, deserved to be successful. Why was this apparently not so? In the analysis, the total resistance, reduced to smooth water and no air resistance, was regressed on the smooth viscous resistance and the non-viscous resistance. The term α_1 represented the increased viscous resistance due to all resistance effects not properly accounted for by the other terms; α_1 did not include any propeller effect, since neither delivered horsepower nor propeller slip was involved in the formulation at this stage; α_2 represented Hughes' form factor which would vary with draught and trim; α_3 was a scaling constant if Hughes' deductions in wavemaking resistance were valued for the rough ship, but would also vary with draught and trim as shown in Hughes' recent paper.

Difficulties could immediately be foreseen when it came to estimating α_1, α_2 and α_3 from voyage data. R_n and F_n were both proportional to speed, and confounding of the α_2 and α_3 terms would almost certainly occur in practice, even if this did not happen in Dr. Doust's particular sample. Any values of α_2 and α_3 obtained would be averages for the period covered by the data, and these would conceal any variation in α_1 occurring during this period. Dr. Doust's method of overcoming this disadvantage meant that great reliance must be placed on the allowance made for weather. Mr. Canham's experience had been that the weather formulation would be inadequate for a 10,000-ton cargo vessel.

B.S.R.A. had adopted a similar method for estimating thrust increase in waves, using Series 60 data, but found that these particular data only gave sensible results in head and bow waves. It had been necessary to make separate allowance for sea and swell, the latter allowance not being based on a wave spectrum. If wave records formed part of the data, full allowance for weather could probably be made in the manner proposed in the paper. As in practice, only subjective measurements of sea state were obtained, it was found vital to test the validity of weather formulations before attempting to estimate viscous resistance. Viscous resistance had not been divided into smooth and rough components, as only the upper limit was of economic importance to the ship's operation.

B.S.R.A. had felt obliged to disregard thrust deduction as a matter of expediency, as very little was known about it, on a rough ship. Perhaps they did not know so much about it on a smooth model, if one looked at Dr. Doust's Fig. 4. If that figure was to be believed, thrust deduction was a fickle thing. However, did those curves really represent the influence of the propeller on the resistance of the hull? Surely experimental error must be a prime factor.

On the subject of propeller roughness, reference could also be made to the model work of Ferguson and the full-scale work reported by Schmierschalski. Mr. Canham agreed that it was reasonable to assume no major change in wake fraction or thrust deduction purely out of a change in blade surface roughness. He was puzzled by the statement that the effect of blade roughness could be considered as a thrust change in equation (6). This was without question a hull resistance equation. In neither paper did the authors explain how they translated changes in K_T/K_Q at constant K_Q or constant advance coefficient into changes of thrust. In both cases the assumption was made of constant wake fraction. Unfortunately, changes in wake would occur as a result of changes in draught and trim and in hull roughness. Experience showed that these changes would happen more quickly than any change in blade surface roughness. It had therefore to be emphasized that using an advance coefficient, based on apparent slip instead of real slip, would mask the effect of propeller deterioration if wake fraction increased while the propeller roughened. The apparent improvement in the propeller performance of *Serenia* between August 1963 and March 1965 arose directly from this invalid assumption, for the upper curves in Fig. 16 of the paper, by Mr. Duggan and Mr. Field, showed clearly the hull deterioration which occurred during that period. With the restoration of the hull to the original condition, genuine propeller deterioration should then be revealed by this method of analysis.

It stood to Dr. Doust's credit that he had attempted to define a more rational approach to the analysis of voyage data than had previously been reported to the two Institutions. There were definite snags in this approach, but the proof of the pudding was in the eating. The method did not appear to have been tested very fully so far, and B.S.R.A. had offered to provide a copious supply of voyage data so that Dr. Doust could pursue his studies. If he could show that his method could produce results of practical importance, that was what counted in the long run. It also stood greatly to Shell's credit that they had done so much to improve the recording and processing of voyage data. It was to be hoped that the analysis side of their work would be developed accordingly.

MR. J. BELL, M.Sc. (Member, R.I.N.A.) remarked upon the amount of the paper which had been devoted to discussing the method of transmitting information and the errors which arose in transmission. It was a surprise that no reference was made to the possibility of using the facsimile method instead of code for the transmission of data. His organization had used facsimile transmission in experiments between aircraft and ground, and this transmission was also widely used for the transmission of data for the weather service. An early transmission from a vessel was the facsimile transmission from H.M.S. *Vanguard,* off South Africa, sending photographs to this country. This was some 18 years ago and considerable developments had occurred since that time. It might be a simplification in the case of transmitting the data being discussed in this paper to use facsimile, since the ship's officers would not be required to do any coding; they would merely transmit the information on a record or data sheet and all the analysis and coding for computer purposes could be done at the receiving end.

During the presentation of the papers, Mr. Duggan had remarked on the variation of resistance, occurring during the course of successive voyages, on the *Serenia.* Dr. Doust had also stressed the point that the resistance of the vessel, depending on the kinematic viscosity, varied with the temperature of the water. It was suggested that these, taken together might indicate that the variation in water temperature could be responsible for the variation of resistance which had been observed.

Referring to power meters which provided important data which had to be transmitted, it was evident that Mr. Duggan had concentrated on the resonant type of strain gauge meter which had now been made practicable by the use of short distance radio transmission between a moving shaft and the receiver in the ship. This feature avoided the limitation of slip-rings which it was agreed was an important point in giving consistent and reliable results. The author had, however, referred to other strain gauges as suffering from inaccuracies due to distortion of the hull of the vessel. Mr. Bell questioned the significance of this error, and with the aid of a blackboard sketch discussed the stiffness of the vessel. It was evident that no torsional distortion of the vessel could occur between the propeller and the engine seating, since this portion of the hull was not subject to the torque of the propeller. The torque was taken by the main part of the hull and in the case of oil tankers this was all forward of the engines. Also the part of the hull after the engines, was shaped or triangulated in such a way that it would be extraordinarily stiff in torsion; the deflexion therefore of the (about) 20 feet length supporting the power meter reference units might reasonably be expected to be negligible.

Mr. Bell pointed out that a reference was made, in the section under the heading "Analysis", to the fluctuating torque conditions of a Diesel engine and a statement was made to the effect that a torsionmeter or power meter was not capable of giving a true measurement of shaft horsepower under these conditions. Probably it was the case that the resonant type of gauge did not follow or take a true mean of these fluctuations, but, considering the Muirhead-Pametrada type of power meter, this difficulty had been overcome by progressive sampling of the torque over the whole cycle so that the true average was obtained. Experience in the fitting of these power meters on large Diesel-engined tankers had shown that reliable results were obtainable and further installations were proceeding.

In conclusion, Mr. Bell asked, referring back to the question of hull distortion, whether Mr. Duggan could provide any measurements or specific information on this point.

MR. C. A. LYSTER (Member, R.I.N.A.) said that congratulations to the authors were the prerogative of the chairman, but in this work the degree of success achieved was a point of very material importance, and he hoped he could congratulate the authors on the success they were achieving in the work they were doing.

At Vickers they had been doing work on data loggers since 1960 in connexion with ship trials. They had not ventured on a wireless link or any other kind of link for transmitting the answers ashore. But they had been working steadily on data logging, and they now felt that they had something they could be pleased about. Their data logger contained three cubicles, not quite as large as those shown in the paper. It had the property of being portable. It was taken to the ship four days before the trial, and in those four days it was erected, connected, set going, all temporary cables were run, transducers fitted, adjusted and calibrated; when the trials began it was expected to be reliable and produce answers accurately. This it was now able to do.

They did appreciate the extraordinary difficulties of getting apparatus of that kind to work successfully in a ship, where the circumstances in which they had to operate were completely different from those in the laboratory, the quay side, or even in dry dock.

One depended a great deal in this work upon one's staff and the people who built the data loggers. Those people who wanted to operate the data loggers should make them themselves, and not employ other people to do it. It might be necessary to operate a complete electronic department. This was the most satisfactory method of getting electronics under control at sea. He still remembered a gentleman he encountered on a recent trial; it would be unfair to mention that he had a beard, corduroy slacks and sandals. He was carrying in one hand a pressure transducer made in California, in the other hand a length of electric wire, on his face a vacant expression, and on his lips a request to be shown where the thrust block was. They had shown him and helped him to connect up the transducer. It was not calibrated in position, and it had a number of other faults.

In this connexion, he asked Mr. Duggan and Mr. Field how often their gear was calibrated, and if it was done in the ship position, because he thought this was of importance.

The paper included an interesting diagram showing the movement of some buoys past which a ship sailed, and observations taken of the movements of those buoys. In his own opinion, this merely indicated the state of the tidal currents in the region where the buoys were dropped. They had taken very similar observations of buoys used for turning circle measurements on trials and observed very similar types of movement; in general, it could all be attributed to the tide.

He agreed with a point made by a previous speaker that the ship's speed should be measured relative to the water outside the boundary layer, but not too far outside it.

MR. P. R. HUTTON-PENMAN said that he was one of the engineers concerned in setting up the early experiments and he would limit his comments to the data transmission part of the paper. One of the authors, Mr. Field, had said that what he wanted was quite simple; five minutes, one hundred per cent perfect transmission from a ship anywhere in the world. It seemed that not too bad a showing had been made and although a perfect transmission medium had not been provided it had proved adequate; this showed the necessity of being clear from the start regarding the standard of performance required.

A forward-acting detecting system had been chosen because, for one thing, it did not rely on a return path, and an adequate information service could be obtained with a very inadequate return path. In other systems the return path was important, and whilst under certain circumstances, they might produce less errors, in other circumstances they might produce no information at all.

With regard to Fig. 10 of the paper by Mr. Duggan and Mr. Field, and the assumptions drawn from it, that S.S.B. and D.S.B. were equally good over certain areas—a word of caution—there was not really sufficient information to make such an all-embracing assumption. Furthermore, the actual method of conveying the information, whether by amplitude modulation, frequency modulation or phase modulation, was equally important in determining the overall error rate.

Another point brought out in the paper was that the receiving equipment tended to wander off in search of red herrings. This was so, but it must be remembered that in a system of this sort it was necessary, at the receiving end, to use elaborate devices to follow the frequency variations of the ships' emission and such devices were not perfect, what was really required was more stable equipment on the ship so that automatic frequency correction need not be used.

Most of the improvement in performance indicated on page 373 arose from the fact that at the shore end it was possible to put up a very adequate space-diversity system which was considered necessary to attain the required error rate.

A word of warning about the future—the authors were obviously only interested in the exercise from the point of view of the information obtained—from the communication engineering point of view the overall performance of the communications system was equally interesting. For the first time it had been shown that accurate printed information could be regularly transmitted from ships at sea to a shore station. This was a step which had to come and the exercise had given communication engineers a chance to spread their wings and "have a go". He thanked the Shell Company for their forbearance whilst so many teething troubles were overcome. Not only had it been necessary to educate themselves, but also to educate the operating personnel in entirely new techniques, and ways of working of which they had never thought.

It was now necessary to decide what future systems should do. Was the error rate as now demonstrated good enough or should a system with more elements be introduced? If a better error rate was wanted, it could be provided but it would take longer per transmission and it would cost more. Finally, if a low error rate was required, it was most essential to ensure a high standard of maintenance.

MR. J. B. OTTEWILL said that he represented a company of data logger manufacturers. In the last paragraph of the paper it was stated that instrumentation was the major cause of faults in present day marine data-handling systems. While he agreed with this, he was puzzled by the statement that high accuracy transmission networks could detect small changes in instrument calibrations which might normally go undetected for several weeks. His own experience had shown that nearly all the instruments used in marine automation had the characteristic of becoming either short-circuit or open-circuit on failure. Should either of these modes occur, the data-handling instrument would normally give a full range or a zero range output, both of which were readily detected, thus allowing the watchkeeping engineer to establish that a particular instrument was out of order. With regard to the question of instruments going off calibration, it would be exceedingly difficult to establish whether, in actual fact, the reading had risen or fallen or whether the instrument itself had gone off calibration. He suggested that the main reason for employing sophisticated transmission equipment was not so much that small changes in instrument calibration might be detected, but that a reading from an instrument might be transmitted with one hundred per cent reliability.

As regards electronic data-handling equipment not standing up to the peculiar and hard conditions experienced at sea, results had shown that it was nearly always electro-mechanical devices which failed. His company had had a data logger working satisfactorily at sea in the engine room of a Diesel-engined ship for the past two years. This equipment had been subjected to large amplitude vibrations, high temperatures and the normal dust and oil mist conditions experienced in that type of ship. The only serious failures had been those connected with electro-mechanical relays and power equipment. The first was solved by using reed type relays in place of electro-mechanical, and the second by using a power pack of higher ratings than would normally be necessary. Mechanically and electronically, this equipment had stood up to the test exceedingly well, but this was perhaps because wrapped joint techniques were being used with fully sealed cards and not plugs and sockets.

The problem of suitable protection for micro-switches was one that was common to all electronic equipment—protection from oil, water, dust, etc. This could only satisfactorily be achieved by completely encapsulating the item concerned in a synthetic resin or something similar. There were many circuits, push-button switches and toggle switches of this type available on the market, most of which satisfactorily overcame the problem of working in dirty atmospheres. The point was raised that push-button switches were highly affected by dirt and dust, but there were several types of wiping-action, totally-enclosed push-button switches available on the market.

The authors mentioned thermocouples. It was a known fact that the electronic noise pick-up in ships was exceedingly high, and that any low level signals (of the order of 4-10 mV) were almost bound to be difficult to read when combined with an average interference level of 4-6 mV. He recommended the use of resistance thermometers where the signal concerned was largely in the hands of the electronic designer and could be of the order of 40-50 mV thus making the noise suppression problem a great deal easier, and increasing the accuracy of the equipment. Financially, resistance thermometers were far more expensive than thermocouples (£14 to £8 would be comparative figures) but when one took into account the cost of cold-junction compensation and the special leads which were required by thermocouples, he suspected that resistance thermometers proved more economical in the long run.

The CHAIRMAN, Mr. B. Hildrew, M.Sc. (Member of Council, I.Mar.E.) referred to the authors' experience with instrumentation, and particularly electronic components such as transducers, as it drew attention to the necessity for high reliability in modern instrumentation aboard ship. The list of failures chronicled was a perturbing sidelight on the suitability of many existing instruments under seagoing conditions. It was noted that the Michell pattern thrustmeter was criticized as unsatisfactory under the conditions of use required. Had the authors experience of any alternative design? It would be interesting to know if they had resolved the problem which they had found associated with the Michell instrument. Could the authors also advise what degree of repeatability of zero reading was obtained with the modified Maihak torsionmeter?

The problems associated with the data logger again indicated the misplaced confidence manufacturers could have in their ability to design equipment which operated satisfactorily afloat as well as ashore. It was also noted that some faults were experienced in the operation of the land-based data-processing equipment which could be subjected to surveillance in such circumstances. It was obviously desirable that components intended for shipboard use should be subjected to environmental testing ashore and this was becoming more essential as automation became a common feature on shipboard. With this in mind, Lloyd's Register of Shipping had installed a large vibrator capable of subjecting machinery modules to a vibration spectrum equivalent to that which would be experienced on board ship. It was hoped to extend this facility to undertake temperature and humidity assessment. Shipowners would thus be able to require that all equipment, particularly electronic equipment, installed on board a ship, should be capable of withstanding seagoing conditions.

Thermocouples, which were probably the earliest of all electrical instruments used at sea, could give satisfactory service but the flowmeter shown in Fig. 4 of the paper, by Mr. Duggan and Mr. Field, was typical of deterioration observed on a similar device purchased at great price and installed ashore to meter feed water during an investigation carried out by Lloyd's Register.

With reference to the Ventimeter in Fig. 8 of the same paper, it was noted that, in the film which was shown, the reading was taken at the front of the bridge. The wind deflector must have made this a false reading and this did show how interpretation of readings, even from an accurate instrument, was not necessarily truly representative of conditions obtaining. The most surprising thing in the data-processing section of the paper was the high error rate which existed for a long period of time in the tapes received in London.

The other item relating to data processing which was surprising was that the data could take up to ten days to be processed. The speaker had been examining the possibility of utilizing long distance transmission of data to a central computer where data contained in a master file of ship records could be continuously uprated with information abstracted periodically or on demand.

While the acceptable transmission linkages from countries overseas varied from the U.K. and between each other, it was realized that considerable problems existed in transmission of data from abroad and direct transmission by wide-band telegraphy would have seemed one of the more reliable ways of transmitting information.

Correspondence

MR. M. C. JOURDAIN (Member, I.Mar.E.) wrote that the report by Mr. Duggan and Mr. Field on their problems connected with instrumentation was not misleading. They were perfectly aware of the fact that measurements, provided that they were all accurate, could always be dealt with and made to reveal basic features. On the other hand, if measurements were poor in any respect, the most sophisticated mathematical treatment could produce nothing but fancy.

The authors had pointed out the effect on the Pitot log of the increasing thickness of the boundary layer, but did not mention any wave effect. Mr. Jourdain wondered if they had had an opportunity to check the calibration in a head sea, a following sea and a beam sea. The results of Doppler techniques were awaited with great interest, but it was not easy to evaluate a log in all circumstances at sea.

The authors seemed to prefer the acoustic strain gauge for thrust measurements, yet found it successful for torque measurements. Did they not fear any trouble due to temperature variations? Had they considered using the new Kingsbury electric strain gauge thrustmeter?

As far as analysis was concerned, the use of the coefficient $C_P = \frac{P}{\frac{1}{2} V^3 S}$ was very similar to the procedure* adopted by Mr. Jourdain, who usually reckoned first both coefficients, $a = \frac{V}{\text{r.p.m.}}$ and $\gamma = \frac{P}{(\text{r.p.m.})^3}$, hoping that the measurement of r.p.m. was generally good and that at least one of the others (V or P) might be so.

The correction to still air left the wave effect uncorrected, which might be important at high Beaufort numbers; Mr. Jourdain used an empirical correction derived from comparison of data at various wind forces.

Finally he was interested in the explanation given for the deterioration during each loaded voyage, for he had observed something like that from previous data.

Referring to the paper by Dr. Doust, Mr. Jourdain wrote that the proposed statistical model looked sound in its concepts but, as a general rule, perfect as the instrument might be, its output could not be better than its input.

Then, the input consisted of two distinct sets of data: the one set derived from model measurements, the other directly issued from the ship at sea.

The first set might be assumed to be pretty good, but their extrapolation to the ship was not straightforward, if only t and $\partial\ (T)_K$ were considered. According to reference (8), especially §36, a high accuracy was not claimed for C_{wa}.

Regarding ship data, it might be hoped soon to reach sufficient accuracy in measurements of speed, revolutions, thrust, torque and wind, but a correct evaluation of h_w and the factors of $\partial(T)_K$ was not so easy.

Now it should be instructive to show the influence, on each of the regression coefficients, of given systematic errors affecting the various data in order to prove that it was not prohibitive.

Would not it be worth checking the α_2 value assessed by the least-squares technique against the Hughes form factor obtained by the usual process?

The argument on correlation between $[\log (R_n - 2)]^{-2}$ and F_n^4 was not very clear to the writer. He thought that R_n and F_n (or any function of either of them), depending on the same variables except the sea temperature which affected R_n only were dependent variables when the temperature was constant, becoming strongly correlated when the temperature varied; of course, if, by chance, the temperature was the unique variable in a set of data (V and L being constants) there was no correlation since F_n remained constant whereas R_n varied, but was there not something artificial in such a concept?

MR. K. J. LOROCH, B.Com., M.B.A., wrote that the paper on "A Statistical Approach to Ship Performance" by Mr. Duggan and Mr. Field and the complementary paper by Dr. Doust outlining "A Statistical Model of Ship Performance in Service Conditions", made fascinating reading in the very much neglected field of vessel operation. These contributions,

---

*Dieudonné, J., and Jourdain, M. C., 1959-60. Symposium on "Ship Trials and Service Performance Analysis"—"Performance in Service of Cargo Vessel and Passenger Ships". *Trans. N.E.C.I.E.S.*, Vol. 76, p. 595.

undoubtedly, represented a most significant step forward. Regretfully, he could not discuss the specific approaches and techniques on equal terms with the three eminent authors.

The rejection of measured mile trials and vessel log-book data appeared to be justifiable from the scientific point of view. Neither guaranteed the accurate and continuous operating record that was required to show changes in ship performance. The telemetry system for recording and transmittal of shipboard data, as developed by Shell International Marine, did offer, on the other hand, a high degree of continuity and accuracy.

But, as Mr. Duggan and Mr. Field had said, what one had here was a research tool, rather than a management tool. While the introduction of sophisticated recording instruments, performance data loggers, and statistical models might solve the scientists' problems as regards certain specific vessel-performance data, this was not yet true of the ship operator. The latter needed bases for his accounting system and the economic decisions he must make; log-book data, properly collected, analysed, and presented, were still his best bet. Mr. Duggan and Mr. Field did indeed, he was glad to say, see value in voyage reports (presumably based on log-book data) for providing adequate ship management control.

In his book, *Vessel Voyage Data Analysis: A Comparative Method,* Mr. Loroch had made an attempt to devise a standardized approach to vessel voyage data. It strived to organize the flow, analysis, presentation, and interpretation of the mass of vessel-operating data that was available, or should be made available, to those who operated the vessels, built them, and engaged in ship research, as well as various maritime agencies on governmental and intergovernmental levels. The vital two-way link between sea and shore operations remained obscure and neglected. There existed as many systems for dealing with voyage data as there were steamship companies, ranging from extremely elaborate and often computerized methods to the simple filing away and forgetting of the engine and deck log-books.

In the book although primarily intended for the shipowner and his operating man, he addressed himself on many occasions to the scientist and shipbuilder as well. With the kind permission, of the authors of the papers, he would like to quote from the concluding chapter of his book:

"In this volume we have traced the evolution of voyage-data analysis to its current status. Because of the dearth of material on the subject, a survey was conducted which readily disclosed that consistent recording and analysing of voyage data has not become, with some notable exceptions, a matter of standard practice. It further disclosed willingness and readiness among the majority of steamship operators to consider an acceptable universal method of voyage-data analysis.

Two chapters have been dedicated to exploring the formulation of a uniform comparative method of embracing a set of appropriate standardized forms for analysing voyage results, and then exposing the value of these forms to a test of practical application.

After expounding on some of the economic and practical aspects of analysing voyage data, determining standards that represent a desired performance, and evaluating that performance, we have looked at the new and exciting transportation concepts and the role of research. It had been shown that the current drive and desire to automate planning and decision-making functions make research absolutely necessary both as a ground-breaking and a supplementary feature. Transportation research, as all research, requires the use of a heterogeneous mass of changing data. Computers, automatic data-processing, operations research, programme evaluation and review technique (PERT), input-output models, etc., all call for the institution of new and special data-collection techniques to feed the expanding research activities. This volume suggests large areas that would be productive in projects that are susceptible to programming and solution by means of the computer.

The economic demands of the period we are now entering are gradually but surely relegating shipping to the role of being but one element in a total distribution system. The ship and port will diminish slowly as focal points of international commerce and business activity to become, like other modes of transport, merely a link in a system of transportation. The minimum economical cargo flow required by highly mechanized terminals is likely to produce a very distinct trend towards minimizing the number of transfer points and increasing the size and speed of carriers. This, in turn, will create standard conditions that will require the application of standardized methods. All of the far-reaching changes and developments that are taking place in cargo-handling, ship design and construction, and automation make vessel-voyage-data collection and analysis an indispensable ingredient in progress. The "clearing house" idea has the best chance of coming up with the right models and guidelines by placing centralized research and concentrating forward-thinking under one roof.

The specialized bulk-carrier and the container vessel serving only the major and most generally utilized routes of traffic are best suited to fill the role of the ocean carrier in the new transportation concept. The need for optimum utilization and economical operation clearly calls for the use of a uniform vessel-voyage-data collection and analysis system. The standardized comparative method for analysing voyage results, as described in these pages, may, it is hoped, fill the need for this kind of an operational and managerial tool. The changing transportation concepts not only emphasize the value of this control tool, but also facilitate its introduction and profitable application."

Mr. J. R. Scott wrote, in a further contribution, that when a dependent variable depended upon two or more variables which were themselves correlated, it was misleading to assess the dependence by adding the results of simple regressions of the dependent variable on each of the independent variables. In such cases, to obtain unbiased results, multiple regressions must be performed. Somewhere along the line Dr. Doust had converted this fact into the phobia that multiple regressions on correlated independent variables could not be relied on, and any data in which there was such correlation must be augmented until they vanished. If this were true, polynomial curve-fitting would be a very dubious process, for x, x^2, etc., were all strongly correlated. Furthermore, the very many practical demonstrations of the value of multiple regression on correlated independent variables in statistical literature would be grossly misleading. However, they were not, and Dr. Doust had adopted a piece of nonsense as a guiding principle.

A plot of R_n on F_n for observations at constant sea temperature consisted of a number of points exactly on a positively-sloped straight line. Random variation of sea temperature over the set of points produced scatter about the same line, i.e. there would still be correlation between R_n and F_n and, consequently, correlation between $(\log R_n - 2)^{-2}$ and F_n^4. This correlation could only vanish when the sea temperature varied systematically with ship speed in such a way that the constant temperature values were displaced to be scattered about a horizontal line in the R_n/F_n diagram, i.e. it vanished only for a particular negative average rate of increase of sea temperature with ship speed. Thus, in demanding no correlation between $(\log R_n - 2)^{-2}$ and F_n^4, he was demanding a very special relation between sea temperature and ship speed. This was clearly a demand which no raw data could satisfy.

Turning next to Dr. Doust's numerical example, one read that he found no stability of the coefficients α_2 and α_3 when he regressed y on $(\log R_n - 2)^{-2}$ and F_n^4 for the five three-day periods of the 15-day test period of the *Serenia.* Such instability was a characteristic of statistical non-significance of the coefficients. That this was so here could not be judged directly because Dr. Doust persisted in his habit of not giving the results of such tests. However, Dr. Doust might rest assured that, had his dependence been significant, the coefficients would have been stable, irrespective of the degree of correlation between $(\log R_n - 2)^{-2}$ and F_n^4. When such instability existed it might be arbitrarily and artificially reduced by selecting the samples so that certain data were common to two or more samples. This was a process analogous to discarding outlying observations because they did not permit one to find what one wanted to find; a dangerous practice used by many pseudo-statisticians. Here Dr. Doust overlapped his data to the extent that one-third of each sample was common to each of the three nine-day samples and only one-third of two of the three samples did not appear in another sample. It was small wonder that he achieved the appearance of stability. This, he failed to see, was the result of an entirely erroneous and grossly misleading operation on data, and attributed it to the diminution of correlation between $(\log R_n - 2)^{-2}$ and $F_n{}^4$. Did he test this? He could not have done, because, as shown above, such correlation could only be non-existent when ship speed and sea temperature were strongly negatively correlated; the probability of this existing in his data was small enough for it to be certain that correlation between $(\log R_n - 2)^{-2}$ and $F_n{}^4$ existed in each one of his nine-day overlapped samples. Again it was not possible to test this directly because of the persistent habit of not giving the raw data.

In the same section of the paper one read that the "stabilized" values of α_2 and α_3 found "were much more in keeping with the values expected on other experimental evidence". If one substituted typical values of R_n and F_n in the expression $\alpha_1 + \alpha_2 (\log R_n - 2)^{-2} + \alpha_3 F_n{}^4$ together with the mean values of the coefficients given in Tables II and III of the advance copy, one found that the ship was satisfactorily operated with a very substantial negative thrust during the period concerned. This was a discovery similar to the ship scouring action of warm sea water to which Mr. Scott referred in his verbal discussion. It would be interesting to hear what "other experimental evidence" supported this unusual result.

There was a number of injections of physical knowledge into Dr. Doust's model which appeared to have been made in a manner far too uncritical for one to expect valid and unbiased results from regression analysis based on them. In fact, practically every aspect of the model was open to criticism. Mr. Scott proposed to discuss only one of these in the following paragraphs. This was the breakdown of ship resistance into its viscous and wave-making components.

There was difference of opinion amongst naval architects about the nature of ship viscous resistances. Some believed, as Dr. Doust did, that the effect of hull roughness was merely to raise bodily a curve representing the viscous resistance coefficient of an hydraulically smooth ship, leaving this coefficient a function of Reynolds number. Another school of thought believed that the rough ship was more likely to behave like a Nikuradse sand roughened surface, i.e. the ship viscous resistance coefficient was a function of the surface roughness and not of Reynolds number. That this controversy could not be settled by ship model correlation studies was clearly shown by Todd in reference (10). Dr. Todd reiterated the relevant conclusion with emphasis in his discussion of reference (9), where he stated that any necessary allowance for roughness "depends very greatly on the assumptions made in the extrapolation method used". Professor Telfer, in the same discussion, also realized that roughness allowances so calculated had the stability of the tip of a whip, for he developed the conclusion that "Dr. Allan on ship roughness is at the mercy of Dr. Hughes on ship smoothness". After this and much more discussion, and the recent acquisition of much more evidence that ship model correlation studies could not and had not resolved the controversy, Dr. Doust introduced his variation with Reynolds number as though the controversy did not exist, and even quoted reference (10) as though it supported the view he had taken.

Fortunately, there was a method of resolving the controversy which was not affected by the caprices of ship model extrapolators. It relied for its decision on the fact that ship performance would improve with increasing sea temperature if there was a dependence on Reynolds number, but would not vary with sea temperature if there was no such dependence. Mr. Scott had found no such dependence on sea temperature in two recent independent studies, and therefore concluded that Dr. Doust had no justification for introducing a Reynolds number dependence at all. In the absence of a temperature variation there was as much justification for splitting the resistance into viscous and wave-making components as there was for splitting it into the resistance of the port and starboard sides of the hull. Even if there was a variation with temperature Mr. Scott would prefer to take care of it empirically, using a temperature term in regression of voyage data, rather than inject the caprices of ship model extrapolators into a problem which should be attacked with the minimum possible reference to model results.

Mr. B. S. Bowden, B.Sc. (Associate Member, R.I.N.A.) wrote that it would seem that an implicit assumption of the method presented by Dr. Doust for determining propeller deterioration was that, for a given roughness of the propeller, the decrease in K_T/K_Q from that of the smooth propeller would be independent of K_Q and real slip. If this was not so, variation of the quantity DE would reflect changes in hull roughness and wake as well as propeller deterioration. Furthermore, unless K_T/K_Q for the smooth propeller varied linearly with K_Q, the error involved in approximating the difference in K_T/K_Q corresponding to the points C and D of Fig. 5 by DE would also be a function of hull roughness. The extent to which these assumptions were invalidated in practice would, therefore, influence the effectiveness of the quantity DE for determining propeller deterioration alone. Comments by Dr. Doust would be welcome.

Authors' Reply

Reply by Mr. DUGGAN and Mr. FIELD

In reply to the discussion the authors said that many comments had centred round the balance between accurate instrumentation and sophisticated analysis. It must be remembered that the object of the exercise described in the paper was to seek a research tool giving a much greater degree of precision than was necessary for management control and aiming to analyse the performance according to the fundamental laws governing ship performance. For such a purpose, accurate instruments were essential, and the method of analysis no more complicated than the underlying hydrodynamics.

The authors were interested in Mr. Scott's observation that he had succeeded in analysing a passenger liner's log-book data. They agreed that performance controls for management could be based on log-book data—preferably the data which relied least on instrumentation and most on the staff's ability. The quality of the information was poor and the method of analysis required was simple, but useful results could be obtained. Perhaps it was relevant to note that with a passenger ship on liner trade, there was a tendency for regularity in wetted surface, speed, sea temperature and weather comparing one voyage with another, while the instrumentation and staff were often of above average quality; such factors simplified the problems of the analyst. However, any successful steps in this direction were to be welcomed, and it was to be hoped that Mr. Scott, the British Ship Research Association and other individuals or organizations who felt that they could contribute to the subject of performance analysis would not hesitate to publish their work.

Mr. Kaye had rightly stressed the basic role of the submerged log readings, and suggested a method of checking log calibration. This method had been tried since the discussion and found successful, although the short-term accuracy could be considered improved at little extra cost by making allowance for currents based on pilot chart or current atlas predictions.

Captain Jenks had suggested a procedure for selecting the basic parameters essential to the exercise, and then examining available instrumentation to see if it was suitable. This step was essential and the authors had given much thought to the level of accuracy and reliability to be demanded of the instruments. In their view instruments were available which could reach these levels of accuracy for most of the basic readings, and research effort was commissioned on developing a more reliable torsionmeter. It had since been evident that the authors' estimates of reliabilities were too optimistic. However, Mr. Bell had made one aspect of the authors' experiences sound more depressing than need be; the modified torsionmeter based on the resonant strain gauge accurately followed the cyclic variation in torque produced by a Diesel engine.

The chairman had stated that in the film accompanying the presentation of the paper, the Ventimeter reading was taken at the front of the bridge. In fact it was taken at the end of the bridge wing on the windward side, which had been found the most satisfactory position short of climbing the signal mast.

The authors had much sympathy with Mr. Lyster's comments on the design and operation of data loggers. Now several manufacturers had experience of marine installation, the authors felt that there was a much greater chance of getting satisfactory designs and service. The authors' colleagues who were experts in electronics and instrumentation had provided invaluable assistance in this exercise, and some of the problems encountered with the data loggers might not have arisen had they been available to examine the specification initially. Calibration of transducers should always be carried out *in situ* when possible, but preferably when the plant was in an operational condition, not on a dead ship. The only real solution was to commission instrumentation during operational voyages. While Mr. Ottewill might praise resistance thermometers, the authors' experiences had been that they failed frequently and unpredictably. These experiences were gained three or four years earlier, and such criticisms might be no longer valid. Thermocouples, on the other hand, appeared to be fairly reliable.

On data transmission systems, Mr. Doorninck lauded the virtues of the Netherlands design compared to the British system. The authors agreed that a system which produced a perfect tape but took a little longer was preferable to a system which required tapes to be repeated and merged. An early and limited experience with the Netherlands system suggested that in bad conditions of repeated cycling, the error rate was considerably higher than the one-in-a-million figure quoted. Indeed the authors understood that a limit to the number of rejected cycles had been introduced since the time of choice to reduce this source of error.

The final choice on the system for world-wide use lay with the International Telecommunications Union, whose next meeting would be in 1967, and other systems such as those used in the United States might yet prove better than either the British or the Netherlands systems.

Mr. Kaye had questioned the need for a data transmission system. Certainly the system had added to the complexity of the exercise; it had also yielded significantly greater control over the quantity of data received in the office. Perhaps the best justification of the use of this equipment was the view that radio teleprinter services would replace radio telegraphy as the normal means of ship-shore and ship-ship communication, and this exercise was one in which the benefits of such a service could be clearly seen.

Mr. Bell had suggested that facsimile transmitters were suitable for data transmission. Such equipment had been tried, but while it was useful for weather chart transmission, it was unsuitable to the transmission of data. Too large a scale was needed for adequate character recognition, resulting in excessive transmission times.

Mr. Silverleaf had raised one point, echoed by Mr. Canham, concerning the authors' statement that "some of the assumptions required by the mathematical model proved to be invalid". This statement was clearly too brief and the authors were pleased to take advantage of Mr. Silverleaf's question to expand upon this point. In the theoretical model relating thrust to resistance and hence to functions of Reynolds number and Froude number, there appeared a term, the thrust deduction factor. Conceptually such a factor existed, numerically a value for it could be obtained from tank trials on models. There could be no doubt that the assumption of its existence was valid. But one difference between the conceptual model and the mathematical model used for the analysis was that in the latter all parameters must be known, measured, or unknowns to be estimated. It was assumed that the thrust deduction factor was a known parameter of constant value. As a result of model trials, this assumption proved to be invalid. This assumption was required by the mathematical model since data were not available to cover the variation of thrust deduction with changes in speed and condition, except for the one model tested. The authors had no desire to suggest that the conceptual model was invalid, and hoped indeed that the National Physical Laboratory and other concerns interested in hydrodynamics would pursue research into the numerical estimation of the factors involved in the model.

Another fault was the assumption that data drawn from loaded and ballast voyages could be treated together. This assumption implied that the wetted surfaces of the hull which were submerged when the ship was changed from the ballast to laden condition had the same properties as the rest of the hull. For the smooth ship this might be approximately true, though the form factor of the hull might change slightly, but it was certainly not true when the hull was fouled with weed, since the growth of weed was concentrated on the sides of the hull, on and closely below the boot-top area. In addition, the rapid growth of fouling during the course of a loaded voyage, which was not anticipated, resulted in a blurring of the analysis if loaded and ballast data were analysed jointly.

This led to a valuable comment by Mr. Scott who pointed out correctly that variations in speed and sea temperature were necessary to isolate the estimates of the coefficients of the viscous and non-viscous coefficients of resistance. The authors had been prepared for the ships to carry out slow-speed runs for a few hours every fortnight in order to obtain data over a wide range of speeds. Variations in sea temperature were a matter of chance as it was not possible to re-route the ships in the exercise simply to experience changes in temperature.

It was hoped in this way to obtain estimates of the coefficients based on ship data, rather than model data. Mr. Scott might feel that model data led to estimates that were entirely reliable; but he represented a model testing tank while the authors, who were associated with shipowners, were less sanguine about the accuracy of such results. Having obtained good estimates of these coefficients, then a method of analysis could be adopted along the lines suggested by Mr. Scott, making the allowances for smooth viscous and for non-viscous resistance explicitly. A possible compromise would have been to use the tank model estimates of the two coefficients as *a priori* estimates of the values of the coefficients for the ship. The effect of this would have been to tend to stabilize the estimates in the region of model estimates, but allowing the coefficients to adjust slightly to each new set of data.

Mr. Scott returned to the paper with written comments where he attacked Dr. Doust for being unhappy about multiple regression where the so-called independent variables were highly correlated. Dr. Doust had reason to be unhappy, for though correlation among independent variables in no way reduced the value of a regression analysis for prediction purposes (Mr. Scott's point) this characteristic in a set of data made physical interpretation of the values of the estimated coefficients quite impossible. For illustration the following coastal journeys had been invented.

The vessel took, on average, one day for each port visited, and travelled an average 400 miles a day at sea. The following results might be found:

No. of ports	*Miles steamed*	*Time, days*
3	1,300	6
5	1,800	9
2	800	4½

Independent regression of the duration of the voyage on to the number of ports as a single independent variable would suggest two days stay in each port, presumably with almost instantaneous travel between them. Multiple regression on to the number of ports and the miles steamed suggested 0·6 per day per port call, and a sea speed of about three hundred miles per day.

Obviously, the figures were misleading, and they were misleading because the sea mileage increased as the number of ports visited increased; that is, sea mileage and port calls were correlated. However, a very good estimate of the duration of voyages could be obtained from either the simple or multiple regression. The former gave estimates of six, ten and four days, while the latter yielded 6·1, 9·0 and 3·9. Clearly for the purpose of curve fitting correlation was unimportant; for interpretation of the coefficients in real terms, it was most important.

Since it was intended to interpret the coefficients estimated in the study as indications of the relative importance of different types of resistance, correlation was a serious problem.

Several speakers including Mr. Kaye, Captain Jenks and Mr. Canham had commented on the problem of estimating the effect of the surface waves on the performance of ships. With tankers, the problem was less severe than with smaller ships, and it seemed that for general purpose vessels of 18,000 d.w.t. the effect on performance of surface waves corresponding to a wind Beaufort number of less than 5 was negligible, while for the crude carriers of 60,000 tons, the critical level was force six. In weather conditions less severe than this, the allowances for the direct effect of wind were adequate. Weather more severe than the critical level was only rarely encountered, on about five per cent of occasions.

Several formulations for the effect of wave on performance had been examined, and the formula presented in Dr. Doust's paper was being used to calculate an allowance. This allowance was not being applied directly, until evidence had been gained to support the formulation. Further investigations in the effect of weather such as were being undertaken by B.S.R.A. were to be welcomed.

Mr. Canham's suggestion that 100 wave encounters were needed to give a valid estimate of the prevailing frequency of encounter appeared to the authors to arise from a misunderstanding of the problem. During a short recording period such as was used in this exercise, the frequency of encounter during the recording period was what influenced the performance of the ship at that time. The characteristics of the waves encountered during that period might not be typical of the total wave system in the area, but this did not matter since the ship did not encounter the total system. Captain Jenks rightly questioned the ability of observers to make good estimates of sea conditions. The long term solution might well lie in ignoring wave conditions and measuring ship motions with a heave, pitch and roll indicator, using these measurements as the basic for allowances to ship performance.

There were two general comments that needed replies. Captain Jenks had stressed that staff on board ship should be treated as responsible individuals. The authors felt that their views had been made quite clear in the paper (page 378, column 2, § 1) but it must be agreed that shipowners could use new developments in analysis and control, and in communications, either to assist their staff on board ship to manage their responsibilities more efficiently, or to shift responsibility and attempt to run ships from the office. It was always tempting for senior management to try to centralize control; but except where demands of integrated planning made such centralization essential, this temptation should be firmly resisted.

Mr. Silverleaf had asked how the authors would modify the plans they had made earlier if they were now to make a fresh start.

The first question to ask would be whether, in the light of the present standard of instrumentation, such a study should be undertaken at this time, or whether the study should be delayed until instrument manufacturers had improved their offerings. The second question to ask was whether more preparatory work in the development of the mathematical model, using more model test results and making more use of available measured mile trials data, might have resulted in a more firmly established basis for analysis before the information came flooding in. With any research study, there was a choice between dabbling one's toes in the shallow end or diving into the deep end. The latter might be more painful, but it was more productive. On one point the authors would make a change; the system of data processing used for verifying the information had proved too cumbersome during the earlier stages when changes were still being made to the system, and a simple but more robust process would have been better until the details of the analysis had been settled. Otherwise, the authors would no doubt concentrate rather more effort on the testing and development of instrumentation, but the study would still take place, and along much the same lines as it had.

Finally, the authors would like to thank all the contributors, and especially Mr. Kaye, for their interesting and valuable contributions to the paper.

Author's Reply

Reply by Dr. DOUST

Dr. Doust in his reply said that Mr. Kaye's contribution outlined most of the problems of both measurement of physical quantities and the application and development of new analytical techniques, required to investigate ship performance in service conditions. The author agreed that instrumental errors, either due to zero shift or systematic drift could sometimes introduce "apparent" effects which any mathematical model of performance would have difficulty in avoiding. He was not surprised therefore, to learn that Mr. Kaye had found that there could be as much as 8 per cent error in the skin friction resistance, when drift in the Pitometer log occurred in some extreme cases. Mr. Kaye had raised some excellent philosophical points regarding such analyses and on the question of the time-dependent coefficients the author regarded the term α_1 as the main quantity so affected. One of the main requirements of the mathematical model of performance (apart from its main practical purpose of indicating performance deterioration) should be that it enabled verification of our present knowledge concerning ship resistance components to be made or otherwise disproved.

In reply to Mr. Scott, to whose remarks many people would now have become accustomed, the author found himself in almost complete disagreement. Probably the main point of this disagreement was that concerning the correlation of variables and the effect of this on the physically-based model proposed. In the simplest case of a multi-variate analysis, with variables X_1 and X_2, which for convenience would be regarded as normalized, i.e., ranging from -1 to $+1$, the appropriate regression equation corresponding to equation (9) of the paper became:

$$Y = A_1 + A_2X_1 + A_3X_2 \qquad (15)$$

in which A_1, A_2 and A_3 corresponded to the coefficients α_1, α_2 and α_3 of equation (9) and X_1 and X_2 were the normalized values of

$$[\log R_n - 2]^{-2} \text{ and } [F_n{}^4]$$

respectively.

The following observations regarding the subsequent analysis by the method of "least squares" might then be made.

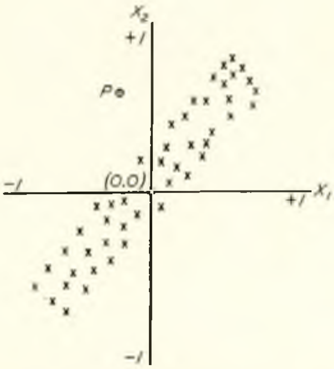

FIG. 6—*High correlation of variables X_1 and X_2*

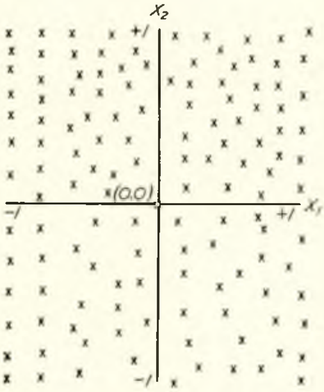

FIG. 7—*Numerical independence of variables X_1 and X_2*

1) If X_1 and X_2 were highly correlated, as would be the case shown in Fig. 6, the coefficients A_2 and A_3 would *only* be applicable to the region covered by the data and it would therefore be highly dangerous to expect reliable estimates of Y at a point such as P, outside this region.

2) Even although X_1 and X_2 might be highly correlated for some samples, one could expect reliable estimates of Y to be obtained if the regression equation adequately represented the data in this region.

3) Provided there were some data points in the region of the origin (0, 0), the value of A_1 (the author's measure of deterioration) could be expected to be reliable, even in the case when X_1 and X_2 were highly correlated. In general, A_1 was the value of Y when $X_1 = X_2 = 0$.

4) To avoid misuse of any derived set of values for (A_1, A_2, A_3) for cases as shown in Fig. 6 and to make the values obtained for A_2 and A_3 of more general application, one should ideally have data of the kind shown in Fig. 7. In these circumstances the parameter space for (X_1, X_2) was completely filled, X_1 and X_2 were numerically independent of each other, and the derived values of A_2 and A_3 would apply over the whole region for all possible combinations of X_1 and X_2.

5) Due to the fact that the data from any one ship in the exercise were not systematically ordered, but of a random nature, one had little or no control on the distribution of points (X_1, X_2). In this situation, the author had therefore proposed, and demonstrated, that more satisfactory values of A_2 and A_3 could be obtained by selective sampling.

6) In the case of fitting a polynomial curve y in terms of a simple variable x, high correlations between x, x^2, x^3, etc. would occur naturally and the distribution of points for, say, x plotted against x^2 would lie on an unique curve. Points such as P in Fig. 6, which in the case of two variables could lie

outside the area covered by the experimental points, could not therefore occur within the normalized range of *x*, and there was, therefore, no possibility of misusing the derived regression equation for *y*.

Mr. Scott seemed to have overlooked this fact entirely.

Regarding the question of "humps and hollows" in the resistance curve of a tanker or similarly full-bodied ship, these did not exist, even beyond the practical service speed ranges in which one would normally be interested. The Hughes approximation was, therefore, particularly appropriate for such ships and, even for finer, faster ships, it was considered that good results would be expected within the usual operating speed range. On the general question of making calculated corrections to measured thrust, prior to performing the regression analysis, the author considered that this should be done wherever possible, rather than additionally complicating the equation. It had already been seen that, even in the case of two variables, there were problems which could arise from the correlation between them and as the number of variables was increased the additional complexity and interpretation of the results obtained became much greater.

Mr. Silverleaf's remarks concerning the analytical approach adopted in the National Physical Laboratory model were much appreciated. Since going to press, it had been possible to make a further study of the sample records for *Serenia* referred to in the paper and to make some additional calculations with this model. Opportunity had therefore been taken to amend the values given in the preprint (Tables II and III) which were derived by using scaling factors applicable to an origin remote from the centre of the data. The values of α_1, α_2, α_3 were now applicable to normalized variables, about an origin having mean values of

$$[\log R_n - 2]^{-2} \text{ and } [F_n^4]$$

for the 15-day sample. It could be seen that the maximum change in α_1 represented a change in performance deterioration of about five per cent, which corresponded to a speed reduction of nearly 0·2 knot from the beginning to the end of this voyage. Fig. 8 was a plotting of the performance deterioration index α_1 which, for two samples of data analysed, increased with time on voyage.

Mr. Canham had asked a very interesting question. The performance model proposed was physically based on the results of much research into ship resistance components, including the effects of wind and wave action on the measured thrust values. As already noted by the author, if it were true that the model was inadequate (and his evidence suggested that it was not), then much of our present procedure in translating model results to ship estimates must be in error and he agreed with Mr. Canham that this matter deserved further investigation. No doubt some arrangement could be worked out between the British Ship Research Association and the National Physical Laboratory, whereby the data which Mr. Canham had available could be analysed by using the N.P.L. computer programme. There seemed no doubt that thrust deduction fraction *t* was a rather variable quantity which depended very markedly on changes in draught and trim, especially for full ships. The author could not however agree that experimental error could be the main cause of such variations, although, as noted in his paper, he was quite sure that there was a marked change in the level of *t* between model and ship. There was also some evidence, from the sample records analysed, that *t* might be much more speed-sensitive on full ships, such as the *Serenia*, than had previously been imagined.

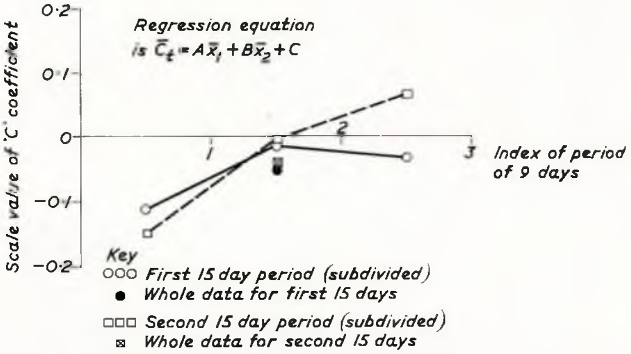

FIG. 8—*Shell tanker* Serenia— *Sample analysis for two periods of 15 days in loaded conditions, each split into 3 periods of 9 days*

In reply to Mr. Bell, the variation of kinematic viscosity with temperature was quite marked as the following values indicated:

$$\partial \text{ at } 60^\circ \text{ F} = 1{\cdot}2641 \times 10^{-5}$$
$$\partial \text{ at } 85^\circ \text{ F} = 0{\cdot}92873 \times 10^{-5}.$$

This represented a variation of Reynolds number of about 30 per cent, even if speed remained constant, and made uncertain any kind of regression analysis in which such variations of kinematic viscosity were ignored. Mr. Bell could rest assured however that this point had not been overlooked in the proposed model, which included Reynolds number directly as a variable determining the level of viscous resistance of the smooth ship.

Mr. Jourdain had raised some interesting points concerning the quality of the input data and the author would certainly agree that any statistical model could only be as good as this input data allowed. Despite the fact that high accuracy was not usually claimed for C_{wa}, it did form the basis of most wind corrections to ship trial performance and, in the case of tankers, should be known with good accuracy. In any case, some correction had to be made for windage effects and the author knew of no better system than that adopted by B.S.R.A. and used in the N.P.L. model. As Mr. Field had already stated, for tankers the effect of wave action on these vessels was relatively small, although it was clear that wave forces on certain ship types could be important and estimations of the wave height and frequency of encounter were difficult to make without recourse to additional instrumentation. Checking the values of α_2 from the ship data, assessed by using the least squares technique, was, of course, one of the points of interest made possible by using the statistical model proposed and it was of some importance that the values obtained were certainly of the right order, which was 0·100-0·200 in terms of thrust coefficient. As already noted however, when sample size was restricted or high correlations occurred between the two variables, the values of the coefficients α_2 and α_3 so obtained were not for general application.

INSTITUTE ACTIVITIES

Minutes of Proceedings of the Joint Meeting Held at the Memorial Building on Tuesday, 22nd February 1966

A Joint Meeting of the Institute of Marine Engineers and the Royal Institution of Naval Architects was held at the Memorial Building, 76 Mark Lane, London, E.C.3, on Tuesday, 22nd February 1966, at 5.30 p.m. Mr. B. Hildrew, M.Sc. (Member of Council, I.Mar.E.) was in the Chair, supported by Mr. G. Buchanan, B.Sc., Vice-Chairman, R.I.N.A., and Mr. L. A. Tiltman, Secretary, R.I.N.A.

Approximately one hundred and twenty-eight members and visitors were present.

Two papers, "A Statistical Approach to Ship Performance" by R. M. Duggan, M.A., A.M.I.Mech.E. (Associate Member of Council, I.Mar.E.) and R. S. Field, M.A., F.S.S., and "A Statistical Model of Ship Performance in Service Conditions" by D. J. Doust, M.Sc., Dr. Techn.(Member, R.I.N.A.) were presented by the authors and discussed.

Eleven speakers took part in the discussion which followed.

A vote of thanks to the authors proposed by the Chairman, was received with prolonged acclaim.

The meeting closed at 8.25 p.m.

Branch Meetings

Auckland

An ordinary meeting of the Branch was held on Friday, 29th July 1966, in the Conference Room at Shell House, Albert Street, Auckland, at 7.30 p.m.

Chairman of the Branch, Mr. H. Whittaker (Local Vice-President), presided at the meeting which was attended by twenty-three members and six guests, and welcomed Mr. R. Leighton, Chief Chemist, New Zealand Co-operative Dairy Company, who presented his lecture on "Corrosion of Metals and Feed Water Treatment for Boilers". Mr. Leighton, whose company operates a large number of boilers throughout the North Island, is an authority on the conditions prevailing in the various districts.

A vote of thanks to the speaker was proposed by Mr. D. C. R. McFarquhar (Member of Committee) and endorsed by all present.

Western Australia

A general meeting of the Branch was held on Wednesday, 10th August 1966. The meeting which was also the Annual Students Night, was again very well supported with a total attendance of 135. It was estimated that one hundred of those present were students and apprentices.

A paper entitled "Education and Training of Marine Engineers" by E. T. Harper, M.R.I.N.A., was presented by the author who is Principal Examiner of Engineers for Australia.

A lively discussion ensued which the Chairman, Mr. E. E. Freeth, B.Eng (Chairman of the Branch), was obliged to curtail as time was running out.

Before calling on Mr. A. G. L. Perman (Member of Committee) to propose a vote of thanks to the speaker, the Chairman, who had just returned from London, reported on the progress being made with regard to the new professional standard of marine engineers now that the Institute was a member of the Council of Engineering Institutions.

After the vote of thanks which was carried by acclamation, the meeting closed with a short film "The Launch of the *British Admiral*".

Institute Awards

Members are reminded that the following awards are now made:

The Denny Gold Medal for the best paper read by a member during the session.

The Institute Silver Medal for the best paper read by a non-member during the session.

The Junior Silver Medal and Premium of £5 for the best paper by a Graduate or Student read before the Junior Section during a session.

The W. W. Marriner Memorial Prize, value £5, given annually to the candidate who submits the Engineering Knowledge paper (Steam or Motor) of the highest merit in the Board of Trade examinations for the Second Class Certificate of Competency.

The Extra First Class Engineers' Certificate Examination—Institute Award of a Silver medal for the candidate obtaining the highest marks in the Board of Trade examination.

The Herbert Akroyd Stuart Award, value £50, available biennially, open to members of all grades and non-members for the best paper read at the Institute on "The Origin and Development of Heavy Oil Engines".

The Yorkshire Award, value £40, available biennially for the writer of an essay or the author of a paper read before the Institute dealing with any development related to any aspect of marine engineering or a product applicable to marine engineering.

A cash prize of £25 awarded annually from the interest on the John I. Jacobs, W. Murdoch, D. F. Robertson and A. Girdwood funds for the best essay on the technical advantages to be gained by taking the Extra First Class Engineers' Certificate course—available to engineers taking such a course at a technical college.

Awards, value £4 4s., are given annually to students of technical colleges in marine centres for the best year's work in the study of heat engines.

Prizes for students taking the Ordinary National Diploma Course under the alternative scheme for the training of seagoing engineers. Two prizes are given each year to each technical college operating the scheme, a prize of two guineas being awarded to the best first year student and a prize of six guineas to the best second year student.

The Frank Roberts Award of books or instruments to the value of £7 10s., given annually to the Student or Probationer Student member of the Institute gaining the highest aggregate marks in the courses and examinations in Phase III of the alternative scheme for the training of seagoing engineers.

Administered by the Institute

The William Theodore Barker Award—£100 annually to the candidate who gains the highest marks in the Board of Trade examinations for the First Class Certificate of Competency, provided that such candidate takes the course for the Extra First Class Engineers' Certificate at a technical college.

OBITUARY

HARRY ARNOLD (Member 8910) died on 15th June 1966, at the age of fifty-eight.

Mr. Arnold was apprenticed to the Goole Shipbuilding and Repairing Co. Ltd., from 1924 to 1929, after which he went to sea as a junior engineer with the Peninsular and Orient Steam Navigation Co. Ltd. Altogether he had seventeen years sea service, in grades from junior to second engineer, with Peninsular and Orient, the New Zealand Shipping Co. Ltd. and the Blue Star Line; he was the holder of a First Class Board of Trade Steam Certificate with Motor Endorsement. In 1947, he was appointed chief engineer at the Co-operative Wholesale Society's glass works at Worksop and still held that position at the time of his death.

Mr. Arnold was elected a Member of this Institute in June, 1939, and was also an Associate Member of the Institution of Mechanical Engineers. He leaves a widow.

GEORGE MCCONNOCHIE CAMPBELL (Member 6225) died on 29th May 1966, aged sixty-seven years. He was elected a Member of the Institute in January 1929.

Mr. Campbell was born in Glasgow and, on leaving school, was employed on the Stock Exchange. He enlisted in the Army, at the age of 17½, for service during the Great War, deciding, after the Armistice, that he wanted to serve as a seagoing engineer. Therefore, at the age of twenty, he became apprenticed to John Brown and Co. Ltd. of Clydebank. On completion of his apprenticeship, he joined the Blue Funnel Line as an engineer and, during his six years sea service, studied for, and obtained, his First Class Certificate of Competency. He left the sea to join the then newly-formed company, Insurance Engineers Ltd., as an engineer surveyor. He became district superintendent, in 1939, and retired, at the age of sixty-five, in 1963.

Mr. Campbell is survived by his wife.

JOSEPH PATRICK GATELEY (Member 10806) died on 6th June 1966, at the age of sixty-two.

Mr. Gateley was apprenticed to Messrs. Bow, McLachlan and Sons of Paisley, from 1918 to 1924, after which he joined the British India Steam Navigation Co. Ltd. as a seagoing engineer. He served with them for six years, gaining a First Class Steam Certificate and Motor Endorsement, and, joining the British Tanker Co. Ltd. in 1931, served with that company as a second engineer. He left the sea in 1940, to become a ship and engineer surveyor with the British Corporation Register of Shipping and Aircraft and, at the time of the fusion of the Corporation with Lloyd's Register of Shipping, he was stationed at Bremerhaven. Mr. Gateley was later transferred to to Glasgow, where he served for five years, during which time he was promoted to senior engineer surveyor. He was appointed the senior surveyor in charge of the Society's Leeds office in February 1956 and remained there until the time of his death.

Mr. Gateley was elected a Member of the Institute in May 1946. He is survived by his wife.

ALISTER THOMAS GRAY (Member 15114) died on 24th June 1966, at Sully Hospital, Glamorgan, after a short illness. He was forty years of age.

Mr. Gray served his apprenticeship with the Penarth Slipway and Pontoon Co Ltd. and also attended Cardiff Technical College. On completion of his indentures he joined the Reardon Smith Line Ltd., as a seagoing engineer, and served in the company's vessels in all grades up to second engineer. He gained a First Class Steam Certificate in 1950 and a First Class Motor Endorsement just under two years later. He came ashore in 1954, to rejoin the Penarth Slipway and Pontoon Co. as assistant works manager, being there in charge of extensive refits of smaller vessels, including a number of naval vessels. He returned to the Reardon Smith Line as a superintendent, in October 1956, and was particularly concerned with new construction, first at Wm. Doxford and Sons Ltd. and, later, at the Fairfield Shipbuilding and Engineering Co. Ltd.

Mr. Gray was elected an Associate of the Institute in June 1954 and transferred to the grade of Member in February 1966. He is survived by his wife.

FREDERICK THOMAS GREEN (Member 5620), a Member of this Institute since November 1926, died on 7th November 1965, at the age of seventy-eight. Mr. Green was very active in the affairs of the Institute, serving for many years on the Committee of what is now the Kingston upon Hull and Humber Area Branch; he was at one time Vice-Chairman of that Committee.

Mr. Green was educated at Jarrow High School, and at Rutherford and Armstrong Colleges in Newcastle. He served his apprenticeship with the North Eastern Engineering Co. Ltd., after which he joined Smith's Dock Co. Ltd., with whom he later became chief draughtsman and ultimately, assistant manager. He subsequently held appointments as manager, first with Amos and Smith, in Hull, and then with J. Samuel White and Co. Ltd., in Southampton. His last professional appointment was as general manager with the Humber St. Andrews Engineering Co. Ltd. He retired from business in December 1959.

During the First World War, Mr. Green was engaged on a large design programme for Admiralty vessels on completion of which he was loaned to the Imperial Munitions Board in Canada as technical adviser on the construction of merchant ships. During the second world conflict, he was appointed by Admiralty as Assistant Director, Merchant Shipbuilding and Repairs (Repairs) for the United Kingdom; he was also connected with the design of "Mac-ships"—tankers converted to aircraft carriers.

Mr. Green is survived by his wife; he also leaves four sons and a daughter.

Obituary

EDWARD LEA (Member 13058), a senior engineer and ship surveyor on the staff of the Engineer Surveyor-in-Chief, Marine Safety Branch of the Board of Trade, died in hospital on 23rd April 1966. He was forty-six years of age.

Mr. Lea was apprenticed to Armstrong Whitworth and Co. Ltd., from 1936 to 1937, and to Clelands (Successors) Ltd., from 1937 to 1941; he also attended evening classes, for a five-year course, at the Marine School of South Shields. At the conclusion of his apprenticeship he commenced his sea service as a marine engineer, sailing in all ranks from assistant to chief engineer in both steam and motor vessels until the end of 1949; he gained an Extra First Class Certificate in April 1948. In January 1950, Mr. Lea took up an appointment as an engineer and ship surveyor with the Ministry of Transport and, in August 1963, he was promoted to the position he held at the time of his death.

Mr. Lea was elected a Member of the Institute in October 1950.

JOHN DEWAR PAUL (Member 6454) was born on 15th October 1895. He was apprenticed to Denny and Co. Ltd. of Dumbarton and saw twelve years sea service on completion of his indentures. He was the holder of a First Class Board of Trade Certificate in Steam with a Motor Endorsement. When he retired from the sea, he became superintendent engineer with the Bank Line Ltd., in New York.

Mr. Paul was elected a Member of the Institute in June 1930.

JOHN ALBERT POLLOCK (Member 6483), who died on 29th January 1966, was elected a Member of the Institute in June 1930. He served his apprenticeship with Mort's Dock and Engineering Co. Ltd. of Sydney, New South Wales, after which he went to sea for five years with the Huddart Parker Line and the Dalgliesh Line; during this latter period he gained a First Class Certificate of Competency (Melbourne). When he came ashore, he accepted an appointment as an engineer with Biddell Bros. of Sydney, but later joined the Shell Company of Australia Ltd., as an industrial engineer. He retired from professional life in 1957.

Mr. Pollock is survived by his wife.

ALEXANDER BLACKLEY SINCLAIR (Member 13629) was born on 3rd March 1903. He was educated in Greenock and served his apprenticeship there with Messrs. G. and J. McCrie, engineers and founders, from 1919 to 1924. On completion of his indentures, he joined Lang and Fulton Ltd. as a junior engineer and remained with them until October 1927. From 1928 to 1951, he served at sea with the China Navigation Co. Ltd., in ranks from third to chief engineer, gaining a First Class Steam Certificate in 1933. He was appointed an engineer surveyor to Lloyd's Register of Shipping in 1951 and so remained until the time of his death; the whole of his time with the Society was spent in Glasgow, except for short spells of temporary duty in London, in 1961, and in Aberdeen, in 1963.

Mr. Sinclair was elected a Member of the Institute in January 1952. He leaves a widow.

WILLIAM GILBERT THOMSON (Member 7377) died on 1st January 1966 at the age of sixty-one.

Mr. Thomson served an apprenticeship with Hall, Russell and Co. Ltd., from 1919 to 1924, after which he went to sea as a junior and, later, a fourth engineer with the Peninsular and Orient Steam Navigation Co. Ltd. Following his seagoing experience he embarked upon an active and varied career ashore in the shipbuilding and oil industries. He also, at one time, acted as an engineer consultant. During the Second World War, Mr. Thomson served as an officer, first with the Territorial Army, and later with the Royal Naval Volunteer Reserve, attaining the rank of Lieutenant-Commander (E) in the latter service. After demobilization, he took up an appointment as representative and engineer with a company based in Scotland.

Mr. Thomson was elected an Associate Member of the Institute in October 1933 and transferred to the grade of Member in June 1945. He is survived by his wife.

MALCOLM DOUGLAS WATTS (Probationer Student 20950) was born on 28th August 1942. Educated at Rains Foundation School for Boys, he joined Ellerman Lines Ltd., in September 1958, as an apprentice and, in the same month, enrolled at Poplar Technical College for the Ordinary National Diploma course.

Mr. Watts was elected a Probationer Student in January 1959. He died in Cambridge on 26th February 1966.