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A Statistical Approach to Ship Performance

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Tankers, especially crude carriers, experience severe deterioration in performance from hull fouling. Measured mile trials can only give spot values of the performance at widely spaced intervals in time, and a more continuous record is required to show the detailed variations in performance.

Fifteen ships, selected as a sample of varying size, trade and nationality, were equipped with improved instrumentation and, in the case of three vessels, with data loggers. A ship-to-shore system of high-speed data transmission by radio teleprinter was pioneered to transfer the data quickly to the office. The data are reproduced by the radio teleprinter on punched tape which is used as the source of punched cards. These feed a system of computer programmes which check the validity of the data and store good information on punched tape.

One set of readings is taken on board each ship every watch. These are analysed in a further programme to give boiler and plant efficiencies, and after suitable modification, they are pooled over a week to give hull and propeller performance indicators.

While the project has met many problems, results have been obtained which show unexpected short-term variations in hull performance.

INTRODUCTION

For some time, the organization with whom the authors are associated has made considerable use of measured mile trials to investigate the deterioration of ships' performance in service. A three-man team of trials specialists was built up with the initial guidance of B.S.R.A. The team has carried out over 50 measured mile trials since then, the results of which have all been given to B.S.R.A.

This paper is not the place to discuss the techniques involved in measured mile trials, but it is worth noting that the experience gained in instrumentation from these trials and on an earlier experimental ship, has proved a most valuable starting point for the choice of instruments in the performance exercise described in this paper.

The programme of measured mile trials produced most valuable results. When the trials programme started, it was confined to general purpose product carriers of 18,000 d.w.t. and a pattern of limited annual deterioration in performance with an underlying long-term deterioration became apparent. This is well illustrated by Fig. 1 showing the performance of s.s. *Hemifusus*.

As larger vessels entered the exercise, some straight from the builders, the picture became confused. The difference between performance before and after annual docking rose to new levels of up to 38 per cent on power for a given ship at service speed. It seems that the newer crude carriers, trading between sea-water terminals at both loading and discharge ports, were not benefiting from the regular visits to fresh water which typified the up-river trading of the smaller ships.

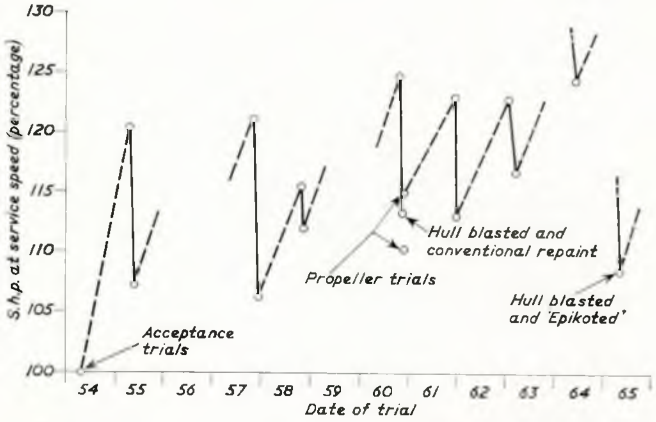

FIG. 1—*Performance curve for s.s.* Hemifusus *obtained from measured mile trials—s.h.p. required at loaded condition and service speed*

As a result, weed could become firmly established on the sides of the ship, and firmly established as a serious source of inefficiency.

Another problem, common to both the smaller ships and the large crude carriers, was the difference between sister ships, built from the same drawings, sometimes from the same yard, even built at the same time in adjacent slips. Yet such differences were not merely apparent on the first owner's trial, but persisted for several years.

The differences, amounting in one case to 14 per cent on power, have never been satisfactorily explained. In some cases

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there were variations in the treatment of the hull to protect the steel, resulting in variations in hull roughness. However, this was not sufficient explanation of the variation; possibly the manufacturing tolerances of the shipbuilding industry result in sufficient variation of hull lines from ship to ship to contribute measurable differences in performance. A penalty of 14 per cent increased power at service speed, and hence in fuel consumption, makes a serious change in the economics of tanker operation.

However, to return to the main problem, that of fouling, it is one thing to have established a problem, another to overcome it. Many questions were raised by the results: was the deterioration a gradual process?; did it all take place during the first or last three months of the period between dockings?; what protection, if any, was provided by anti-fouling paints?; and for how long would this protection last?; what make and recipe of anti-fouling paint was most effective?; did some types of anti-fouling paint really reduce the speed of the ship by presenting a soft rough surface to the water?

It would have been of great value to identify this deterioration more closely, by carrying out more trials each year on these ships. However, trade routes changed; sometimes these large crude carriers worked from the Persian Gulf eastwards, only returning to the west annually for docking, and the pressure from the ships' operators, seeking to reduce the time out of service, extended this period to eighteen months and then to two years. Each measured mile trial gave one point of the performance curve of the vessel, and these points were too infrequent.

Just as the large ships presented new problems, the use of 18,000-ton vessels for small ports created new hazards in monitoring ship performance. Of the original seven ships, five sustained hull or propeller damage due to their arduous service conditions In each case this was sufficient to make comparisons of hull performance between one year and the next inexact or impossible.

It was, therefore, decided to seek a method of performance control using information collected during the course of normal operations. The vessels that had taken part in the measured mile trial programme were included in the sample, which was expanded to fifteen to provide a better coverage of the types of ship in service and a better insurance against loss of continuity from damage.

This exercise was decided upon in the Summer of 1962. However, it would never have been attempted were it not for work which started in the Autumn of 1961, in the Operational Research Unit of Shell International Petroleum Co. Just as the experience in the marine function of performance indicators using measured mile trials had shown the need for a continuous performance monitor, so the work in the Operational Research Unit suggested a method of approach which might be successful.

It is well known that the data regularly inscribed in the log books of ships are rarely used on a routine basis. The information is too diffuse, and for practical purposes it is grouped together into voyage reports. It occurred to one statistician that here was a field in which his techniques might be fruitfully employed, to extract the maximum information available from the recorded log-book data.

Using simple multiple regression techniques to relate shaft horsepower to ship's speed, draught and weather conditions, it was possible to remove the majority of outside influences and to correct the speed to standard conditions, giving an indication of overall ship performance. There were two difficulties; of a sample of log-book data, 80 per cent had to be rejected because of missing or obviously inaccurate reading, and the basic accuracy of the instruments was inadequate. It was necessary to improve the quality of the instrumentation, and to improve the quality of the reading and recording of those instruments. From these requirements, the details of the exercise developed.

OBJECTIVE

Briefly, the purpose of the study was to provide a monitor

TABLE I—PARTICULARS OF THE SHIPS TAKING PART IN THE EXERCISE

Vessel							Machinery			Data			
Name	D.w.t. (tons)	L.o.a. (ft.)	Trade	Nationality		Speed (kts.)	Type	S.h.p.	Thrust-meter	Collection	Transmitter	
				Builder	Operator					Manual or Auto	Power	Type
Aluco	19,340	559·9	White	British	British	15	Steam	7,200	Yes	Manual	1,200	D/S.S.B.
Amoria	18,062	559·0	White	British	British	15	Motor	7,500	Yes	Manual	1,400	D/S.S.B.
Arianta	19,310	559·9	White	British	British	15	Steam	7,200	Yes	Manual	600	D.S.B.
Capulus	28,281	624·6	Black	U.S.A.	German	16¼	Steam	12,500	No	Manual	375	D.S.B.
Hemifusus	18,102	555·7	Lub. oil	British	British	15	Steam	7,500	Yes	Manual	600	D.S.B.
Hemimactra	18,219	555·7	Black	British	British	15	Steam	7,500	No	Manual	1,400	D/S.S.B.
Ondina	49,790	748·0	Black	Dutch	Dutch	16	Steam	16,000	No	Manual	400	D.S.B.
Sepia	68,125	817·8	Black	British	Dutch	16¾	Steam	21,300	Yes	Automatic	300	D.S.B.
Serenia	67,850	817·8	Black	British	British	16¾	Steam	21,300	Yes	Manual	1,400	D/S.S.B.
Sitala	78,458	852·0	Black	French	French	17	Steam	24,000	No	Automatic	400	D.S.B.
Solen	67,849	817·8	Black	British	British	16¾	Steam	21,300	Yes	Automatic	300	D.S.B.
Varicella	33,423	665·0	Black	British	British	15¼	Steam	11,000	No	Manual	300	D.S.B.
Vivipara	32,308	660·0	Black	Dutch	Dutch	16¼	Steam	13,000	Yes	Manual	400	D.S.B.
Volvatella	32,308	665·0	Black	British	British	16¼	Steam	13,000	Yes	Manual	300	D.S.B.
Vola	32,330	665·0	Black	British	French	16¼	Steam	11,000	No	Manual	400	D.S.B.

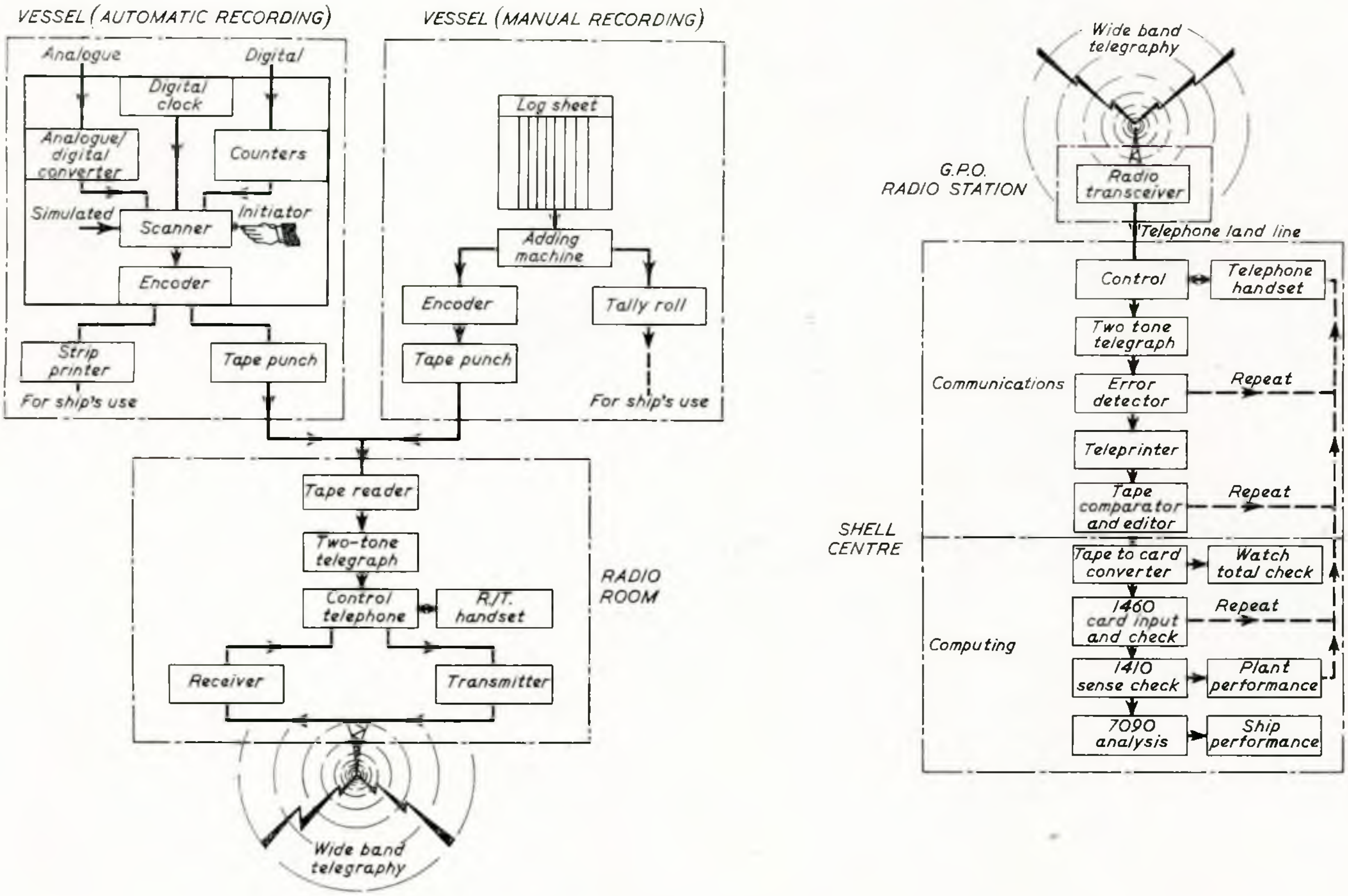

FIG. 2—*Schematic diagram of the exercise*

of ship performance—in particular the performance of hull and screw, using data collected during normal ship operations on loaded and ballast voyages. The information from the performance indicator is needed for investigating the phenomenon of performance deterioration, and for testing methods of combating this deterioration. Since this is a research tool rather than a management tool, it can be applied to a limited sample of ships, and relatively costly techniques can be applied to achieve the desired accuracy.

There are three main elements in the system set up to provide the necessary information (see Fig. 2). On board ship, accurate instrumentation and reliable recording are needed. To these ends, all fifteen ships were equipped with specially-selected instruments and three of the fifteen had data loggers as well. For the data to reach the office, a quick and reliable means of data transmission was required; for this each ship was fitted with an error correcting high-speed data transmitting system, with another terminal at Shell Centre. To check the data for errors and to analyse the information to provide performance indicators, a system of computer programmes was devised.

The success of these stages in the exercise is analysed in the following paragraphs.

BACKGROUND

There has long been interest in analysing voyage data to give an indicator of performance, but the use to which the results have been put were generally confined to gaining an impression of overall deterioration in performance. Relatively straightforward checks, such as voyage reports, may provide adequate management control, especially if the vessel is on liner trade.

Performance analysis in more detail has rarely appeared worth while, although suggestions have been put forward from time to time on the best methods of achieving the necessary corrections. Papers on the subject can be found from 1926(4) down to the present, with an occasional step forward in technique, as in Clement's paper(1) on the analysis of voyage data, in his suggestions on analysing propeller efficiency.

Few of these approaches have sought to examine the underlying mechanics of ship resistance and propulsion (see Lackenby(3)), but such formulations have long been used on a limited basis by ship model testing tanks in extrapolating model data to give estimates of ship performance. The practice of testing tanks is to alter the measured coefficient of resistance (which coefficient is immaterial to this argument) by using a mathematical formulation of the contribution of viscous resistance; if a formula could be found which described adequately the remaining component of the resistive coefficient, then it might be possible, if ship resistance could be estimated from power and thrust readings, to analyse performance data into changes in fundamental properties, and, by using the same approach to performance analysis as the testing tank used for performance prediction, ship-model correlation studies might also benefit.

This philosophy led to the authors seeking help from NPL Ship Division; and the result of this approach is presented in Dr. Doust's paper(2).

DATA RECORDING

The first decision was to collect the data once every watch, so that the process of collection best fitted shipboard routine and averaged out variation in operating requirements from watch to watch. The second, to choose a recording period of five minutes as a compromise between a long period, enabling short term variations due to ship movement to cancel out, and permitting rate measurements (such as water speed, shaft speed, fuel rate) to be taken, and the balancing requirement of avoid-

S.S. ..."SERENIA"................ **PERFORMANCE DATA LOG SHEET** Date:....13-8-65....................

No.	Measurement	Noon-4 p.m. Watch	4-8 p.m. Watch	8-12 p.m. Watch	12-4 a.m. Watch	4-8 a.m. Watch	8 a.m.-Noon Watch	Line Totals
1	Ship's Reference	31	31	31	31	31	31	186
2	Year & Day	5224	5224	5224	5225	5225	5225	31347
3	Time	1510	1910	2310	310	710	1110	7860
4	Wind Speed	100	200	260	260	90	260	1170
5	Wind Direction	340	350	290	360	90	10	1440
6	Swell Height	5	5	5	4	4	3	26
7	Swell Frequency	6	6	6	3	12	10	43
8	Swell Direction	270	270	270	220	40	30	1100
9	Ship's Speed	167	167	164	165	169	164	996
10	Draft Forward	425	425	425	425	425	425	2550
11	Draft Aft	430	430	430	430	430	430	2580
12	Rudder Angle	4	4	5	4	3	4	24

(a) bridge data

S.S......"SERENIA".................. **PERFORMANCE DATA LOG SHEET** Date:...13-8-65....................

No.	Measurement	Noon-4 p.m. Watch	4-8 p.m. Watch	8-12 p.m. Watch	12-4 a.m. Watch	4-8 a.m. Watch	8 a.m.-Noon Watch	Line Totals
13	Propeller R.P.M.	1056	1054	1052	1050	1052	1024	6288
14	S.H.P.	1986	1981	1976	1994	1973	1795	11705
15	Card Identity No.	00001+	00001+	00001+	00001+	00001+	00001+	00006−
	End of Burst Signal	◁	◁	◁	◁	◁	◁	◁
16	Thrust	1520	1520	1520	1496	1496	1448	9000
17	Sea Temperature	64	63	63	63	60	59	372
18	Fuel Consumption	1182	1176	1175	1178	1176	1152	7039
19	Fuel Sp. Gravity	960	960	960	960	960	960	5760
20	Fuel Temperature	240	240	242	242	242	244	1450
21	Main Steam Pressure	590	590	590	590	590	590	3540
22	Main Steam Temp. (P)	899	901	902	901	902	903	5408
23	Main Steam Temp. (S)	897	902	902	901	890	894	5386
24	Flue Gas Analysis (P)	125	125	125	125	125	125	750
25	Flue Gas Analysis (S)	130	130	130	128	125	125	768
26	Funnel Gas Temp. (P)	384	386	387	388	384	384	2313
27	Card Identity No.	00002+	00002+	00002+	00002+	00002+	00002+	00012−
	End of Burst Signal	◁	◁	◁	◁	◁	◁	◁
28	Funnel Gas Temp. (S)	390	392	393	394	383	384	2336
29	Air Inlet Temp. (P)	222	222	222	222	221	222	1331
30	Air Inlet Temp. (S)	214	214	213	213	212	212	1278
31	Alternator Output	445	410	410	410	440	500	2615
32	Cargo Htg. Steam Flow							
33	Cargo Htg. Steam Press.							
34	Cargo Htg. Steam Temp.							
35	T.C. or Ballasting							
36	Fill-up Zeroes	00000+	00000+	00000+	00000+	00000+	00000+	00000−
37	Fill-up Zeroes	00000+	00000+	00000+	00000+	00000+	00000+	00000−
38	Hull Fouling or Fill-up Zeroes	1000	2000	3000	4000	5000	6000	21000
39	Card Identity No.	00003+	00003+	00003+	00003+	00003+	00003+	00018−
	End of Burst Signal	◁	◁	◁	◁	◁	◁	<
40	Watch Totals	20822	22294	23688	22698	23466	24729	37697

N.B. Decimal Points To Be Ignored. Grand Total

(b) engineroom data

FIG. 3—*Sheets on which data are recorded by ships' personnel—The bottom of a) has an adhesive strip so that the two sheets may be joined*

ing an excessive period during which changes in wind speed and direction, or changes of course, might affect the performance of the ship.

Within the five-minute period, a routine was established so that bridge and engine-room data are collected concurrently, and spot readings, such as temperatures and pressures, and wind speed and direction, are taken during the course of the five-minute period over which the rate measurements are established against stop-watches. A list of all data collected is given in Fig. 3.

From the preliminary work, it was decided to aim for an accuracy of one per cent in main parameters, with a higher accuracy if possible for water speed ($\frac{1}{3}$ per cent).

Provided that the instruments are themselves accurate, the data obtained are as reliable as the ships' staffs who take the readings. Any addition to the work load on board is inevitably viewed with some distrust, so that any precautions which would either reduce the effort involved in the data collection, or would make the staff more sympathetic towards the exercise, were potentially valuable. To this end, the list of variables was kept to a minimum compatible with the information required; where possible, direct reading instruments and centralized instruments were fitted in place of local instruments and office staff made short voyages, on most of the fifteen vessels, to instruct the staff in the purpose and practice of the exercise.

A final step in eliminating extra work for the watchkeeping staff was the installation of automatic data recording equipment, "data loggers", on three of the fifteen ships. With the exception of nine readings which must be set in by hand (only five of which change watch-to-watch in normal operation), the work involved in recording a set of data consists of pressing a button. These five must be hand-set because no transducers exist for measurement of swell parameters, or of ship draught when the vessel is in motion. The value of such a data logger is that it is free of human error, it eliminates human donkey work, and it permits, when required, a very high rate of data recording.

Having established the objectives in data collection, it is possible to discuss the degree with which these objectives were met. This approach is repeated in subsequent sections.

It must be stressed that the interest and co-operation of the ships' staffs are the most valuable contributions possible to the success of such an exercise. Response has naturally varied, but the help has generally been good, with three or four outstanding examples. Indeed when interest on board has flagged, it has often been due to a feeling that the office is losing enthusiasm, and it has become obvious that with the limited contact possible between ship and office staff, a maximum of information on the purpose and progress of the exercise must be passed back to ships.

To concentrate on instruments, there are five whose readings are of prime importance—fuelmeter, torsionmeter, revolutions counter, thrustmeter and speedmeter. Some five fuel flowmeters were tried out in this exercise, with typical results shown in Fig. 4 (in fact the photograph shows a flowmeter which was running in nothing more harmful than distilled water, but similar catastrophes happened with fuel oil). Those flowmeters which failed, as did most, to maintain sufficient accuracy, did so because of excessive wear, often in less than six months operation. The most successful fuelmeter has been a German positive displacement meter, which uses meshing elliptical gearwheels, and the only other possibility has been another positive displacement meter, of the piston type, which requires frequent overhaul to avoid inaccuracy and breakdown from high wear rates. The other three meters were more liabilities than assets.

The standard type of thrustmeter, the Michell, does not have an intrinsic accuracy as high as the exercise required, though it seems to be a robust instrument with a long time between failures. It has three characteristics which appear undesirable. Read-out of the instrument is on a Bourdon tube, whose reading is sensitive to the skill of the operator in checking that the system is fully pressurized, in operating the damping to obtain a steady but unbiased reading, and in avoiding too rapid release of the system valve which can cause the needle to bend on violently striking the zero peg.

Counting revolutions is relatively straightforward; counters triggered mechanically or electrically are generally reliable, though even the Selsyn-type frequently show a slight, but unfortunately erratic, degree of slip between the counter on the shaft-mounted transmitter and the counter on the remote-reading instrument. During measured mile trials, a plastic strip strapped to half the circumference of the shaft, operating a micro-switch, has proved a reliable and effective source of pulses, but at 10^6 cycles/week, the life expectancy of the micro-switches is not sufficient for continuous operation.

Experience with torsionmeters has been discouraging be-

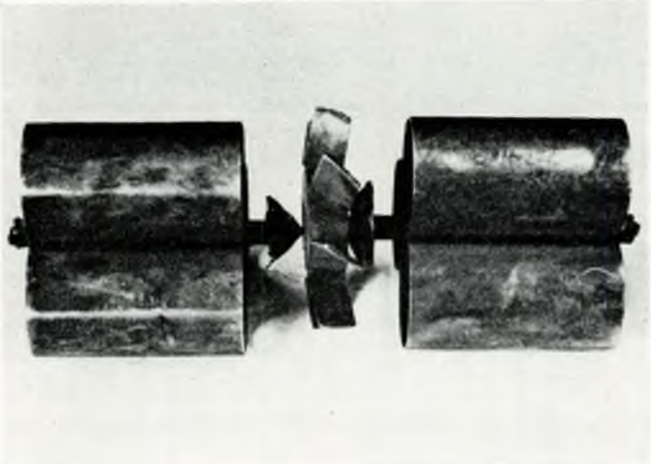

Fig. 4—*Flowmeter which failed in service*

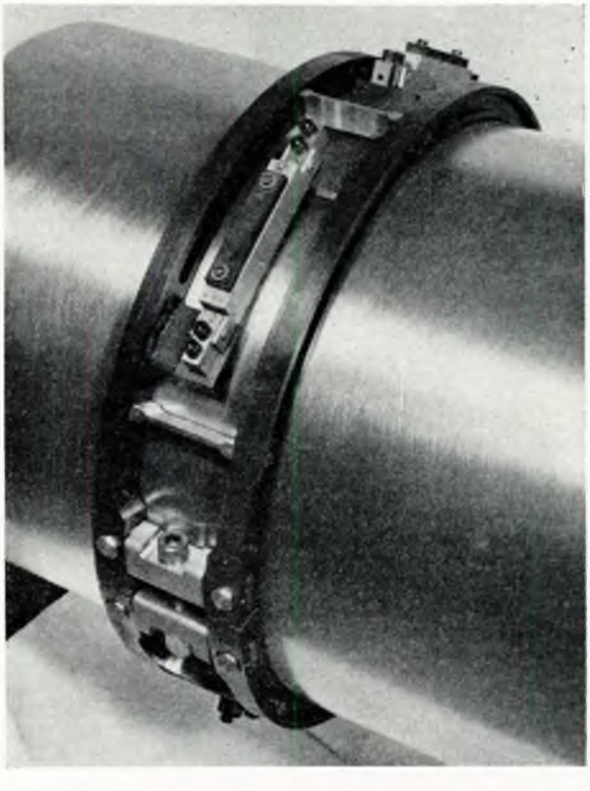

Fig. 5—*An experimental version of the Maihak torsionmeter, modified to eliminate slip-rings and to reduce husk weight*

cause torsionmeters have tended to suffer from two basic weaknesses; either the signal has been fed from the transducer by slip-rings giving rise to the possibility of loss of sensitivity; or there are two transducers, separately mounted some distance apart on the hull structure, in which case hull distortions from temperature differences, varying cargo dispositions and weather conditions can alter the zero calibration unpredictably.

At this stage in the review of instruments, a note of optimism may be sounded. Using the principle of the vibrating strain gauge, found in the Maihak torsionmeter, Thornton Research Centre has developed a radio torsionmeter (see Fig. 5).

The frequencies of the vibrating strain gauges are used as modulators of a pair of carrier frequencies which are radiated from two rotating aerials to a pair of fixed aerials only centimetres away. The strain gauges and the transmitter are powered by a small battery pack, which is sufficient for a year's normal operation. This long life is achieved by switching on the torsionmeter only when required, the switch being triggered magnetically and the torsionmeter automatically switching off a few minutes later. Prototypes (without switches) have been in operation for two years with a fair measure of success, using larger battery packs lasting over six months in continuous operation. Although there are two strain gauges set so that any temperature variations tend to be compensated, the zero shifts from temperature changes have tended to be excessive, but the latest model has been built with steel torsion collars instead of aluminium, which experiment has shown may correct this source of inaccuracy. A further virtue that the radio torsionmeter possesses is that the husk weight is much lower than on conventional torsionmeters, thus reducing the chance of slip from inertial forces.

The final measurement—of speed through the water—is bedevilled by the problem of defining to which body of water the motion of the vessel is to be related. Early experiments relating the motion of the ship to radar-reflector buoys by Doppler techniques, or more enjoyably, if less accurately, by timing the passage of empty beer cans, demonstrated that the random motions in the surface of the sea invalidate these techniques. The random movements of free-floating buoys at sea was studied in a most illuminating trial carried out in conjunction with B.S.R.A. at Polperro in June 1961. A line of buoys was set down and the motion of these buoys studied in relation to each other and a passing ship by aerial photography. The results shown in Fig. 6, for the first run, indicate both the random movement of buoys 1, 4, 5 and 6, and the effect of wake on buoys 2 and 3. These two buoys were dropped from the ship, one from either quarter, but within two minutes of dropping both appeared on the port side.

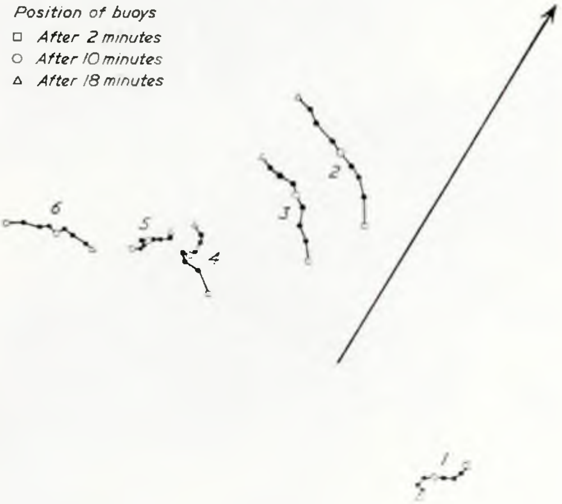

FIG. 6—*Movement of buoys at sea—Position of each buoy is shown at successive intervals of about two minutes —The ship has steamed through one end of the line and dropped two buoys 2 and 3, one on each quarter—Length of the arrow is the length of the ship*

The traditional technique is to measure the speed relative to water only one or two feet from the surface of the ship. In a large tanker, the thickness of the boundary layer in the region of the probe has been estimated from three to five feet, so that the normal penetration of one or two feet is well within the boundary layer. When the hull of the vessel fouls in service, the streamline on which the probe lies may change; thus apart from any tendencies of the log to change calibration from wear or aging, it may be faithfully reporting speed relative to a body of water different to that against which it was first calibrated. There are two possible solutions: one is to project a probe further out from the vessel so that the transducer is influenced by water closer to the edge of the boundary layer or beyond it, thus reducing the effect of changes in the boundary layer (the first two attempts at this solution are shown in Fig. 7; they were Pitot-static probes, and failed in 14 and 20 minutes as a result of vibration), the other is to relate the speed of the ship to the general mass of water around it using, for example, a forward-projected flat sonar beam and estimate the speed by Doppler techniques from echoes of all the discontinuities in the sea; débris, eddies, temperature variations and sea life.

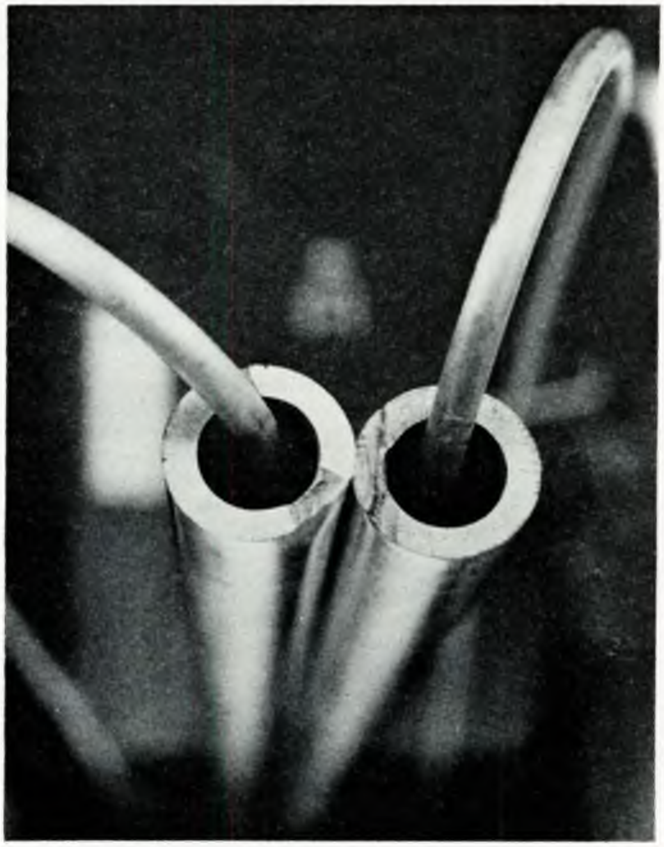

FIG. 7—*Two Pitot-static tubes which failed through vibration —The inner tube was connected to the static opening— The outboard sections of the main tubes were lost*

In the short term, investigations are proceeding with longer probes, using two measuring techniques; the Pitot-static and electro-magnetic methods.

All the ships in the exercise have been fitted with multipoint temperature indicators, the signal being provided by thermocouples. Thus all the temperatures which are recorded can be read from a central position near the control platform. Such a system was a most welcome feature to ships' staffs. Provided that the thermocouples and leads were carefully installed to avoid temperatures drops across the thermocouple probes and to avoid failure of thermocouples and leads from exposure to mechanical damage, corrosion and degradation of the insulation of the leads by heat, the temperature indicators have given good service. Within the electronic units, the main problem has been the dust and oil mist in the atmosphere, reducing the sensitivity and even affecting the calibration in some cases by insulating effects on the switches and slide wires. The problem of the switches has been overcome by replacing press-button contacts with lever switches, whose wiping action keeps the contacts clean.

The main demand on the ship's staff in taking a set of observations is in the timing of the fuel consumption, shaft revolutions and distance run over the five minute period. Not only does this interfere with normal watchkeeping duties, but the accuracy of the reading depends upon the accuracy of the stop-watches. While in normal operation the watches were accurate, the first type used failed to stand the shocks and strains of use in ships' engine rooms.

The watches must then be returned for repair, so that the total time out of service may be two or three months.

It was thought that the staff might be relieved of the chore of timing these three quantities, and the problems of fragile time-pieces overcome, if these pulses generated by the fuelmeter, revolutions counter, and distance counter on the log could be totalled on a miniature digital logger. The design for such a mini-logger was developed under contract, but the cost of such a device was out of proportion to its value. Much of this cost arose in the internal timing mechanism, and in view of the increasing need for accurate timing pulses in various devices—submerged log integration, for example—a centralized source of accurate time impulses seems desirable on board ship. Using such a source of time pulses, the cost of a mini-logger would be almost halved.

The picture looking to the future is not so grim as the past suggests. Instruments for marine use have not been designed for the accuracies demanded by this exercise, and instruments designed for land use are frequently not sufficiently robust. However, the development of the acoustic strain gauge torsionmeter will provide accurate measurement of torque and the use of similar techniques may well lead to a shaft-mounted thrustmeter. A good fuelmeter exists. Longer probes for submerged logs are becoming available which have been tested for vibration in test tanks, and the Doppler sonar technique mentioned is embodied in a design due in commercial form during 1966. It seems that the marine world may soon have available robust instrumentation, sufficiently accurate for continuous performance measurement.

Finally, on the subject of data collection, the performance of the three data loggers must be recorded. These units were specified to replace the manual logging. The records logged are not confined to spot readings but, as on the manually-logged ships, rate measurements are taken over a fixed time period (see Fig. 9).

FIG. 8—*A Ventimeter—a cheap, reliable maintenance-free instrument for measuring wind speed*

FIG. 9—*Data logger on board s.s.* Sepia

All three manufacturers found that the design, construction and testing of these loggers were more difficult than they anticipated, and though the six-month delivery period ended in September 1963, the three loggers were installed on the vessels in December 1963 and January 1964. Since the vessels were already in service, installation took place either during the annual docking or while cargo was being discharged at a European terminal. The major part of the installation task was cabling, and in the two vessels which did not dock conveniently, this work was carried out at sea by extra staff, prior to the installation of the logger units themselves. One logger was installed and tested within a month of being placed on board, the commissioning of the second logger took until August 1964 before all the problems of installation had been overcome, while the third logger was never accepted as fully commissioned, the decision being taken in October 1965 to abandon further attempts to make the logger operationally worth while. It was removed from the ship in November 1965.

These were three first generation marine data loggers, of a complexity beyond that of most others of their kind, though the number of parameters logged is reasonably small. The design faults were principally failures to accept the realism of reported conditions at sea with the wide variations in ambient temperatures and the low frequency vibration, so that mechanically and electrically the logger failed to stand up to the test; on shore, they would probably have been perfectly adequate.

The two loggers which have been commissioned are now providing data just as reliably as on those ships where the data are collected manually. The weakness on the data logger ships is the same weakness as on the manually logged vessels—the primary elements, the transducers, cannot be relied upon for continuous accurate signals.

DATA TRANSMISSION

Data having been collected on board ship, they must be sent to the office where they are to be analysed. The vessels taking part in the exercise have no set patterns of voyage which return them frequently to N.W. Europe, and often call at ports whose postal services tend to be erratic in when, and whether, they deliver. However, the decision to investigate techniques of radio transmission was based primarily on the lack of confidence in shipboard measuring instruments, engendered by previous experience. Rapid analysis of the data once received in the office would permit a check on the proper functioning of the instruments which might be delayed six weeks if the postal services were used.

Initially, the British Post Office appeared confident that the wireless telegraphy service using the Area Scheme would provide a rapid and reliable data service. Tests carried out from the Indian Ocean and the Pacific showed this assumption to be over-optimistic, with error rates in the region of one per cent and a transmission time of 40 minutes for one day's data.

The radio-telephony service was somewhat better, the operator on board reciting the numbers which were copied down at this end by an experienced radio-telephony operator; error rates were very low since this is an error-correcting system, and the transmission time was reduced to 20 minutes. Neither alternative seemed an attractive proposition.

When enquiries were first made about data transmission systems, there was only one enthusiastic response. A system had been developed for land-line communication, and the manufacturers adapted the system for use over a radio link to meet the needs of this exercise. Although a certain measure of success was achieved, the manufacturers felt that the system was not best suited to radio communications, and they decided to concentrate on the land-line applications of their system. While this was disappointing, the initiative shown by A.E.I. served to stimulate other radio companies.

One system that had been available in prototype form was the two-path error-correcting system developed by the Netherlands P.T.T. Indeed, the first had been at sea for about three years before the authors' interests were aroused in radio data transmission, but the system had not been developed commercially. The third system was in the process of development when the enquiries were being made, a single-path forward error-correcting and detecting system called Marconi "Editor".

The two systems differ in approach. The "Editor" equipment transmits the data (precoded on five-hole punched tape) with 100 per cent redundancy: thus each five-element character on tape is recoded into a ten-element code for radio transmissions. The receiving terminal recombines the elements into a five-unit code in such a way that characters with one element in ten in error are reproduced correctly, while most of those characters with more than one element in ten in error are recognized as erroneous characters and a special error symbol is inserted in place of the mutilated character. No return path is used. Thus a burst of overwhelming interference or a very deep fade will cause a series of error symbols to be thrown up. The system relies on the synchronous working of transmitting and receiving units, so that a phasing period is required at the start of each transmission.

The Dutch equipment uses a code with seven elements for each character to provide error detection, and sends a burst of three characters at a time. If accepted, a signal is returned to the transmitting unit requesting the next three characters: if rejected, another signal requests a repeat. In error-free conditions the two systems work at approximately the same character speed since the Dutch equipment uses shorter element times.

Preliminary experience with the two systems suggested that in their performance for the strictly limited task of transmitting numeric data there was little to choose between them. In good conditions both worked without error; in bad conditions neither could manage; and 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. "Editor" equipment was chosen because delivery could be promised six months earlier.

Having settled for this data transmission system, more properly known as a radio teleprinter system, it was necessary to encode the data on board ship in a suitable form, five-hole punched paper tape. However, while the radio teleprinter system was error-detecting and correcting, it was not error-free, so a second level of error protection was devised.

Setting out the data for six watches in a table as in Fig. 3, the figures recorded are added together for each watch to give watch totals (column totals) while the figures in each row are added across to create a dummy watch of row totals. On receipt of a transmitted data tape, the row and column totals can be checked against the body of the table to detect errors and if they are few, correct them. To perform the chore of creating the totals and preparing the punched tape, the radio officer on board each ship is provided with a combined adding machine and tape punch.

The radio teleprinter service started in June 1964, operating through the British Post Office radio-telephony terminal at Brent, the ship-to-shore contact being extended thence by the ordinary telephone network through International Exchange to Shell Centre, London. There was the usual rash of teething troubles—International Exchange operators inserting three-minute pips into the middle of data calls or enquiring against the background of the strange noises emanating from the ship whether the conversation had finished; technical operators at Brent working at cross-purposes with radio officers until proper procedures were hammered out; unusually high land-line losses influencing the performance of "Editor". In general these problems were quickly sorted out, and the technical operators and duty engineers at Brent are to be praised for their efforts which were primarily responsible for the successful introduction of the system.

To support the radio teleprinter equipment, it was necessary to ensure that all ships had adequately powerful transmitters. It was felt initially that 400 watt double side band transmitters would prove adequate, and all vessels in the exercise were brought up to this level when necessary. However, as three of the largest vessels traded predominately across the Indian Ocean, trials were made with a 1,000 watt single side band transmitter.

Comparison of the performance of these units showed that as far east as the Red Sea, and in the Atlantic, there was no appreciable advantage in the more powerful unit (see Fig. 10). Further eastward the S.S.B. unit was far more successful than the D.S.B. Beyond Singapore and north into the China Sea there was no advantage, since neither transmitter provided a sufficiently reliable link direct with the U.K., but successful transmissions of data have been obtained on vessels running from Persian Gulf to New Zealand, except while passing south of Australia. In general vessels on eastern trade justified the more powerful sets and where prolonged eastern trade could be foreseen, these sets were fitted.

Just as the radio teleprinter service had teething troubles, so did the equipment, though there have been very few failures in the "Editor" equipment itself. The tape readers supplied to read the paper tape into the equipment were the main cause of trouble initially. Many radio officers assisted in some cases by engineering officers, bravely and successfully adjusted the tension on the reading peckers to a proper working setting; in one case when a radio officer telegraphed Shell Centre for advice

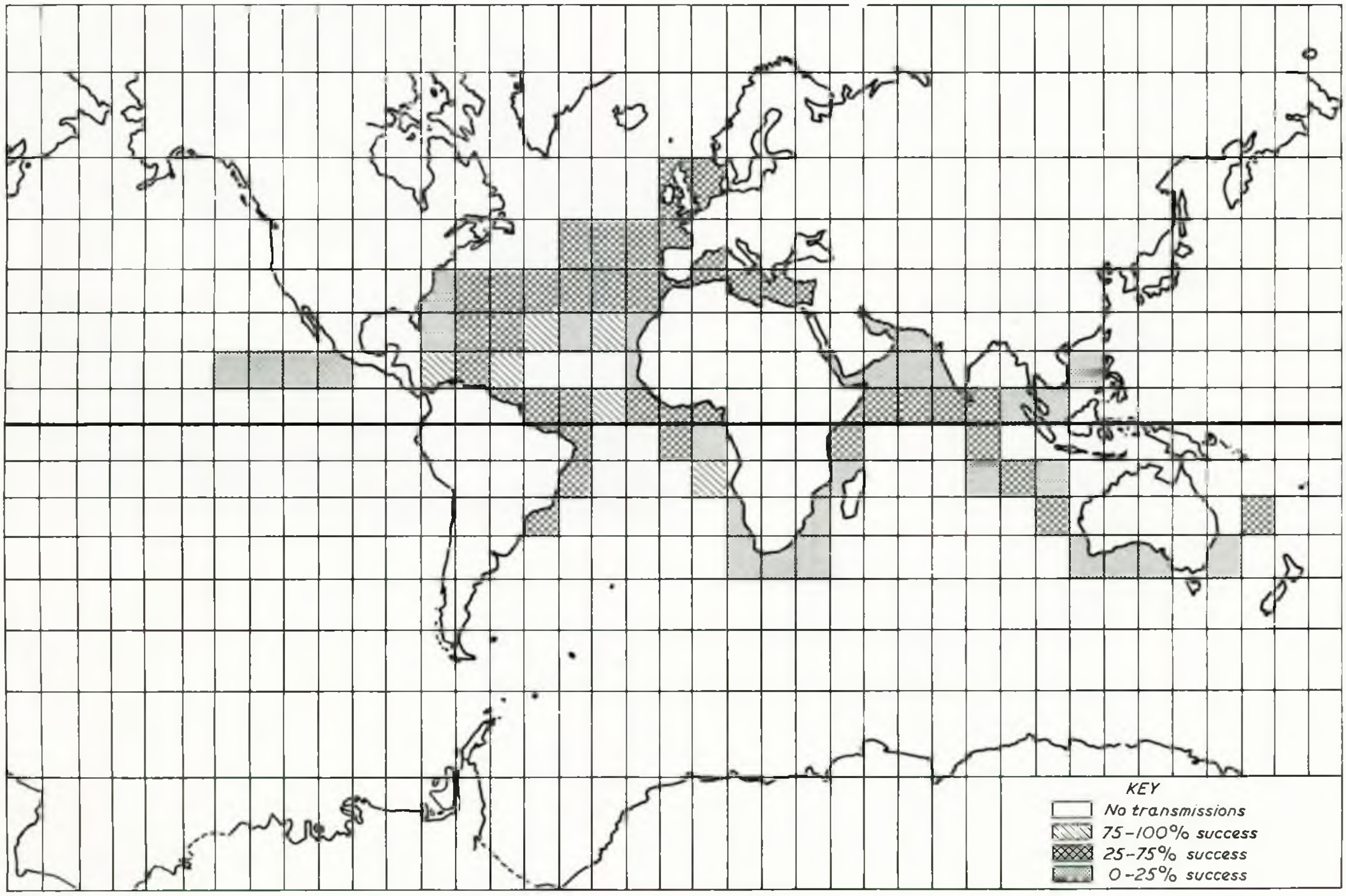

FIG. 10—*Map showing the ease of transmission of perfect tapes from given areas—Best areas are in mid-Atlantic*

on adjusting a defective tape reader, a Post Office engineer at Burnham, where the message was received, anticipated any such advice by giving blow-by-blow instructions in tape reader maintenance by W.T.

Once the majority of teething troubles were past, in the Autumn of 1964, it became clear that the error rate being experienced was not as low as had been anticipated. There were many possible explanations: the D.S.B. transmitters on board ship were not used to continuous operation at full modulation, and those sets which were not in best condition suffered from overheating and overloading; the equipment being used by the Post Office had been altered to suit the needs of the radio teleprinter service, rather than specifically built for the job, in the interest of speed; the losses on the land lines were high, and the exchange noises on the line, almost unnoticed against speech, might fall within the band-width of a discriminator's filter and swamp the signal; while the automatic equipment used by the Post Office to lock on to the ship's carrier frequency showed a distressing tendency to follow any red herrings. Indeed, there were too many such red herrings initially; the frequencies used were designated for wide-band telegraphy, but had carried little appropriate traffic, so that those seeking quiet air space, who were carefree of official disapproval, found these bands attractive. Nevertheless at this stage with a transmission time of just under three minutes per tape, the performance of the system was dramatically superior to other radio systems.

To improve the service and relieve congestion at Brent, the Post Office installed new terminal equipment at Burnham, and control of the service was transferred there in May 1965. The link from Burnham to Shell Centre is a private wire. While the immediate result of the move was fiasco, as shown by Fig. 11, the troubles induced by this change were overcome by the end of June, and so far as can be judged, a real improvement in the error rate has been achieved. This has resulted in a substantial reduction in the level of manual error correction and in the total number of transmissions.

The level of errors is critical to the success of the system. A perfect tape is passed directly to the computing centre for further processing. An imperfect tape must be retransmitted, and the two versions merged. It takes the operator about four times longer to deal with an imperfect tape than with a good tape. At a higher level of errors, calls may have to be abandoned because the process of tape merging becomes too involved. Levels have been set at 25 errors on a tape for rejection, and three errors per tape for retransmission. When there are less than three errors they can usually be eliminated in other ways.

Provided that average rates stay below two to three errors per tape, only one in ten, or one tape each day, needs to be repeated.

DATA PROCESSING

The data from the ships enters Shell Centre on punched tape; the information is thus already encoded and suitable for automatic data processing. Before any analysis can be carried out, the data must be checked for errors, and a system of data processing has been designed to reject erroneous records as soon as possible after receipt.

The first check lies with the "Editor" terminal in Shell Centre (see Fig. 12). A counter on the front of the console indicates the number of detected, but uncorrected, errors (i.e. error symbols) in the tape received; if there is none, the tape is accepted as free of transmission errors and sent to the next

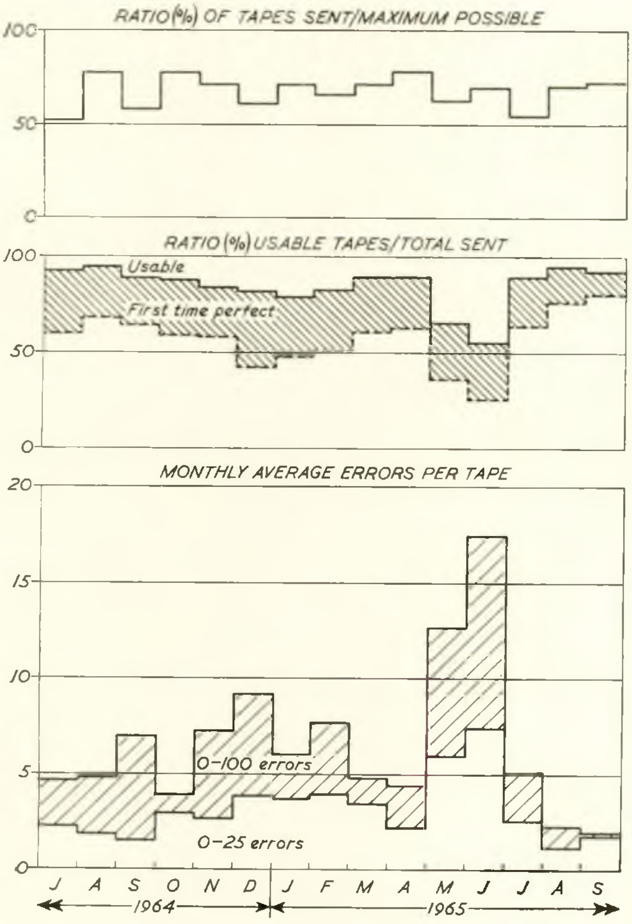

FIG. 11—*Historigram of errors in data transmission*

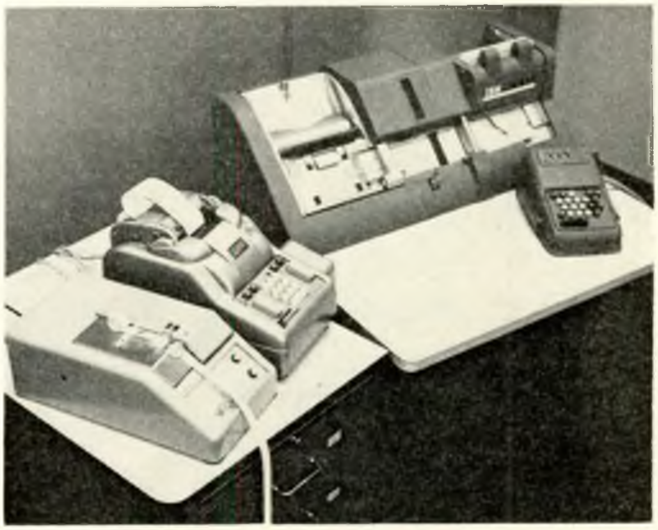

FIG. 13—*Tape-to-card converter—Left to right, tape reader, adding machine with strip printer and card punch*

stage; if there are errors, the ship is requested to retransmit the tape, and the two versions of the tape are combined in a tape comparator.

This equipment reads one character from each tape simultaneously and compares them. If the two characters are the same, this character is reproduced on a third tape; if one character is the error symbol, the other character is assumed to be correct and is reproduced on the output tape; and if both characters are error symbols, or if the two characters differ in any way other than that described, the equipment locks and an operator must insert a figure through the keyboard. Two fairly mutilated tapes can in this way be combined without much manual interference.

Tapes which appear error-free, and those which have been retransmitted and merged, are sent daily to the Computer Centre. Here the tapes are fed into a tape-to-card converter

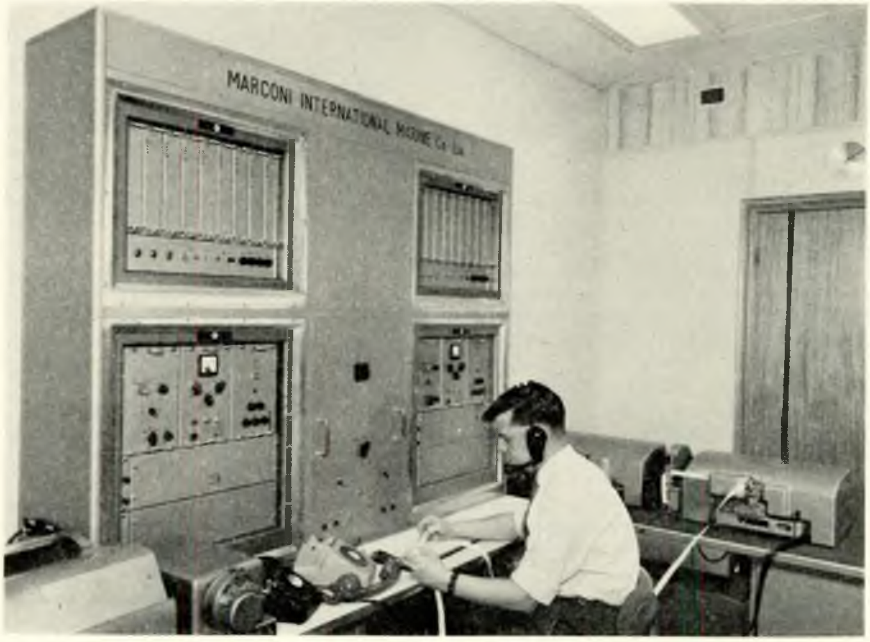

FIG. 12—*Marconi "Editor" data terminal in Shell Centre—Printing reperforators which reproduce the data on punched tape are on the right*

(see Fig. 13), which reproduces the data on to 80 column punched cards. A similar procedure to that adopted on board ship is used, in that the data are read into the tape-to-card converter through an adding machine which checks calculated watch totals against the transmitted totals. This enables the operator of the tape-to-card converter to pick out defective data and in the case of simple errors, correct them.

The punched cards are used as input to the first stage in computer analysis. This programme checks more thoroughly against transmission and punching errors by computing both column and row totals. Any data which fail this test are rejected, but the remainder are written on to magnetic tape storage. A record of the data is printed at this stage and kept as the only permanent basic record.

It may be felt that the system of processing from the reception of the tape until the first storage of the data is too complicated (see Fig. 14). It is too complicated; but, despite many enquiries, it has been impossible to find any other system which provides all the facilities of the tape editor and the first computer programme. The tape-to-card conversion is a necessary process with data entering in the form of punched tape and being processed on a card-reading computer.

It would be attractive if a simpler technique could be adopted for data processing and verification. To achieve such simplification there seemed two possibilities; either all the error correction should be carried out in the computer using the direct output from "Editor"; or all these preliminary checks should be carried out in a calculator or by hand off-line from the computer, so that data on reaching the computing centre can be assumed to be valid.

In the first approach, the output from "Editor" must be transferred in some way to the computer. Ultimately, computers with time-sharing facilities will permit direct access without any intermediate storage; in the more immediate future, the next generation of computers will be more flexible and will be more suitable for paper tape input, a facility usually found at present only on computers designed for scientific purposes. At present, the data must be stored on either punched cards or magnetic tape, and the equipment for either solution is more expensive than the saving in work and time can justify.

The second approach is more attractive, and calls for a small computer with a store of 2,400 words plus the programme, say a machine with 4,000 words storage. It need not be a fast machine—all storage could be on drums—and input would be on-line, with a card punch output. This is conceptionally a good approach, since the main computing equipment does not waste time on indifferent data. However, at the present time, no suitable small computers exist for the first-stage data checking. Ultimately such computers will be cheaper than the present cost of labour involved in tape-to-card conversion and tape editing, but at present they do not exist in suitable form.

The second programme checks the validity of the data by testing the consistency of one reading with another and by comparing the value of any individual reading with preset limits. Examples of useful consistency tests are slip, specific fuel rate, overall propeller efficiency and boiler efficiency; all have values which do not vary greatly in service conditions. Also the vessels in the exercise from European fleets record data in metric units, and at this stage the values are standardized into British units. Data which fail this programme are rejected, and are punched out on cards for re-insertion if correction is possible. Data which pass the test are stored on magnetic tape, and it is assumed that these sets of watch information are error-free.

The first two stages in data processing are mechanical and, except on a few occasions, the performance of these items has been adequate.

The authors are tempted to criticize the tape-to-card converter which, at the time of writing, has given an intermittent fault resulting in one month's data piling up unprocessed. In fairness to the manufacturers, it must be admitted that this is the first serious fault to occur, but it points up the drawbacks in using a non-standard item of equipment. It might have been preferable to forsake the advantage of the totals check on the tape-to-card converter so that standard machinery could be used; in the event of failure, a replacement can be obtained while repairs are effected on the original.

Indeed by the Spring of 1965, when the transmission system was permitting regularly-spaced data to be fed to the tape-to-card converter, the system of conversion and verification was working to schedule, with data passing through the first computer programme within three days of recording, and completing the stage of data processing within a maximum of ten days. This routine and speedy analysis permits a constant check to be kept on the performance of instruments, and the reliability of data improved considerably once the system was working smoothly.

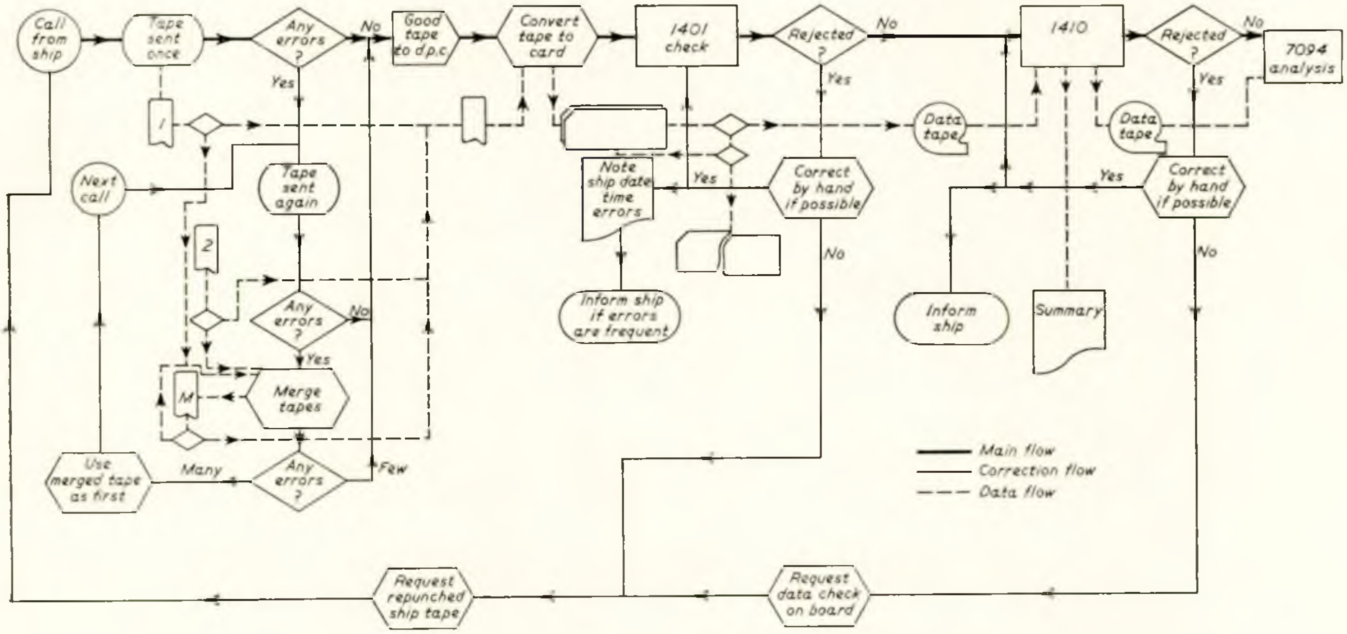

FIG. 14—*Schematic diagram of data processing and verification*

TABLE II—OUTPUT OF FINAL DATA PROCESSING PROGRAMME

(Ship performance analysis: 18th August, 1965)

Ship No.	Date	Watch	Fuel Cons.	Sp. Fl. Rate	Therm Eff.P	Cycle Eff.P	Therm Eff.S	Cycle Eff.S	S.h.p.	Thrust	Q.P.C.	PLIN	PLO1	PLO2	PLO3	K_Q	K_T/K_Q	Rejection(s)
31	5221	15·10	113·0	0·55	89·4	54·2	89·4	54·1	19,140·0	144·2	0·876	3,280·0	811·0	28·0	0·0	0·0238	10·92	
31	5221	19·10	115·0	0·55	89·3	54·2	89·0	53·7	19,490·0	144·2	0·860	3,335·0	826·0	27·0	0·0	0·0240	10·85	
31	5221	23·10	115·0	0·54	89·3	54·2	89·1	53·9	19,620·0	144·2	0·854	3,327·0	832·0	27·0	0·0	0·0240	10·84	
31	5222	3·10	115·0	0·55	89·2	54·0	89·2	54·0	19,580·0	144·2	0·851	3,324·0	830·0	27·0	0·0	0·0238	10·92	
31	5222	7·10	115·0	0·55	89·4	54·2	89·3	53·9	19,430·0	144·2	0·863	3,335·0	824·0	29·0	0·0	0·0238	10·95	
31	5222	11·10	115·0	0·54	89·5	54·4	89·2	54·1	19,830·0	146·6	0·860	3,335·0	841·0	27·0	0·0	0·0242	10·76	
31	5222	15·10	96·0	0·45	89·3	54·4	89·1	54·3	19,780·0	144·2	0·843	2,773·0	839·0	28·0	0·0	0·0240	10·82	Sp. Fl. Rate = 0·454 Reject
31	5222	19·10	114·0	0·54	89·3	54·8	89·0	54·6	19,640·0	144·2	0·834	3,301·0	833·0	27·0	0·0	0·0239	10·87	
31	5222	23·10	114·0	0·54	89·3	54·9	89·0	54·7	19,740·0	144·2	0·839	3,306·0	837·0	27·0	0·0	0·0241	10·79	
31	5223	3·10	114·0	0·54	89·2	54·8	89·0	54·7	19,730·0	141·9	0·826	3,308·0	836·0	26·0	0·0	0·0241	10·80	
31	5223	7·10	113·0	0·55	89·2	55·1	89·1	55·0	19,230·0	146·6	0·865	3,281·0	815·0	28·0	0·0	0·0242	10·74	
31	5223	11·10	112·0	0·54	89·5	55·2	89·3	54·8	19,230·0	149·0	0·880	3,230·0	815·0	25·0	0·0	0·0241	10·77	
31	5223	15·10	111·0	0·54	89·6	55·1	89·2	54·6	18,980·0	153·8	0·914	3,221·0	805·0	26·0	0·0	0·0238	10·91	
31	5223	19·10	114·0	0·55	89·5	54·8	89·2	54·4	19,190·0	153·8	0·921	3,292·0	813·0	23·0	0·0	0·0236	11·00	
31	5223	23·10	113·0	0·53	89·5	54·8	89·0	54·2	19,700·0	153·8	0·892	3,282·0	835·0	23·0	0·0	0·0241	10·78	
31	5224	3·10	113·0	0·57	89·4	54·8	88·9	54·2	18,630·0	153·8	0·954	3,286·0	790·0	23·0	0·0	0·0228	11·43	
31	5224	7·10	114·0	0·54	89·6	54·8	89·2	54·4	19,540·0	149·0	0·892	3,307·0	828·0	25·0	0·0	0·0235	11·09	
31	5224	11·10	114·0	0·53	89·5	55·0	89·2	54·6	20,020·0	149·0	0·855	3,296·0	849·0	24·0	0·0	0·0244	10·67	
31	5224	15·10	114·0	0·53	89·4	55·0	89·2	54·8	19,860·0	149·0	0·862	3,290·0	842·0	25·0	0·0	0·0241	10·79	
31	5224	19·10	113·0	0·53	89·4	55·1	89·2	54·9	19,810·0	149·0	0·865	3,274·0	840·0	23·0	0·0	0·0242	10·76	
31	5224	23·10	113·0	0·53	89·4	55·1	89·1	54·9	19,760·0	149·0	0·851	3,269·0	838·0	23·0	0·0	0·0243	10·72	
31	5225	3·10	113·0	0·53	89·3	55·0	89·0	54·8	19,940·0	146·6	0·835	3,277·0	845·0	23·0	0·0	0·0246	10·57	
31	5225	7·10	113·0	0·53	89·4	55·3	89·2	54·9	19,730·0	146·6	0·864	3,271·0	836·0	25·0	0·0	0·0242	10·74	
31	5225	11·10	111·0	0·57	89·4	55·4	89·2	55·0	17,950·0	141·8	0·892	3,202·0	761·0	28·0	0·0	0·0239	10·89	
31	5227	7·10	354·0	1·68	89·5	55·3	89·4	54·9	19,680·0	145·8	0·882	10,248·0	834·0	28·0	0·0	0·0238	10·92	Fuel Rate = 354·1 Sp. Fl. Rate = 1·680 Reject
31	5227	11·20	114·0	0·54	89·2	55·1	89·1	55·0	19,570·0	150·6	0·916	3,306·0	830·0	27·0	0·0	0·0241	10·80	

Table III—Hull and propeller analysis: computer output for s.s. "Serenia"
(These results are shown graphically in Fig. 16)

Ship's Name	Date		L or B	VO	V	VP	VW	DVW	DVP	DVT	DVB	DVL	Draught	Trim	DPW	DPM
	From	To														
Serenia	2.	8. 1.65	L	16·75	16·45	16·45	16·45	0·00	−0·30	−0·47	0·56	−0·38	43·5	1·9	0	2
Serenia	9.	12. 1.65	L	16·75	16·10	16·09	16·10	0·00	−0·66	−0·88	0·61	−0·38	43·3	0·7	20	4
Serenia	15.	16. 1.65	B	16·75	17·15	17·19	17·16	0·02	0·44	0·28	0·40	−0·23	24·3	5·4	−60	14
Serenia	17.	19. 1.65	L	16·75	16·35	16·04	16·35	0·00	−0·71	−1·13	0·81	−0·39	38·9	4·0	22	0
Serenia	27.	27. 1.65	L	16·75	16·50	16·18	16·50	0·00	−0·57	−0·97	0·82	−0·40	38·5	10·0	16	0
Serenia	3.	9. 2.65	L	16·75	16·53	16·28	16·53	0·01	−0·47	−0·95	0·96	−0·47	40·3	3·9	−22	0
Serenia	10.	11. 2.65	L	16·75	16·28	15·90	16·27	−0·01	−0·85	−1·20	0·76	−0·41	40·2	2·9	53	0
Serenia	16.	17. 2.65	L	16·75	15·94	15·79	15·94	0·01	−0·96	−1·38	0·84	−0·42	42·5	2·5	−22	1
Serenia	18.	22. 2.65	L	16·75	15·83	15·79	15·83	0·00	−0·96	−1·43	1·05	−0·57	42·4	1·7	12	0
Serenia	23.	25. 2.65	L	16·75	15·43	15·41	15·42	−0·01	−1·34	−1·67	0·80	−0·46	42·2	0·7	57	0
Serenia	27.	28. 2.65	B	16·75	16·28	16·74	16·29	0·01	−0·01	−0·18	0·79	−0·62	30·8	7·7	−2	0
Serenia	4.	5. 3.65	B	16·75	16·43	16·86	16·43	0·00	0·11	0·09	0·46	−0·43	32·0	12·0	0	0
Serenia	22.	24. 3.65	L	16·75	16·89	16·72	16·88	−0·01	−0·03	−0·26	0·84	−0·60	41·5	2·2	70	0
Serenia	25.	25. 3.65	L	16·75	16·90	16·75	16·88	−0·02	−0·00	−0·12	0·70	−0·58	41·4	1·5	151	0
Serenia	27.	30. 3.65	L	16·75	17·23	17·04	17·22	0·00	0·29	−0·06	1·05	−0·69	41·2	0·6	16	0
Serenia	2.	3. 4.65	B	16·75	17·95	17·95	17·96	0·01	1·20	1·23	0·14	−0·16	25·3	10·5	−60	0
Serenia	4.	9. 4.65	B	16·75	17·86	17·91	17·86	0·01	1·16	1·23	0·11	−0·17	25·5	8·8	−1	0
Serenia	11.	13. 4.65	L	16·75	16·92	16·88	16·90	−0·01	0·13	0·28	0·04	−0·19	43·3	2·3	80	0
Serenia	13.	14. 4.65	L	16·75	16·88	16·83	16·86	−0·02	0·08	0·30	−0·01	−0·19	43·2	1·8	134	0
Serenia	15.	15. 4.65	L	16·75	17·00	17·01	17·00	0·00	0·26	0·21	0·38	−0·32	43·2	1·5	19	0
Serenia	19.	19. 4.65	L	16·75	16·40	16·33	16·40	0·00	−0·42	−0·55	0·52	−0·38	43·0	0·2	13	0
Serenia	24.	25. 4.65	B	16·75	17·90	17·90	17·90	0·00	1·15	1·24	0·07	−0·15	24·6	10·3	13	0
Serenia	26.	26. 4.65	B	16·75	18·10	18·24	18·13	0·03	1·49	1·42	0·22	−0·14	25·5	9·8	−134	0
Serenia	5.	5. 5.65	B	16·75	17·77	18·20	17·79	0·02	1·45	1·32	0·35	−0·22	24·0	9·8	−85	0
Serenia	6.	6. 5.65	B	16·75	17·77	18·19	17·79	0·02	1·44	1·36	0·25	−0·16	24·0	9·5	−82	0
Serenia	18.	20. 6.65	B	16·75	16·20	16·41	16·21	0·01	−0·34	−0·13	−0·16	−0·04	27·2	9·8	−13	0
Serenia	20.	20. 6.65	B	16·75	17·20	17·44	17·22	0·02	0·69	0·61	0·30	−0·21	24·8	10·5	−63	0
Serenia	21.	23. 6.65	B	16·75	17·31	17·29	17·31	−0·00	0·54	0·65	0·04	−0·14	22·3	6·4	48	0
Serenia	24.	25. 6.65	L	16·75	16·75	16·73	16·75	0·00	−0·02	0·08	0·02	−0·10	43·0	2·0	17	0
Serenia	29.	1. 7.65	B	16·75	17·58	17·58	17 60	0·02	0·83	0·87	0·06	−0·09	23·3	10·8	−61	0
Serenia	3.	3. 7.65	L	16·75	16·75	16·72	16·74	−0·01	−0·03	0·12	−0·05	−0·10	43·0	1·0	57	0
Serenia	8.	8. 7.65	L	16·75	14·70	16·60	14·71	0·01	−0·15	0·08	−0·19	−0·03	42·8	2·3	−11	0
Serenia	9.	9. 7.65	L	16·75	14·40	16·26	14·38	−0·02	−0·49	−0·01	−0·57	0·10	42·8	2·0	67	0
Serenia	10.	10. 7.65	L	16·75	14·71	16·32	14·66	−0·04	−0·43	0·08	−0·37	−0·13	42·8	1·9	123	0
Serenia	12.	12. 7.65	L	16·75	16·55	16·45	16·56	0·01	−0·30	−0·44	0·38	−0·23	42·8	1·6	−54	0
Serenia	16.	19. 7.65	B	16·75	17·47	17·59	17·48	0·01	0·84	0·89	0·08	−0·12	23·5	8·4	−59	0
Serenia	20.	21. 7.65	B	16·75	17·26	17·26	17·25	−0·00	0·51	0·47	0·37	−0·33	21·5	12·0	55	0
Serenia	23.	29. 7.65	L	16·75	16·57	16·47	16·57	−0·00	−0·28	−0·11	−0·09	−0·07	42·9	1·7	36	0
Serenia	1.	7. 8.65	B	16·75	17·15	17·21	17·15	−0·00	0·46	0·69	−0·18	−0·03	24·4	11·2	41	0
Serenia	8.	13. 8.65	L	16·75	16·69	16·60	16·69	0·00	−0·15	−0·11	0·13	−0·16	42·9	0·8	4	0
Serenia	15.	21. 8.65	B	16·75	16·99	17·29	16·99	0·00	0·54	0·64	0·05	−0·15	23·6	9·2	16	0
Serenia	22.	22. 8.65	B	16·75	17·38	17·40	17·39	0·02	0·65	0·60	0·18	−0·13	22·5	7·9	−72	0
Serenia	24.	26. 8.65	L	16·75	16·45	16·46	16·44	−0·01	−0·29	−0·23	0·23	−0·29	43·0	2·2	79	0
Serenia	27.	28. 8.65	L	16·75	16·50	16·50	16·50	−0·00	−0·25	−0·31	0·41	−0·33	42·9	2·1	34	0
Serenia	29.	1. 9.65	L	16·75	16·13	16·11	16·11	−0·01	−0·64	−0·69	0·44	−0·38	42·7	1·0	77	0

ANALYSIS

The principle aim of the exercise has been to develop, prove and use performance indicators for hull and propeller. However, when data were collected on board, it was possible to extend the scope to include some more simple performance indicators, such as boiler efficiencies. The lesser aspects of the exercise are treated first.

Of the fifteen ships (see Table I), fourteen are steamships; this reflects the present balance in the company's fleets, although many of the ships now on order will have Diesel engines. The single Diesel ship will not figure in the description that follows, for there are problems with instrumentation on motor ships for which no solution seems to exist at present. Under the fluctuating conditions of Diesel torque, measurement of shaft horsepower and thrust takes on new difficulties. The true analysis of i.h.p. is not possible until more representative records of engine cycles are possible than those given by indicator cards. An indicator card can give a good record of one cycle, but this cycle may not give a true indication of the average conditions in that cylinder. Several cards must be taken for each cylinder and representative values of i.h.p. computed by averaging. Until a more convenient device can be developed to provide indications of the average conditions in a cylinder, it is not possible in this exercise to record the i.h.p. each watch, since the ship's engineering staff cannot be expected to take and analyse a sample of indicator cards for each cylinder every watch. To analyse the total losses in the main propulsion system and assign them to the respective causes, an accurate indication of i.h.p. is essential.

With steam turbine machinery, it is easy to separate some of the losses in the system and assign them to the appropriate unit. Difficulties are encountered when fluid dynamics enter the analysis; so this section is confined to the stages up to the tailshaft.

An overall view of the efficiency of this part of the system can be found by comparing the fuel rate (or rather, taking into account fuel calorific value, the rate of heat generation) to the rate of dissipation, principally as shaft horsepower, electrical energy and steam used for useful purposes such as cargo heating (it may be argued that much of the electricity generated is only consumed in driving elements of the steam cycle, but a limit must be drawn somewhere in the precision of this bookkeeping).

The shaft horsepower is corrected for the additional power which is generated electrically and rate of fuel consumption, corrected for the loss of steam to cargo heating. Ideally it would be better if the hotel requirements could also be eliminated from the analysis, but the improvement did not seem worth the considerable extra instrumentation and effort of recording.

The ratio of these terms, in consistent units and bringing in the fuel calorific value, is the non-dimensional plant propulsive efficiency.

This figure, the plant efficiency, is by definition the product of the separate efficiencies of the stages from fuel combustion to gearing. Of these, boiler efficiency (thermal efficiency) is calculated by the heat loss method, and the theoretical Carnot cycle efficiency from superheat and sea-water temperatures. These two (especially the latter) account for most of the inefficiency.

The remainder can be ascribed to the actual inefficiency of turbine and gearing, and the time-trend of this residual may reveal some interesting patterns; alternatively, being a residual, it may only reveal how successful is this approach by its short-term stability. There is nothing revolutionary about these calculations except that they are available as a routine calculation.

Figures such as these appear on a weekly operator's report, a final computer programme which summarizes the data received from a vessel over the course of a week, including the calculations made from the data. This report is intended for the ship's staff themselves, and also for the superintendents responsible for the docking and performance of the ship. This raises a point about the exercise which has been often misunderstood. Clearly the information provided by this report can be used by fleet management to give a tighter and more informed control over their ships, because the information is more accurate and is obtained sooner than posted voyage reports. It is not, and never has been, the purpose of the exercise to develop management controls so that ships can be virtually run from the office. It is possible of course that similar techniques, using slightly different and more extensive reports, might be used to develop such a system. In the end, the development of such management tools depends on an attitude of mind towards ships' staffs—whether the staff, in particular the master and chief engineer, are the responsible managers on the spot, to be supervised, but to whom day-to-day decisions are delegated; or whether they are regarded as craftsmen on whose shoulders responsibility has been laid beyond their capabilities by their remoteness, and from whom the vestiges of authority should be stripped as soon as communication techniques permit. There is a tendency now for responsibility to be denied those who have risen from the shop floor without benefit of advanced education and, while there is a real need that the standards of education of seagoing staff, particularly technical education, should be increased to meet the growing technical complexity of ships, the authors would personally regret to see the developments involved in this exercise used to abrogate the responsibilities of ship's staff.

It has been noted earlier that the main purpose of the exercise was to provide a continuous monitor of hull and propeller performance.

The first approaches to this problem were based on the mathematical model described by Dr. Doust[(2)], and it was a serious setback when some of the assumptions required by the mathematical model proved to be invalid. Not only has it meant using more primitive means of analysing the data, but the final computer programme used for the analysis of data has had to be extensively rewritten, delaying the stage at which results were obtained from the system. Indeed owing to the difficulty of maintaining continuity of programmers, the writing of the computer programme has been a slow business, and though many other stages in setting up the system have met with problems, the delays, mistakes and false starts of the final analysis of the data have had the worst effect in postponing the final working of the whole system.

The present system of analysis is based on correcting the recorded speed through the water for variations in other variables. Just as analysis of the performance within the engine room terminates with the torsionmeter, so analysis of the hull and propeller performance starts with them. The first, general indicator of performance uses the shaft horsepower, corrected

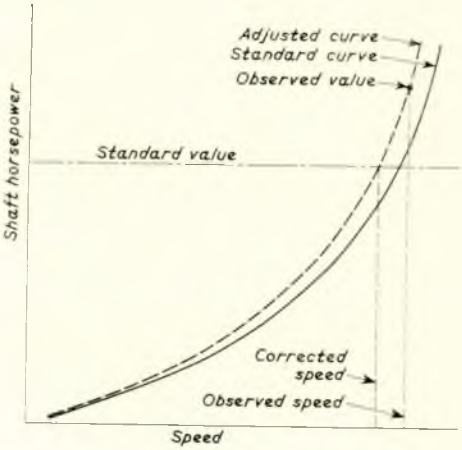

FIG. 15—*Method of correcting observed speed for variations in the observed shaft horsepower (corrected for changes in draught, trim, wind speed, etc.)—The standard curve is based on measured mile trials*

for the power of the wind on the superstructure to the equivalent of still air conditions.

From this value, and the ship's draught, speed and the sea-water temperature, the coefficient: $C_P = \frac{P}{\frac{1}{2}\rho V^3 S}$ is formed. The elements of a curve of this coefficient, as a function of speed, are stored in the computer, and the curve is adjusted so that it passes through the observed point (see Fig. 15). Another point is then found on the curve which satisfies the value of the coefficient obtained using standard values of shaft horsepower, wetted surface and sea density. The corrected speed thus obtained is used as the indicator of performance. Basically this approach corrects the speed through the water for variations in power, sea temperature and draught. To minimize the corrections, the standard values of power, wetted surface and density are chosen to be close to normal operating values. In the case of wetted surface, observations are separated into the two classes of loaded and ballast, and separate standard values are used.

Trends shown by the variations in this standardized speed should indicate the overall deterioration in hull and propeller performance. The values of the figures are subject to two main reservations; both relate particularly to the submerged log. In the short term, basic inaccuracies in the instruments will give rise to day-to-day variations in readings, and if this variation is too large then the trend may not easily be discerned under the noise of the short-term variations. In the long term, and this is far more serious, there may be long-term trends in the accuracy of instruments which can mask the real variations in performance. One possibility is that as the hull fouls, changes may occur in the boundary layer in which the log probe operates, so that the indicated speed changes in relation to the true speed. Other effects may be caused by temperature; in one torsionmeter, the true zero is a function of temperature, so that in the course of a trip from the Persian Gulf to North-West Europe, the zero value may be constantly changing with the varying ambient temperature.

Unless the staff check the torsionmeter zero regularly, there may be impressed upon the true change in corrected speed, a trend caused by the annual variation in temperature. Many of these problems arise from the degree of sophistication sought by this approach, and the owner who is interested in a rough control on performance may be well advised to use speed over the ground by observation, possibly corrected from the current atlas, as being a far more reliable source of speed indication not prone to these disadvantages.

Just as it is possible to standardize the ship's speed with respect to shaft horsepower, it is possible to standardize the speed using the thrust on the propeller. The measured thrust is corrected for hydrostatic pressure and for the force of the wind against the superstructure before being used for standardization.

This approach is close to the towing-tank work which is frequently concentrated on the resistance of models and is as fundamental as normal operations permit. The difference between thrust and resistance depends upon the thrust-deduction factor, the value of which is difficult to specify. It tends to change with trim, draught and speed, and is undoubtedly a function of the wake, while the wake fraction itself depends on the surface condition of the hull. It seems certain that the thrust-deduction factor will vary with the state of the hull, but the influence of variations in hull surface condition may be small. If so, the use of thrust in place of resistance in assessing the deterioration of the hull alone will not be misleading and may be used to give an indicator of hull deterioration. Since the total deterioration is indicated by the calculation based on shaft horsepower, and the pure hull deterioration is shown by the use of thrust readings, the difference must show the deterioration in the propeller.

Some of this deterioration is hull-induced, being caused by the change in loading on the propeller; the remainder is due to changes in the propeller itself, changes due to blade roughness or sometimes to damage.

The portion due to blade roughness can be calculated by assuming that the quasi-propulsive coefficient can be separated into two parts. One part consists of the hull-dependent terms, and the advance coefficient, and the other of the ratio K_T/K_Q. It follows that if the change in these two values can be estimated, the two effects may be separated. It is not possible, without knowing the wake fraction or some related measure, to estimate truly changes in the advance coefficient term due to wake fraction. However, it is possible to calculate this on the assumption of fixed wake conditions, and the value of K_T/K_Q for the propeller when it was new is stored in the

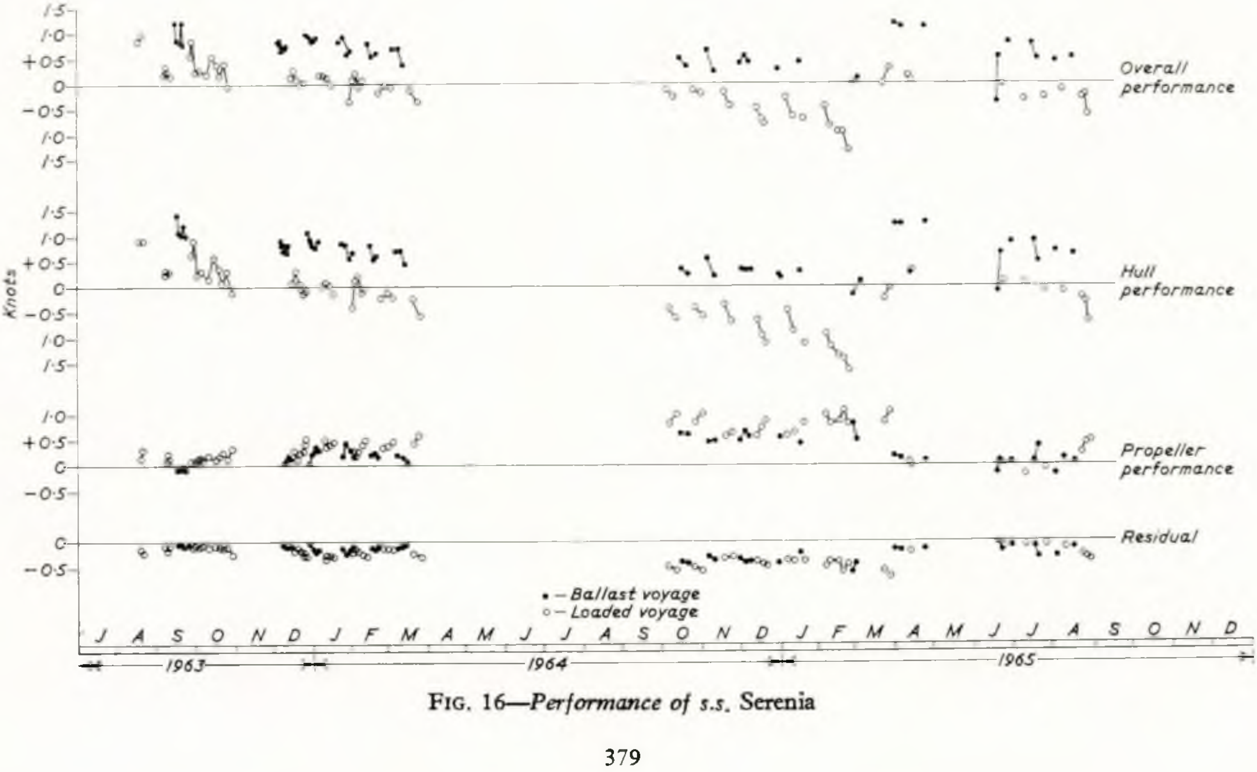

FIG. 16—*Performance of s.s.* Serenia

computer in a look-up table against the advance coefficient. The change in the actual value of this ratio compared with the estimated value is used to correct the standardized thrust and, from the resulting change, the equivalent change in speed is calculated. While it is not true to say that this change is entirely due to true propeller deterioration, it is perhaps as good an estimate of this deterioration as can be obtained in the circumstances. The remaining deterioration due to changes in propeller efficiency is attributed to changes in wake effect, and is therefore truly part of the hull deterioration.

It is unfortunate that even when great trouble has been taken in collecting data, there is no really satisfactory way of separating deterioration into its true components. Indeed apart from the *Lucy Ashton* trials(5) there has been little real work in measuring such basic facts as the resistance of ships; the very measurement which is most basic to the work of a ship model testing tank.

However, the performance of analysis just described does at least give a breakdown of the deterioration of performance into portions broadly based on the principal stages in ship propulsion, and as such may help to give more insight into the way in which ships deteriorate.

RESULTS

The results of the final performance analysis are shown graphically in Fig. 16 for s.s. *Serenia*. The record starts soon after the dry docking in June 1963, and continues to August 1965. The ship was docked once during this period in March 1965.

There is a long gap from April to September 1964. The data for this period were stored on magnetic tape while the analysis programme was rewritten, and the tape records were accidentally destroyed. There are shorter gaps during the period either when data were not recorded, or when the data were all rejected. In general the cause of such a break is instrument failure.

The upper record is a plot of the speed corrected on the basis of horsepower, while the second is corrected on the basis of the thrust. As might be expected, these two records show very similar trends.

An approximate analysis carried out on the missing six months data before they were lost, showed that the steady deterioration in the loaded condition continued from January to May 1964, but that there was virtually no further deterioration in ballast. In June 1964, the vessel changed from her usual trade from Persian Gulf to Singapore to make a single run to New Zealand. The performance on this run deteriorated rapidly, but recovered afterwards to the level of April.

Using this information in addition to that shown in Fig. 16, the following trends can be seen. During the first four months after docking there is a rapid deterioration, followed by a slower fall-off in performance over the next six months. An unusual voyage results in apparent recovery for a time, but then deterioration reappears at the old slow rate. After the next docking the information is a little scanty (partly due to data transmission troubles in May and June 1965), but there is evidence that deterioration has again set in, although it does not seem to be at the same high rate as in the first four months after docking in 1963

It is interesting to note that twice as much anti-fouling paint was applied to the hull in 1965 as in 1963.

A further point of interest is the spread of performance, particularly during a loaded voyage. While some of this is undoubtedly due to inaccuracies in the method, there remains a distinct impression (supported in the missing data and by the results for other ships) that the performance of a ship deteriorates during the course of each loaded voyage. This does not appear to be due to temperature effects, and it is thought to be a genuine result. A possible explanation could be that fouling grows on the boot-top area during the course of a loaded voyage and disappears on the ballast voyage when it is exposed to sun and wind. Such fouling is presumably a mere slime which is barely discernible but sufficient to influence the ship's performance.

The bottom two lines show the propeller performance and the residual, changes in the latter being attributed to changes in the propeller loading. It is obvious from the results, since the two lines tend to be mirror images, that the method of calculating propeller roughness effects is over-compensating for changes in propeller loading. Combining the two terms gives a figure which shows gradual improvement as hull deterioration takes place, showing that changes in propeller loading as the hull deteriorates, are more than compensating for any increases in blade roughness. Comparing figures in 1965 after dock with those for 1963 suggests a genuine propeller deterioration equivalent to about one tenth of a knot in two years.

CONCLUSIONS

The exercise has succeeded in obtaining a continuous performance indicator from voyage data; as with most development projects, success was neither as soon nor as complete as was originally hoped.

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. Otherwise small changes in instrument calibrations might go unnoticed for several weeks.

Although sophisticated equipment is expensive, the annual running cost of the exercise is less than the cost of conducting two measured mile trials for each ship in the exercise.

The exercise is of little value until the results of the continuous performance indicator can be applied. From this viewpoint, the exercise is not completed, but just beginning.

SYMBOLS

C_P = Performance coefficient = $\dfrac{P}{\frac{1}{2}\rho V^3 S}$

P = Shaft horsepower

V = Speed

ρ = Density

K_T = Thrust coefficient = $\dfrac{T}{\rho n^2 D^4}$

K_Q = Torque coefficient = $\dfrac{Q}{\rho n^2 D^5}$

n = Shaft revolutions per second

D = Propeller diameter

S = Wetted hull surface

T = Thrust

Q = Torque

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REFERENCES

1) Clements, R. E. 1957. "A Method of Analysing Voyage Data". *Trans. N.E.C.I.E.S.*, Vol. 73, p. 197.
2) Doust, D. J. 1966. "A Statistical Model of Ship Performance in Service Conditions". Paper to be read at a Joint Meeting of the Institute of Marine Engineers and the Royal Institution of Naval Architects, on Tuesday, 22nd February 1966.
3) Lackenby, H. 1962. Thomas Lowe Gray Lecture—"The Resistance of Ships with Special Reference to Skin Friction and Hull Surface Condition". *Proc.I.Mech.E.*, Vol. 176, p. 981.
4) Telfer, E. V. 1926. "The Practical Analysis of Merchant Ship Trials and Service Performance". *Trans. N.E.C.I.E.S.*, Vol. 43, p. 63.
5) B.S.R.A. Report 1952. "Resistance Tests on the *Lucy Ashton* I—Naked Hull Conditions". Report No. 107.