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## FURTHER SEA TRIALS ON THE *LUBUMBASHI*


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*Read in London at the Spring Meeting of The Institution of Naval Architects on March* 27, 1957, *Mr. L. Woollard, M.A.* (*Honorary Vice-President I.N.A.*), *in the Chair, supported by Mr. T. W. Longmuir* (*Chairman of Council, I.Mar.E.*).



**Summary**

The *Lubumbashi* trials of which the results have been published hitherto, were carried out on a newly-built ship. It was decided by the Centre Belge de Recherches Navales to take advantage of the instrumentation of this ship, especially the torsionmeter, the thrustmeter and the pitometer log, to make further investigations on the behaviour of this vessel as she became older.

Renewed measurements on the engine running on heavy fuel made it clear that heavy fuel is appropriate to a diesel motor from the point of view of the economy of the ship.

Records taken in varying weather conditions during two Atlantic winter voyages, with two different draughts, threw new light on the effect of weather on ship's speed.

Great attention was paid during the first three years of the life of this vessel to the increase of frictional resistance. Information on the subject is given by speed, thrust and power data, as well as by pitot traverses taken over the bottom in the centreline, fore, amidships, and aft. An attempt is made to correlate these data with the results of roughness measurements.


### 1. Instrumentation for the Trials and Accuracy of Measurements

The location of the instruments concerning propulsion is shown in the general arrangement, Fig. 1. The principal ship and machinery particulars are given in the 1955 *Lubumbashi* paper.(1)

The Siemens–Ford torsionmeter, the Michell thrustmeter, the Richard anemometer and windvane were given the same location as for the previous trials. Wind force and wind direction were read in the chartroom. Again ship's speed was measured with a pitometer log fitted in the bottom of the hull.

During the measured-mile trials this pitometer log was given the most forward position possible, 188 ft. from the forward perpendicular. The rod could be transferred to any given position up to 4 ft. from the surface of the hull for measurement. This enabled a relation to be established between pitot traverses, roughness measurements of the hull, and propulsion data. It was expected that more knowledge could be gained on ship's resistance and propulsion if pitot traverses were taken in two further places, fore and aft of the tunnel.

After the third voyage the pitot log was transferred from its first place C1 to C2, 267 ft. from the forward perpendicular. After the fourth voyage, the pitot log of the Victory ship *Tervaete*, which had also an extensible rodmeter, was installed in C1. For several voyages this enabled simultaneous traverses to be taken in C1 and C2. In February 1956 the pitot log C1 was transferred to C3, 370 ft. from the forward perpendicular. Simultaneous readings were then taken in C2 and C3.

An analysis of the traverses and their relation to hull roughness and skin frictional resistance is given in Section 4B.

The propeller revolutions were obtained from the revolution counter and a stop watch.

Again, the main engine operated regularly on heavy fuel, the auxiliaries on diesel oil. By means of simple soundings of the day tanks it was possible to measure the fuel consumption of the main engine. Whenever a consumption test was carried out a sample of fuel was taken for determination of heat value, specific gravity, viscosity, and other inspection data.

The displacement of the ship when leaving and entering port was calculated from the recorded draught fore and aft and the density of the water. At any time of the voyage the displacement was estimated on a basis of the daily fuel and water consumption.

The accuracy of measurements is within the following limits of error:—

*Speed through the water*, the pitot log being calibrated on the measured mile: in smooth water, 1 per cent; in rough water, 2 per cent; in a following sea with waves above 15 ft., 3 per cent.

*Torque*, the shaft being calibrated in the shop: in smooth water, 2 per cent; in rough water, 3 per cent.

*Thrust:* in smooth water, 3 per cent; in waves up to 15 ft., 8 per cent; in waves above 15 ft., not measurable.

*Revolutions:* in smooth water, 0·5 per cent; in rough water, 1 per cent.

*Heat value of fuel oil:* 0·5 per cent.


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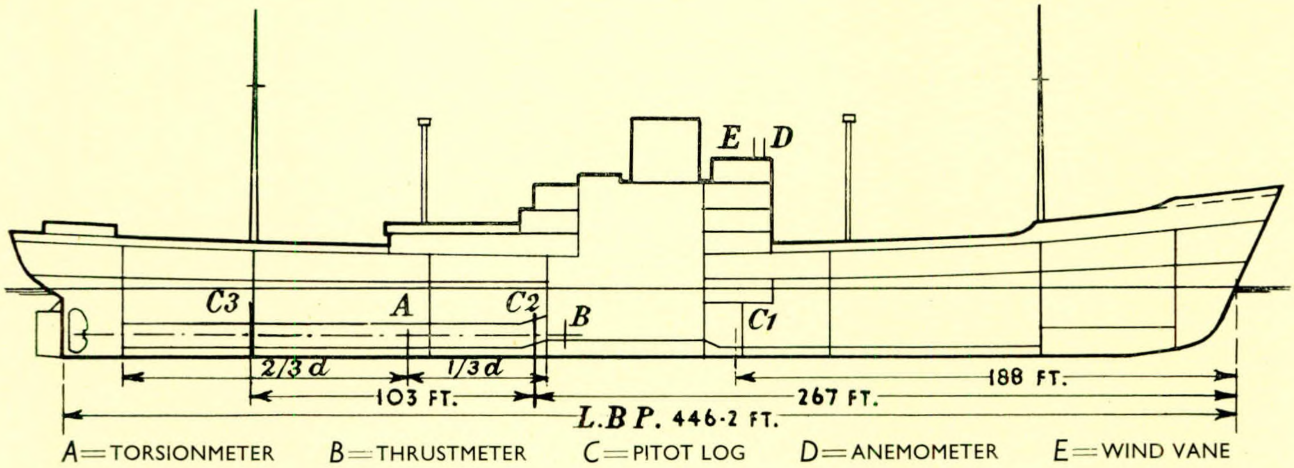


FIG. 1.—INSTRUMENTATION IN M.V. "LUBUMBASHI"

*Indicated horsepower:* 4 per cent in smooth water.

*Main engine mechanical efficiency:* 6 per cent in smooth water.

*Fuel consumption per shp main engine:* 5 per cent in smooth water.

### 2. The m.v. "Lubumbashi" Trials

At the end of July 1954, after six months' service, M.V. *Lubumbashi* was dry-docked. The hull was cleaned and painted and during the following two voyages to the Canary Islands many pitot traverses were taken, in C2 during the first, in C1 and C2 during the second of these voyages. During the following voyages of the year 1955 some pitot traverses were taken again by the ship's engineers, before and after dry-docking of the ship in New York in May 1955. The whole of these traverses give a picture of the fouling of the hull.

The *Lubumbashi* dry-docked again in February 1956 and left Antwerp for New York on February 7th. Trials took place on this voyage and on the subsequent October voyage Antwerp–New York, on the first voyage with a full loaded ship, the draught being nearly 26 ft., on the second voyage with a medium loaded ship, the draught being nearly 19 ft. Renewed interest was taken in these voyages because until that time weather effect had been experienced only on the route Antwerp–Congo, and further because it was important to establish the effect of roughening of the hull after two years' service.

During both winter North Atlantic voyages new series of records of speed, power, and fuel consumption, thrust, revolutions, ship motions, wind and waves, were collected. Weather and propulsion data are given in the Appendix.

Fig. 2 shows the weather experienced during these winter voyages. Most of the measurements were made by day; since wind speed, however, was recorded each hour even during the night, it is assumed, by establishing this diagram, that weather, during the night, was determined by wind force.

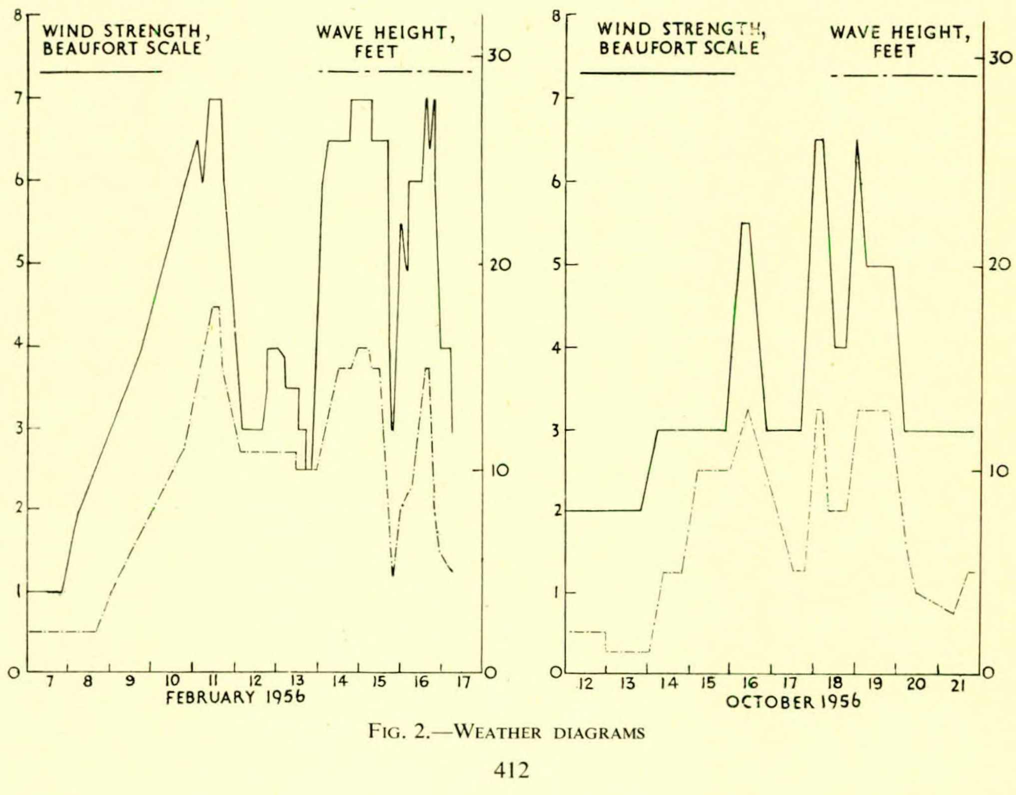


FIG. 2.—WEATHER DIAGRAMS

During both voyages weather conditions were fortunately with a wind force varying in the Beaufort scale from 0 to 7, and sea varying from calm to very rough in different directions to the ship. Especially for the loaded condition it was possible to obtain a good picture of weather effect on propulsion.

On the other hand, pitot logs being installed in C2 and C3, opportunity was taken to have another series of pitot traverses for varying speeds.

### 3. Analysis of Machinery Data

The 6,000 bhp main engine was operating regularly on heavy fuel, except for entering and leaving ports and rivers. The normal power developed by the engine in fine weather varied between 5,400 and 5,100 bhp. This power dropped in bad weather. The revolutions, 106 *rpm* in fine weather and a calm sea, went down to 95 *rpm*, the vessel facing a very rough sea in Beaufort scale 7, the wave height being 16 ft.; the power then dropped nearly 6 per cent.

A consumption test of a duration of two hours was carried out in fine weather during the February voyage. The fuel rate, corrected for a standard high heat value of 18,500 B.Th.U., was 0·420 lb. per shp per hour. The engine shp was obtained from measured power at torsionmeter by adding to it *rpm*/2 (cf. Section 5).

During the February voyage 1956, in fine weather, the motor usually ran at 105 revolutions with a power of 5,100 shp, a mechanical efficiency of 0·795, a mean indicated pressure nearly 85 lb. per sq. in. top, 67 lb. per sq. in. bottom. The mean temperatures of exhaust gases were: cylinder top 524° F., cylinder bottom 430° F.; manifold top 608° F., manifold bottom 500° F. The maximum pressures were 710 lb. per sq. in. top, 650 lb. per sq. in. bottom.

The fuel inlet temperature in the main engine was 258° F. The temperatures of cooling water were: inlet 122° F., outlet piston valves top 133° F., bottom 143° F., cylinders 133° F. The temperatures of piston cooling oil were: inlet 95° F., outlet 133° F. The temperatures of cooling water for fuel valves were: inlet 104° F., outlet 109° F. The temperature of sea water varied between 41° F. and 55° F.

These conditions were altered in October so far that the inlet temperature of piston cooling oil was then 110° F.

The purifiers were operating on temperatures varying from 180° to 190° F., the clarifier on temperatures from 190° to 200° F. The mean load of the auxiliaries for the February 1956 voyage was 285 kW., for the October 1956 voyage 245 kW.

When this paper was written the *Lubumbashi* had been operating on heavy fuel for almost three years and no special incidents occurred which were connected with the use of heavy fuel. Except for the first voyage, heavy fuel was used continuously at sea, from pilot to pilot, even:—

(i) In a very rough sea; the revolutions at full fine weather power 5,100 shp falling from 105 *rpm* to 95 *rpm* with oscillations between 92 and 100 *rpm*.

(ii) In misty weather; the revolutions being reduced to 50 *rpm*.

The consumption of lubricating oil was 18 gallons, of cylinder oil 24 gallons per day. The mean wear of the cylinders over three years was 0·01 in. per 1,000 hours in February 1956; it came down to 0·007 in. in October 1956. It must be emphasized that the motor was usually running at a power not higher than 5,200 shp and that the cylinders were lubricated with an emulsion oil.

The fuels burnt were as heavy as the fuels burnt in the boilers of the Victory ships. The specific gravity at 70° F. was 0·959 for the February voyage, 0·974 for the October voyage. The viscosity Redwood No. 1 at 100° F. was 1,725 for the February, 3,525 for the October voyage. The sulphur content was 2·78 resp. 2·45 per cent. The pour point was 23° F. resp. 32° F. The asphaltene content was 6·28 resp. 7·11 per cent, the Conradson carbon 11·2 resp. 10·3 per cent. The ash content was 0·11, resp. 0·17 per cent.

### 4. Analysis of Resistance Data

*A. The Measurement of Hull Roughness.*

Whenever it was practicable, the roughness of the hull was measured. Just before the measured mile trials took place, extensive roughness measurements had been carried out on the newly-built ship, both with the pneumatic feeler and the Talysurf machine. At the same time the hull was sandblasted and painted, some steel plates were distributed around the vessel in dry-dock, and these plates were treated, sandblasted and painted in the same way and simultaneously with the hull of the vessel. These sample plates were taken to the Talysurf machine and some Talysurf roughness records with their analysis carried out according to the B.S.R.A. method, together with the data obtained with a pneumatic feeler have been given in the previous *Lubumbashi* paper.(1)

It was believed that the Talysurf records gave a good picture of the hull roughness, because the ship was new and the sample plates reproduced accurately the hull's surface. Unfortunately the roughness measurement of the hull could not be renewed in this way at a further stage of ship's life, because even the first time she dry-docked, six months later, in July 1954, the hull's surface was rather severely deteriorated by corrosion.(1) Sample plates treated in the same way as the hull would not have reproduced any more the ship's surface.

The roughness of the hull was then measured solely by means of the pneumatic feeler. The measurement was renewed in dry-dock in February 1956, just before the trial voyage Antwerp–New York, and again in October 1956 between the loaded waterline and the light waterline, just before the second trial voyage Antwerp–New York.

Because of these frequent measurements with the pneumatic feeler and because it was the most practical way in which the roughness of the hull could be measured in later stages of the ship's life, it might be interesting to give the special features of the instrument.(3)

The instrument is adapted to the usual compressed air supply of, say, 100 lb. per sq. in. as used in shipyards and dry-docks. This supply is converted by means of the Solex equipment to a strictly constant pressure of 19·7 in. (50 cm.) in height of water. It is this constant pressure, regulated by a water column, which is conveyed to the pneumatic feeler on the hull plate over a diaphragm. The rougher the surface of the plate, the higher the delivery of air through the feeler and the bigger the pressure loss through the diaphragm. This pressure differential is measured with a water U-tube manometer. It relates directly to the average height of the irregularities of the surface.

Calibration of the instrument is carried out by applying the feeler on a plate with grooves of known depth and breadth. This calibration assumes on the ship a serrated roughness with equal full and empty spaces.

The instrument is currently used in the General Hydraulic Laboratory of the University of Liège (Belgium) for the roughness measurement of pipes. It is portable and has a quick response.

In a report of the General Hydraulic Laboratory it is pointed out that, from roughness measurements carried out with this instrument on plates artificially roughened by sand in Nikuradse's manner, it appeared that the correlation between these measurements and the actual dimensions of the sand sieve was satisfactory.

Jorissen measured with this instrument the roughness of different new commercial steel pipes. He measured also the hydraulic pressure losses in these pipes. He showed[4] that the correlation between the average height of the asperities given by the feeler and Nikuradse's artificial roughness deduced from the pressure losses is satisfactory. It must be remarked that Jorissen's roughnesses of new commercial pipes ranged from 1,600 to 5,900 microin.

The roughness measurements of the hull of the *Lubumbashi*, when she was dry-docked for the first time in July 1954, were carried out before cleaning and after cleaning and painting, because propulsion data are available for the voyages just before and just after docking.

The mean roughness, taken over 583 readings before cleaning the hull, was 3,620 microin. After the hull was cleaned and painted with one coat of anticorrosive and one coat of anti-fouling, the mean roughness taken over 104 readings was reduced to 2,250 microin. Neither roughness data account for the large number of rust flakes, of a height 0·05 to 0·1 in., which were spread over the hull.

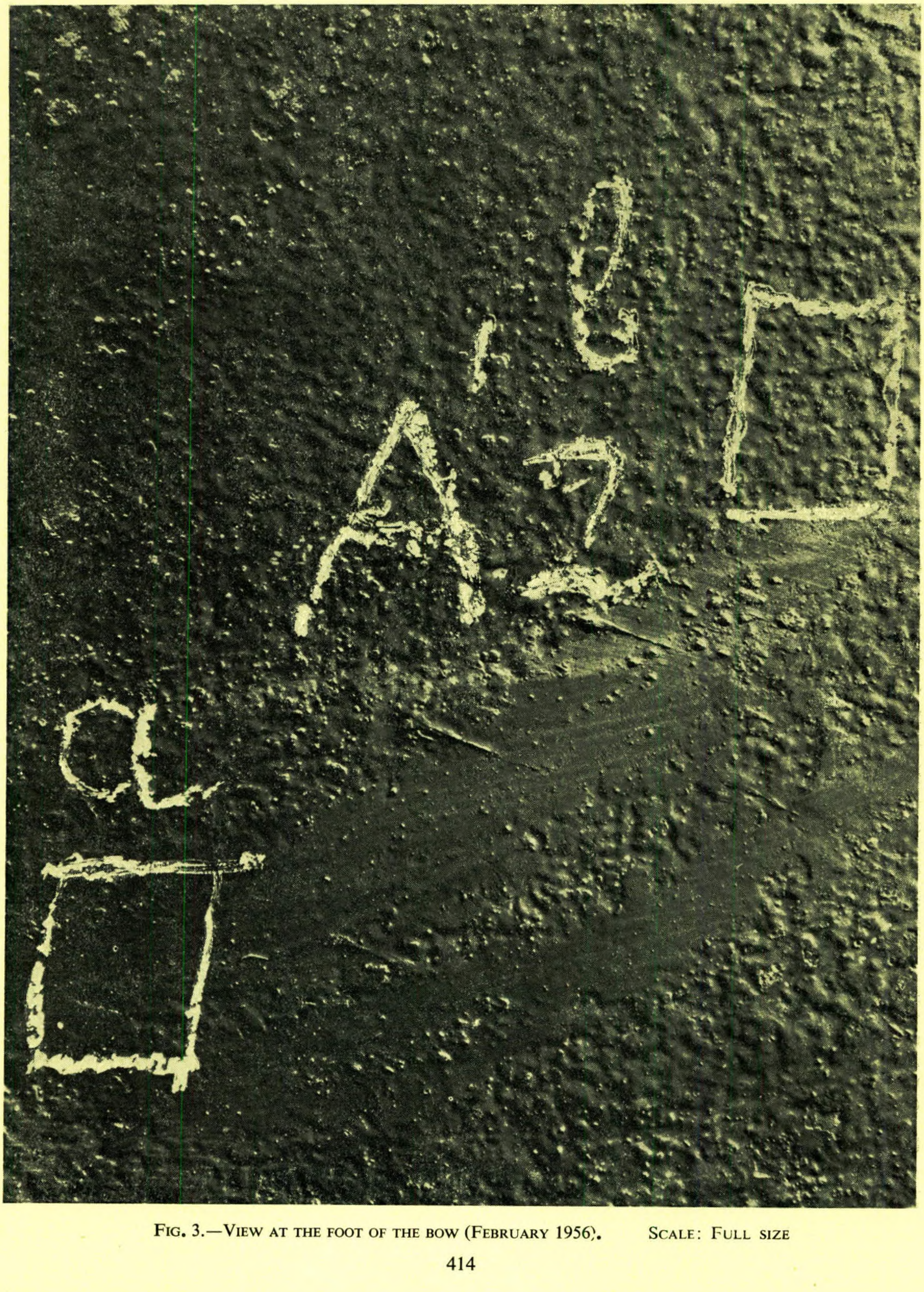

FIG. 3.—VIEW AT THE FOOT OF THE BOW (FEBRUARY 1956). SCALE: FULL SIZE

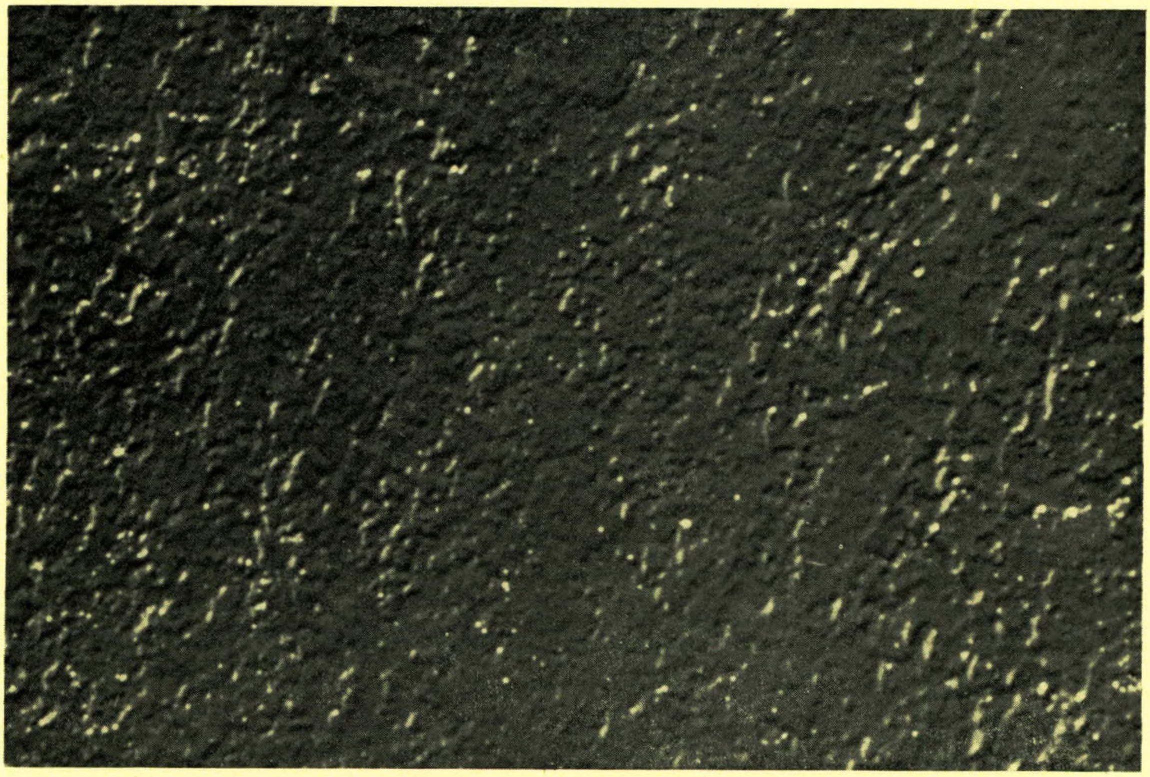

FIG. 4.—VIEW OF SHIP'S SIDE BETWEEN LOADED AND LIGHT WATERLINE (FEBRUARY 1956). SCALE: FULL SIZE

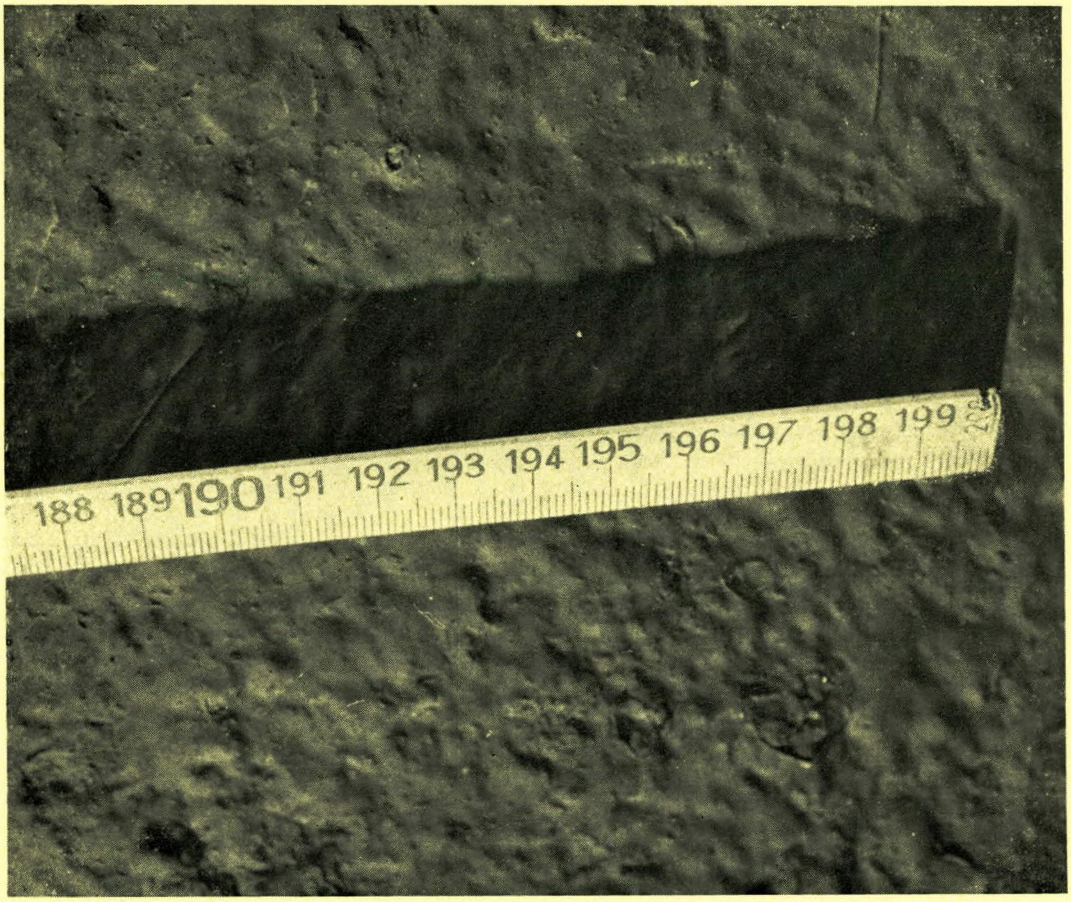


FIG. 5.—VIEW BETWEEN LOADED AND LIGHT WATERLINE: PAINT NOT DETERIORATED (OCTOBER 1956). SCALE: FULL SIZE

Again, roughness measurements were carried out when the ship was dry-docked in February 1956. The hull was not really dirty; paint, however, had generally disappeared and a large number of rust flakes roughened the plates. As practically no time was left for measuring the roughness of the hull before cleaning and painting, just three readings could be taken: their mean value gives a roughness of 27,300 microin.

Measurements were carried out again after cleaning and painting with one coat of anticorrosive and one coat of anti-fouling on February 2nd. The mean roughness, taken over 396 readings, was 21,550 microin.; the maximum value was 31,500 microin., the minimum value 6,300 microin.

The figure of 21,500 microin. is surprisingly high. However, cleaning and painting were carried out in very cold weather and were rather poor. Temperature, at the time the ship was in dry-dock, varied between 23° and 7° F. Figs. 3 and 4 are full-size views of the painted hull, Fig. 3 at the foot of the bow, Fig. 4 midship port between loaded and ballast waterline where the hull was painted with one coat of anticorrosive and one coat of boot-topping. Where these views were taken, the roughness was measured with the pneumatic feeler: in *a* (Fig. 3) the roughness was 23,800 microin., in *b* (Fig. 3) the mean of three readings was 26,100 microin.; for Fig. 4 the mean of seven readings gave a roughness of 19,200 microin.

The roughness was measured again eight months later before the October voyage Antwerp–New York, between light and loaded waterline. The draught was then 10·5 ft. forward, 19 ft. aft. Many rust scales 0·05 to 0·1 in. thick covered the hull. No fouling whatsoever could be seen, but paint had disappeared in many places. The measured mean roughness was 17,169 microin.

Again, full-size views, taken by the Laboratory of General Hydraulics of Liège, are shown in Figs. 5, 6, and 7. A meter was put on the photographed places, not only to give the size in surface, but also to allow an appreciation of the height of the asperities. The photographs were taken at the bow of the ship. In Fig. 5 paint has not deteriorated, in Figs. 6 and 7 paint has disappeared, partially in Fig. 6, entirely in Fig. 7, disclosing plates of different aspects. The measured roughness in these places was: in Fig. 5, 21,024; in Fig. 6, 18,031; in Fig. 7, 17,638 microin. The magnification of the height of the asperities by shadow was estimated to be double.


FIG. 6.—VIEW BETWEEN LOADED AND LIGHT WATERLINE: PAINT PARTLY DISAPPEARED (OCTOBER 1956). SCALE: FULL SIZE

Some oxyd scales covered with paint could be detached from the plates. Their surface was examined in the Laboratory of Strength of Materials of the University of Ghent, and three reliefs are given in Fig. 8. Obviously there is no inconsistency between the measured height of the asperities, of a mean value 0·05 in., their average height on the photographs and the readings with the pneumatic feeler.

It must be emphasized that, if in January and July 1954 the roughness measurements with the pneumatic feeler were carried out on the newly-built ship with a satisfactory accuracy, the surface was so poor in February and October 1956 that readings with an accuracy better than 20 per cent could not be expected. Moreover, readings were taken in the very cold weather of February in hard conditions: the water in the pressure column of the Solex equipment had to be mixed with glycerine and the calibration carried out in a refrigerated compartment. Fig. 9

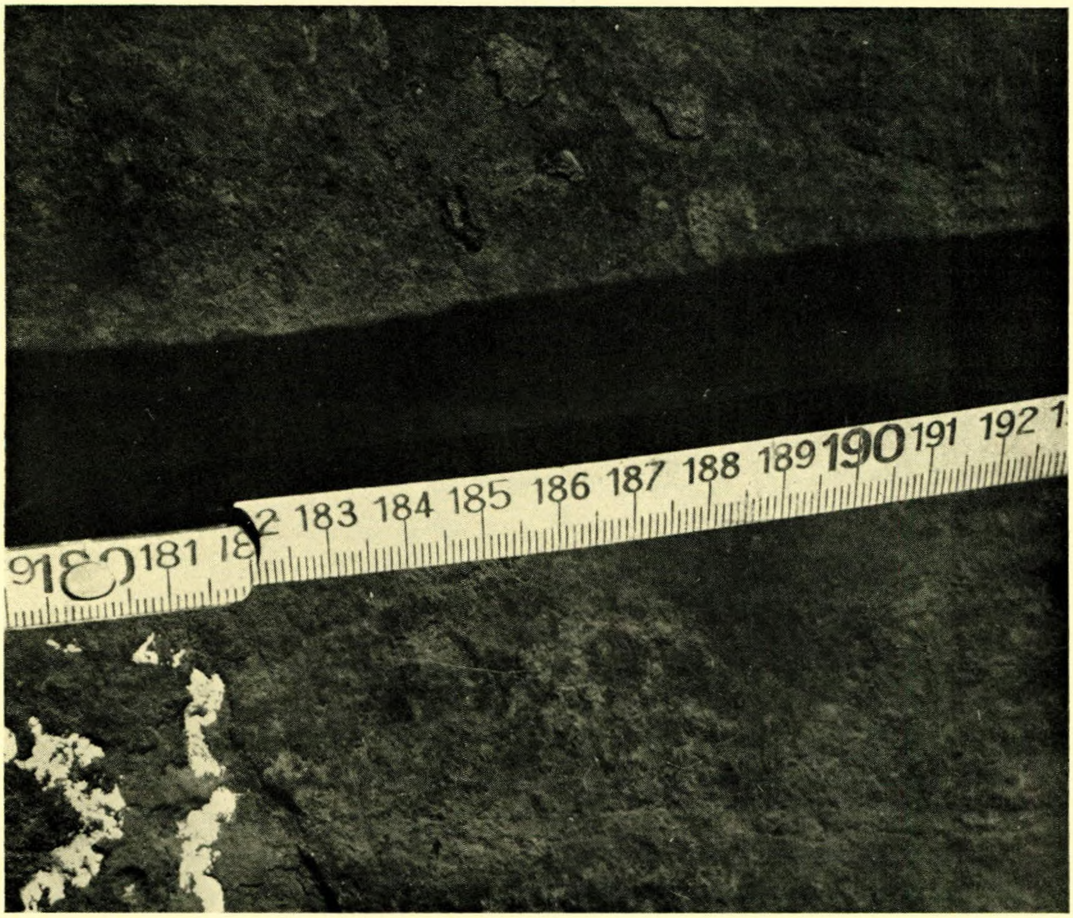


FIG. 7.—VIEW BETWEEN LOADED AND LIGHT WATERLINE: PAINT HAS DISAPPEARED (OCTOBER 1956). SCALE: FULL SIZE

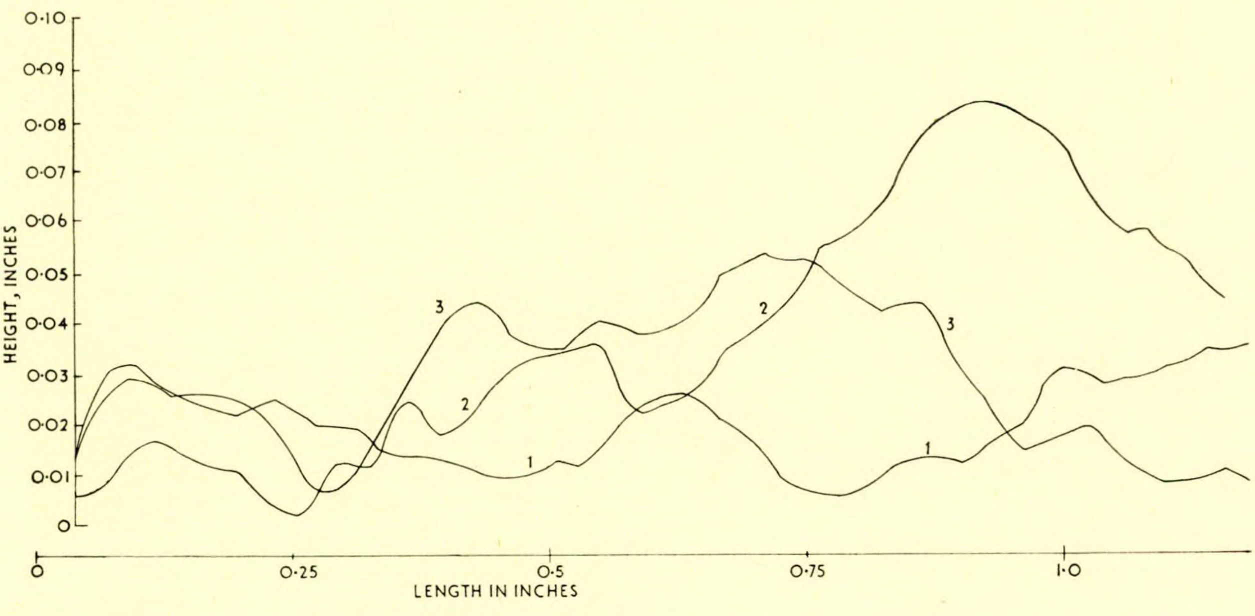


FIG. 8.—THREE RELIEFS ON OXYD SCALES COVERED WITH PAINT (OCTOBER 1956)

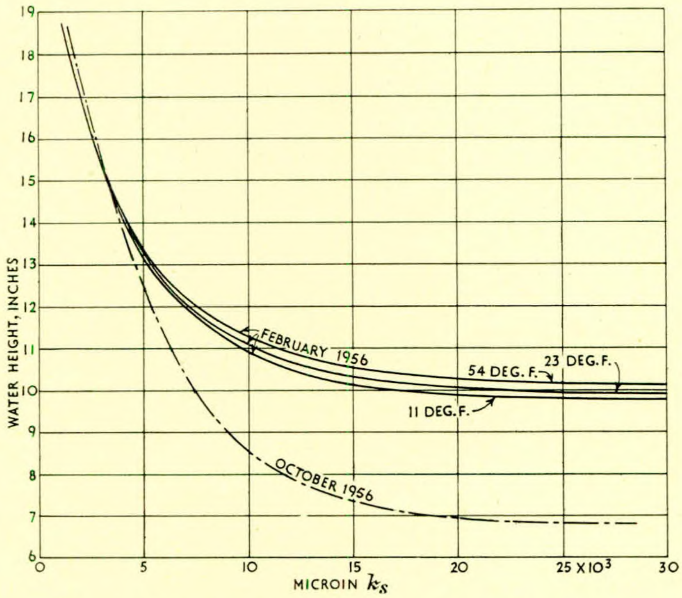


FIG. 9.—CALIBRATION CURVES FOR PNEUMATIC ROUGHNESS MEASUREMENT

shows the calibration curves of the instrument. It is apparent from the curves that the accuracy of measurement is rather poor for roughnesses which, in the case of this ship two years old, ranged from 10,000 to 30,000 microin.

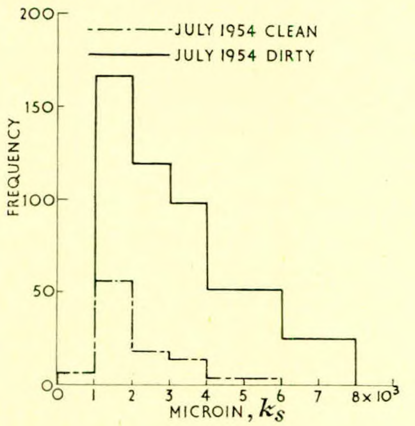


FIG. 10.—FREQUENCY CURVES OF ROUGHNESS MEASUREMENT (JULY 1954)

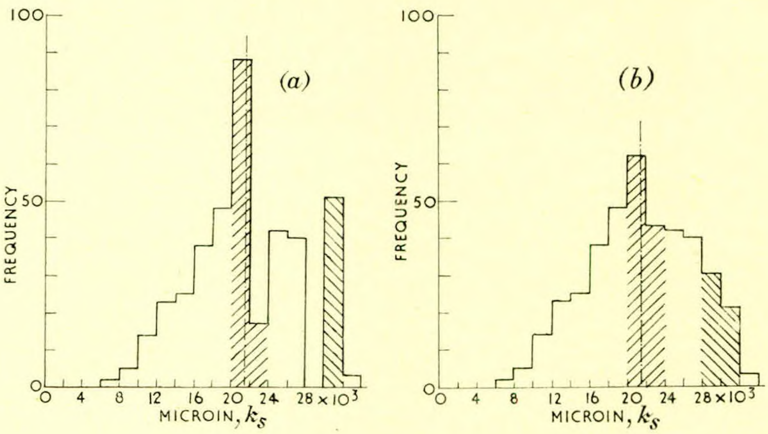


FIG. 11.—FREQUENCY CURVES OF ROUGHNESS MEASUREMENT (FEBRUARY 1956)

A statistical value has been given to the roughness measurements by grouping the readings, so as to give a picture of their scattering. A certain number of readings could not be taken into consideration, especially because of the feeler penetrating into the rather mellow paint. Figs. 10, 11, and 12 show the scatter of readings. They give the frequency of readings for different intervals of roughnesses recorded on the hull. The high values of roughness at the right side of Fig. 11(*a*) are probably erroneous, because of their illogical distribution. This conclusion is consistent with the calibration curve Fig. 9. A more reasonable frequency curve is deduced from Fig. 11(*a*) and shown in Fig. 11(*b*); assuming that, at the right side of the diagram, the frequencies decrease as roughness increases, identity of hatched surfaces gives a more probable curve of frequencies. The most probable value of roughness taken from the diagram, 21,550 microin., is found to be the arithmetical mean of all the readings.

The frequency curve of the readings of October 1956 [Fig. 12(*a*)] has been altered in the same way in order to obtain a more Gaussian distribution [Fig. 12(*b*)]. The probable value of roughness, given by the frequency curve, is very near the mean value of readings 17,169 microin.

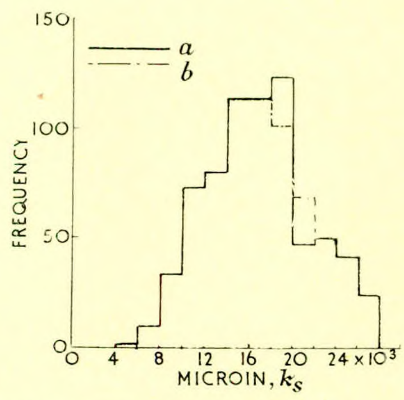


FIG. 12.—FREQUENCY CURVES OF ROUGHNESS MEASUREMENT (OCTOBER 1956)

It is most surprising that the measured roughness was higher, when the ship was painted, in February 1956, than eight months later. It must, however, be remarked:—

(i) The decrease of roughness was not more than 20 per cent, which is about the limit of error of measurements for these big roughnesses.

(ii) Measurements in October were only made between light and loaded waterline, and it is probable that the bottom of the ship was rougher than the sides so that practically roughness remained unchanged after eight months' service.

The ship, cleaned and painted in exceptionally cold weather, was rather rough when she started for her February voyage, and, as fouling on the route Antwerp–U.S.A.–Congo is small with good commercial paints, it is not unlikely that, upon the whole, the aspect of the surface remained unchanged. This was confirmed by pitot traverses and power measurements (cf. Section 4B).

*B. Pitot Traverses and Roughness Effect.*

A further description of the roughness of the hull was given by the shape of the velocity curve in the friction belt. During the trials which were carried out with the newly-built ship, only one pitot log was installed, primarily for measuring ship's speed.

The discussion of the results of these trials[1] made clear that more information could be gained from other extensible pitometer rods distributed over the bottom.

Many pitot traverses were taken, but only the most typical are given here. Following the B.S.R.A. figuration, the vertical scale is the distance out from the shell, while the horizontal scale is the velocity in the boundary layer expressed as a fraction of the velocity in the free potential flow. It must be remarked that the

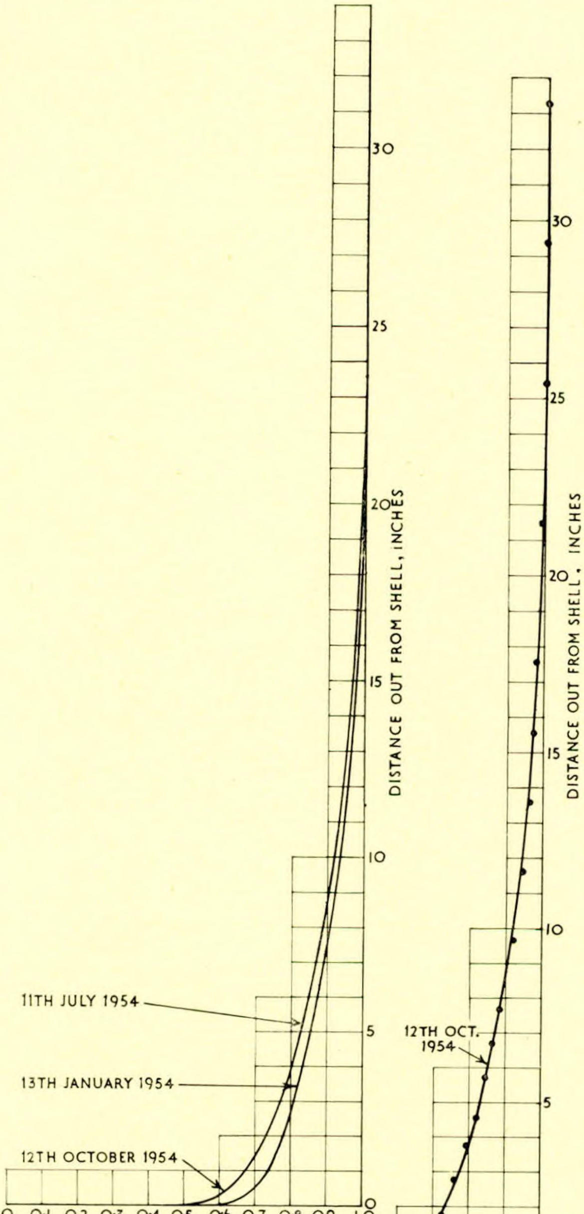


FIG. 13.—PITOT TRAVERSES C1

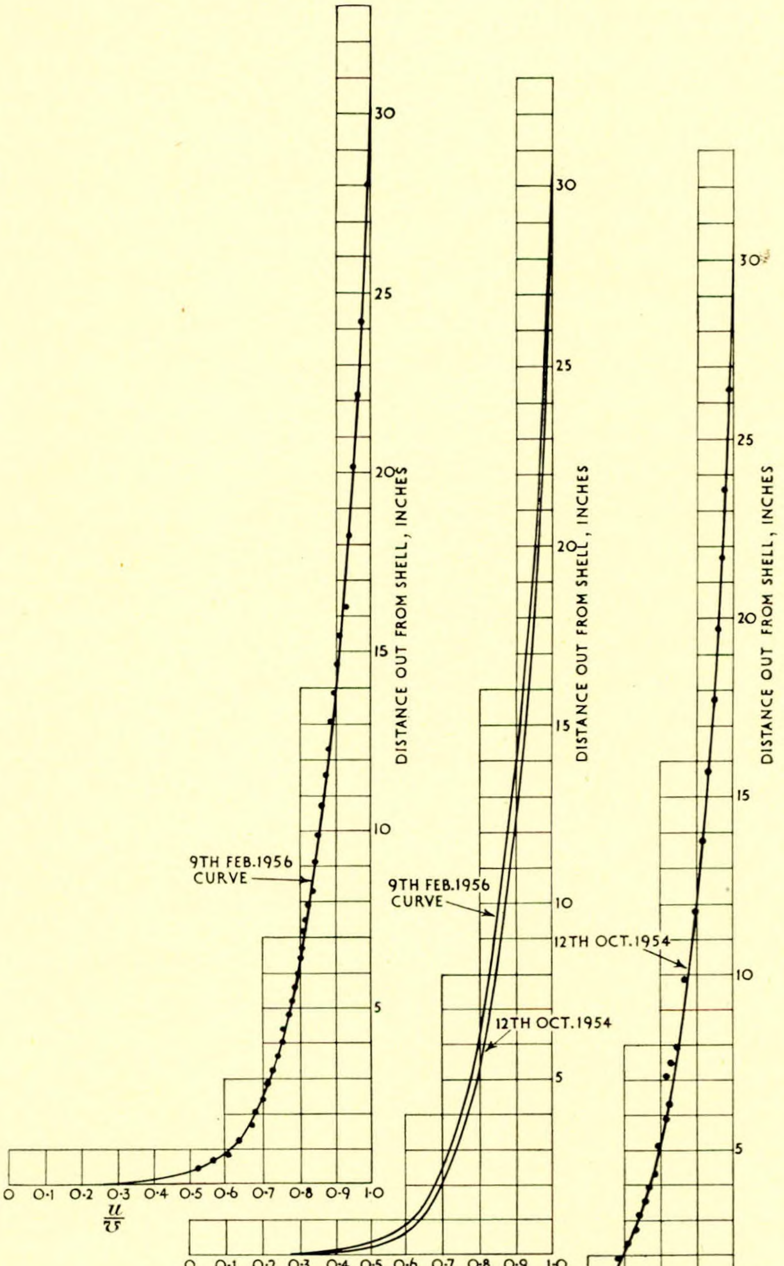


FIG. 14.—PITOT TRAVERSES C2

| Date | 13 Jan. 1954 | 11 July 1954 | 12 Oct. 1954 |
|---|---|---|---|
| Hull condition .. | Clean, new-built | Fouled 6 months | Cleaned |
| Ship's speed in knots | 16·00 | 14·95 | 15·40 |
| Veloc. pot. flow $\upsilon$.. | 16·10 | 15·05 | 15·50 |
| Reynolds number .. | $3{\cdot}0 \times 10^8$ | $3{\cdot}4 \times 10^8$ | $3{\cdot}4 \times 10^8$ |
| Frict. resist. coeff... | 0·00180 | 0·00208 | 0·00201 |

| Date | 12 Oct. 1954 | 9 Feb. 1956 | | 13 Oct. 1956 | |
|---|---|---|---|---|---|
| Hull condition .. | Clean, 6 months | Clean, 26 months | | Fouled 8 months | |
| Ship's speed in knots | 15·40 | A 15·00 | B 15·05 | A 15·15 | B 15·00 |
| Veloc. pot. flow $\upsilon$ .. | 15·40 | A 15·00 | B 15·05 | A 15·15 | B 15·00 |
| Reynolds number .. | $5{\cdot}2\times10^8$ | $4{\cdot}4\times10^8$ | $4{\cdot}4\times10^8$ | $4{\cdot}6\times10^8$ | $4{\cdot}6\times10^8$ |
| Frict. resist. coeff. .. | 0·00185 | 0·00207 | 0·00211 | 0·00220 | 0·00210 |

velocity in the free potential flow is not strictly the speed of the ship: calibration of the logs C1, C2, and C3 on the measured mile showed that the velocity in the free potential flow was in excess of the speed of the ship of resp. 0·1, 0·0 and 0·7 knots.

Figs. 13, 14, and 15 show the results for the traverses in C1, C2, and C3 in different conditions of fouling of the ship. The traverses for the newly-built ship are shown again in the new

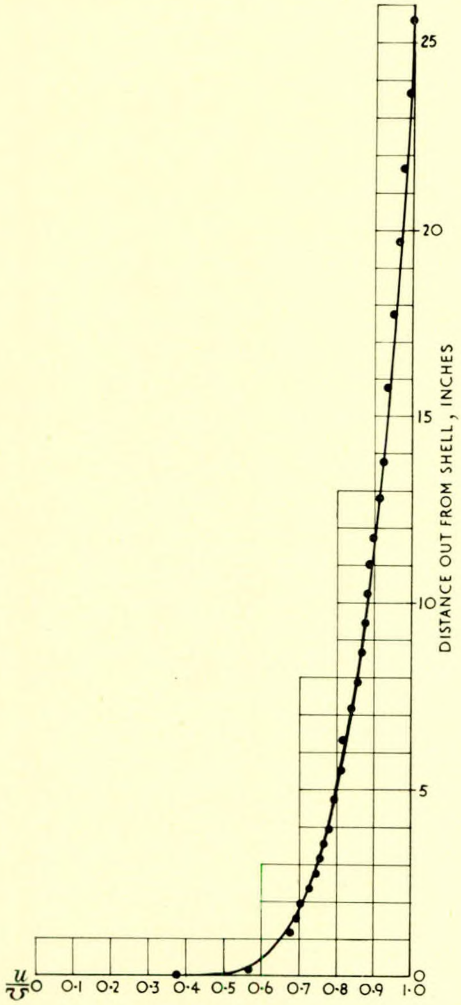


FIG. 15.—PITOT TRAVERSE C3

| Date 8 Feb. 1956 | |
|---|---|
| Hull condition .. | Clean, 26 months old |
| Ship's speed in knots | 15·20 |
| Veloc. pot. flow $v$.. | 15·90 |
| Reynolds number.. | $6·4 \times 10^8$ |
| Frict. resist. coeff. | 0·00134 |

figuration, as this allows a comparison to be made between cleaned and fouled hull surface.

There is a scatter in the observations, but a mean curve can be drawn for each traverse, as shown for some traverses. The mean curves are then taken together in order to show the effect of fouling or deterioration of the hull's surface.

The frictional resistance coefficient has been obtained by integrating the loss of momentum in the boundary layer corresponding to a surface whose length is equal to the distance of the log from the fore end of the ship.

There is certainly an influence of potential flow. No attempt, however, has been made to correct for this potential flow. The analysis is based upon the assumption that the flow from the foot of the stem to the pitot logs C1, C2, and C3 located at a distance of 147 ft., 226 ft., and 329 ft. respectively from this foot is comparable with the frictional longitudinal flow along a flat surface.

It must be said that all the traverses were not taken with the same care. Traverses were taken in May and October 1955 by the ship's engineers: they show that difficult measurements made in usual service, without special care, but in good faith, may give valuable information. It is interesting to correlate the resistance coefficient given by the traverses with the roughness measurements and the propulsion data (see Section 5).

It has been argued that no reliable information could be gained from pitot traverses. The most important result of the traverse being the momentum loss, an attempt has been made to evaluate correctly the accuracy of calculation of these values. Six traverses were taken with great care, three up and three down, in very fine weather, August 2nd, 3rd, and 4th, during a voyage Antwerp–Canary Islands, just after dry-docking, the hull being cleaned and painted. The average speed was 15·4 knots, the average Reynolds number $5·1 \times 10^8$. The resistance coefficient has been calculated and the deviation from a mean value appeared to be 5 per cent.

FRICTIONAL RESISTANCE COEFFICIENT FROM TRAVERSES, AUGUST 1954

| Traverse number | Reynolds number | Speed in potential flow in knots | Resistance coefficient | Deviation from mean value in per cent |
|---|---|---|---|---|
| 1 up | $4·8 \times 10^8$ | 14·90 | 0·00184 | −1 |
| 2 down | $4·9 \times 10^8$ | 15·20 | 0·00195 | +5 |
| 3 up | $5·1 \times 10^8$ | 15·15 | 0·00195 | +5 |
| 4 down | $5·1 \times 10^8$ | 15·00 | 0·00187 | +1 |
| 5 up | $5·4 \times 10^8$ | 15·70 | 0·00179 | −3 |
| 6 down | $5·4 \times 10^8$ | 15·80 | 0·00178 | −4 |

From the traverses of pitot C1 the increase of $C_f$ from January 13th to July 11th is established as 0·00028 (Fig. 13). This increase of frictional resistance due to fouling is 15 per cent, which gives an increase of total resistance of some 10 per cent. This correlates very well with the measured increase of power of this vessel, 9 per cent, after six months' service.(1)

The hull was then cleaned and painted in dry-dock, but the value of $C_f$ did not return to the newly-built vessel value. The hull was rather severely deteriorated by corrosion and, as shown by the traverses of pitot C1 taken on January 13th and October 12th, $C_f$ remained increased by 0·00021 (Fig. 13). This increase of frictional resistance of 11 per cent correlates with a measured increase of total resistance, deduced from power data of some 7 per cent.

The increase of $C_f$ during the nine months' service between the dry-dockings of July 1954 and May 1955 was 0·00024, which relates to an increase of frictional resistance of 12 per cent or an increase of total resistance of 8 per cent. It must be pointed out that the traverses of May 1955 were taken by ship's engineers.

The ship again was painted on February 2, 1956, and, from the traverses of pitot C2, the increase of $C_f$ from October 12, 1954, after the first dry-docking, to February 9, 1956, just after the third dry-docking, is established as 0·00022 (Fig. 14). The deterioration of the hull, by continued roughening, even when cleaned and painted, appeared to give an increase of frictional resistance of 12 per cent or an increase of total resistance of 8 per cent.

Adding this 8 per cent to the 7 per cent increase of resistance by deterioration during the first six months' service gives 15 per cent increase by deterioration of the surface after 26 months' service. Propulsion data give an excess of power of 14 per cent after this 26 months' service (see Section 5).

These figures correspond to the first two years' service. However, for the last year's service, the fouling figure is surprisingly low. Fig. 14 shows that there is very little difference between the traverses of pitot C2 taken on February 9 and October 13, 1956. The increase of $C_f$ after eight months' service is 0·00008, corresponding to an increase of frictional resistance of not more than 4 per cent, or an increase of total resistance of 3 per cent.

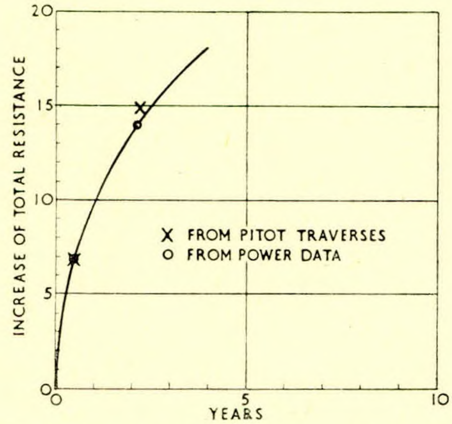


Fig. 16.—Effect of surface deterioration on total resistance

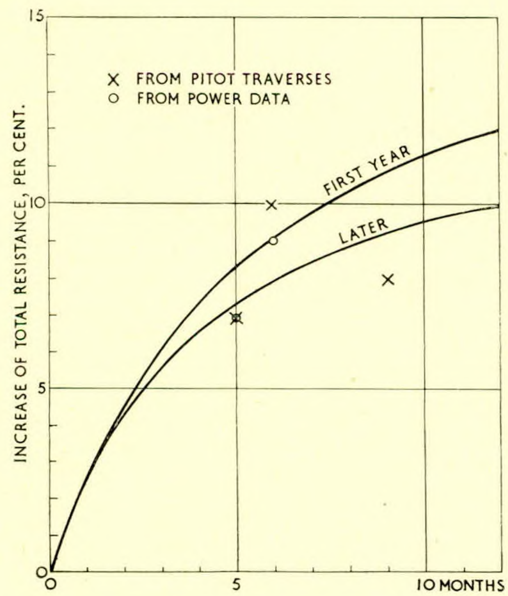


Fig. 17.—Effect of fouling on total resistance

The increase of total resistance, if there is any, deduced from power data, is 4 per cent (see Section 5).

Fouling of the hull, from previous figures, spread over three years' service of the ship, gives an overall increase of resistance of 9 or 10 per cent after ten months' service. Figs. 16 and 17 show the effect on total resistance of surface deterioration and fouling.

Fig. 18 shows the Nikuradse scale of sand roughness with the

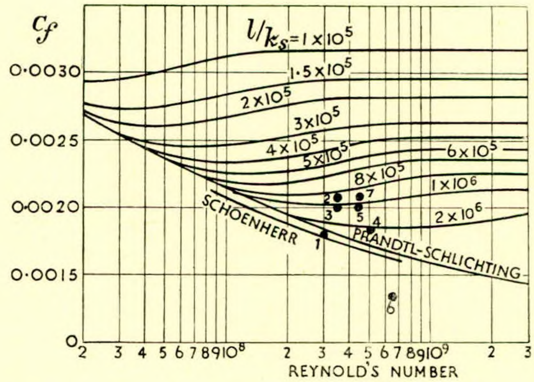


Fig. 18.—Correlation of roughness allowances with scale of uniform sand roughness

| Condition | $C_f$ |
|---|---|
| Newly-built, clean .. .. .. | 1 from C1 |
| Fouled, 6 months out of dock .. | 2 from C1 |
| Cleaned, 6 months old .. .. | 3 from C1 |
| Cleaned, 6 months old .. .. | 4 from C2 |
| Cleaned, 26 months old .. .. | 5 from C2 |
| Cleaned, 26 months old .. .. | 6 from C3 |
| Fouled, 34 months old and 8 months out of dock .. .. | 7 from C2 |

Prandtl–Schlichting line for the skin friction of smooth surfaces. The Schoenherr line is also drawn on this diagram and the position is shown of the frictional resistance coefficients obtained from traverses. This makes it possible, in the first place, to examine whether there is a satisfactory correlation between these resistance coefficients and the extrapolators.

Taking only the resistance coefficients $C_f$ in very clean condition of the hull, the year the ship was built, it is clear these coefficients are compatible with the Prandtl–Schlichting and the Schoenherr formulation, as far as the traverses from the fore and middle pitot logs are concerned. From a comparison of the coefficients obtained from the traverses fore and middle it is further concluded that with increasing Reynolds number the frictional resistance coefficient decreases, as shown by the following Table. The resistance coefficients obtained from the traverses of the aft pitot log C3 are well beneath the Schoenherr line.

Frictional Resistance Coefficient from Traverses

| Reynolds number | Date | Location pitot | Resistance coefficient from traverses | Schoenherr value | $\Delta C_f$ to Schoenherr value |
|---|---|---|---|---|---|
| $3 \cdot 0 \times 10^8$ | January 13, 1954 | C1 | 0·00180 | 0·00178 | 0·00002 |
| $3 \cdot 4 \times 10^8$ | October 12, 1954 | C1 | 0·00201 | 0·00175 | 0·00026 |
| $5 \cdot 1 \times 10^8$ | August 2–4, 1954 | C2 | 0·00186 | 0·00166 | 0·00020 |
| $5 \cdot 2 \times 10^8$ | October 12, 1954 | C2 | 0·00185 | 0·00166 | 0·00019 |
| $6 \cdot 4 \times 10^8$ | February 8, 1956 | C3 | 0·00134 | 0·00162 | −0·00028 |

The values of $C_f$ given by the aft pitot log C3 traverses are surprisingly low, and should be even lower if consideration is taken of the deterioration of the hull's surface. The thickness of the boundary layer in C3 is slightly less than the thickness in C2, and this might suggest that there is an influence of screw suction on the boundary layer of C3. The distance, however, from C3 to the propeller is 68 ft., the diameter of the propeller being 17·65 ft. At that distance from the propeller the influence of the screw must be very small. According to Korvin-Kroukovsky,[(5)] about 75 per cent of the thrust deduction is generated within a radius equal to less than three propeller radii from the propeller centre.

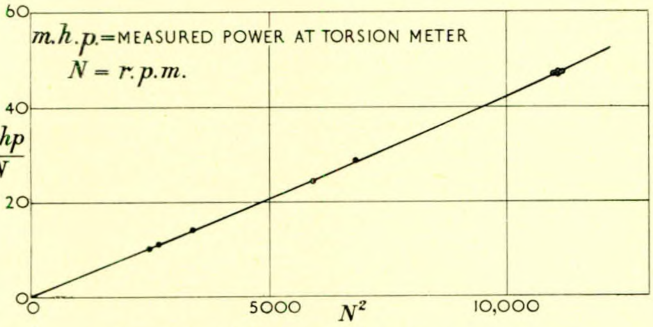


Fig. 19.—Calculation of shaft losses

On the other hand, there is no indication of flow separation in C3. Similar low values of $C_f$ have been found from pitot traverses in the after part in other vessels. An investigation of the boundary layer at the fore bulkhead of the engine-room of a supertanker of 638 ft. between perpendiculars gave also a very low value of $C_f$ well beneath the Schoenherr line. The distance of the log to the fore perpendicular was 466 ft., so that there could not be any influence of the screw.

An attempt has been made to determine the mean local frictional resistance between C1 and C2 from the traverses. If $l_1$ and $l_2$ are the distances to the foot of the stem, the local frictional resistance $C_f'$ between C1 and C2 is given by:—

$$C_f' = \frac{C_{f2}\, l_2 - C_{f1}\, l_1}{l_2 - l_1} + 0\cdot00012$$

The correction 0·00012 is to be added to $C_f'$ because of the finite length $l_2 - l_1$. This correction has been found from the Prandtl–Schlichting line, which is believed to be near the friction line of the ship.

Because of the local frictional resistance being calculated from the difference of traverses which give the frictional resistance with an accuracy not better than 5 per cent, a more or less acceptable value of this local frictional resistance cannot be expected unless the traverses are taken with the utmost care. The traverses taken on October 12, 1954, are mean values of many traverses taken in fine weather. The value $C_{f2} = 0\cdot00185$ is very near to the mean value 0·00186 obtained August 2–4, 1954. From the traverses of October 12th a value of $C_f' = 0\cdot00167$ is obtained for a Reynolds number $4\cdot3 \times 10^8$, and this value seems to give a good support to the Schoenherr line. The Schoenherr line indeed gives for this Reynolds number $C_f' = 0\cdot00158$, hence $\Delta C_f' = 0\cdot00009$. For this Reynolds number $\Delta C_f$ on the Schoenherr line was $\Delta C_f = 0\cdot0002$.

It must be emphasized that $C_f'$ was obtained from $C_f$ values which are known with an approximation not better than 5 per

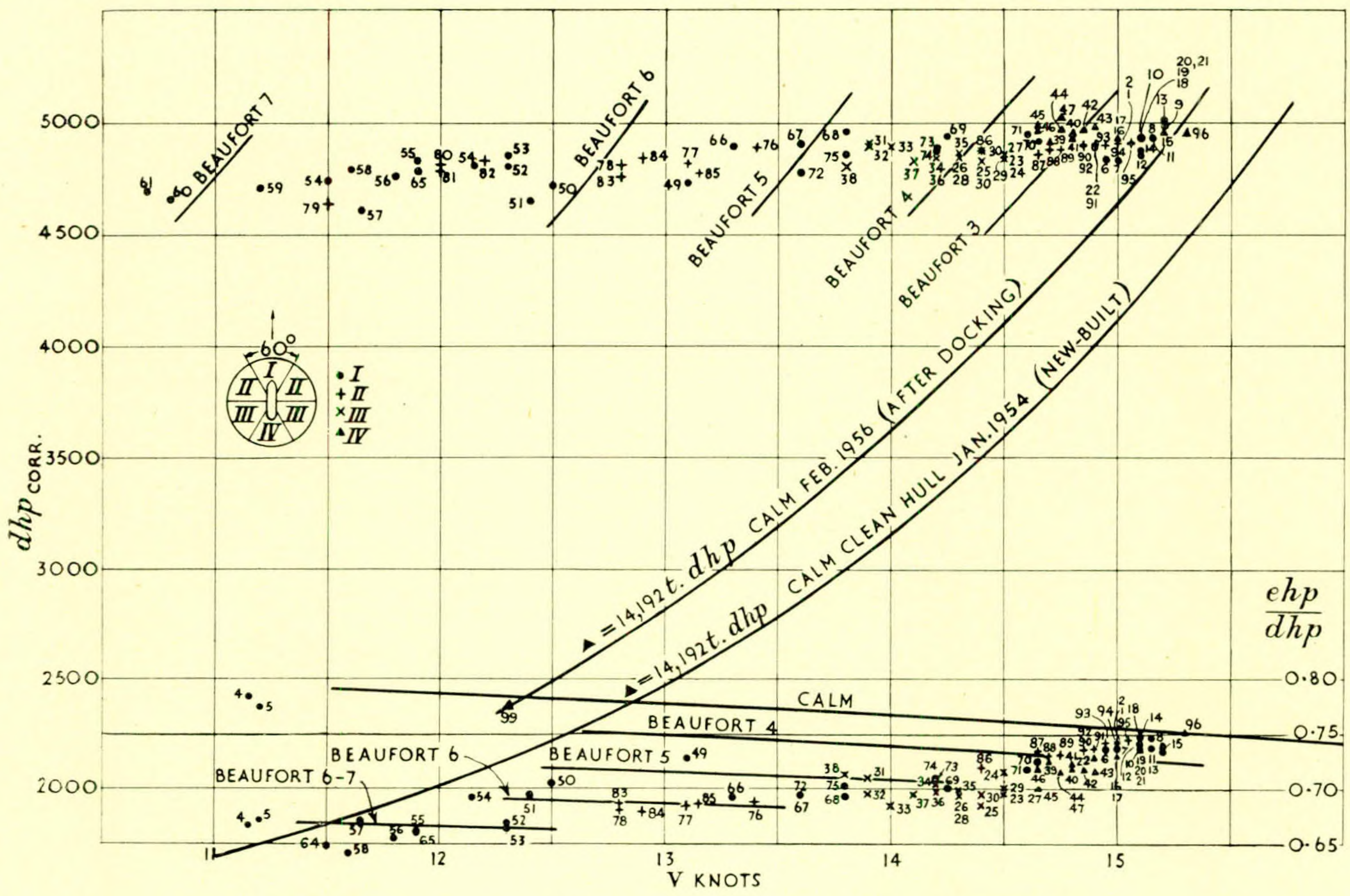


Fig. 20.—Relation dhp-speed. Voyage Antwerp–New York (February 1956, fully loaded)

cent. The error on $C_f$ may be 10 or even 20 per cent. It seems very difficult to obtain local resistances from pitot logs installed over the length of the bottom of the ship.

If on one side there is a satisfactory correlation between the figures of frictional resistance given by the pitot traverses and the propulsion data, it is more difficult to correlate these figures with the results of roughness measurements.

The resistance coefficients obtained from the pitot traverses taken in August and October 1954, after the first dry-docking and cleaning of the ship, correlate in the Prandtl–Schlichting diagram with an equivalent sand roughness number of Nikuradse

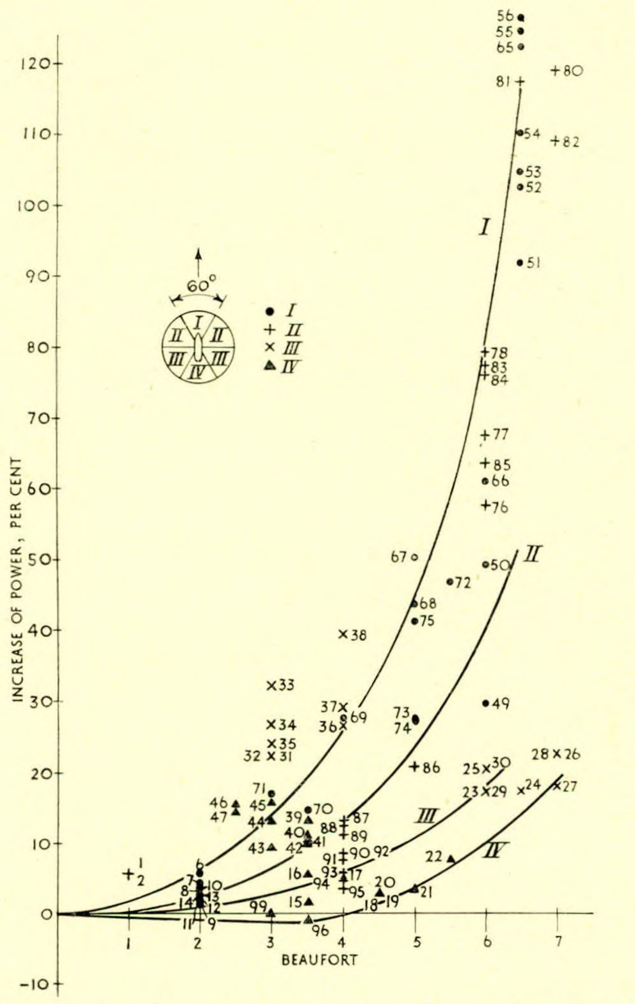


FIG. 21.—RELATION INCREASE OF POWER—WEATHER BEAUFORT (FEBRUARY 1956, FULLY LOADED)

$k_s = 2{,}000$ microin. On the other hand, the mean roughness given by the pneumatic feeler was 2,250 microin. These two figures are in satisfactory correlation, but no allowance is made for a certain amount of corrosion on one side, and of structural roughness on the other side.

The correlation is certainly not so good for the roughness data obtained after painting the hull in February 1956. The very high figure of 21,550 microin., measured with the pneumatic feeler, relates in C2 to a relative roughness $l/k_s = 1 \cdot 25 \times 10^5$, which gives in the Prandtl–Schlichting diagram a resistance coefficient of 0·00306 for a Reynolds number $5 \times 10^8$. On the other hand, $C_f$ given by the traverses in C2—and confirmed by the power data—is 0·00207. As a conclusion the frictional resistance coefficient given by the Prandtl–Schlichting diagram is 50 per cent higher than the resistance coefficient from traverses and power data.

The figure of 17,169 microin obtained on October 6, 1956, just before the October voyage, gives in C2 from the Prandtl–Schlichting diagram, a frictional resistance coefficient of 0·00292 for a Reynolds number $4 \cdot 6 \times 10^8$. This coefficient again is much higher, here 35 per cent, than the resistance coefficient 0·00215 obtained from traverses and confirmed by power data.

Although the pneumatic feeler gives the average height of the irregularities of the surface, there now appears to be no correlation whatever between this height and the equivalent sand roughness Nikuradse. Obviously the aspect of this roughness, a waviness, is quite different from the artificial roughness of Nikuradse, and this waviness, as shown by Allan and Cutland,[6] gives a frictional resistance considerably lower than the roughness obtained by a coverage of emery powder or sand grains. This

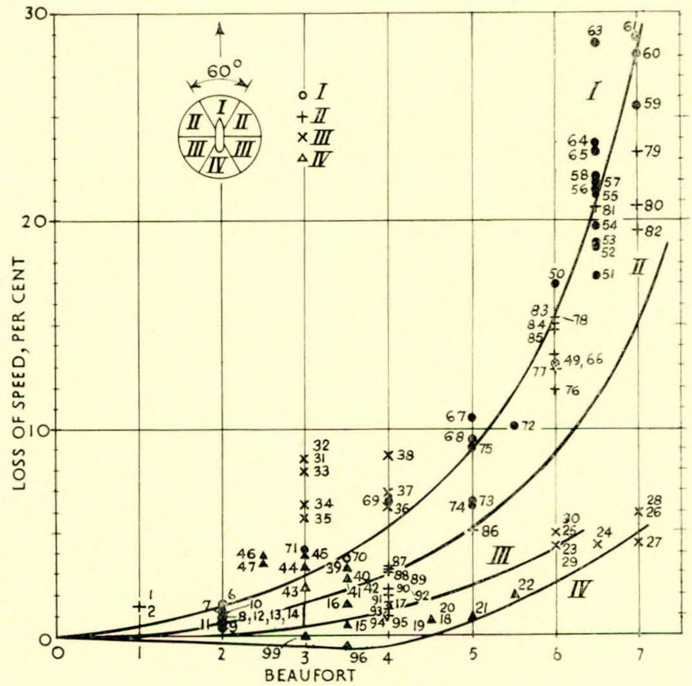


FIG. 22.—RELATION LOSS OF SPEED—WEATHER BEAUFORT (FEBRUARY 1956, FULLY LOADED)

concerns the smooth waviness of a hull's surface freshly painted as well as a surface on which paint has been deteriorated after several months' service. From previous experience, however, on the *Lucy Ashton*[7] as well as on the *Tervaete*,[8] it is known that thin sown sharp barnacles of even small size give rise to a substantial increase in resistance.

Upon the whole, the roughness measurements made the first year of ship's life with the pneumatic feeler, ranging from 1,000 to 4,000 microin., correlate not so badly, when introduced as equivalent sand grain number in Prandtl–Schlichting's diagram, with the resistance coefficients obtained from pitot traverses and power data. For the more important roughnesses, ascertained in the later life of the vessel, it is apparent that, although the feeler gives figures for the average height of the asperities, these figures, when introduced in Prandtl–Schlichting's diagram as equivalent sand grain number, give resistances which do not correspond at all with the resistance coefficients obtained from pitot traverses and power data.

### 5. Analysis of Propulsion Data

Readings of speed, torque, thrust, revolutions, wind force, ship's course, pitch and roll angles, were made on every occasion of a change in weather conditions or revolutions. Circumstances did not permit of all these readings being taken simultaneously. The time taken in collecting all the data during each observation was about half an hour. It was unlikely that weather and state of sea would change in that time.

Tables I and II give weather data for each observation (Appendix). The pitch angles are out to out values; they were measured with a pendulum.

The effective horsepower is derived from the recorded thrust and speed with introduction of a thrust-deduction coefficient taken from the model-tests.[1] The torsionmeter gives the measured power mhp. In the same way as was done for the analysis of previous trials an attempt was made to have correct values of delivered horsepower dhp. Fortunately, during the February voyage readings were made with revolutions as low as 50 *rpm*. Plotting for this voyage *mhp*/N against $N^2$ (Fig. 19) yields for N = 0 a *mhp*/N = $\frac{1}{2}$, hence a shaft loss of $\frac{1}{2}$ hp per revolution. This value is in agreement with a loss of 1 per cent at full power from torsionmeter to screw. Assuming then the same loss from engine to torsionmeter, $\frac{1}{2}$ hp per revolution, gives a shaft loss at full power of 2 per cent. This value is very low indeed, but several authors suggest low values for shaft losses.[9]

Since all the measurements were made in the North Atlantic, the propulsion data are not corrected for water temperature. They are corrected for the displacement: the standard displacement was 14,192 tons for the first, 10,000 tons for the second voyage.

Tables III and IV (Appendix) give the propulsion analysis. The effect of weather on ship's speed is shown in Figs. 20, 21, and 22 for the February voyage, in Figs. 23 and 24 for the October voyage, in the same way as was done in the previous *Lubumbashi* paper.

There was no appreciable deterioration of the propulsive efficiency since the ship was built.

It was possible to establish the effect of weather in the loaded condition (February voyage). It was more difficult to have this effect of weather established for the medium loaded condition of October: during this last voyage a strong wind 6 to 7 in the scale Beaufort blew only a few hours during two nights, and it was rather doubtful whether the state of the sea was in accordance with this wind strength.

The results in loaded condition confirm broadly what had been found in previous voyages. There is a small gain of speed with following wind, but only in a moderate sea. In a following sea, more than 4 in the scale Beaufort, this gain changes to loss until, in a sea Beaufort 7, the loss of speed goes so far as 5 per cent.

It was possible now to have a better picture of the loss of propulsive efficiency in bad weather (Fig. 25). In a heavy sea, 7 in the Beaufort scale, the loss of propulsive efficiency is 18 per cent.

There seems to be no appreciable difference between fully loaded and medium loaded condition in so far as the effect of weather on speed and propulsive efficiency are concerned.

An attempt was made to establish the increase of power due

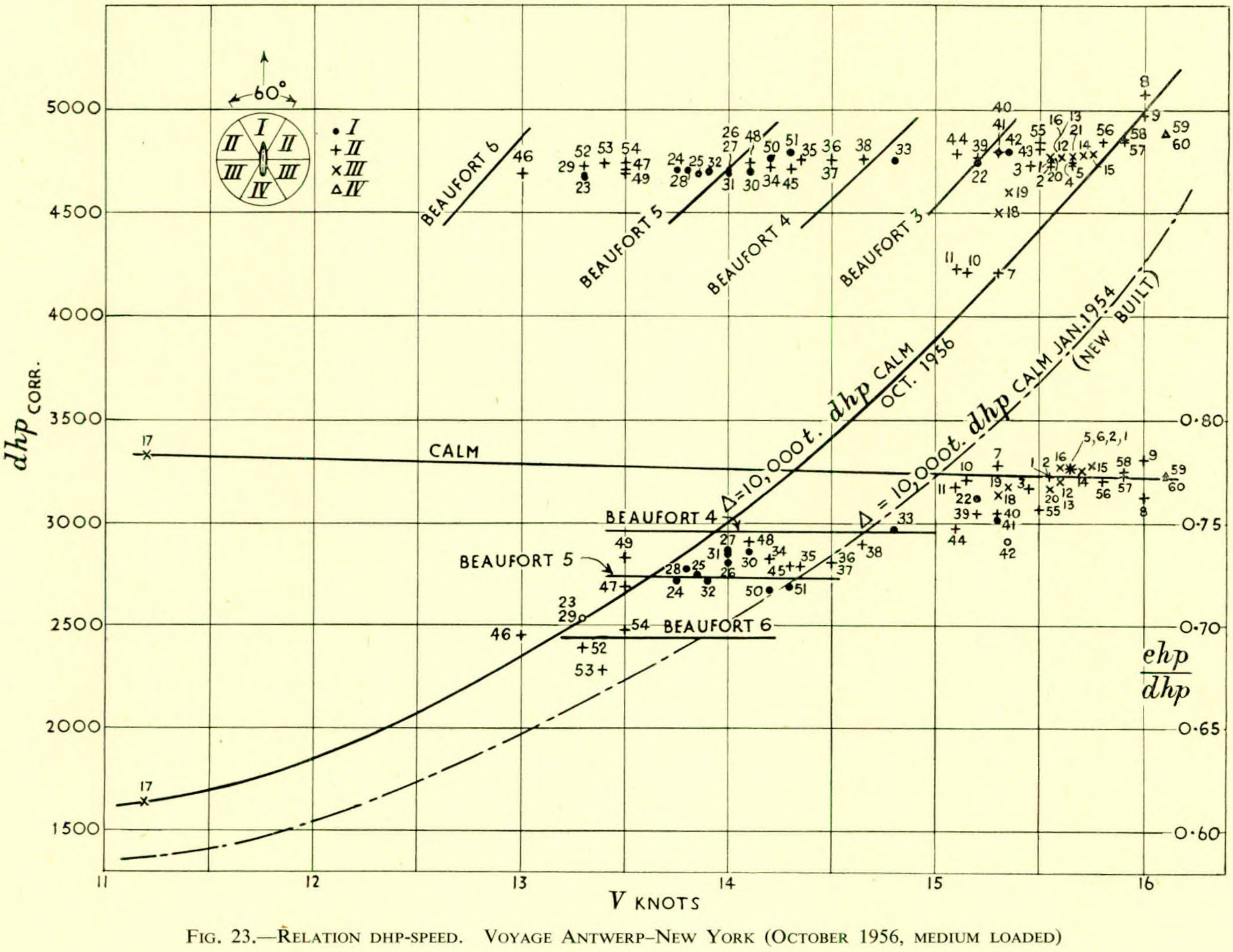


FIG. 23.—RELATION DHP-SPEED. VOYAGE ANTWERP–NEW YORK (OCTOBER 1956, MEDIUM LOADED)

to weather conditions for both Atlantic voyages. The mean value was 37 per cent for the February voyage in fully loaded condition, 29 per cent for the October voyage in medium loaded condition.

The percentage of 37 per cent for a winter North Atlantic voyage in fully loaded condition is very high compared with the mean value of 15 per cent obtained for the route Antwerp–Canary Islands.

compositions. On the route Antwerp–Congo the effect of fouling on the newly-built ship was 9 per cent after six months' service. In the later life of the ship, when her hull surface had deteriorated, the effect of fouling became smaller—the route of the ship was then Antwerp–New York–Congo—and upon the whole this effect of fouling after two or three years' service appears to be no more than 9 or 10 per cent for a ten months' service.

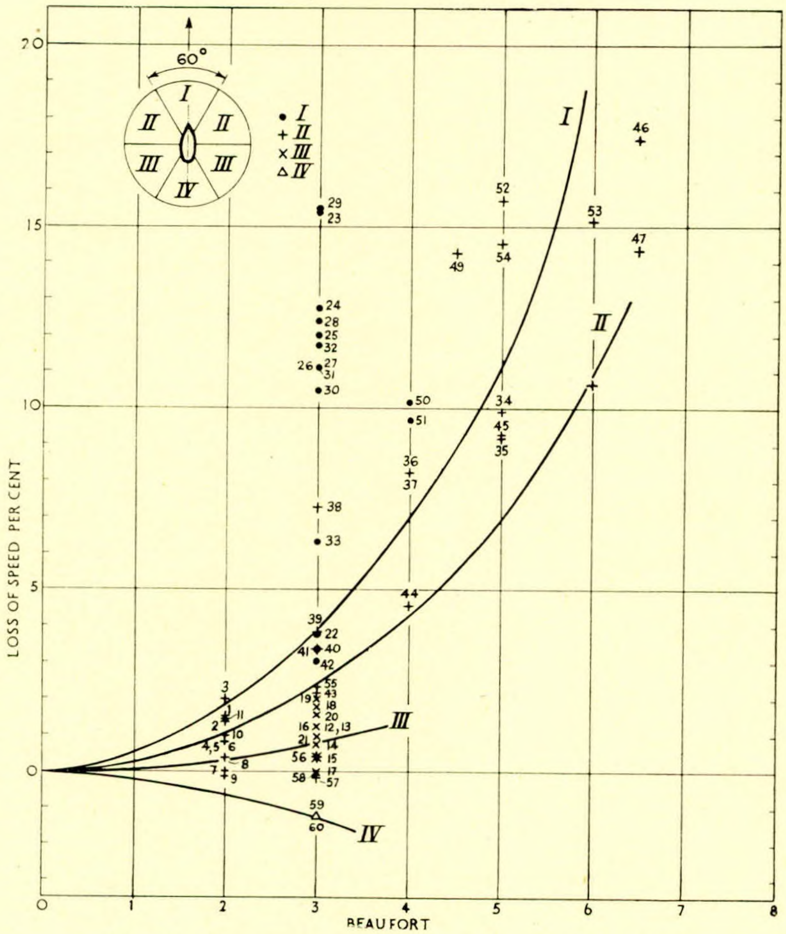


FIG. 24.—RELATION LOSS OF SPEED—WEATHER BEAUFORT (OCTOBER 1956, MEDIUM LOADED)

From the dhp diagrams the effect of fouling on power and speed has been deduced. This effect of fouling has already been described in Section 4. The smooth water curve newly-built ship has been drawn for both voyages. There was a difficulty for the October voyage in that the curve newly-built ship had to be reduced from 14,192 to 10,000 tons. This has been done in the usual way, but as the difference of displacement is very large a high accuracy cannot be obtained by this method.

From Fig. 20 the increase of power from newly-built ship to roughened-clean ship after 26 months' service was established as 14 per cent. From Fig. 23 the increase of power from clean newly-built to fouled is established as 19 per cent. Hence the effect of fouling alone appears to be 4 per cent.

This effect of fouling, after eight months' service, is very low and is even lower when calculated from traverses (Fig. 17). Roughness measurements and a survey of the hull did not reveal any fouling. The result is surprising, but it must be remembered that the ship was painted in very cold weather.

In the previous *Lubumbashi* paper attention was drawn to the low values of fouling effect on vessels painted with modern

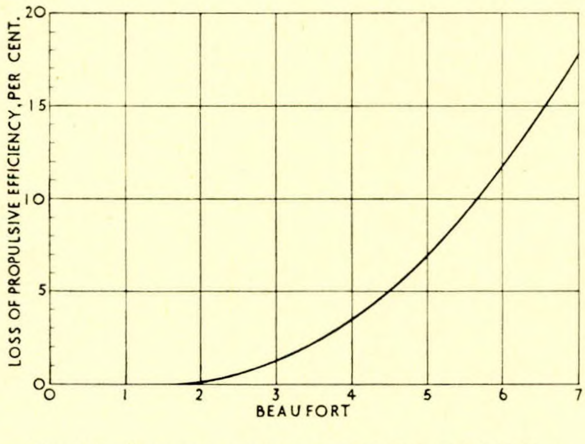


FIG. 25.—RELATION LOSS OF PROPULSIVE EFFICIENCY—WEATHER BEAUFORT

**Acknowledgments**

This investigation was carried out under the auspices of the Centre Belge de Recherches Navales (Ceberena), with the financial assistance of the Institut pour l'Encouragement de la Recherche scientifique dans l'Industrie et l'Agriculture (Irsia).

The author is very much indebted to all those who helped him, especially the shipowners, the Compagnie Maritime Belge (Lloyd Royal), both engine works, Cockerill–Ougrée and Mercantile Marine Engineering and Graving Docks Co., and Mr. van Maanen, technical director of Ceberena.

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## APPENDIX

### TABLE I

WEATHER DATA, VOYAGE ANTWERP–NEW YORK (FEBRUARY 1956)

| No. | Date | Hour | | Course deg. | Description of sea | True wind | | Rel. wind | | Waves | | | Pitch angle deg. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | hrs. | min. | | | Beaufort scale | Direction | Strength knots | Direction deg. | Height feet | Length feet | Direction deg. | |
| 1 | 7 | 21 | 30 | 255 | Smooth | 1 | S. | 15 | 0 | 2 | 50 | 70 P. | — |
| 2 | 7 | 22 | 0 | 255 | Smooth | 1 | S. | 15 | 0 | 2 | 50 | 70 P. | — |
| 3 | 8 | 7 | 0 | 255 | Smooth | 2 | N.N.W. | 12 | 30 S.B. | 2 | 50 | 0 | — |
| 4 | 8 | 7 | 20 | 255 | Smooth | 2 | N.N.W. | 13 | 30 S.B. | 2 | 50 | 0 | — |
| 5 | 8 | 7 | 30 | 255 | Smooth | 2 | N.N.W. | 13 | 30 S.B. | 2 | 50 | 0 | — |
| 6 | 8 | 9 | 20 | 258 | Smooth | 2 | N.N.W. | 16 | 20 S.B. | 2 | 50 | 0 | — |
| 7 | 8 | 10 | 0 | 258 | Smooth | 2 | N.N.W. | 16 | 20 S.B. | 2 | 50 | 0 | — |
| 8 | 8 | 11 | 0 | 258 | Smooth | 2 | N.N.W. | 16 | 20 S.B. | 2 | 50 | 0 | — |
| 9 | 8 | 13 | 30 | 262 | Smooth | 2 | N. | 15 | 20 S.B. | 2 | 50 | 0 | — |
| 10 | 8 | 14 | 30 | 262 | Smooth | 2 | N. | 15 | 20 S.B. | 2 | 50 | 0 | — |
| 11 | 8 | 15 | 30 | 262 | Smooth | 2 | N. | 15 | 20 S.B. | 2 | 50 | 0 | — |
| 12 | 8 | 17 | 45 | 266 | Smooth | 2 | N. | 15 | 20 S.B. | 2 | 50 | 0 | — |
| 13 | 8 | 20 | 30 | 263 | Smooth | 2 | N. | 15 | 20 S.B. | 2 | 50 | 0 | — |
| 14 | 8 | 23 | 0 | 269 | Smooth | 2 | N. | 15 | 20 S.B. | 2 | 50 | 0 | — |
| 15 | 9 | 7 | 0 | 269 | Moderate | 3–4 | N.E. | 6 | 50 S.B. | 5 | 200 | 160 S.B. | — |
| 16 | 9 | 14 | 0 | 264 | Moderate | 3–4 | N.E. | 6 | 50 S.B. | 5 | 200 | 160 S.B. | — |
| 17 | 9 | 16 | 40 | 264 | Moderate | 4 | E.N.E. | 2 | 0 | 5 | 160 | 160 S.B. | — |
| 18 | 10 | 3 | 45 | 264 | Rath. rough | 4–5 | E. | 1 | 0 | 7 | 230 | 160 S.B. | — |
| 19 | 10 | 4 | 30 | 264 | Rath. rough | 4–5 | E. | 1 | 0 | 7 | 230 | 160 S.B. | 2·0 |
| 20 | 10 | 10 | 0 | 264 | Rath. rough | 4–5 | E. | 1 | 0 | 7 | 230 | 160 S.B. | 2·0 |
| 21 | 10 | 14 | 0 | 270 | Rough | 5 | E. | 3 | 0 | 10 | 230 | 160 S.B. | 2·0 |
| 22 | 10 | 15 | 0 | 270 | Rough | 5–6 | E. | 6 | 0 | 11 | 230 | 170 S.B. | 2·0 |
| 23 | 10 | 19 | 30 | 270 | Rough | 6 | E.S.E. | 10 | 130 P. | 11 | 230 | 150 P. | 2·0 |
| 24 | 11 | 3 | 30 | 270 | Very rough | 6–7 | E.S.E. | 14 | 135 P. | 15 | 400 | 150 P. | 3·0 |
| 25 | 11 | 7 | 0 | 270 | Very rough | 6 | E.S.E. | 10 | 150 P. | 15 | 400 | 150 P. | 2·0 |
| 26 | 11 | 10 | 0 | 270 | Very rough | 7 | E.S.E. | 16 | 130 P. | 17 | 420 | 130 P. | 2·0 |
| 27 | 11 | 11 | 0 | 270 | Very rough | 7 | E.S.E. | 16 | 130 P. | 18 | 450 | 130 P. | 2·0 |
| 28 | 11 | 14 | 30 | 270 | Very rough | 7 | E.S.E. | 16 | 130 P. | 18 | 450 | 130 P. | 2·0 |
| 29 | 11 | 17 | 0 | 270 | Very rough | 6 | S.E. | 12 | 120 P. | 15 | 400 | 130 P. | 2·0 |
| 30 | 11 | 21 | 30 | 270 | Very rough | 6 | S.E. | 14 | 110 P. | 15 | 400 | 130 P. | 2·0 |
| 31 | 12 | 6 | 45 | 265 | Moderate | 3 | N. | 18 | 30 S.B. | 11 | 200 | 135 P. | 2·0 |
| 32 | 12 | 9 | 0 | 255 | Moderate | 3 | N. | 18 | 30 S.B. | 11 | 200 | 130 P. | 2·0 |
| 33 | 12 | 10 | 45 | 255 | Moderate | 3 | N. | 17 | 30 S.B. | 11 | 230 | 140 P. | 2·0 |
| 34 | 12 | 11 | 30 | 255 | Moderate | 3 | N. | 17 | 30 S.B. | 11 | 230 | 140 P. | 2·0 |
| 35 | 12 | 15 | 30 | 247 | Moderate | 3 | N.W. | 16 | 30 S.B. | 11 | 250 | 140 P. | 2·0 |
| 36 | 12 | 16 | 30 | 247 | Moderate | 4 | N.W. | 20 | 40 S.B. | 11 | 220 | 130 P. | 2·0 |
| 37 | 12 | 17 | 40 | 247 | Moderate | 4 | N.W. | 21 | 40 S.B. | 11 | 220 | 130 P. | 2·5 |
| 38 | 12 | 20 | 30 | 247 | Moderate | 4 | N.W. | 22 | 40 S.B. | 11 | 220 | 130 P. | 2·0 |
| 39 | 13 | 5 | 30 | 240 | Moderate | 3–4 | N.N.E. | 8 | 60 S.B. | 11 | 250 | 160 P. | 1·0 |
| 40 | 13 | 9 | 0 | 240 | Moderate | 3–4 | N.N.E. | 8 | 60 S.B. | 11 | 250 | 160 P. | 1·5 |
| 41 | 13 | 10 | 0 | 240 | Moderate | 3–4 | N.N.E. | 8 | 60 S.B. | 11 | 250 | 160 P. | 1·5 |
| 42 | 13 | 11 | 0 | 240 | Moderate | 3–4 | N.N.E. | 8 | 60 S.B. | 10 | 230 | 160 P. | 1·0 |
| 43 | 13 | 12 | 0 | 240 | Moderate | 3 | E.N.E. | 6 | 10 S.B. | 10 | 230 | 160 P. | 1·0 |
| 44 | 13 | 13 | 30 | 240 | Moderate | 3 | E.N.E. | 5 | 0 | 10 | 230 | 160 P. | 1·0 |
| 45 | 13 | 14 | 30 | 240 | Moderate | 3 | E.N.E. | 5 | 0 | 10 | 230 | 160 P. | 1·0 |
| 46 | 13 | 15 | 45 | 240 | Moderate | 2–3 | E.N.E. | 7 | 0 | 10 | 230 | 160 P. | 1·0 |
| 47 | 13 | 19 | 0 | 240 | Moderate | 2–3 | E.N.E. | 7 | 0 | 10 | 230 | 160 P. | 1·0 |
| 48 | 13 | 20 | 0 | 240 | Moderate | 2–3 | E.N.E. | 1 | 0 | 10 | 230 | 160 P. | 1·0 |
| 49 | 14 | 4 | 0 | 253 | Rough | 6 | W. | 35 | 10 S.B. | 12 | 400 | 15 S.B. | 2·5 |
| 50 | 14 | 6 | 0 | 253 | Rough | 6 | W. | 35 | 10 S.B. | 13 | 420 | 15 S.B. | 2·5 |

TABLE I—*continued*

| No. | Date | Hour | | Course deg. | Description of sea | True wind | | Rel. wind | | Waves | | | Pitch angle deg. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | hrs. | min. | | | Beaufort scale | Direction | Strength knots | Direction deg. | Height feet | Length feet | Direction deg. | |
| 51 | 14 | 7 | 0 | 253 | Very rough | 6–7 | W. | 38 | 10 S.B. | 13 | 420 | 15 S.B. | 2·5 |
| 52 | 14 | 8 | 0 | 253 | Very rough | 6–7 | W. | 40 | 10 S.B. | 13 | 420 | 10 S.B. | 2·5 |
| 53 | 14 | 10 | 0 | 253 | Very rough | 6–7 | W. | 40 | 10 S.B. | 14 | 420 | 10 S.B. | 3·0 |
| 54 | 14 | 12 | 0 | 253 | Very rough | 6–7 | W. | 40 | 10 S.B. | 15 | 450 | 10 S.B. | 3·0 |
| 55 | 14 | 14 | 0 | 253 | Very rough | 6–7 | W. | 40 | 10 S.B. | 15 | 450 | 10 S.B. | 4·0 |
| 56 | 14 | 15 | 30 | 253 | Very rough | 6–7 | W. | 38 | 10 S.B. | 15 | 450 | 10 S.B. | 4·0 |
| 57 | 14 | 16 | 45 | 253 | Very rough | 6–7 | W. | 39 | 10 S.B. | 15 | 450 | 10 S.B. | 5·0 |
| 58 | 14 | 17 | 45 | 253 | Very rough | 6–7 | W. | 39 | 0 | 15 | 450 | 10 S.B. | 5·0 |
| 59 | 14 | 22 | 0 | 253 | Very rough | 7 | W. | 43 | 0 | 15 | 450 | 10 S.B. | 5·0 |
| 60 | 15 | 5 | 0 | 253 | Very rough | 7 | W. | 44 | 10 S.B. | 16 | 470 | 15 S.B. | 5·5 |
| 61 | 15 | 8 | 0 | 253 | Very rough | 7 | W. | 44 | 10 S.B. | 16 | 470 | 15 S.B. | 5·5 |
| 62 | 15 | 9 | 45 | 253 | Very rough | 6–7 | W. | 34 | 10 S.B. | 15 | 470 | 15 S.B. | 7·0 |
| 63 | 15 | 10 | 0 | 253 | Very rough | 6–7 | W. | 34 | 10 S.B. | 15 | 470 | 15 S.B. | 7·0 |
| 64 | 15 | 11 | 0 | 253 | Very rough | 6–7 | W. | 40 | 10 S.B. | 15 | 450 | 15 S.B. | 5·5 |
| 65 | 15 | 11 | 45 | 253 | Very rough | 6–7 | W. | 40 | 10 S.B. | 15 | 450 | 15 S.B. | 4·5 |
| 66 | 15 | 14 | 0 | 254 | Rough | 6 | W. | 37 | 10 S.B. | 12 | 300 | 15 S.B. | 3·0 |
| 67 | 15 | 15 | 0 | 254 | Rough | 5 | W. | 32 | 10 S.B. | 12 | 300 | 15 S.B. | 2·5 |
| 68 | 15 | 16 | 0 | 254 | Rough | 5 | W. | 32 | 10 S.B. | 11 | 280 | 15 S.B. | 1·5 |
| 69 | 15 | 17 | 0 | 254 | Rath. rough | 4 | W. | 28 | 5 S.B. | 7 | 230 | 10 S.B. | 1·0 |
| 70 | 15 | 17 | 30 | 254 | Moderate | 3–4 | W. | 24 | 5 S.B. | 5 | 180 | 10 S.B. | 1·0 |
| 71 | 15 | 20 | 0 | 254 | Moderate | 3 | W. | 22 | 5 S.B. | 5 | 180 | 10 S.B. | 1·0 |
| 72 | 15 | 23 | 0 | 254 | Rough | 5–6 | W. | 34 | 5 S.B. | 8 | 230 | 10 S.B. | 2·5 |
| 73 | 16 | 6 | 45 | 254 | Rough | 5 | W. | 32 | 20 S.B. | 8 | 230 | 15 S.B. | 1·5 |
| 74 | 16 | 7 | 30 | 254 | Rough | 5 | W. | 32 | 20 S.B. | 9 | 230 | 30 S.B. | 1·5 |
| 75 | 16 | 9 | 0 | 254 | Rough | 5 | W. | 32 | 20 S.B. | 9 | 270 | 30 S.B. | 2·0 |
| 76 | 16 | 10 | 15 | 254 | Rough | 6 | W.N.W. | 32 | 30 S.B. | 11 | 300 | 45 S.B. | 3·0 |
| 77 | 16 | 11 | 10 | 254 | Rough | 6 | W.N.W. | 34 | 30 S.B. | 12 | 320 | 45 S.B. | 2·5 |
| 78 | 16 | 12 | 0 | 254 | Rough | 6 | W.N.W. | 34 | 30 S.B. | 13 | 340 | 45 S.B. | 3·0 |
| 79 | 16 | 14 | 0 | 260 | Very rough | 7 | W.N.W. | 44 | 30 S.B. | 15 | 420 | 40 S.B. | 3·5 |
| 80 | 16 | 15 | 0 | 260 | Very rough | 7 | W.N.W. | 44 | 30 S.B. | 14 | 420 | 40 S.B. | 4·0 |
| 81 | 16 | 16 | 0 | 260 | Very rough | 6–7 | W.N.W. | 38 | 30 S.B. | 13 | 410 | 40 S.B. | 3·5 |
| 82 | 16 | 17 | 0 | 265 | Very rough | 7 | W.N.W. | 40 | 30 S.B. | 13 | 410 | 40 S.B. | 4·5 |
| 83 | 16 | 17 | 30 | 265 | Rough | 6 | N.W. | 35 | 25 S.B. | 10 | 330 | 45 S.B. | 4·0 |
| 84 | 16 | 18 | 0 | 270 | Rough | 6 | N.W. | 35 | 25 S.B. | 10 | 330 | 45 S.B. | 4·0 |
| 85 | 16 | 18 | 30 | 270 | Rough | 6 | N.W. | 34 | 25 S.B. | 10 | 330 | 45 S.B. | 3·0 |
| 86 | 16 | 22 | 0 | 270 | Rough | 5 | N.W. | 33 | 25 S.B. | 8 | 250 | 35 S.B. | 1·5 |
| 87 | 16 | 22 | 40 | 270 | Rath. rough | 4 | N.W. | 28 | 25 S.B. | 8 | 230 | 60 S.B. | 1·5 |
| 88 | 16 | 23 | 30 | 270 | Rath. rough | 4 | N.W. | 24 | 25 S.B. | 7 | 220 | 60 S.B. | 1·5 |
| 89 | 17 | 0 | 0 | 270 | Rath. rough | 4 | N.W. | 22 | 25 S.B. | 6 | 200 | 60 S.B. | — |
| 90 | 17 | 0 | 30 | 270 | Rath. rough | 4 | N.N.W. | 21 | 35 S.B. | 6 | 200 | 70 S.B. | — |
| 91 | 17 | 1 | 0 | 270 | Rath. rough | 4 | N.N.W. | 21 | 35 S.B. | 6 | 200 | 70 S.B. | — |
| 92 | 17 | 1 | 30 | 270 | Rath. rough | 4 | N.N.W. | 21 | 35 S.B. | 6 | 200 | 70 S.B. | — |
| 93 | 17 | 2 | 30 | 270 | Rath. rough | 4 | N. | 20 | 40 S.B. | 6 | 200 | 80 S.B. | — |
| 94 | 17 | 3 | 0 | 270 | Rath. rough | 4 | N. | 20 | 40 S.B. | 6 | 200 | 80 S.B. | — |
| 95 | 17 | 3 | 30 | 270 | Rath. rough | 4 | N. | 20 | 40 S.B. | 6 | 200 | 80 S.B. | — |
| 96 | 17 | 7 | 0 | 270 | Moderate | 3–4 | E.N.E. | 4 | 15 S.B. | 5 | 180 | 160 S.B. | — |
| 97 | 17 | 7 | 30 | 270 | Moderate | 3 | E.N.E. | 3 | 70 S.B. | 5 | 180 | 160 S.B. | — |
| 98 | 17 | 9 | 0 | 270 | Moderate | 3 | E.N.E. | 3 | 70 S.B. | 5 | 180 | 160 S.B. | — |
| 99 | 17 | 9 | 40 | 270 | Moderate | 3 | E.N.E. | 4 | 50 S.B. | 5 | 180 | 160 S.B. | — |

## TABLE II

### Weather Data, Voyage Antwerp–New York (October 1956)

| No. | Date | Hour hrs. | Hour min. | Course deg. | Description of sea | True wind Beaufort scale | True wind Direction | Rel. wind Strength knots | Rel. wind Direction deg. | Waves Height feet | Waves Length feet | Waves Direction deg. | Pitch angle deg. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 12 | 17 | 0 | 265 | Smooth | 2 | S.W. | 20 | 10 P. | 2 | 50 | 45 P. | — |
| 2 | 12 | 17 | 30 | 265 | Smooth | 2 | S.W. | 20 | 10 P. | 2 | 50 | 45 P. | — |
| 3 | 12 | 21 | 30 | 265 | Smooth | 2 | S.W. | 20 | 10 P. | 2 | 50 | 45 P. | — |
| 4 | 12 | 22 | 15 | 257 | Smooth | 2 | S.W. | 20 | 10 P. | 2 | 50 | 45 P. | — |
| 5 | 13 | 6 | 30 | 257 | Calm | 2 | S.E. | 10 | 30 P. | 1 | — | 45 P. | — |
| 6 | 13 | 7 | 30 | 257 | Calm | 2 | S.E. | 10 | 30 P. | 1 | — | 45 P. | — |
| 7 | 13 | 9 | 40 | 257 | Calm | 2 | S.E. | 10 | 30 P. | 1 | — | 45 P. | — |
| 8 | 13 | 11 | 30 | 257 | Calm | 2 | S.E. | 10 | 30 P. | 1 | — | 45 P. | — |
| 9 | 13 | 13 | 15 | 257 | Calm | 2 | S.E. | 10 | 30 P. | 1 | — | 45 P. | — |
| 10 | 13 | 20 | 35 | 270 | Calm | 2 | S.E. | 10 | 30 P. | 1 | — | 45 P. | — |
| 11 | 14 | 1 | 0 | 270 | Calm | 2 | S.E. | 10 | 30 P. | 1 | — | 45 P. | — |
| 12 | 14 | 9 | 30 | 270 | Moderate | 3 | S.S.E. | 12 | 40 P. | 5 | 120 | 130 P. | — |
| 13 | 14 | 10 | 30 | 270 | Moderate | 3 | S.S.E. | 12 | 40 P. | 5 | 120 | 120 P. | — |
| 14 | 14 | 11 | 30 | 270 | Moderate | 3 | S.S.E. | 12 | 40 P. | 5 | 120 | 120 P. | — |
| 15 | 14 | 12 | 0 | 270 | Moderate | 3 | S.S.E. | 12 | 40 P. | 5 | 120 | 120 P. | — |
| 16 | 14 | 14 | 0 | 270 | Moderate | 3 | S.S.E. | 12 | 40 P. | 5 | 120 | 120 P. | — |
| 17 | 14 | 14 | 30 | 270 | Moderate | 3 | S.S.E. | 12 | 40 P. | 5 | 120 | 120 P. | — |
| 18 | 14 | 14 | 50 | 270 | Moderate | 3 | S.S.E. | 12 | 40 P. | 5 | 120 | 120 P. | — |
| 19 | 14 | 15 | 0 | 270 | Moderate | 3 | S.S.E. | 12 | 40 P. | 5 | 120 | 120 P. | — |
| 20 | 14 | 15 | 30 | 270 | Moderate | 3 | S.S.E. | 12 | 40 P. | 5 | 120 | 120 P. | — |
| 21 | 14 | 17 | 30 | 270 | Moderate | 3 | S.S.E. | 12 | 40 P. | 5 | 120 | 120 P. | — |
| 22 | 14 | 21 | 45 | 270 | Moderate | 3 | S.W. | 22 | 20 P. | 6 | 150 | 0 | — |
| 23 | 15 | 5 | 0 | 270 | Swell | 3 | W.S.W. | 24 | 15 P. | 10 | 400 | 0 | 4·0 |
| 24 | 15 | 6 | 0 | 270 | Swell | 3 | W.S.W. | 24 | 15 P. | 10 | 400 | 0 | 3·5 |
| 25 | 15 | 6 | 45 | 270 | Swell | 3 | W.S.W. | 24 | 15 P. | 10 | 400 | 0 | 3·5 |
| 26 | 15 | 7 | 15 | 270 | Swell | 3 | W.S.W. | 22 | 15 P. | 10 | 400 | 0 | 3·0 |
| 27 | 15 | 9 | 0 | 270 | Swell | 3 | W.S.W. | 22 | 15 P. | 10 | 400 | 0 | 3·0 |
| 28 | 15 | 10 | 0 | 255 | Swell | 3 | S. | 16 | 15 P. | 10 | 400 | 0 | 3·5 |
| 29 | 15 | 10 | 30 | 255 | Swell | 3 | S. | 16 | 30 P. | 10 | 400 | 0 | 3·5 |
| 30 | 15 | 15 | 0 | 255 | Swell | 3 | S. | 16 | 30 P. | 10 | 400 | 20 P. | 3·0 |
| 31 | 15 | 17 | 30 | 255 | Swell | 3 | W. | 20 | 0 | 10 | 400 | 20 S.B. | 3·0 |
| 32 | 15 | 20 | 0 | 255 | Swell | 3 | W. | 20 | 0 | 10 | 400 | 20 S.B. | 3·0 |
| 33 | 15 | 22 | 30 | 255 | Swell | 3 | N.W. | 20 | 20 S.B. | 10 | 400 | 30 S.B. | 1·5 |
| 34 | 16 | 11 | 20 | 251 | Rough | 5 | N.W. | 30 | 30 S.B. | 13 | 400 | 45 S.B. | 2·5 |
| 35 | 16 | 15 | 0 | 251 | Rough | 5 | N.W. | 28 | 30 S.B. | 11 | 400 | 60 S.B. | 2·5 |
| 36 | 16 | 16 | 30 | 251 | Swell | 4 | W.N.W. | 26 | 20 S.B. | 11 | 400 | 40 S.B. | 2·5 |
| 37 | 16 | 17 | 30 | 251 | Swell | 4 | W.N.W. | 26 | 20 S.B. | 11 | 400 | 40 S.B. | 2·5 |
| 38 | 16 | 20 | 20 | 251 | Swell | 3 | N.W. | 18 | 30 S.B. | 10 | 300 | 50 S.B. | 2·5 |
| 39 | 17 | 9 | 0 | 251 | Moderate | 3 | W.N.W. | 22 | 20 S.B. | 6 | 180 | 40 S.B. | 1·5 |
| 40 | 17 | 11 | 0 | 251 | Moderate | 3 | W. | 21 | 0 | 5 | 180 | 40 S.B. | 1·0 |
| 41 | 17 | 13 | 45 | 251 | Moderate | 3 | W. | 21 | 0 | 5 | 180 | 30 S.B. | 1·0 |
| 42 | 17 | 15 | 45 | 249 | Moderate | 3 | S.W. | 20 | 15 P. | 5 | 180 | 30 S.B. | 1·0 |
| 43 | 17 | 17 | 30 | 249 | Moderate | 3 | S. | 16 | 30 P. | 5 | 180 | 35 S.B. | 1·0 |
| 44 | 17 | 19 | 30 | 249 | Moderate | 4 | S.W. | 24 | 15 P. | 6 | 180 | — | 1·5 |
| 45 | 17 | 22 | 0 | 249 | Rath. rough | 5 | W.S.W. | 32 | 0 | 7 | 200 | — | 1·5 |
| 46 | 18 | 3 | 0 | 249 | Very rough | 6–7 | W. | 41 | 20 S.B. | 13 | 300 | — | — |
| 47 | 18 | 4 | 0 | 249 | Very rough | 6–7 | W. | 41 | 20 S.B. | 13 | 300 | — | — |
| 48 | 18 | 6 | 30 | 249 | Rough | 6 | W.N.W. | 34 | 30 S.B. | 10 | 300 | 40 S.B. | 3·0 |
| 49 | 18 | 10 | 30 | 249 | Rough | 4–5 | W.N.W. | 27 | 20 S.B. | 8 | 200 | 40 S.B. | 2·0 |
| 50 | 18 | 15 | 30 | 244 | Rough | 4 | W. | 28 | 0 | 8 | 200 | 0 | 2·0 |
| 51 | 18 | 17 | 0 | 244 | Rough | 4 | W. | 27 | 0 | 8 | 200 | 0 | 2·0 |
| 52 | 19 | 6 | 30 | 260 | Very rough | 5 | N.W. | 28 | 30 S.B. | 13 | 300 | 80 S.B. | 4·0 |
| 53 | 19 | 9 | 0 | 260 | Very rough | 5 | N. | 24 | 50 S.B. | 13 | 300 | 80 S.B. | 3·0 |
| 54 | 19 | 17 | 0 | 261 | Very rough | 5 | N. | 22 | 40 S.B. | 13 | 300 | 80 S.B. | 3·5 |
| 55 | 20 | 6 | 30 | 263 | Moderate | 3 | N.N.E. | 12 | 30 S.B. | 6 | 160 | 80 S.B. | 1·0 |
| 56 | 20 | 9 | 30 | 263 | Moderate | 3 | N.N.E. | 10 | 30 S.B. | 6 | 160 | 80 S.B. | 1·0 |
| 57 | 20 | 12 | 0 | 263 | Moderate | 3 | N.E. | 8 | 30 S.B. | 4 | 120 | 80 S.B. | 1·0 |
| 58 | 21 | 11 | 0 | 259 | Smooth | 3 | N.N.E. | 10 | 30 S.B. | 3 | 60 | 80 S.B. | 0 |
| 59 | 21 | 16 | 0 | 259 | Moderate | 3 | E.S.E. | 7 | 20 P. | 5 | 100 | 150 P. | 0 |
| 60 | 21 | 17 | 0 | 259 | Moderate | 3 | E.S.E. | 7 | 20 P. | 5 | 100 | 150 P. | 0 |

## TABLE III

PROPULSION DATA, VOYAGE ANTWERP–NEW YORK, FEBRUARY 1956

| No. | Speed, knots | *rpm* | dhp | Thrust, in tons | ehp | $\frac{\text{ehp}}{\text{dhp}}$ | Δ | dhp corr. for Δ | Increase of power, per cent | Loss of speed, per cent |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 15·00 | 105·3 | 4,918 | 45·4 | 3,650 | 0·742 | 14,290 | 4,893 | 5·5 | 1·4 |
| 2 | 15·00 | 104·9 | 4,918 | 45·6 | 3,665 | 0·745 | 14,290 | 4,893 | 5·5 | 1·4 |
| 3 | 8·55 | 58·6 | 816 | — | — | — | 14,260 | 813 | — | — |
| 4 | 11·15 | 77·0 | 1,842 | 23·5 | 1,446 | 0·785 | 14,260 | 1,835 | — | — |
| 5 | 11·20 | 77·0 | 1,869 | 23·5 | 1,451 | 0·777 | 14,260 | 1,862 | — | — |
| 6 | 14·95 | 104·8 | 4,863 | 44·8 | 3,590 | 0·736 | 14,260 | 4,844 | 5·7 | 1·5 |
| 7 | 15·00 | 104·9 | 4,858 | 44·6 | 3,585 | 0·737 | 14,260 | 4,839 | 4·4 | 1·1 |
| 8 | 15·15 | 105·4 | 4,957 | 45·6 | 3,700 | 0·747 | 14,260 | 4,937 | 2·6 | 0·6 |
| 9 | 15·20 | 105·8 | 4,962 | 45·1 | 3,670 | 0·740 | 14,260 | 4,942 | 1·4 | 0·3 |
| 10 | 15·10 | 105·4 | 4,942 | 45·0 | 3,640 | 0·737 | 14,260 | 4,922 | 3·6 | 0·9 |
| 11 | 15·15 | 105·5 | 4,922 | 44·7 | 3,630 | 0·738 | 14,260 | 4,902 | 1·9 | 0·5 |
| 12 | 15·10 | 105·3 | 4,877 | 44·6 | 3,610 | 0·741 | 14,260 | 4,857 | 2·2 | 0·6 |
| 13 | 15·20 | 106·1 | 5,007 | 45·1 | 3,675 | 0·734 | 14,260 | 4,987 | 2·3 | 0·6 |
| 14 | 15·10 | 105·4 | 4,882 | 45·1 | 3,650 | 0·748 | 14,260 | 4,862 | 2·3 | 0·6 |
| 15 | 15·20 | 105·4 | 4,972 | 45·1 | 3,675 | 0·739 | 14,225 | 4,962 | 1·6 | 0·5 |
| 16 | 15·00 | 104·6 | 4,918 | 44·6 | 3,585 | 0·729 | 14,225 | 4,908 | 5·5 | 1·4 |
| 17 | 15·00 | 104·5 | 4,913 | 45·1 | 3,625 | 0·738 | 14,225 | 4,903 | 5·2 | 1·4 |
| 18 | 15·10 | 104·8 | 4,913 | 45·6 | 3,690 | 0·750 | 14,190 | 4,913 | 3·0 | 0·7 |
| 19 | 15·10 | 104·6 | 4,903 | 44·6 | 3,610 | 0·735 | 14,190 | 4,903 | 2·7 | 0·7 |
| 20 | 15·10 | 104·9 | 4,918 | 44·6 | 3,610 | 0·734 | 14,190 | 4,918 | 3·1 | 0·7 |
| 21 | 15·10 | 105·2 | 4,932 | 44·6 | 3,610 | 0·732 | 14,190 | 4,932 | 3·3 | 0·8 |
| 22 | 14·90 | 104·3 | 4,893 | 44·6 | 3,560 | 0·728 | 14,190 | 4,893 | 7·7 | 1·9 |
| 23 | 14·50 | 103·4 | 4,848 | 43·2 | 3,360 | 0·694 | 14,190 | 4,848 | 17·9 | 4·3 |
| 24 | 14·50 | 103·4 | 4,848 | 44·6 | 3,465 | 0·715 | 14,155 | 4,853 | 17·9 | 4·3 |
| 25 | 14·40 | 103·1 | 4,833 | 42·7 | 3,300 | 0·684 | 14,155 | 4,838 | 20·5 | 4·9 |
| 26 | 14·30 | 102·4 | 4,799 | 43·2 | 3,315 | 0·691 | 14,155 | 4,804 | 22·7 | 5·9 |
| 27 | 14·50 | 104·1 | 4,858 | 43·2 | 3,360 | 0·691 | 14,155 | 4,863 | 18·2 | 4·4 |
| 28 | 14·30 | 102·8 | 4,799 | 43·2 | 3,315 | 0·691 | 14,155 | 4,804 | 22·7 | 5·9 |
| 29 | 14·50 | 103·6 | 4,838 | 43·6 | 3,390 | 0·701 | 14,155 | 4,843 | 17·7 | 4·3 |
| 30 | 14·40 | 103·3 | 4,823 | 43·2 | 3,340 | 0·693 | 14,155 | 4,828 | 20·2 | 4·8 |
| 31 | 13·90 | 101·6 | 4,789 | 45·6 | 3,400 | 0·710 | 14,120 | 4,803 | 22·4 | 8·5 |
| 32 | 13·90 | 101·6 | 4,784 | 44·6 | 3,330 | 0·696 | 14,120 | 4,798 | 22·3 | 8·5 |
| 33 | 14·00 | 101·6 | 4,784 | 43·6 | 3,275 | 0·685 | 14,120 | 4,798 | 32·1 | 7·8 |
| 34 | 14·20 | 102·5 | 4,829 | 44·6 | 3,400 | 0·704 | 14,120 | 4,843 | 26·7 | 6·2 |
| 35 | 14·30 | 103·2 | 4,853 | 44·1 | 3,390 | 0·699 | 14,120 | 4,868 | 24·1 | 5·6 |
| 36 | 14·20 | 102·7 | 4,829 | 44·1 | 3,360 | 0·696 | 14,120 | 4,843 | 26·7 | 6·2 |
| 37 | 14·10 | 102·4 | 4,814 | 44·1 | 3,338 | 0·693 | 14,120 | 4,828 | 29·4 | 6·8 |
| 38 | 13·80 | 101·9 | 4,799 | 46·1 | 3,415 | 0·711 | 14,120 | 4,813 | 39·5 | 8·7 |
| 39 | 14·70 | 104·2 | 4,898 | 45·1 | 3,560 | 0·727 | 14,120 | 4,913 | 13·3 | 3·2 |
| 40 | 14·80 | 104·7 | 4,923 | 44·6 | 3,540 | 0·719 | 14,085 | 4,948 | 11·1 | 2·7 |
| 41 | 14·80 | 104·4 | 4,908 | 44·6 | 3,540 | 0·722 | 14,085 | 4,933 | 10·7 | 2·6 |
| 42 | 14·85 | 105·2 | 4,947 | 44·6 | 3,550 | 0·718 | 14,085 | 4,972 | 10·1 | 2·6 |
| 43 | 14·90 | 105·6 | 4,967 | 44·6 | 3,560 | 0·717 | 14,085 | 4,992 | 9·4 | 2·3 |
| 44 | 14·75 | 105·1 | 4,942 | 44·6 | 3,530 | 0·715 | 14,085 | 4,967 | 13·0 | 3·2 |
| 45 | 14·65 | 105·1 | 4,942 | 44·1 | 3,460 | 0·700 | 14,085 | 4,967 | 15·7 | 3·9 |
| 46 | 14·65 | 104·9 | 4,933 | 45·1 | 3,540 | 0·718 | 14,085 | 4,958 | 15·5 | 3·8 |
| 47 | 14·75 | 105·9 | 5,002 | 45·1 | 3,565 | 0·713 | 14,085 | 5,027 | 14·4 | 3·5 |
| 48 | 7·80 | 52·6 | 569 | — | — | — | 14,085 | 572 | — | — |
| 49 | 13·10 | 100·0 | 4,735 | 48·6 | 3,440 | 0·727 | 14,050 | 4,768 | 64·4 | 13·0 |
| 50 | 12·50 | 99·7 | 4,720 | 48·6 | 3,325 | 0·705 | 14,050 | 4,753 | 88·0 | 16·9 |

Trim by stern: 0·8 ft. for Nos. 1 to 60, 2·7 ft. for Nos. 61 to 99.

TABLE III—*continued*

| No. | Speed, knots | *rpm* | dhp | Thrust, in tons | ehp | $\frac{\text{ehp}}{\text{dhp}}$ | Δ | dhp corr. for Δ | Increase of power, per cent | Loss of speed, per cent |
|---|---|---|---|---|---|---|---|---|---|---|
| 51 | 12·40 | 98·4 | 4,656 | 47·6 | 3,240 | 0·695 | 14,050 | 4,689 | 92·0 | 17·3 |
| 52 | 12·30 | 99·3 | 4,805 | 47·6 | 3,220 | 0·670 | 14,050 | 4,839 | 102·7 | 18·6 |
| 53 | 12·30 | 99·2 | 4,855 | 47·6 | 3,220 | 0·664 | 14,050 | 4,889 | 104·8 | 18·9 |
| 54 | 12·15 | 97·5 | 4,806 | 49·6 | 3,320 | 0·691 | 14,050 | 4,840 | 110·3 | 19·7 |
| 55 | 11·90 | 98·1 | 4,836 | 48·6 | 3,190 | 0·660 | 14,050 | 4,870 | 124·9 | 21·4 |
| 56 | 11·80 | 97·7 | 4,761 | 48·1 | 3,125 | 0·656 | 14,050 | 4,795 | 126·7 | 21·8 |
| 57 | 11·65 | 94·5 | 4,603 | 48·1 | 3,090 | 0·671 | 14,050 | 4,636 | — | 22·0 |
| 58 | 11·60 | 97·9 | 4,791 | 48·1 | 3,075 | 0·642 | 14,050 | 4,825 | — | 23·2 |
| 59 | 11·20 | 95·5 | 4,707 | 48·6 | 3,000 | 0·637 | 14,050 | 4,740 | — | 25·5 |
| 60 | 10·80 | 94·2 | 4,658 | — | — | — | 14,015 | 4,700 | — | 28·0 |
| 61 | 10·70 | 95·2 | 4,692 | — | — | — | 14,120 | 4,706 | — | 28·8 |
| 62 | — | 87·3 | 4,301 | — | — | — | 14,120 | — | — | — |
| 63 | 10·50 | 90·1 | 4,125 | 46·2 | 2,678 | 0·649 | 14,120 | 4,137 | — | 28·5 |
| 64 | 11·50 | 96·6 | 4,742 | 48·2 | 3,058 | 0·645 | 14,120 | 4,756 | — | 23·7 |
| 65 | 11·90 | 99·2 | 4,785 | 48·2 | 3,162 | 0·661 | 14,120 | 4,799 | 122·5 | 21·2 |
| 66 | 13·30 | 101·4 | 4,884 | 47·2 | 3,380 | 0·692 | 14,120 | 4,899 | 61·0 | 12·5 |
| 67 | 13·60 | 102·4 | 4,909 | 46·7 | 3,405 | 0·694 | 14,120 | 4,924 | 50·3 | 10·5 |
| 68 | 13·80 | 103·9 | 4,943 | 46·2 | 3,420 | 0·693 | 14,120 | 4,958 | 43·6 | 9·4 |
| 69 | 14·25 | 104·3 | 4,928 | 45·2 | 3,455 | 0·701 | 14,120 | 4,943 | 27·6 | 6·4 |
| 70 | 14·65 | 104·6 | 4,903 | 45·2 | 3,550 | 0·724 | 14,120 | 4,918 | 14·8 | 3·6 |
| 71 | 14·60 | 104·4 | 4,933 | 45·2 | 3,540 | 0·718 | 14,120 | 4,948 | 17·0 | 4·1 |
| 72 | 13·60 | 101·7 | 4,799 | 45·7 | 3,335 | 0·695 | 14,120 | 4,814 | 46·9 | 10·0 |
| 73 | 14·20 | 103·1 | 4,863 | 45·2 | 3,440 | 0·707 | 14,085 | 4,887 | 27·6 | 6·4 |
| 74 | 14·20 | 102·9 | 4,853 | 45·2 | 3,440 | 0·709 | 14,085 | 4,877 | 27·3 | 6·3 |
| 75 | 13·80 | 102·6 | 4,859 | 46·2 | 3,420 | 0·703 | 14,085 | 4,883 | 41·2 | 9·0 |
| 76 | 13·40 | 101·5 | 4,889 | 46·7 | 3,360 | 0·688 | 14,085 | 4,913 | 57·7 | 11·8 |
| 77 | 13·10 | 101·2 | 4,829 | 46·7 | 3,300 | 0·684 | 14,085 | 4,853 | 67·6 | 13·5 |
| 78 | 12·80 | 100·4 | 4,790 | 46·7 | 3,255 | 0·680 | 14,085 | 4,814 | 79·4 | 15·3 |
| 79 | 11·50 | 95·4 | 4,637 | — | — | — | 14,085 | 4,660 | — | 23·2 |
| 80 | 12·00 | 98·7 | 4,811 | — | — | — | 14,085 | 4,835 | 118·1 | 20·6 |
| 81 | 12·00 | 98·4 | 4,796 | — | — | — | 14,085 | 4,820 | 117·5 | 20·6 |
| 82 | 12·20 | 99·2 | 4,835 | — | — | — | 14,085 | 4,859 | 109·3 | 19·4 |
| 83 | 12·80 | 98·7 | 4,741 | 46·7 | 3,250 | 0·686 | 14,085 | 4,765 | 77·5 | 15·0 |
| 84 | 12·90 | 100·3 | 4,820 | 46·7 | 3,270 | 0·679 | 14,085 | 4,844 | 76·2 | 14·7 |
| 85 | 13·15 | 100·8 | 4,775 | 46·2 | 3,280 | 0·687 | 14,085 | 4,799 | 63·8 | 12·9 |
| 86 | 14·40 | 103·4 | 4,853 | 45·2 | 3,490 | 0·719 | 14,085 | 4,877 | 21·0 | 5·0 |
| 87 | 14·65 | 103·2 | 4,838 | 45·2 | 3,550 | 0·734 | 14,085 | 4,862 | 13·3 | 3·3 |
| 88 | 14·70 | 103·6 | 4,863 | 45·0 | 3,545 | 0·729 | 14,085 | 4,887 | 12·5 | 3·1 |
| 89 | 14·75 | 103·6 | 4,863 | 44·9 | 3,550 | 0·730 | 14,050 | 4,897 | 11·2 | 3·1 |
| 90 | 14·85 | 103·8 | 4,873 | 44·9 | 3,575 | 0·734 | 14,050 | 4,907 | 8·5 | 2·2 |
| 91 | 14·90 | 104·0 | 4,883 | 45·0 | 3,595 | 0·737 | 14,050 | 4,917 | 7·5 | 1·9 |
| 92 | 14·85 | 103·8 | 4,873 | 45·0 | 3,580 | 0·735 | 14,050 | 4,907 | 8·5 | 2·2 |
| 93 | 14·95 | 104·3 | 4,868 | 45·0 | 3,605 | 0·741 | 14,050 | 4,902 | 5·8 | 1·5 |
| 94 | 15·00 | 104·6 | 4,883 | 45·0 | 3,620 | 0·741 | 14,050 | 4,917 | 4·8 | 1·3 |
| 95 | 15·05 | 104·6 | 4,883 | 45·0 | 3,630 | 0·744 | 14,050 | 4,917 | 3·5 | 0·9 |
| 96 | 15·30 | 105·4 | 4,917 | 45·0 | 3,690 | 0·751 | 14,050 | 4,951 | −0·9 | −0·1 |
| 97 | 8·00 | 51·6 | 550 | — | — | — | 14,050 | 554 | — | — |
| 98 | 7·95 | 49·9 | 498 | — | — | — | 14,050 | 501 | — | — |
| 99 | 12·30 | 82·7 | 2,339 | 26·2 | 1,770 | 0·758 | 14,050 | 2,355 | 0·0 | 0·0 |

Trim by stern: 0·8 ft. for Nos. 1 to 60, 2·7 ft. for Nos. 61 to 99.

## TABLE IV

PROPULSION DATA VOYAGE ANTWERP–NEW YORK, OCTOBER 1956

| No. | Speed, knots | *rpm* | dhp | Thrust, in tons | ehp | $\frac{\text{ehp}}{\text{dhp}}$ | Δ | dhp corr. for Δ | Loss of speed, per cent |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 15·55 | 105·8 | 4,852 | 44·7 | 3,725 | 0·773 | 10,340 | 4,742 | 1·5 |
| 2 | 15·55 | 105·9 | 4,830 | 44·8 | 3,730 | 0·773 | 10,340 | 4,720 | 1·3 |
| 3 | 15·45 | 106·0 | 4,835 | 44·8 | 3,710 | 0·767 | 10,340 | 4,725 | 2·0 |
| 4 | 15·65 | 106·1 | 4,840 | 44·9 | 3,760 | 0·777 | 10,340 | 4,730 | 0·8 |
| 5 | 15·65 | 106·0 | 4,835 | 44·8 | 3,755 | 0·777 | 10,305 | 4,737 | 0·8 |
| 6 | 15·65 | 106·0 | 4,835 | 44·8 | 3,755 | 0·777 | 10,305 | 4,737 | 0·8 |
| 7 | 15·30 | 102·8 | 4,300 | 40·8 | 3,345 | 0·778 | 10,305 | 4,212 | 0·0 |
| 8 | 16·00 | 108·5 | 5,175 | 46·0 | 3,945 | 0·763 | 10,305 | 5,069 | 0·3 |
| 9 | 16·00 | 107·8 | 5,075 | 46·2 | 3,960 | 0·781 | 10,305 | 4,972 | −0·1 |
| 10 | 15·15 | 102·8 | 4,300 | 40·8 | 3,315 | 0·771 | 10,305 | 4,212 | 0·9 |
| 11 | 15·10 | 102·4 | 4,300 | 40·8 | 3,305 | 0·768 | 10,265 | 4,224 | 1·4 |
| 12 | 15·60 | 106·3 | 4,850 | 44·7 | 3,735 | 0·771 | 10,265 | 4,764 | 1·2 |
| 13 | 15·60 | 106·4 | 4,855 | 44·7 | 3,735 | 0·770 | 10,265 | 4,769 | 1·2 |
| 14 | 15·70 | 106·6 | 4,865 | 44·9 | 3,775 | 0·776 | 10,265 | 4,779 | 0·7 |
| 15 | 15·75 | 106·7 | 4,870 | 44·9 | 3,790 | 0·778 | 10,265 | 4,784 | 0·4 |
| 16 | 15·60 | 106·3 | 4,850 | 45·1 | 3,770 | 0·778 | 10,265 | 4,764 | 1·2 |
| 17 | 11·20 | 75·0 | 1,670 | 21·5 | 1,307 | 0·783 | 10,265 | 1,640 | 0·0 |
| 18 | 15·30 | 104·2 | 4,585 | 42·7 | 3,500 | 0·764 | 10,265 | 4,504 | 1·7 |
| 19 | 15·35 | 105·0 | 4,685 | 43·7 | 3,595 | 0·768 | 10,265 | 4,602 | 2·0 |
| 20 | 15·55 | 106·4 | 4,855 | 44·7 | 3,725 | 0·767 | 10,265 | 4,769 | 1·5 |
| 21 | 15·65 | 106·3 | 4,850 | 44·9 | 3,765 | 0·777 | 10,265 | 4,764 | 0·9 |
| 22 | 15·20 | 105·2 | 4,825 | 45·2 | 3,680 | 0·763 | 10,265 | 4,740 | 3·7 |
| 23 | 13·30 | 102·0 | 4,745 | 46·2 | 3,335 | 0·703 | 10,230 | 4,672 | 15·4 |
| 24 | 13·75 | 103·2 | 4,775 | 46·2 | 3,450 | 0·722 | 10,230 | 4,702 | 12·7 |
| 25 | 13·85 | 102·3 | 4,755 | 46·2 | 3,450 | 0·725 | 10,230 | 4,682 | 12·0 |
| 26 | 14·00 | 103·2 | 4,775 | 46·2 | 3,490 | 0·731 | 10,230 | 4,702 | 11·1 |
| 27 | 14·00 | 103·2 | 4,775 | 46·6 | 3,515 | 0·737 | 10,230 | 4,702 | 11·1 |
| 28 | 13·80 | 102·9 | 4,770 | 46·7 | 3,475 | 0·728 | 10,230 | 4,697 | 12·3 |
| 29 | 13·30 | 102·3 | 4,755 | 46·4 | 3,350 | 0·704 | 10,230 | 4,682 | 15·5 |
| 30 | 14·10 | 103·1 | 4,770 | 46·2 | 3,510 | 0·736 | 10,230 | 4,697 | 10·4 |
| 31 | 14·00 | 102·9 | 4,770 | 46·4 | 3,505 | 0·735 | 10,230 | 4,697 | 11·1 |
| 32 | 13·90 | 103·2 | 4,770 | 45·9 | 3,440 | 0·722 | 10,230 | 4,697 | 11·7 |
| 33 | 14·80 | 104·5 | 4,810 | 45·2 | 3,590 | 0·747 | 10,190 | 4,749 | 6·3 |
| 34 | 14·20 | 103·1 | 4,770 | 45·6 | 3,490 | 0·732 | 10,190 | 4,710 | 9·9 |
| 35 | 14·35 | 104·2 | 4,810 | 45·3 | 3,505 | 0·729 | 10,190 | 4,749 | 9·1 |
| 36 | 14·50 | 104·5 | 4,810 | 44·9 | 3,515 | 0·731 | 10,190 | 4,749 | 8·2 |
| 37 | 14·50 | 104·6 | 4,810 | 44·9 | 3,515 | 0·731 | 10,190 | 4,749 | 8·2 |
| 38 | 14·65 | 104·6 | 4,810 | 45·0 | 3,555 | 0·740 | 10,190 | 4,749 | 7·2 |
| 39 | 15·20 | 104·8 | 4,810 | 44·6 | 3,630 | 0·755 | 10,150 | 4,762 | 3·8 |
| 40 | 15·30 | 106·0 | 4,840 | 44·6 | 3,655 | 0·755 | 10,150 | 4,792 | 3·3 |
| 41 | 15·30 | 105·7 | 4,840 | 44·4 | 3,640 | 0·752 | 10,150 | 4,792 | 3·3 |
| 42 | 15·35 | 105·8 | 4,840 | 43·6 | 3,585 | 0·741 | 10,150 | 4,792 | 3·0 |
| 43 | 15·50 | 106·5 | 4,855 | 43·9 | 3,610 | 0·744 | 10,150 | 4,806 | 2·1 |
| 44 | 15·10 | 105·3 | 4,830 | 44·6 | 3,610 | 0·747 | 10,150 | 4,782 | 4·5 |
| 45 | 14·30 | 102·0 | 4,750 | 44·9 | 3,460 | 0·729 | 10,150 | 4,703 | 9·2 |
| 46 | 13·00 | 100·7 | 4,720 | 46·5 | 3,280 | 0·695 | 10,110 | 4,686 | 17·4 |
| 47 | 13·50 | 101·9 | 4,740 | 46·5 | 3,410 | 0·719 | 10,110 | 4,705 | 14·3 |
| 48 | 14·10 | 103·2 | 4,770 | 45·8 | 3,535 | 0·741 | 10,110 | 4,735 | 10·6 |
| 49 | 13·50 | 101·0 | 4,720 | — | 3,460 | 0·733 | 10,110 | 4,686 | 14·2 |
| 50 | 14·20 | 104·0 | 4,800 | 44·9 | 3,440 | 0·717 | 10,110 | 4,765 | 10·1 |
| 51 | 14·30 | 104·7 | 4,825 | 45·0 | 3,470 | 0·719 | 10,110 | 4,790 | 9·6 |
| 52 | 13·30 | 101·8 | 4,745 | 45·3 | 3,270 | 0·689 | 10,070 | 4,723 | 15·7 |
| 53 | 13·40 | 103·0 | 4,760 | 44·3 | 3,225 | 0·678 | 10,070 | 4,738 | 15·1 |
| 54 | 13·50 | 103·0 | 4,760 | 45·3 | 3,320 | 0·698 | 10,070 | 4,738 | 14·5 |
| 55 | 15·50 | 105·7 | 4,845 | 44·1 | 3,665 | 0·757 | 10,030 | 4,835 | 2·3 |
| 56 | 15·80 | 105·9 | 4,850 | 44·2 | 3,740 | 0·771 | 10,030 | 4,840 | 0·4 |
| 57 | 15·90 | 106·2 | 4,850 | 44·0 | 3,750 | 0·773 | 10,030 | 4,840 | −0·2 |
| 58 | 15·90 | 106·0 | 4,850 | 44·1 | 3,760 | 0·775 | 9,990 | 4,853 | −0·1 |
| 59 | 16·10 | 106·8 | 4,875 | 43·7 | 3,770 | 0·774 | 9,990 | 4,878 | −1·2 |
| 60 | 16·10 | 107·0 | 4,875 | 43·6 | 3,765 | 0·773 | 9,990 | 4,878 | −1·2 |

Trim by stern: varying from 6·0 ft. on October 12th to 5·2 ft. on October 21st.

## DISCUSSION

**Monsieur G. Dufour** (*M.I.N.A.*): I represent the owners of the *Lubumbashi* and this paper is therefore of particular interest to us.

Professor Aertssen, once again, went to sea with his instruments. He sometimes goes alone, sometimes with only a couple of assistants and, as you can see from the paper, he spares no pains in measuring everything that is measurable in the ship, under the ship, above the ship, and next to the ship. He has done this again with his usual care, accuracy, and scientific probity.

But Professor Aertssen is more than an efficient scientist. He is also a seaman and, as such, he is accepted by the ship's personnel. He has a way of interesting them in his instruments. His influence on them is lasting. Long after he has left the ship, the ship's officers and engineers continue, as far as is in their power, to keep as good records as they can.

Indeed, that is an important point to a shipowner: the wealth of data and curves which Professor Aertssen gives us in his papers are no doubt interesting; they give us a more accurate knowledge of the behaviour of our ships at sea. But no matter how many voyages Professor Aertssen is able to do, he can never be at sea all the time and in all the ships.

Therefore what he measures is inevitably a particular case, not an average. At best he is measuring accurately a few spots on a general pattern. If the shipowner can also rely on sufficiently well kept voyage records, he can in the long run get the general pattern.

I do not propose to discuss the results given here by Professor Aertssen, but I would like to mention the effect of surface deterioration. The measurements made by Professor Aertssen over a period of 26 months give an increase of total resistance by surface deterioration of 14 per cent (Fig. 16). The analysis of voyage results of the same ship over the same period gives us an increase of 12 per cent.

I am quite certain that the measurements taken by Professor Aertssen are the more accurate of the two, but it is encouraging to us to know that even from ordinary voyage result analysis we can arrive at a figure which is not so far off the scientific measurement.

But 14 per cent or even 12 per cent is a large figure. The *Lubumbashi* in that respect was a disappointment to us. We took the trouble to sandblast the hull in dry-dock before delivery and painted her with what we thought was the best available paint and yet very quickly there was a surface deterioration just as bad as on many older ships where no such care had been taken. She seems, however, to have settled down to that figure and it is not getting worse. The *Lubumbashi* is the first of a series of seven vessels and luckily she seems to be a particular case.

The second ship, the *Lubilash*, was sandblasted when new and painted in very good weather with a different paint from that used on *Lubumbashi*. After 18 months of service the surface deterioration tends to show only 4 per cent increase in total resistance.

The next vessel, the *Lufira*, was not sandblasted when new, but was painted in bad weather with the same paint as the *Lubilash*. The result here also after 18 months of service seems to be about 5 per cent.

Of course those figures are not accurate, and I will not draw conclusions from them. They are based on voyages subsequent to each dry-docking to eliminate as far as possible the effect of fouling, which means only three voyages for each ship. But, as time goes on, we might have sufficient data to be able to see (1) whether the sandblasting was really worth the expense, and (2) whether the second quality of paint was indeed better than the first one.

In conclusion, I think I might emphasize once more how important good paint and a good application of good paint really is to a shipowner. All the ingenious devices the engineer and the naval architect introduce to increase the propulsive efficiency of the vessel or to lower the fuel consumption can be spoiled by a bad coat of paint.

I thank Professor Aertssen very much for his paper and I hope he may be able to help us again later in such investigations as this.

**Mr. H. J. S. Canham** (*A.M.I.N.A.*): It is apparent from Professor Aertssen's work that the measurement of hull surface roughness by means of the pneumatic feeler has considerable advantages for new ships. A large number of readings can be taken in a short time, with an accuracy which appears to be quite acceptable for the size and type of roughness which is normally to be found on a new hull. Moreover, there is a satisfactory correlation between the average roughness given by this method at the first dry-docking of the *Lubumbashi* after six months in service and the Nikuradse sand roughness deduced from resistance coefficients obtained from pitot transverses taken shortly afterwards. Since this correlation was not obtained 19 months later when the roughness of the hull had increased considerably, this suggests that the dimensions of the pneumatic feeler might have an important influence. It would be interesting to learn whether Jorissen experimented with different types of feeler in order to obtain one which gave a satisfactory correlation over the range of roughness of new commercial pipes.

The B.S.R.A. has now obtained a considerable amount of hull surface roughness data and has found that the skew distribution shown in Fig. 10 is typical of a new ship. In order to assess the probable accuracy of the mean roughness value obtained from a set of records, a logarithmic transformation is applied to the data to obtain a satisfactory Gaussian distribution. The number of records taken on a hull by the B.S.R.A. is much less than that generally taken by Professor Aertssen on the *Lubumbashi*, but since each B.S.R.A. gauge record covers more surface, there is probably little difference in the total area of hull surface covered by each method.

The B.S.R.A. has not obtained nearly so much roughness data from ships in service, but examples have been found of frequency distributions similar to that shown in Fig. 11(*b*). The absence of any readings within certain ranges of roughness amplitudes was attributed to the smallness of the samples.

I note that Fig. 11(*a*) shows a few of the measurements taken in February 1956 coming within the range 32,000-34,000 microin., although it is stated that the maximum value obtained was 31,500 microin. This is a point of no great importance, however, because clearly the accuracy of the pneumatic feeler is very low in the region of high roughness amplitudes.

I think it is unwise to assume that the bottom of the *Lubumbashi* was rougher than the sides in October 1956. In one case within the experience of the B.S.R.A. the same average roughness was found on the flat bottom and sides of a ship which had been in service for about twelve months. In this particular case the side shell plating had been flame-cleaned before the initial painting, whilst the bottom had only been wire-brushed. In two cases where B.S.R.A. has measured roughness on a new ship and again after entering dry-dock after the first year in service, the average roughness had increased by 130 and 160 per cent respectively. After cleaning and re-painting the increase in average roughness was halved in each case. I note that the *Lubumbashi* showed an increase in roughness of 70 per cent after the first 6–7 months in service, but that after cleaning and re-painting the average roughness was only about 6 per cent above that for the new ship. The cleaning and re-painting must have been done very well indeed.

It is clear from the increase in power derived from the performance data and from the increase in resistance estimated from pitot transverses that the pneumatic feeler greatly overestimates the *effective* roughness of the hull in the later stages, since a tenfold increase in average roughness between July 1954 and

February 1956 is very considerable. The B.S.R.A. have roughness data for a 17-year-old ship recorded after cleaning and re-painting. The average roughness was four to five times the expected value for a new and well-painted hull. This result suggests that the rate of increase in roughness falls off significantly as the age of a vessel increases, and support is given to this view by the 3 per cent increase in total resistance during the third year's service of the *Lubumbashi*.

Figs. 16 and 17 show separately the effects of surface deterioration and fouling on total resistance. In my opinion they cannot be considered as separate effects. I believe that there is a tendency to underestimate the effectiveness of modern anti-fouling compositions. On the other hand, however well the anti-corrosive paint is applied, the painted hull surface is always liable to suffer damage from abrasion, and corrosion of the plating will start. Perhaps cathodic protection will help to overcome the problem of hull surface deterioration.

It is plain from Figs. 20 and 23 that the *Lubumbashi* is operated at constant power in service. One might question, therefore, the value of Figs. 21 and 22, showing the estimated increase in power at constant speed under the different weather conditions encountered. I believe that it is of greater practical importance to consider the loss of speed under constant power conditions, rather than to compare powers corresponding to good and bad weather conditions, at a speed which is actually attained in bad weather but which is significantly less than that attainable in fine weather at the same power.

I am encouraged by Fig. 16, which has an abscissa scale extending to 10 years, to hope that Professor Aertssen will be able to present further data for the *Lubumbashi* in the future.

**Mr. D. J. Doust, M.Sc.** (*A.M.I.N.A.*): The paper contains valuable information on many important aspects of ship research and of ship performance in service conditions. In this latter respect, it is interesting to note that the author's experience with propeller thrust measurement in waves above 15 ft. in height (approximately one-thirtieth of the wave-length) supports the conclusion reached from similar work on the model scale, that it is very difficult to obtain good quality thrust records for other than near calm water conditions.

In Section 5 of the paper it is stated that pitch and roll angles were taken on every occasion of a change in weather conditions or revolutions, these readings being obtained with a pendulum type recorder. It would be of value if the roll angles could be included in Tables I and II, as they give an indication of the interrelation of the ship's rolling motion with the pitch, for various headings of the vessel in relation to the prevailing wave front. A continuously recording gyroscope is of value in this respect, and has the virtue of being free from some of the possible sources of error met with in a pendulum type recorder.

Comparing these recorded pitch angles in Tables I and II with the maximum theoretical values of wave slope ($\pi h/L$) it would appear that they are approximately 50 per cent of this value in the worst sea and wind conditions, which indicate that even larger pitch angles would have been obtained in longer wave-lengths in the region 500–550 ft., where synchronism might be expected to occur. In view of the increase in power of 120 per cent shown in Fig. 21 at Beaufort scale 6–7, and the likelihood of this value being exceeded in longer and higher waves, one is prompted to examine the components which go to make up this figure and their respective magnitudes. These may be summarized as:—

(1) Increase in power due to wind resistance of the above-water form (approximately 15 per cent).
(2) Increase in power due to pitch, heave, and roll of the vessel (approximately 63 per cent).
(3) Increase in power due to fouling and surface deterioration of the hull surface (approximately 19 per cent for 26 months' service).
(4) Increase in power due to deterioration of the engine (say 5 per cent).
(5) Increase in power due to the inefficiency of the propeller in fluctuating non-axial flow conditions (approximately 18 per cent).
(6) Increase in power due to deterioration of the propeller blade surface (approximately 18 per cent).

This approximate assessment of the individual power losses in service conditions, partly dependent on the data presented in the paper, does emphasize that some 50 per cent of the total power losses are due to the motion of this vessel in conditions corresponding to Beaufort scale 6–7. Important reductions in the power losses in service conditions, with consequent increase in speed, are therefore most likely to result by reductions in ship motion. In the case of trawlers and small craft, where maximum pitch angles of 13 deg. have been recorded in Beaufort scale 9 conditions, some measure of success in reducing the pitching motion has been achieved by fitting a bulbous bow.

In Section 5 it is stated that there seems to be no appreciable difference between fully loaded and medium loaded condition in so far as the effect of weather on speed and propulsive efficiency are concerned. This would appear to be contrary to expectations, and not in accord with the data presented in Figs. 22 and 24. More particularly in the case of wind conditions where the wind direction is $\pm 30$ deg. from the bow, these diagrams show differences in percentage loss of speed up to 5 per cent in favour of the deeper condition of loading. In terms of power this amounts to some 20 per cent.

One difficulty which is met with more in the case of smaller vessels is the effect of the deterioration of the engine performance in service on the propeller revolutions. When the vessel goes on trial the power-revolutions relationship may be found to be quite satisfactory, but after a few years in service the propeller may be found incapable of attaining maximum *rpm*, and it is sometimes decided in advance to under-pitch the propeller on this account. With the vast amount of data for the *Lubumbashi* at the author's disposal, it would be interesting to know whether the graph of ihp versus measured horsepower at the torsionmeter shows any significant change as between the original trial results and the later observations obtained in service.

**Mr. J. F. Allan, D.Sc.** (*Member of Council I.N.A.*): This is a very interesting paper and I add my congratulations to Professor Aertssen. For a number of years I have had discussions with him on these subjects, and I am sure you will all agree when I express our appreciation of the effort he has put into this study. As Monsieur Dufour has indicated, it is to quite a considerable extent a personal effort on the part of Professor Aertssen. It is not just a question of sending a team to sea to get the answers; he goes to sea and works very hard to get the answers himself, and those who have had experience of that sort of thing will appreciate just what it means.

I appreciate the frank statement in the early part of the paper concerning the limits of accuracy of the various measurements which were made. This matter was discussed during the presentation of his previous paper, and we need not dwell on it. But it is important to bear in mind these limits of accuracy when looking at the paper generally; and the worse the weather, the greater is the spread we must expect in the data.

Some remarks have been made already on Figs. 16 and 17, showing the effects of surface deterioration and of fouling on total resistance, and I agree with Mr. Canham that it is rather a difficult matter to separate the effects of fouling from those of deterioration of surface in general. From what Monsieur Dufour has said, there was a kind of saturation in the effect of surface deterioration around 14 per cent increase of total resistance, but the curve in Fig. 16 does not indicate this.

The fairly reasonable agreement between the integration of the pitot traverse work and the power measurements and roughness measurements in the smaller sizes is to be noted, and it is very interesting to me personally because we are doing some similar work. As regards the greater roughnesses—and this point has been referred to by a previous speaker—there is some doubt about just how far the matter is one of disagreement between the deduced roughness and the measured roughness, and how far it is a question of the accuracy of the roughness measurements. I think that needs further examination.

Turning to the voyage analyses, the broad picture here is fully justified and is very interesting. The fact that in a moderate following sea one gets some advantage is known to most of us from experience and log analyses. I note with particular interest the increase of power figures of 29 and 37 per cent for the two Atlantic voyages. Those are increases due to weather conditions only; if we add at least 5 per cent for general deterioration and fouling we arrive at a figure of between 35 and 40 per cent, and that is of the same order as we would allow for such vessels in general service conditions. There is a tendency in some quarters to consider that allowances of that order are too large. I feel that the evidence produced in this paper supports the view that an allowance of the order of 35 per cent is necessary for services in the North Atlantic.

There is no mention that much rolling was experienced. The waves were about 450 ft. long, and it is perhaps a little surprising that during two fairly bad voyages in the North Atlantic the ship did not meet waves longer than that. A wave of 450–500 ft. length does not move a large liner at all, and yet liners experience quite a lot of pitching in the North Atlantic.

I was very interested in Monsieur Dufour's observation that to a first degree of accuracy there was agreement between log analyses and Professor Aertssen's analyses. Perhaps that suggests that the officers were pretty well trained in the job.

I can quite understand Monsieur Dufour's disappointment concerning the bad deterioration of the hull surfaces of the *Lubumbashi*, despite the trouble that was taken to sandblast the hull to obtain a good adhesion. This matter of protection is very important, and Mr. Canham's point about cathodic protection is one to which we should pay particular attention. The chemists assure me that there is no paint known which will prevent corrosion taking place under it in time, that the water will penetrate in time, and therefore there is bound to be deterioration of the surfaces eventually, no matter how carefully the steel has been cleaned to give a good adhesion. Probably the use of the cathodic type of protection will be necessary before deterioration of the surfaces can be prevented.

This is the third paper by Professor Aertssen, and we look forward to further contributions. We know he is doing some work on a different type of ship, and perhaps we may hope for a further paper in due course.

**Professor L. C. Burrill, M.Sc., Ph.D.** (*Member of Council, I.N.A., M.I.Mar.E.*): I, too, have followed Professor Aertssen's voyages with great interest. I think The Belgian Shipbuilding Research Association (CeBeReNa) are very fortunate in being able to find a person having his profound knowledge of the subject and his undoubted care in taking all these readings, who will go to sea for long periods at short notice. I cannot help wondering whether we could not do the same sort of thing in this country; it seems to me that a young research student, if we can get the right man, who would do the work really conscientiously, might render very useful service, not only for our benefit, but for his own, by going to sea and taking these voyage records in the same careful way and later presenting the results in the form of an analysis such as this.

I do not propose to say much about the skin friction and boundary layer work; others might well refer to that. In connection with the log analysis work, I would specially commend Fig. 21; the effects of weather from different directions are brought out very clearly here, and in some ways the figures are rather disturbing. There is, for the extreme cases, an increase of power of the order of some 120 per cent, and I can only think that these records are the results of really bad weather. But the diagram in Fig. 20 attracts my attention most of all, dealing as it does with the relation dhp-speed. This is typical of many diagrams I have obtained from the analysis of ship logs kept by the ships' personnel, and a diagram of this kind reveals a good deal of what is happening on the ships. It is quite evident, for example, that the engineers are trying to maintain, as far as possible, the full power of 5,000 dhp all the time and that this object is being defeated only to a very small extent, i.e. the falling off of power is quite small as between good conditions at sea, when they can maintain 15–15¼ knots, and very bad conditions, when they can maintain only 12 knots. It seems, therefore, that the main reason for the differences in performance is related to the heavier loading of the propeller, which occurs when there is bad weather.

I would not wish to criticize Professor Aertssen's work in any way, but I would like to see whether we can draw some further information from this diagram.

For instance, I would suggest to him that it would be very useful to analyse these results using the open water curves of the propeller to determine the analysis wake values in the different types of weather. From my experience, the torque wakes, even in conditions where the speed has fallen as low as 12 knots, should not vary very much from the similar analysis figures which are obtained at 15 or 15½ knots.

In these tests, Professor Aertssen has been able to do something we cannot do normally, he has measured the thrust horsepower under various conditions at sea, and I should like in particular to see what the relationship is between the ehp obtained in the tank and the ehp derived from his thrust measurements at different Beaufort numbers.

For example, ($ehp_n$ + 10 per cent) is frequently taken to represent good trial conditions and (ehp + 35 per cent) to represent average conditions at sea in moderate weather. How do these values fit in with the ehp values derived from the thrust records?

Furthermore if, for instance, the analysis of the results do not show consistent wake fractions when analysed on the thrust identity principle but do give consistent values when analysed on the basis of torque (or $K_Q$) identity, we should learn something more about the working of the propeller.

In relation to the usual open water $K_T$ (or $K_Q$) $-$ J diagram the propeller is normally designed to work at a point on the efficiency curve which lies only slightly to the left of the peak of the efficiency curve, but in bad weather or heavy slip conditions it develops more power at given revolutions and is, therefore, forced to work at a point higher up the slope of the $K_Q$ curve (i.e. further to the left in the usual open-water diagram) where the efficiency is considerably lower than was originally intended. The figure of 18 per cent loss in efficiency which is quoted by Professor Aertssen is at first sight difficult to account for by this change alone. I therefore suggest to Professor Aertssen that a useful extension of the analysis would be to try to explain the performance of the propeller alone in terms of its position of working on the open water diagram, and I think he will be delighted with the results he obtains. When he mentions a loss of 18 per cent, he is of course comparing the (ehp/dhp) he obtains in bad weather conditions with the figure obtained in calm weather conditions at a different speed of advance.

This seems to me to be a little harsh. For example, he compares his figure of 0·67 with 0·79 and I feel that this exaggerates the loss in efficiency.

Finally, Monsieur Dufour's most excellent comments on the manner in which Professor Aertssen and the shipowners have co-operated in this research tempt me to ask for just a little more. If, for example, he can allow Professor Aertssen to run one of these ships for two or three hours at a lower speed, say 12 or 13 knots, in both good and bad weather conditions, it may be possible to obtain the necessary spots to fill in the diagram shown in Fig. 23, and thus complete the history of the performance of the ship at different Beaufort numbers.

**Professor E. V. Telfer, D.Sc., Ph.D.** (*Vice-President I.N.A.*): Like previous speakers I am delighted to welcome Professor Aertssen back amongst us and once more to thank him for the data he is wresting from the sea on our behalf.

I find Figs. 16 and 17 very interesting. They clearly show that increase in resistance whether due to surface deterioration or fouling is not a linear function with time, but appears initially to increase quite rapidly, and later continues only to increase at an increasingly slower rate. This shows that any statistical analysis of fouling using the assumption of a linear increase is likely to be invalid; and such an analysis can only be accepted when the fouling-time function is much more closely approximated. The danger here is, of course, that errors in this function are thrown on to the effects of other variables and then successfully cloud the general issue.

Fig. 18 is also very interesting and very informative, but it should not be interpreted in the light of the Prandtl–Schlichting sharp roughness behaviour. The behaviour indicated is undoubtedly that of undulant roughness For example, spots 3 and 4, both for the same hull condition, are contradictory on a Prandtl–Schlichting basis, but are what one would expect of undulant roughness, the higher Reynolds' number of 4 producing a lower specific resistance. The other spots, with the exception of 6, also conform to undulant roughness. Spot 1 should be regarded as showing that the smooth Prandtl–Schlichting line is too high and that the Schoenherr *and other lines of less magnitude* are not disproved. Actually, as even the new surface cannot be entirely smooth, spot 1 really suggests that the Schoenherr line is also somewhat high. Spot 6 is a puzzle, and as Professor Aertssen finds this marked drop in value to be typical of measurements made in the afterbody, some fundamental explanation must be sought. Tests on the model boat, *D. C. Endert*, might throw some light on the matter. Some tests by Professor Nordstrom in which he measured the separate aft and fore end resistances of a specially constructed model may also prove enlightening. These tests showed that the aft end resistance could be materially less than the nominal frictional resistance. Professor Aertssen's tests appear to suggest a sampling of the same phenomenon. There is a field of research here which should pay excellent dividends.

I am very sorry to note that the author continues to present his weather data in terms of the traditional Beaufort number. His diagrams, Figs. 21 to 25, clearly show that the weather losses do not increase linearly with Beaufort number, but at a much higher rate. As only linear or known relations are really suitable for statistical treatment and as direct measurements were made of relative wind velocity it is far simpler and more enlightening to divide percentage speed loss (or power increase) by relative wind velocity squared and to plot these factors to a base of relative wind angle. This would enable a single curve to replace the author's presentation or alternatively would allow of additional curves being added to separate wind from sea influence. I hope that Professor Aertssen may be able to follow up these suggestions.

**Mr. B. N. Baxter, M.Sc.** (*M.I.N.A.*): I would like to congratulate Professor Aertssen on the enormous amount of information that he has made available to students of naval architecture and marine engineering.

I am particularly interested in the values shown in Tables I and II, which give the relationship between the heights and lengths of waves.

Considering only those waves which are formed when the weather is classified as very rough, the mean ratio of height to length is found to be 1 to 28. This is far removed from the standard L/20 wave used in strength calculations. A wave height formula, based mainly on the results of the *Ocean Vulcan* trials, is:—

$$h = 21 \cdot 5 \left(1 \cdot 0 - e^{-\frac{L}{200}}\right) + \frac{L}{33}$$

where $h$ = 90 per cent of the maximum possible wave height; and L = length of wave.

Using this formula and averaging the results obtained, gives a ratio of height to length of 1 to 13·2. This result indicates that the heights of the waves observed on the *Lubumbashi* trials are considerably smaller than those predicted by the *Ocean Vulcan* formula.

So much information has been given in the paper that I hesitate to suggest that there should be more. In future trials, I wonder if it would be possible to fit a statistical strain gauge? Such a gauge would record how often a particular stress was reached, and how many times some predetermined minimum stress was exceeded. Fortunately, no readings need be analysed during the voyage, but the final results would be of great importance in relating the stress, and hence the bending moment, to known wave conditions.

**Commander Peter Du Cane, O.B.E., R.N.** (*M.I.N.A.*): While not a matter of overriding importance in relation to the information sought after in this paper, I would like to confirm the remarks of Dr. Allan and Professor Telfer in relation to the matter of the presentation of the weather and sea state data.

Beaufort scale for wind velocity is by its definition somewhat approximate in relation to the actual velocity of the wind at any given time.

It is, of course, the sea state which is of importance and it may be conceded that the method of measuring wave height as observed on the ship's side is not altogether satisfactory. To consider the limit case an infinitely small vessel in an infinitely large sea as regards height and distance apart of wave crests would indicate no height difference on the ship's side.

Some method such as that developed by the Institute of Oceanographical Research (Tucker, M. J., "A Shipborne Wave Recorder," TRANS. I.N.A., 1956, p. 236) might be considered. Here vertical accelerations are measured and integrated twice to give velocity and displacement.

May I also suggest that it would be interesting to measure angle of yaw, especially in following sea conditions, as the non-axial flow arising under heavy yawing conditions might well be the cause of unexplained loss of efficiency at the propeller. To a lesser extent this would apply to pitching also.

### Written Contributions to the Discussion

**Professor A. M. Robb, D.Sc.** (*Vice-President I.N.A.*): Professor Aertssen has, with his usual generosity, provided a wealth of information, and the pictorial presentation of the records of dhp on Figs. 20 and 23 is very valuable. It may, however, be permissible to raise the question whether the lower portions of these diagrams, and the associated curve in Fig. 25, indicate valid conclusions. According to record No. 56 in Table III, a speed of 11·80 knots was obtained in heavy weather with 4,795 dhp, whereas according to Fig. 20 the same speed was obtained in calm weather with 2,110 dhp, this figure being derived by extrapolation of the upper curve. The corresponding increase of power because of heavy weather is 127 per cent. According to the analysis the value of ehp in the heavy weather was 3,125, whereas in calm weather it was about 2,100 × 0·79, namely 1,670. Accordingly the percentage increase in ehp was about 87 per cent. Record No. 36 in Table IV shows that a speed of 14·50 knots was obtained in moderate weather with 4,749 dhp and, according to Fig. 23, obtained in calm weather with 3,400 dhp. The percentage increase of power because of weather conditions is nearly 40. In Table IV the figure given for ehp at sea is 3,515, whereas according to Fig. 23 the ehp in calm weather should be 3,400 × 0·775, namely 2,635. The percentage increase because of the weather conditions is about 33. Other figures in the records agree with these in the indication that from two-thirds to three-fourths of the total increase of power required in moderate and heavy weather is explained by increased resistance, with only the lesser part of the increase explained by deterioration in propeller performance. The indication is, however, a consequence of the initial assumption that the thrust-deduction factor at sea is the same as that derived from model experiments in smooth water. Is Professor Aertssen satisfied that the initial assumption is valid? Unfortunately, there does not seem to be any better assumption readily available. There is, however, a disturbing thought suggested by Figs. 20 and 23—the thought that after rather less than three years in service the speed of a ship can deteriorate by about one-half to three-fourths of a knot.

It seems desirable also to raise some questions and comments on the deductions from the plottings of the pitot traverses. Is Professor Aertssen satisfied that integration of the loss of momentum in the boundary layer is a valid method of determining frictional resistance when the motion is turbulent; does the method really take into account the additional energy associated with the turbulence? This question may, or may not, have an association with the results presented in the table at the bottom of p. 512. In that table Professor Aertssen compares the results obtained from the pitot traverses with figures from the Schoenherr line. Is such a comparison valid? It has been suggested elsewhere that the Schoenherr line has no real validity since it stems from results of experiments on pipes which were subjected to a mathematical treatment that is open to suspicion. Apart from that consideration there is the fact that in order to obtain figures for use in estimates of power it was found necessary to increase all Schoenherr figures for ships by 0·0004. With that addition to the values given in the penultimate column of the table—the percentage increase ranges from 22½ at the top to nearly 25 at the bottom—the Schoenherr figures as commonly used all lie well above the figures derived from the pitot traverses. Has Professor Aertssen any explanation of the seeming anomaly that the figures derived from the traverses are all appreciably less than figures which have been associated with good trial conditions?

There is a final consideration. It is a generally accepted assumption that there is no slipping between a real fluid and a body with which it is in contact. Is Professor Aertssen satisfied that velocity curves of the character shown in Figs. 13, 14, and 15 justify unquestioning acceptance of the assumption?

**Ir. A. J. W. Lap** (*M.I.N.A.*): Everybody concerned with full-scale experiments on board ship knows how many difficulties must be overcome before such experiments may lead to reasonable results. Professor Aertssen is to be congratulated in having collected a number of useful experimental results to form the basis of the present paper. No doubt many shipowners will take advantage of the conclusion that can be drawn from it, i.e. that it pays to keep the hull surface in as good a condition as possible. Both corrosion and fouling may raise the total of the fuel bill in a greater degree than is generally realized.

There are a few details which are not completely clear. Probably Professor Aertssen will be able to give some further information. In the first place, Professor Aertssen has tried to account for the fact that the measured roughness of the ship was higher when she was painted in February 1956 than eight months later, by remarking that in October 1956 only measurements were made between light and loaded waterline. It is possible indeed that the bottom of the ship was rougher than the sides. However, the roughness of 21,550 microin. of February 1956 was found as a mean value of 396 readings. Could Professor Aertssen disclose the mean roughness of those readings out of the 396 that were taken between the light and loaded waterlines? Probably these values can throw some light on the problem if they are compared to the readings of October 1956.

Professor Aertssen had the courage to convert the results of his pitot traverses into resistance coefficients, which makes them much easier to handle and to compare. He will certainly agree that not too much value may be attached to the absolute values of these coefficients. For this reason they cannot give much support to an extrapolation line or method, which is suggested by the author.

The bad correlation between the roughness data and the Prandtl–Schlichting diagram may be explained by the fact that the roughness pattern of the hull surface has hydrodynamic characteristics which are completely different from those of Nikuradse's sand roughness pattern. Even if the absolute values of the resistance coefficients were beyond all doubt, a good correlation with Nikuradse's sand roughness could not be expected.

These remarks are certainly not meant as criticism. On the contrary, it is hoped that they may contribute to encourage Professor Aertssen (if this is necessary) to follow the *Lubumbashi* on her further voyages and to let us share in the further interesting results he will certainly find in future.

**Professor Edward V. Lewis** (*M.I.N.A.*): This discussion applies to only one aspect of the subject of weather effects.

It is of interest to note in Figs. 20 and 23 that bad weather does not have much effect on the *rpm* and power of this ship. It is stated in the paper that the 6,000 bhp main engine operated at 5,100–5,400 bhp in fine weather (106 *rpm*) and that power dropped nearly 6 per cent in a very rough sea in Beaufort scale 7 (95 *rpm*). This comparatively small power reduction is in strong contrast to that experienced by higher-powered vessels, such as the 8,500-shp Victory ship (AP-3) of about the same size and fullness as the *Lubumbashi*. Victory data* show small speed reductions so long as weather is good, but in head seas corresponding to Beaufort force 4 and 5 considerable reductions of power and hence speed must be made to avoid shipping seas and slamming. At Beaufort 6 and 7 power and speed were reduced to about the same values or less than *Lubumbashi*.

It is believed that the present tendency to increase the speed of merchant ships has put the problem of powering in a new light, at least for rough weather services such as the North Atlantic. It is no longer possible simply to add a reasonable percentage to trial shp to insure that a desired average sea speed can be maintained, for speed in rough seas is often determined by the hull characteristics rather than by the available power. A percentage power margin which would enable *Lubumbashi* to maintain an average sea speed of, say, 15·0 knots would be far from adequate to give a Victory ship 16½ knots in the same service.

It is to be hoped, therefore, that valuable studies such as this one of Professor Aertssen will be extended to higher-powered vessels, and that the relationship between weather and speed will be given special attention.

* LEWIS, E. V., and MORRISON, M.: "Preliminary Analysis of Moore-McCormack Log Data," *International Shipbuilding Progress, Rotterdam*, Vol. 2, No. 7, 1955.

**Mr. T. W. Longmuir** (*Chairman of Council, I.Mar.E.*): I thank you, Mr. Chairman, for giving me the opportunity to express our thanks to Professor Aertssen for his paper. When I read it my mind went back to the years 1911–12–13, when I served in a ship running between Antwerp and New York; and I do think that, apart from the value of this paper, Professor Aertssen is to be congratulated on the fact that he is a good sailor. His desire for knowledge must have many times overcome his physical anguish. He is to be congratulated on a notable contribution of a practical nature.

I suggest that if Professor Burrill does decide to carry out his excellent idea of sending one of his young men to sea to make similar observations, the fortunate person should first make two winter voyages across the North Atlantic in a 3,000-ton ship and so condition himself to emulate the pioneer work of Professor Aertssen.

### Author's Reply

The author is much indebted to Monsieur Dufour, General Manager of the Compagnie Maritime Belge, for his incessant encouragement. His remarks on the performance of the sister-ships of the *Lubumbashi* complete the author's work. It is very interesting to learn that the analysis of log data showed an increase of resistance, after 26 months' service, of 12 per cent. The 14 per cent of Fig. 16 is to be related to a speed of 14·8 knots, while for a speed of 15·3 knots and 5,000 hp the increase of total resistance is 12 per cent. These percentages are deduced from power measurements (Fig. 20). As 5,000 hp are developed usually, more value is to be given to the figure of 12 per cent than to the figure of 14 per cent, and it is remarkable that the shipowner got these highly accurate figures of performance only from log data.

The comparison between the performances of the various Lu-ships is another point of interest. Sandblasting is only part of the programme of protecting the ship's hull against corrosion. There are many implications in the problem of protecting the ship's plating, and it would be very helpful could the ship-owners discover the reason of the different behaviour of the hull of the *Lubumbashi* and her sister-ships.

The author is very interested to learn from Mr. Canham that B.S.R.A. got for new ships a skew distribution of the surface roughness similar to the distribution of Fig. 10, and for ships in service distributions similar to that shown in Fig. 11(*b*). The maximum roughness of 31,500 microin. calls for an explanation. This maximum was indeed 31,500 or 32,000 microin. (800 micron). This reading 800 micron was obtained several times. Now the accuracy of measurement is so poor in the region of high roughnesses that the observer cannot guarantee the correctness of these readings of 800 micron, but can only certify that the roughness is somewhere between 30,000 and 34,000 microin. That is why in the frequency curve of Fig. 11(*a*) the readings of 800 microin are exceptionally spread over the widened range 30,000–34,000 microin. So finally, we find in this curve a few readings within the range 32,000–34,000 microin.

The effect of the big roughness of the hull in the later stages is overestimated by the pneumatic feeler, and what is appropriately called "effective roughness" by Mr. Canham is much less than the actual height of the asperities. It is confirmed by B.S.R.A. experience on an old ship that the effect of the increase of roughness falls off as the age of the vessel increases: this conclusion is valid as well for the effect of surface deterioration as for the effect of fouling. Surface deterioration is what remains after cleaning and painting in dry-dock: the effect of this deterioration as compared with the surface of the newly-built ship can be measured on the first voyage following the dry-docking. The effect of fouling is just to be added to the effect of surface deterioration. This effect of fouling is certainly less than is generally believed and often the effectiveness of modern anti-fouling paint is indeed underestimated.

The author agrees with Mr. Doust that a gyro pitch and roll recorder would have given more accurate information on ship motions than a recorder of the pendulum type. It must be emphasized, however, that a study of ship motions was not the subject of this *Lubumbashi*-work. Roll, unless it is heavy, does not deteriorate the propulsive efficiency of a ship, and that is why only the pitch angles were given in the paper. It may be interesting to mention for the February voyage in loaded condition the roll angles, where from out to out they exceed 20 deg.: observ. Nos. 24 and 25, 20 deg.; No. 28, 28 deg.; No. 51, 23 deg. The author's opinion is that these roll angles did not influence strongly the propulsive qualities of the ship.

It would be hazardous to draw conclusions from a comparison of Fig. 22 and 24 in favour of one of the draught conditions of the *Lubumbashi*, fully loaded or medium loaded. Only for a wind strength Beaufort 6 there seems to be a difference of 5 per cent in favour of the deeper loading condition, but that part of the curve I in medium loaded condition is not defined by a great number of observations.

In his final remarks Mr. Doust focuses attention on the deterioration of the engine performance, which together with the deterioration of the hull is a reason of the propeller not being capable after a few years of attaining the maximum *rpm*. From a comparison of the power-speed curves the first and the third year's service of the *Lubumbashi*, one readily concludes that this ship especially suffers from this *rpm* and power loss. Under-pitching of the propeller does not seem to be the solution. For a series of ships of the Compagnie Maritime Belge a solution was found in a later stage of the ship's life in supercharging the motors and in removing the hull's deterioration by sand-blasting.

It is a comfort to me to have the encouraging remarks of Dr. Allan. It is quite clear that the rate of increase of the hull's surface deterioration falls off significantly year after year, as stated by Mr. Canham, but from the three years' propulsion data one cannot draw any conclusion regarding the saturation of this deterioration.

The measurement of roughness in the later stage is poor indeed, but the disagreement between measured roughness and what Mr. Canham calls the "effective roughness" is so large that the probable large error is not the only explanation. There is, as was mentioned in the paper, no inconsistency between the average height on the photographs and the readings with the pneumatic feeler.

The author agrees with Dr. Allan that an allowance of the order of 35 per cent, for weather effect and fouling, is necessary for services in the North Atlantic. Weather effect is perhaps less, fouling effect perhaps more than his figures, but altogether an allowance of at least 35 per cent should be considered for the North Atlantic.

The waves, indeed, were not longer than 470 ft. during these winter voyages. It is interesting to note that the pitching was not heavy, even on this 446 ft. long cargo ship. On waves of 470 ft. the pitch angle out to out was 7 deg. Big liners would not have experienced considerable pitching in this sea.

Prof. Burrill and Prof. Lewis both draw attention to the remarkable constancy of power, which from 5,100–5,400 bhp in fine weather, dropped no more than 6 per cent in a very rough sea Beaufort 7. Because of the increase of wind resistance, of ship motions in waves and of a loss of efficiency due to the heavier loading of the propeller, the ship's speed in loaded condition dropped from 15¼ to 12 knots. As Professor Lewis pointed out, a high-powered vessel as the Victory-ship (AP 3) of nearly the same deadweight, facing a sea Beaufort 6–7, has to reduce power and speed to about the same values. It is indeed of considerable interest to give the relationship power—speed—

weather special attention. The author, making this investigation on several Belgian cargo ships of usual dimensions where power had not to be reduced in a sea Beaufort 6, came to the fascinating statement that all the considered cargo ships when plotted in the diagram $V/\sqrt{L}$, $\Delta/(L/100)^3$ of Lewis* gives spots which are on a straight line. This line might well give the limit of power for usual cargo ships in a head sea Beaufort 6.†

The suggestion of Professor Burrill to make a further analysis of wake on a basis of torque and thrust identity, and to place the position of working of the propeller in order to explain the big loss of performance in bad weather is attractive indeed and is being examined. The 18 per cent loss in efficiency in bad weather is related to a constant speed, 11 to 12 knots. The loss would be much less, about 14 per cent, if related to a constant power about 4,800 dhp.

Thrust measurements, indeed, enable one to establish the allowances at sea on the thrust derived by model tests. The allowance in still air deduced from the measured mile trials (Froude prediction) is $-5 \cdot 5$ per cent for 15 knots, $-3 \cdot 0$ per cent for 16 knots. This means, practically, that no allowance has to be added to the ship prediction (Froude law of comparison and Froude friction coefficients). It must be said that the hull of the *Lubumbashi*, as shown by roughness measurements as well as by pitot traverses, was remarkably smooth.

On the other hand, the allowance at sea in moderate weather, say Beaufort 4, is established at nearly 20 per cent.

Professor Telfer draws attention to the distribution of the frictional resistance coefficients deduced from the pitot traverses in the roughness diagram, Fig. 18. Apart from spot 6 there seems to be a more or less constant roughness allowance on the Schoenherr line for a given fouling of the hull. Spot 1 refers to the newly-built ship with no roughness allowance: 3 and 4 are on a line parallel to the Schoenherr line and relate to a clean hull 6 months old with an allowance $\Delta C_f = 0 \cdot 0002$; 5 and 7 give another allowance $\Delta C_f = 0 \cdot 00045$ for the clean hull 26 months old. Altogether there is more roughness allowance $\Delta C_f$ on the Schoenherr line for a given hull condition than an agreement with the equivalent sand roughness lines of Nikuradse.

Spot 7 obtained from $C_3$ gives a $\Delta C_f$ which is negative and as Professor Telfer says, the interaction between pressure variation and friction momentum might explain the low frictional resistance coefficients which have been found in the after body, not only of this ship, but also of a big tanker.

Professor Robb and Mr. Lap have objections against resistance coefficients deduced from the analysis of pitot traverses: there is indeed a certain lack of accuracy of measurements at sea and there is further the mathematically difficult interpretation of the pressure variation along the ship body. But Professor Robb will agree that the old allowance $\Delta C_f = 0 \cdot 0004$ on the Schoenherr line has long since been defeated in fully welded ships, and Mr. Lap will remark that the allowances given by Fig. 18 (spot 6 left apart perhaps) are in line with correlation data for several modern ships. The allowances are somewhat low indeed for this particular ship and the pressure variation might be responsible for it.

* LEWIS: "The Sea Speed of Cargo Ships in Rough Weather Services," *International Shipbuilding Progress, Rotterdam*, Vol. 3, No. 22, 1956.

† AERTSSEN: "The Effect of Weather on the Performance of Ships," *Symposium on the Behaviour of Ships in a Seaway*, Wageningen, September, 1957.

Professor Robb raises the question of the slipping of the water on the hull surface. It is the author's conviction there is no slipping, but it is very difficult to obtain the correct shape of the velocity curve in the vicinity of the surface because:

(i) the oscillations of the pitot readings are important, due to the ship motions;

(ii) the speed variations are important even for a very small distance variation.

Mean velocity curves on a big scale are reproduced, as they were obtained in the surface vicinity for C1 and C2 after a year's service, for C3 after two years' service (Fig. 26).

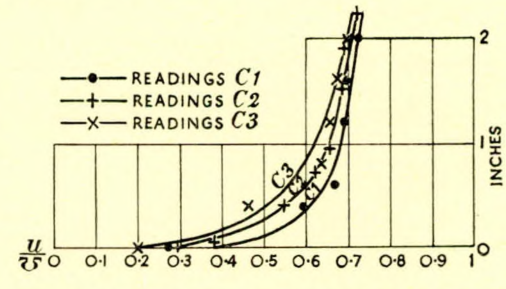



FIG. 26.—VELOCITY DISTRIBUTION CLOSE TO SURFACE

Mr. Baxter raises the question of the height of waves. The wave height is indeed very difficult to appreciate, and in the case of the *Lubumbashi* was estimated in comparison with the height of the plate strakes on ship's side. This method includes, indeed, an error as pointed out by Commander Peter du Cane, because heaving of the ship is not taken in consideration. The shipborne wave recorder certainly gives more accurate data for the wave dimensions; it has been installed successfully on weather ships, but no experience has been gained until now from cargo ships equipped with this instrument. Research work is in hand with this instrument in different countries which will enrich our knowledge on propulsion and ship motions.

A statistical strain gauge would have been of not much use, because no stress investigations were made on the *Lubumbashi*.

Although the big part of power increase due to weather is explained by resistance increase, still a large part of the increase is explained by loss of propulsive efficiency. Regarding record 56, Table III, Professor Robb agrees that it is dangerous to extrapolate the lower parts of Fig. 20 to obtain dhp at $11 \cdot 8$ knots in calm weather. The loss of propulsive efficiency so obtained is very important indeed. It must be emphasized that for this observation the waves were 15 ft. high and that, as stated in the introduction of this study, thrust is not measurable in waves higher than 15 ft.

In order to throw more light on the comparison of the voyages of February and October, 1956, Mr. Lap asked for a separate figure for the roughness between load and light waterline in February, 1956: the mean roughness, taken over 163 readings, was 21,400 microin. The alarming aspect of the comparison is the large difference of displacements. The displacement in October was no more than 10,000 tons and the dhp curve newly-built ship had to be reduced from 14,192 to 10,000 tons, which means overbridging a large gap.

The author highly appreciates the encouraging words of Mr. Longmuir and thanks all who have added to the value of this work by their contributions.

# INSTITUTE ACTIVITIES

**Minutes of Proceedings of the Meeting Held at the Institute on Thursday, 28th March 1957**

The 1957 Lloyd's Register Lecture for Juniors was held at the Institute on Thursday, 28th March 1957 at 5.30 p.m., when a paper entitled "An Introduction to Nuclear Power", by P. T. Fletcher, B.Sc.(Eng.), M.I.C.E., M.I.Mech.E., M.I.E.E.,* was presented. Rear-Admiral F. E. Clemiston, C.B., (ret.) (Vice-Chairman of Council) was in the Chair and 136 junior and senior members were present.

The author was introduced by Mr. H. N. Pemberton, Chief Engineer Surveyor of Lloyd's Register of Shipping (Member of Council), who also explained the nature of the meeting and the purpose of Lloyd's Register in bringing students to London from ports throughout the country on this annual occasion.

Eleven students asked questions relating to the paper, which were answered fully by the author, and a final contribution to the discussion was made by Rear-Admiral G. A. M. Wilson (Rear-Admiral Nuclear Propulsion).

A vote of thanks to the author was proposed by the Chairman and enthusiastically accorded. The meeting ended at 7.40 p.m.

*Lloyd's Register of Shipping Award*

The twenty-three students who were invited by Lloyd's Register of Shipping to take part in a two-day visit to London on 28th/29th March 1957, which included attendance at the Lecture given by Mr. Fletcher and a visit to Harwell, subsequently wrote essays describing their experiences. Prizes for the best of these essays are being awarded by Lloyd's Register as follows:

A first prize of twenty-five guineas to R. H. Chadburn of North Shields and a second prize of ten guineas to D. Reid of Glasgow. In addition, it has been decided to present to Mr. Chadburn and Mr. Reid copies of the book entitled "Marine Steam Boilers" by J. H. Milton (Member) and copies of this book are also being given to M. P. Williams, J. N. Vincent, B. S. Stott and C. R. Willoughby, whose essays were considered to be next in order of merit.

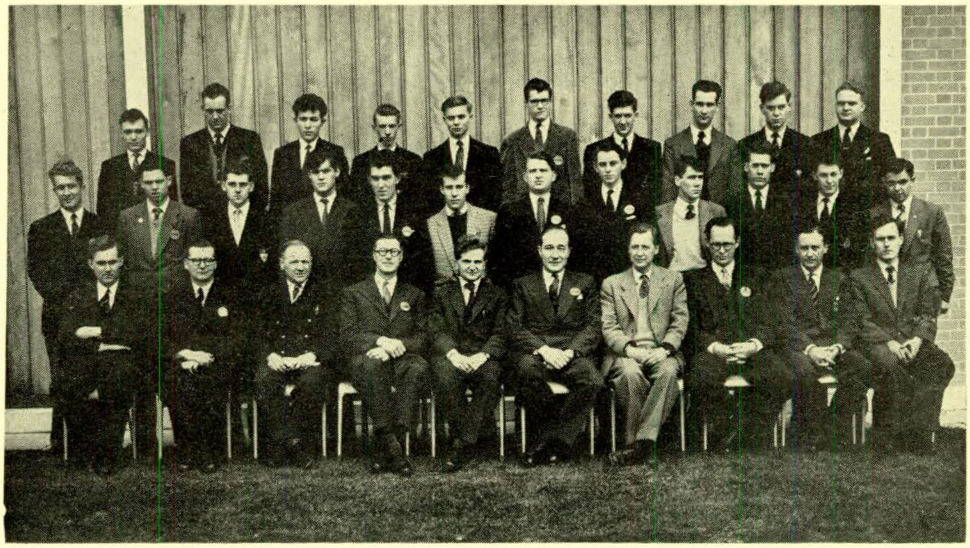
* Published, with the discussion and author's reply, in the Journal of the Joint Panel on Nuclear Marine Propulsion, October 1957, Number 2, pp. 29-46.

**Election of Members**

*Elected 14th October 1957*

MEMBERS

Donald T. Adams, Capt., U.S.C.G.
Robert Geoffrey Anderson
Arthur Edward Baldwin
Robert Newton Cairns
Leonard Albert Charles Cantellow
Thomas Egerton Collier
Alan Wilfred Mervyn Collyer, Lieut.-Cdr., R.N.(ret.)
Sydney Shaw Dixon
John Lisle Foster, Lieut.-Cdr., R.N.
Allan Edward Franklin
Alexander Davidson Fraser
Valere Goemaere
Jack Ernest Hills, Lieut., R.N.
John Howden
Percy William Maynard Jacobs, Lieut.-Cdr., R.N.
David Bell King
Douglas Hatton Lamb
Pughe Davies Lewis, Cdr., D.S.C., R.N.



*Visit of students to Harwell*

John Ernest Morison
Evan Roger Morse
Charles Rigby Newbould
Romolo Panetti
Leo Peterson
Thomas James Lough Renwick, M.B.E.
George Stedman
David Marshall Steel
Leslie John Swayne, Lieut.-Cdr., R.N.
Clement William Walton
Reynolds Caple Wilson
Wilhelmus Zipp

ASSOCIATE MEMBERS

Robert Anthony Babington
William George Callister
Arthur Leslie Candy, Lieut.(E), R.C.N.
Charles Leslie Cheffings, Eng. Lieut., R.N.
Grahame Stanley Cole
James Duncan Davidson
Leslie Davison
Joseph Lawrence Debono
Eric Dinnett
Geoffrey James Morris Evans
Alfred John Keys Ford
Brian Stanley Haddleton
Neil Charles Humphries
Edwin Frank Isaacs
Sidney James Murray Joseph, Eng. Lieut., R.N.
Stanley Killip
Harold John Knights
Jack Sheridan Low
Stanford Alan Ludlow
John MacKenzie MacDonald
William Crawford McGuire
Ronald Edward Mackenzie
Gordon James Dundas Main
Thomas Arthur Mogg
David William Morrell, Lieut., R.N.
Ramalinga Muthukrishnan
Jan Neumann, B.Sc.(Eng.) (London)
Robert William Nickisson
Percival James Padget
Hariprasad Gokalbhai Patel
Ronald Pearson
Herbert Thomas Phillips
Stanley Frederick Rogers
John Turner Shearer
Ronald Wilson Soutter
Arthur Brian Thomas
James Marshall Thomson
William West

ASSOCIATES

Michael Augustine Fitzgerald
Mieczyslaw Kazimierz Hanzewniak
Samuel Kowarski
Boris Saric
Dudley Stewart

GRADUATES

Dinshaw Dhunjishah Bottlewalla
Geoffrey George Carlton
George Cartwright
Godfrey Reginald Dias
Leslie Thompson Dixon
John Straughan Donaldson
Ian David Hay
Lawrence Reginald Frederick House
Jean Le Mee
Iqbal Akhter Mirza
John Strachan
Edward Arthur Thomas
Archie James Webster
George Raymond Wilkins

STUDENTS

James Walter Baldry
Peter George Barrett
George Ian Buchanan, B.Sc.(Durham)
Peter Richard Longley
Michael David Nettell
G. H. Sloss
Geoffrey Michael Stephenson
David Swaysland

PROBATIONER STUDENTS

Edgar Ashworth
Roger Leonard Biddle
Anthony Stephen Botes
Ian Malcolm Calder
Hugh A. Comley
Henry Peter Cooke
John Cooper
James Edward Cornford
John Anthony Creecy
Peter George Duffield
John Arthur Faber
John Robert Gerring
Richard Frederick John Goodey
Michael Frederick Hatt
David Jeckells
Terence Leonard Jones
Lynn Lewis
Roderick James McGinness
Brian Robert Morris
Victor Arthur Nash
William John George Noble
George Douglas Ralph
Michael John Sewell
George Stuart Smith
Robert John Smith
Dennis William Stokes
Andrew John Tappin
Gerald Malcolm Corlvin Taylor
Derek Bryan Wyatt

TRANSFER FROM ASSOCIATE MEMBER TO MEMBER

Denis Knowles
Peter Emerson Melly, Cdr., R.N.

TRANSFER FROM ASSOCIATE TO MEMBER

Douglas Hamilton Cameron, Lieut., R.N.
Walter Percy Noble

TRANSFER FROM ASSOCIATE TO ASSOCIATE MEMBER

John Benney Burdon
Austin James Campbell
Alexander Clapham

TRANSFER FROM GRADUATE TO ASSOCIATE MEMBER

Sydney Charles Burns
Blethyn Charles Morgan
Dara Kaikshroo Parakh

TRANSFER FROM PROBATIONER STUDENT TO STUDENT

John Keith Baker
Robert Edward Mason

# OBITUARY

Leslie Horton Busby (Member 11401) was born in New Zealand in 1899. He served an apprenticeship from 1916/21 with A. and T. Burt, Ltd., Auckland, and then spent fifteen years in steamships of Canadian National Steamships, Ltd., as fourth to chief engineer, obtaining a First Class Steam Certificate in 1926. After a year with the Manz Line as second engineer, he was employed by the Imperial Oil Shipping Company in their motor ships *Ontariolite* and *Beaconoil*, serving in the first as junior to chief engineer and in the second as chief engineer until 1940. For two years he was an engineer surveyor with the British Corporation Register of Shipping and Aircraft and engineer overseer for the British Admiralty Technical Mission in Canada. From 1946/49 he was technical adviser to Marine Industries, Ltd., Sorel, P.Q., and from then until his death on 6th July 1957 engineering draughtsman with H. G. Acres and Company, consulting engineers at Niagara Falls, Ontario.

Mr. Busby was elected to Membership in 1947.

William Edward Harris, M.B.E., D.S.C. (Member 11373) joined H.M.S. *Indus* in 1915 as a boy artificer and served in cruisers, destroyers and submarines from 1919/44. He was awarded a D.S.C. and Bar. At the end of the second World War he served for two years as Naval technical liaison officer, first to the Canadian Army and then to the British Army of the Rhine. In 1945 he was promoted Lieutenant(E) and from 1946/49, when he retired from the Royal Navy, he was engineer officer (submarines) at Londonderry.

Lieut. Harris was appointed in August 1949 to take charge of all the services in the radiochemical laboratory of the Atomic Energy Research Establishment at Harwell and his work in this department earned him the M.B.E. award. His association with the development of frogmen techniques for the handling of radio-active materials was a natural extension of his experience as a deep sea diver. Just before his sudden death on 31st July 1957, while on holiday with his wife and family, Lieut. Harris had been promoted senior engineer in the Engineering Services Division at Harwell. He had been associated with the Institute since 1947, first having been elected an Associate, then transferred to the grade of Member in 1948.

Hugh Henry Lee (Associate Member 13121) died, aged twenty-eight years, when the 75-ft. tug, the *Clearwater*, of which he was chief engineer, sank in Lake Athabasca, Saskatchewan, with the loss of all hands. The cause of this disaster could not be precisely determined as the last radio message from the tug did not mention any difficulties and there was no report of storms in the area at the time. Search planes found only floating wreckage, empty life preservers and three drifting barges.

Mr. Lee served an apprenticeship at the L.M.S. Railway Workshops, Derby, from 1943/48, and then joined the Anglo-Saxon Petroleum Co., Ltd.; in 1953 he obtained a First Class Ministry of Transport Motor Certificate. He then went to Hong Kong where he joined Jardine, Matheson and Co., Ltd., and spent some months sailing the China Seas and visiting Malaya, Borneo, New Guinea and Australia. In 1954 he joined the Western Australian Government Shipping Service in Perth and sailed up the West Coast of Australia, visiting all ports from Perth to Darwin. He returned home in 1955 and visited Spanish ports in the service of MacAndrews and Co., Ltd. In March 1956, however, he decided to go to Canada and again for a short period sailed coastwise from Vancouver with the Canadian Pacific Railway Shipping Service before signing on for his last appointment with the Northern Transportation Company of Edmonton, Alberta.

Mr. Lee was elected an Associate of the Institute in 1950, being transferred to the grade of Associate Member in 1955. He was also a Member of the Canadian Institute of Marine Engineers.

Robert Gerald McPherson (Member 11935) was born in 1900. He served an apprenticeship in London from 1917/20 with Burdick and Company, Victoria Docks, and with the North Eastern Marine Engineering Co., Ltd., Wallsend, from 1920/21. For the next nine years he sailed as junior to senior third engineer with the Shaw, Savill and Albion Co., Ltd., obtaining a First Class Board of Trade Steam Certificate in 1927 and a Motor Endorsement in 1929. He then spent a year as second engineer in ships owned by Lawther, Latta and Co., Ltd. In 1932 he came ashore to take an appointment as fitter with the London County Council. In 1950 Mr. McPherson was appointed regional engineer to the Eastern Regional Hospital Board, which was responsible for a district covering Angus, Perthshire and Kinross. He died in November 1956.

Mr. McPherson was a Member of the Institution of Hospital Engineers and had been a Member of the Institute since 1948.

James Martin Maid (Member 10757) served an apprenticeship with Palmer's Shipbuilding and Iron Works, Jarrow-on-Tyne, from 1902/06. He then went to sea and had about eight years' sea service in foreign going vessels; he obtained a First Class Board of Trade Certificate in 1910. From 1916/21 he was superintendent engineer to the Rome and National Steam Shipping Companies, London, and for the following eight years practised as a consulting engineer and marine surveyor in London and Northumberland. For five years during the second World War Mr. Maid was a chief engineer at sea with John I. Jacobs and Co., Ltd., and from 1945/55 he was superintendent engineer to the company. On his retirement he worked on his own account as a consulting engineer in Newcastle on Tyne until his death on 3rd August 1957. Mr. Maid was first elected to Membership of the Institute in 1921 and continued his association except for a lapse of eight years which covered the period of the 1939/45 war.

Percy R. Owens (Member 10887) was apprenticed to Cammell Laird and Co., Ltd., Birkenhead, from 1910/15, and then served as seagoing engineer with various companies until 1934. He obtained a First Class Steam Board of Trade Certificate in 1927. In 1937 he was appointed a mechanical fitter in the electricity generating station of the County Borough of West Ham and was promoted general foreman in 1946, when he was also elected a Member of the Institute. He died, aged seventy-two, on 25th April 1956.