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Experiences and results of the ship routeing of the Royal Netherlands Meteorological Institute (KNMI)

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Experiences and results of the ship routeing office of the Royal Netherlands Meteorological Institute (K.N.M.I.).

by C.G. Korevaar

Summary.

Since 1960 an increasing number of ships has been routed by the Royal Netherlands Meteorological Institute. This report deals with the result on several routes across the North Atlantic Ocean during the period August 1969 - August 1974. Distinction has been made between westbound and eastbound voyages, winter and summer season, different types of ships and between different speed classes. Some results are also given on a monthly basis. Next to saving of time it is shown that there are other benefits of weather routeing such as less risk of damage to ship and cargo, more comfort for passengers and crew, a better ability to meet schedule and a better estimation of the time of arrival.

Introduction.

Over the past twenty years there has been an increasing interest in the marine forecasting service called ship routeing or weather routeing of ships. The main goal of weather routeing is to assist ship masters in selecting a route on which the passage time and the risk of weather damage to ship and cargo is kept to a minimum under the existing and anticipated weather conditions. This route is called the optimum track.

Before the time of ship routeing masters, when making transoceanic crossings in the Northern Hemisphere, in general chose a northern route in the summer and shifted to a more southerly route in the stormy winter months, adding hundreds of nautical miles to the voyage across the ocean.

One might call this climatic navigation, where the route is selected in consideration of the average climatic conditions during the particular season. These are found in climatic atlases or marine handbooks and are referred to as standard or seasonal tracks.

This choice on climatic grounds served the purpose of avoiding the worst gales, but at a great cost in time and money because of the increased distance travelled, the more because sometimes the real sea conditions are better along the out-of-season route than along the one in use. The reason for this is that the weather is not static as the climatic atlases would seem to indicate, with areas of high winds and waves centered off Iceland and areas of low waves found off Bermuda. On the contrary, weather is dynamic and complex with depressions following a wide variety of paths at various speeds. Intensity, size and movements of these depressions change from day to day, and a route that was ideal to day may be dangerous tomorrow.

Modern ship routeing is based on medium to long-range prediction of the environment. The route is selected after evaluation of present depression tracks and the forecast positions of the depression centres. This approach is an improvement over the climatic track, assuming that the deviation of the weather from normal is correctly predicted.

The performance of a ship at sea.

A forecaster who has to advise a route to a master of a ship must have some knowledge about the performance of the ship at sea. The most important factors which affect the speed of a ship are wind, waves and currents. The effect of ocean currents on the propulsion of a ship is relatively uncomplicated when compared to the multitude of actions and reactions caused by wind and waves. The movement of a ship when acted upon by currents can be found by adding the two vectors representing the ship's velocity and the set and drift of the water current respectively. The problem however is not how currents affect ship's motion, but which current can be expected at a particular location at a specified time. Many shipmasters use monthly climatic current charts to ascertain this information. However, the velocities of the currents as reported on climatic charts are only averages. The propability of a ship encountering the same current at a specified area in the ocean on two different occasions is very small. Any given direction is rarely persistent. So they seldom match the synoptic situation.

However, under some routeing situations currents can be of value, for example in making the final choice between several routes that are of equal merit on the basis of wind and wave conditions alone. Utilization of currents can also be made when a planned route is adjacent to the axis of a major current for some time. For instance, ships proceeding from the Gulf of Mexico to Canadian or European ports, can follow the axis of the Gulfstream for some distance.

However, even with such a strong ever present current one must be careful. Surveys of the Gulfstream have shown a basic variability in the movement of the core of the waterflow. The main stream meanders a great deal and lateral movements of over 11 miles per day can occur.

The effects of wind and waves can hardly be described separately because in practice they act together. There is almost never just wind and no waves. Because as soon a wind starts to blow, waves are built up by this wind. Compared with the wind the waves have the greatest influence on ship's speed, not only because of the change of the skin resistance due to the increased ship surface immersed in the water and the change of the resistance due to the modification of the ship's own induced wave, but especially due to the effect of the ships motions such as pitching and rolling and other associated motions of the ship. Often the master has to reduce power to avoid the adverse effects of violent ship motions, such as shifting cargo, shipping of water, pounding and slamming on ship plates, racing of propeller and discomfort and danger to the crew and passengers.

Model tests and theory have learnt that rolling does not cause appreciable reduction in speed. However at sea often speed is reduced voluntarily to ease the motion to avoid the danger of shifting cargo and the considerable discomfort and hazard to crew and passengers with excessive roll.

The most important motions of the ship in regard to their effect on ship performance appear to be pitching and the associated motion of heaving. If the master maintains the proper ship speed the ship will incur no damage, but if that speed is exceeded, than the ship will either pound on top of oncoming seas or dive into them. Tests and experience both show the desirability of keeping the pitch period and period of encounter as different as possible. When they are the same or nearly the same the largest pitch angles occur, and the greatest increase in resistance is experienced. Slowing down changes the period of encounter, and thus a speed reduction is common when heavy pitching occurs.

When a ship is to be routed it would be ideal if the master could give data about the loss of speed in different wave conditions. But the experience of the Dutch routeing office is that masters are almost never able to give this information. Therefore, to have a more exact estimate of the performance in waves, for each ship that is routed by the Dutch routeing office a ship's speed characteristic is made. To construct such characteristics use is made of the ship's fixes and the wave heights encountered by the ship according to the wave charts. The speed of the ship under different wave conditions is put on a graph. For each wave height a different graph is taken. Figure 1 is an example for a certain type of ship (freighter, 18 knots, 7300 BRT) in wave heights of 3 - 3.5 metres. As the figure shows the speed of a ship at a certain angle of the waves with the course of the ship is not unique. The scattering of the points must be ascribed to several factors. First there is the range of opinions between masters as to when to decrease speed. Each master will decide at a different value of wave height or degree of pitching for which he reduces power to ease the ship off. Thus at a given wave height ten different ships of the same type are likely to make ten different speeds.

Another factor which affects the ship's speed is the condition of the ship bottom: whether it is freshly cleaned and painted or covered with barnacles. The magnitude of this factor is unknown but it may be considerable. Another reason is that there is a variety of wave periods (lengths) possible at a given wave height. Strictly spoken difference should be made between periods too. Further there is the possibility of crossed seas, which cannot be expressed on the graphs.

So the curve drawn through the points on the graph represents a mean performance of the ship, which can be different in each individual case.

Head seas have the largest effect on ship's speed as one would expect, while with an increasing angle between ship and waves this reduction gradually decreases. With following waves, at least at the lower heights (figure 2) one even sees a slight increase in speed.

At larger wave heights the curves are not closed anymore. The reason for this is that under high beam waves the master decides to change course to avoid heavy rolling of the ship. In this case he has two possibilities. Either be brings his ship with the head on the waves or he chooses for following waves. This choice will mostly depend on how the port of destination is situated with respect to the ship's position.

The method of ship routeing applied by the Dutch routeing office.

Ideal for ship routeing would be if one could dispose of reliable prognostic wave charts for a total ocean crossing, i.e. for 6 - 10 days ahead on the North Atlantic. The procedure to be followed in this case would then be to construct the least time route with the help of a series of time fronts by using the prognostic wave charts and the speed graphs of the routed ship. Unfortunately present day forecasting skill permits only prognostic wave charts for 3 days at the very limit.

As at most ship routeing services the further recommendations are based on a so called storm pattern technique (James, 1970). The storm (depression) tracks are determined by means of recent history of the storm together with the upper air flow pattern as predicted for the 500 mbar level. Basic to this practice is that surface systems are steered and governed by this 500 mbar flow pattern. Once the movement and relative intensities of the storms are established a ship route is selected. The actual route selection is a subjective choice depending on the router's experience and the requirements of the shipowner or master. In some cases it is simply a choice between passing north or south of the British Isles, in other cases a decision as to the persistence of a blocking high pressure area or a cut-off low pressure centre must be made. Storm paths are often well to the north. In such cases dependent on the port of departure often the greatcircle route can be sailed. At times however the storm path moves south. Then on a westbound crossing from Europe it is mostly advisable to choose a more southerly route. Always one must weigh the time loss made by the detour against the gain of time by sailing in lower waves. If the storm path moves more south it can be that a northerly route becomes more economic because of the lesser detour. This choice may be a gamble that won't pay off if the storm track returns to the more northerly position. Then the problem arises as to where the ship intersects the storm track to divert south. Timing is of an essence here and the faster ships have an advantage because they can divert more rapidly.

Heavy weather is somtimes unavoidable. Intense storms near the departure point or the destination cannot be avoided except by a late departure or by slowing down. This has be done in the case of very heavy weather or with ships loaded with very vulnerable cargo.

The best routeing results are obtained when the flow pattern of the 500 mbar level is more or less persistent. In some cases there is no clear-cut route owing to complex, transitional changes in the weather patterns. In such cases a recommendation is made to initially follow a strategic track for the first few days until the weather situation is clarified. Such a track must be chosen that, if necessary, a timely deviation both to the north and to the south can be made. So it can occur that the first advise is steaming toward an approaching storm until it is clear whether the best track is to the south or to the north.

Ship routeing based on a storm pattern approach is successful because exact predictions are not required in order to favour one route over another. It is more a relative decision, regarding north or south tracks for instance, without attempting the absolute optimum track. Such tracks will only be realised when accurate long range forecasts are available.

Also in a lot of cases it does not matter so very much if a storm intensifies more than expected. When for example a detour has been advised south of the predicted 4 metre wave height contour with a wave height of 7 metres in the maximum, while in reality the ship passes through for example 6 metre high waves while the wave height in the maximum has become 10 metres, then the ship yet stays in relative lower waves in which it can make a better speed. In such a case the advised route can still be close to the least-time track.

Results of the Netherlands routeing office for the years 1969-1974.

In close co-operation with the Holland-America Line the Royal Netherlands Meteorological Institute (KNMI) started in 1960 routeing two ships of this company on an experimental basis. In view of the encouraging results the number of ships co-operating in the routeing programme was extended in the course of the following years to the whole freighter-fleet of the Holland America Line for all North-Atlantic routes, while in the meantime also a number of other companies joined the routeing service.

Now yearly more than 700 ships from about 20 companies are receiving routeing advices from KNMI. The routeing activity of KNMI is limited to the North Atlantic Ocean. The following results are those obtained during a period of five years: from August 1969 to August 1974.

Working out the results distinction was made between two seasons. For the "winter" season the period 15 August - 15 April was chosen and for the "summer" season the period 15 April - 15 August.

Because of the difference in length between the various routes and because of the differences in position with respect to the tracks of depressions the following routes have been distinguished:

1. Europe - Caribbean Sea
2. Europe - Gulf of Mexico
3. Europe - Bermuda
4. Europe - Eastcoast of United States south of Cape Hatteras (ports of Brunswick, Savannah, Charleston, Wilmington, Morehead City)
5. Europe - Eastcoast of United States and Canada from Cape Hatteras to Nova Scotia (ports of Baltimore, Norfolk, Philadelphia, New York, Boston, Portland, Saint John, Halifax)
6. Europe - St. Lawrence River.

A survey of the ocean legs (greatcircles) of the most important routes is given in figure 4.

The results have been calculated both for westbound and for eastbound voyages, except for the route Europe-Bermuda, where the number of eastbound routeings was too small.

1.1. Europe-Caribbean Sea.

The greater number of routed ships from Europe to the Caribbean Sea are tankers bound for Curaçao and freighters bound for Cristobal in order to pass through the Panama Canal. The shortest route to Curaçao is a greatcircle route via Sombrero Island and to Cristobal a greatcircle via the Mona Passage (figure 4). The second half of these routes lies usually well south of the depression paths. Heavy weather is largely restricted to the first half. For a great part the good routeing results must be ascribed to this fact because a good forecast for the first few days of the route is often enough to pilot the ship to a position from which the further route goes through a climatological quiet area of the ocean. Only in exceptional cases a deviation to the north of the greatcircle route has to be advised.

The results have been compared with those which would have been obtained along the greatcircle and the rhumbline.

1.1.1. Mean time differences and detours with respect to the greatcircle routes.

In table 1.1.1. the travel time difference with a plus sign means gain of time, a minus sign means loss of time with respect to the greatcircle. The table can be interpreted as follows. For example on the route from Bishop Rock to the Mona Passage 32 freighters (first line of the table) with a speed equal or less than 18 knots have been routed during the winter season. If it had been possible to follow always the least-time track an average gain with respect to the greatcircle of 11.5 hours would have been obtained. On the advised route 9.7 hours (of the possible 11.5 hours) were gained with respect to the greatcircle and 9.7 - 8.7 = 1.0 hour (of the possible 11.5 - 8.7 = 2.8 hours) with respect to the rhumbline. The advised route has a mean detour of 65 nautical miles (= 4.1 hours at an average speed of 16 knots). A gain of time in spite of this detour means 9.7 + 4.1 = 13.8 hours less delay due to waves than on the greatcircle. The meaning of this is a decreased chance of damage to ship and/or cargo. It is very difficult however to express this benefit in figures.

For the tankers on the routes from Bishop Rock to Sombrero and from Fastnet to Sombrero a subdivision has been made into four different speed classes with a range of one knot and for freighters in two classes, namely equal or less than 18 knots and more than 18 knots. In spite of the general opinion that a large speed is favourable for weather routeing because of a shortening of the relative long duration of a crossing with respect to the relative short range (48 - 72 hours) for which reliable forecasts are available, the table shows in general better results for the slower ships, not only in an absolute sense but also in a relative sense, when compared with the total voyage durations (table 1.1.2.). Although the faster ships are able to perform an advised deviation of the greatcircle route more easily and so avoid unfavourable wave conditions, the slower ships obviously often have longer profit of a deviation once recommended

When the different routes from Europe to the Caribbean Sea are compared with each other it appears that the best results have been obtained on routes from northern European ports. For example on the route from Skaw (Skagerrak) to Sombrero even an average of 16.6 hours of the possible 17.7 hours was gained with respect to the greatcircle route (north of Scotland) and 16.6 - 3.3 = 13.3 hours were gained with respect to the rhumbline. The advised route has a mean detour of 187 nautical miles (= 12.5 hours with an average speed of 15 knots). A gain of time of 16.6 hours in spite of this detour means 16.6 + 12.5 = 29.1 hours less delay due to waves than on the greatcircle.

A special aspect of this route is that a choice must be made between sailing north or south of the British Isles. If there are unfavourable wave fields on the northern route then notwithstanding the detour of about 10 hours a considerable gain of time can be obtained by sailing through the relatively quiet North Sea and English Channel.

During the summer season no tankers, but only general cargo ships and fruitships have been routed. Although modest, the results are nevertheless positive (gains in the order of 0.5 - 1.1 hours with respect to the greatcircle). Moreover it is clear that in summer time the rhumbline gives mostly loss of time with respect to the greatcircle.

Table 1.1.1. gives the mean results for five years. The results however may vary considerably from year to year. For example the 307 winter routeings of tankers (all speeds) from Bishop Rock and Fastnet to the Caribbean Sea show an average gain of time with respect to the greatcircle of 6.1 hours while for the individual years (for the seasons 1969 - 1970 up to 1973 - 1974) these results are respectively 2.7, 5.6, 4.5, 5.2 and 11.7 hours, always about one hour less than the possible gain of the least-time tracks. The possible gain is determined by the prevailing circulation and its characteristic weather and wave conditions along the shipping routes. So in January 1974 the prevailing circulation was characterized by a southern west circulation with a continuous series of deep depressions during 25 of the 31 days. The 16 tankers crossing in that month and in the first half of February were all advised to follow a southern route via Terceira (one of the Azores) or even still more south. In this way they avoided the successive high wave fields (several times higher than 10 metres) along the greatcircle route. The total gain of time of these 16 routeings amounted to 459 hours, which is about 29 hours on

the average. Without these 16 routes the average gain in that season would have been about 7 hours, which comes very near to the normal time gains.

That this "favourable" situation for weather routeing is an exception appears from a study in which for each day of a period of ten years the circulation type was determined. A number of 25 days in one month with such a southern west circulation only occurred in January 1974. The average number of days per month (December, January, February) with such a circulation was 7. The next highest numbers per month of 19 and 15 days with this circulation occurred in January 1962 and January 1965. Also in these periods this resulted in large gains of time. Only it was not so evident in these months because there were not yet so much routed voyages in the years 1962 and 1965.

In the foregoing the results have been considered for the two seasons "winter" and "summer". The graphs in figures 5 (freighters) and 6 (tankers) are giving the results per month. As is shown by these graphs there is a considerable difference between the individual months. In January routeing appears to be most fruitful. The 20 routeings of freighters during that month resulted in an average gain of 14.1 hours with respect to the greatcircle, while the 34 crossings of tankers resulted in an even higher average gain of 15.9 hours. From January to May the time-gains gradually diminish. During the summer months they range from 0.1 to 0.6 hours, while from August onwards they increase again.

Not all routeings were successful. Of a total of 505 routeings during the winter season to the Caribbean Sea about 70% had a positive result and about 8% a negative result. In about 22% of the cases there was neither gain nor loss of time, which means that the difference between the advised route and the greatcircle was less than half an hour. This does not mean however that routeing in these cases had no profit at all. In many of these cases (28) the advised route did not coincide with the greatcircle (the shortest route in distance), but the ship arrived in spite of a detour at the same time as it would have arrived on the greatcircle. This means that on the advised route the wave conditions were more favourable and that for this reason the risk of damage was less.

During the summer season about 37% of the routeings had a positive result, about 15% a negative result and in about 48% of the cases there was neither gain nor loss.

From the total of 505 routeings during the winter season in 116 of the possible 133 cases a gain of time of 10 hours or more was realized. The maximum gain of time realized in one crossing was 70 hours.

In general the average detour of the route was a little more than that of the least time. This can, especially for the summer season, partly explain the difference in mean time between the advised route and the least time, which ranges from 0.5 to 1.8 hours. These differences could be made smaller by an improvement of the routeing advices,However such an improvement can only be expected when the range of reliable weather forecasts becomes of the same order as the time needed for an ocean crossing. Until that time it will always be necessary to advise such a route which is strategic in view of possible changes in the weather developments after the first two days of a crossing, assuming that the forecasts for the first two days are correct. Inherent to this system is an unavoidable margin in time between the advised route and the least time, which will be very hard to reduce.

1.1.2. Mean duration of voyages and the standard deviation with respect to this mean duration.

Table 1.1.2. gives the mean durations of the advised routes (their ocean legs) as well as the mean durations for the fictitious cases that the ships would have followed always the least time track, the greatcircle or the rhumbline.The standard deviations (in whole hours) are given between brackets. The duration of a voyage depends on the still water speed of the ship and the reduction of that speed due to weather and wave conditions, etc.. The standard deviations have been calculated in order to get an impression of the regularity in sailing time which is important with a view to time schedules.

To get an idea about the possible differences in voyage-time due to weather and wave conditions a subdivision has been made into four speed classes with a range of one knot for tankers on the routes Bishop Rock - Sombrero and Fastnet - Sombrero.

It can be assumed that the distribution of voyage-durations is a normal distribution. Such a distribution is completely determined by the mean value and the standard deviation. The standard deviation is a measure of the dispersion of the individual values around the mean value. In a normal distribution 68.2% (about 2/3) of the distribution lies less than one times the standard deviation away from the mean, 95.4% of the distribution lies less than two times the standard deviation away from the mean. So the smaller the standard deviation the more regular are the ships sailing.

On the route from Bishop Rock to Sombrero for example there were 76 routeings of tankers with a speed range of 14.5 - 15.4 knots (6th line of table 1.1.2.). On the advised route the mean duration was 225.8 hours with a standard deviation of 12 hours. This means that 68.2% of the voyage durations lies in the interval 213.8 - 237.8 hours and 95.4% in the interval 201.8 - 249.8 hours. On the greatcircle route the mean duration would have been 230.5 hours with a standard deviation of 15 hours. This means that if the ships had always sailed along the greatcircle route they would have lost 4.7 hours on the average with respect to the advised route, but also that the spreading in voyage durations would have been larger. On the least time route the standard deviation is a little smaller (11) and along the rhumbline a little larger (13) than on the advised route. If we look to all figures in the table then we see that this is a normal phenomenon. So this table reveals another benefit of weather routeing, namely a more regular sailing.

The only way of demonstrating this is to compare the travel time of routed ships with those that would have been obtained on fixed routes, such as the greatcircle. It would be interesting if these results could be compared with the results of the same types of ships which did not use routeing advices and where the masters had to choose their own route.

The spreading of the travel times in the past, when there were only sailing vessels was very large. The coming of engine-driven ships and later the coming of better navigation systems must have given a large improvement. Now a further improvement has been achieved by weather routeing.

1.1.3. Time spent in higher waves.

Table 1.1.3. gives the mean number of hours per voyage with adverse waves equal to or higher than 6 metres in the "winter season" and equal to or higher than 4 metres in the "summer season". The numbers of hours with following waves equal to or higher than 6 metres (winter) or 4 metres (summer) are given between brackets. For example the 307 routeings of tankers (all speeds) from Bishop Rock and Fastnet to the Caribbean Sea (line 13 of table 1.1.3.) show that on an average along the advised route during 1.5 hours adverse waves equal to or higher than 6 metres have been met.

Along the greatcircle this would have been 5.3 hours and along the rhumbline 3.2 hours. The number of hours spent in following waves ≥ 6 metres, which have less influence on the speed of a ship, are of about the same order along the various routes.

In general it can be concluded that the time spent in higher adverse waves on the advised route is considerably less than on the greatcircle and rhumbline, which is a confirmation of the conclusion in section 1.1.1., nemely that of a decreased chance of damage to ship and/or cargo along the advised route.

Routeing with the purpose of achieving a least time crossing has at the same time the effect of less risk of damage and more comfort for crew and passengers. On the least time route the mean number of hours with adverse waves ≥ 6 metres (1.1 hours in the above mentioned 307 cases) is still less than on the advised route (1.5 hours), but it is not reduced to zero. In these cases the least time route mostly avoids even higher wave-fields, but there are also cases in which high wave-fields are inevitable, for example if a high wave-field exists at the entrance of the English Channel at the time of departure. The only way of avoiding this is waiting in the English Channel for better conditions. In practice this is seldom done because of the loss of time involved. Only in cases in which ships have a very vulnerable deck-cargo and when time does not matter this sometimes occurs.

During the summer season waves of 6 metres or higher seldom occur. Therefore for these months the number of hours with waves ≥ 4 metres has been given. The table (1.1.3.) shows that also in this season the time spent in higher wave-fields is reduced by routeing.

Next to the division in a "winter" and a "summer" season data are given for the "winter" season (August - April) alone. The figures 7 (freighters) and 8 (tankers) are giving the mean number of hours spent in adverse waves ≥ 6 metres per month along the advised routes and the mean number of hours with adverse waves ≥ 6 metres that would have been met if always the great-circle route would have been followed. There is a great difference between the individual months. Waves with a height equal to or more than 6 metres are most frequent in the real winter months December, January and February with a peak in January and are least frequent in August and September. As the figures show a great part of adverse waves ≥ 6 metres has been avoided by routeing. For example for tankers in January the mean time spent in adverse waves ≥ 6 metres was 8.9 hours on the advised routes, while on the greatcircle this would have been 26.6 hours. For freighters these numbers are respectively 4.8 and 15.4 hours.

1.2. Caribbean Sea - Europe.

1.2.1. Mean time differences and detours with respect to the greatcircle route.

In table 1.2.1 again distinction has been made between "winter" and "summer", between different routes, between freighters, fruitships and tankers and some subdivisions have been made in different speed classes as in table 1.1.1.. The real time-gains as well as the possible time-gains with respect to the greatcircle are much smaller than for westbound voyages. This is caused by the fact that, when eastbound, following waves are dominating, which do not have so much influence on the speed of a ship.

The 340 routeings of tankers from the Caribbean Sea to Bishop Rock and Fastnet (line 12 of table 1.2.1) show for example a mean gain of 1.0 hour of the possible gain of 2.0 hours. The rhumbline however looses on the average 2.5 hours with respect to the greatcircle and 2.5 + 1.0 = 3.5 hours with respect to the advised route. This loss is caused mainly by the detour in distance of the rhumbline.

When the different routes from the Caribbean Sea to Europe are compared with each other it appears that the best results can be obtained on routes to northern European ports. So the route to Teesport on the Eastcoast of England shows a mean gain of 8.7 hours of the possible 10.4 hours. The shortest route is north of Scotland, but from the 10 ships on this route 7 were advised to sail through the quiet waters of the English Channel, so avoiding unfavourable wave conditions on the northern route. Also on the route to Skaw (Skagerrak) a larger than usual gain (4.9 hours on an average) was possible. However because of one unsuccessful route through the English Channel only 2.0 hours were gained.

The results on eastbound routes do not vary very much from year to year. The graphs in figures 9 (freighters) and 10 (tankers) are giving the results per month.

The best results (2-3 hours time-gain for tankers) occurred in the months December and January. In the summer months the time-gains are so small that about the same results would have been obtained if always the greatcircle would have been advised.

Of a total of 543 routeings from the Caribbean Sea to Europe during the winter season about 30% had a positive and about 6% a negative result.

In about 64% of the cases there was neither gain nor loss of time. This again does not mean however that routeing in these cases had no profit at all. In 43 of those cases the advised route did not coincide with the greatcircle. To arrive at the same time there must have been better wave conditions along the advised route.

During the summer season about 6% of the routeings had a positive and about 4% a negative result and in about 90% there was neither again nor loss.

From the total of 543 crossings during the winter season in 13 of the 26 possible cases a gain of time of 10 hours or more was realized. The maximum gain of time realized in one crossing was 31 hours.

1.2.2. Mean duration of voyages and the standard deviation with respect to this mean duration.

From the data in table 1.2.2 it can be concluded that on eastbound voyages from the Caribbean Sea to Europe routeing does not result in a more regular sailing than if always the greatcircle or the rhumbline would have been followed. Because of the fact that on eastbound voyages following waves, which have much less influence on the speed of a ship than head waves, are dominating, the time-differences between the various routes are of a more constant character.

1.2.3. Time spent in higher waves.

With respect to the time spent in higher waves (table 1.2.3) the differences between the various routes are small. For example the 340 routeings of tankers (all speeds) from the Caribbean Sea to Bishop Rock or Fastnet show an average of 0.8 hours with adverse and 3.0 hours with following waves $\geqslant$ 6 metres per ocean crossing. Along the greatcircle these numbers would have been 1.1 and 4.0 hours and along the rhumbline 0.8 and 2.6 hours. So the mean wave conditions along the greatcircle route are less favourable, but not so much to allow large gains in time with respect to the greatcircle.

2. Europe - Gulf of Mexico, vice versa.

Because of the Gulfstream the fastest route (without waves) from the English Channel is not the direct greatcircle route to Abaco, but a route consisting of two greatcircle legs via the point 37°N, 57°W (K-route) is considered as the fastest one. The results have been compared with this route. The K-route passes through the area between Nova Scotia and Bermuda with a relative high storm frequency. After this the route goes through an area of low storm frequency, characterized by the often occurring so called Bermuda high. The route to Abaco offers good possibilities for deviations as well to the north as to the south of the K-route. For the second part of the ocean crossing use can be made of the shelter offered by the American Eastcoast or of the Bermuda high. If this high is present deviations to the south during the first part of the crossing are attractive, because they are not followed by new delays on the second part. If the high is not present then deviations to the north during the first part have no drawbacks for the second part of the crossing. The ample possibilities for route deviations are shown clearly in the good results obtained along this route.

Eastbound the route via the axis of the Gulfstream and 42°N, 50°W (on the C-track) has been considered as the shortest route. The results are those compared with this route. When high northerly or northwesterly wavefields occur then it is possible to make use of the lee offered by the American coast without making a great detour.

2.1. Mean time differences and detours with respect to the K-route (westbound) and the Combined Gulfstream C-track (eastbound).

Distinction has been made (table 2.1) between the results obtained with tankers and with freighters. The number of crossings on this route is too small to make distinction between different speed classes.

Table 2.1 shows for example that the 57 westbound routed freighters during the winter season had an average time gain of 10.4 (of the possible 12.9) hours with respect to the K-route and of 10.4 - 4.5 = 5.9 hours (of the possible 12.9 - 4.5 = 8.4 hours) with respect to the rhumbline. The advised route had a mean detour of 126 nautical miles (= 7.9 hours at an average speed of 16 knots). A gain in time of 10.4 hours in spite of this detour means 10.4 + 7.9 = 18.3 hours less delay due to waves than on the K-route, which must mean a considerable decrease of the risk of damage.

The 73 eastbound routed freighters in the winter season had an average gain of 1.7 of the possible 3.8 hours with respect to the combined Gulfstream C-track. During the summer season the mean time gains were westbound 0.4 hours (of the possible 1.5 hours). On eastbound voyages only a mean gain of 0.3 hours would have been possible. In this case the results of routeing are the same as those obtained when always the combined Gulfstream C-track would have been followed.

When the results are compared for each year separately then it appears that on westbound routes just as on the route to the Caribbean Sea the season 1973-1974 gives the best results, which is again due to the southern Westcirculation in January and February of that season.

The graphs in figures 11 (westbound) and 12 (eastbound) are showing the results per month. Especially for westbound voyages there exists a considerable difference between the individual months with the best results in December and January. The 13 routeings in January even show a mean gain of 23.3 hours. The mean time gain in December was 15.5 hours. The mean time gains in the other months are much less, ranging from 3.9 to 7.5 hours from February to April and from 1.3 to 3.7 hours from September to November. During May, June and July the results are zero or even slightly negative.

For eastbound voyages there is not so much difference between the individual months. In general a mean gain of 2-3 hours has been obtained in the winter months, except a mean loss of 3.6 hours in October. This is caused by the fact that one of the five routeings in October was a failure with a loss of 21 hours on the advised route. To avoid higher northeasterly waves expected along the Gulfstream route a southerly deviation had been advised. Unfortunately by a sudden and unforeseen deepening of a weak depression just on the advised route and just before the ship arrived there a 5 metre high northeasterly wave field was built up, which caused the delay.

Of a total of 69 westbound routes to Abaco in the winter season about 81% had a positive result and about 13% a negative result. In about 6% of the cases there was neither gain nor loss of time.

In 20 of the possible 29 cases a gain of time of 10 hours or more was realized. The maximum gain of time realized in one crossing was 60 hours.

Of a total of 80 eastbound routes in the winter season about 42% had a positive and about 17% a negative result. In about 41% there was neither gain nor loss of time. In 5 of the possible 10 cases a gain of time of 10 hours or more was realized, while the maximum gain of time realized in one crossing was 25 hours.

2.2. Mean duration of voyages and the standard deviation with respect to this mean duration.

These data are shown in table 2.2. The table shows that the values of the standard deviation are rather high. This is caused by the fact that the number of voyages was too small to make different speed classes. The speeds of the ships are varying from 10 to 20 knots. However if one compares for example the standard deviations for the advised route with those for the reference routes it can be concluded just as for the route to the Caribbean Sea that in winter time on westbound voyages routeing results in a more regular sailing than when always the K-route would have been followed.

2.3. Time spent in higher waves.

The route to Abaco offers good possibilities for deviations as well to the north as to the south of the K-route. That such deviations can be successful is clearly shown in table 2.3. On an average especially on westbound voyages the wave conditions along the advised routes were considerably better than those along the K-route and they were also better than the wave conditions along the, from a climatological point of view more favourable, rhumbline.

In figure 13 the distribution of the mean number of hours with adverse waves with a height $\geq$ 6 metres for westbound voyages is given for the months August - April, both for the advised routes and for the greatcircle. Especially in the months December and January there is a considerable difference between the advised routes and the greatcircle. Routeing has been very successful in these months in avoiding the higher wave-fields. In January the mean time spent in adverse waves with a height $\geq$ 6 metres was 4.8 hours, while on the greatcircle this would have been 49.5 hours. For December these numbers are respectively 2.0 and 21.1 hours.

3. Europe - Bermuda.

The greatcircle to Bermuda coincides for a great part with the K-route to Abaco via 37°N, 57°W. On westbound voyages many ships first called at the Bermudas before they proceeded to the Gulf of Mexico. Eastbound only a few ships called at the Bermudas. For this reason only results of westbound voyages are given.

3.1. Mean time differences and detours with respect to the greatcircle route.

During the winter season routeing resulted in a mean time gain (table 3.1) of 5.6 hours (of the possible 8.4 hours) of the advised route with respect to the greatcircle route and 5.6 - 1.9 = 3.7 hours with respect to the rhumbline. During the summer season no time gain was realised with respect to the greatcircle and 1.7 hours with respect to the rhumbline.

The graph in figure 14 shows the results per month.

The negative result in May is caused by the fact that one of the six routeings in that month was a failure with a time loss of 12 hours.

Of a total of 46 routes to Bermuda in the winter season about 76% had a positive and about 9% a negative result. In the remaining 15% there was neither gain nor loss of time. In 12 of the 14 possible cases a gain of 10 hours or more was realized. The maximum gain of time realized in one crossing was 31 hours.

3.2. Mean duration of voyages and the standard deviation with respect to this mean duration.

The durations mentioned in table 3.2 apply as for all other routes to the ocean leg of the route, for example between Bishop Rock at the entrance of the English Channel and the Bermudas. In winter time the standard deviation of the advised route is respectively 4 and 3 hours less than that of the greatcircle and the rhumbline, which means that also here routeing contributes to a more regular sailing.

The mean duration of the voyages depends a lot on the season of the year. The difference in mean voyage time in winter and summer along the greatcircle for example is about 25 hours. In figure 15 the mean duration of the advised route is given per month. The figure shows that large differences exist between the individual months. The difference between January and June for example is 61 hours or about 2½ days.

3.3. Time spent in higher waves.

Table 3.3. gives an average of 3.9 hours with adverse waves equal to or higher than 6 metres on the advised route. On the least time route, greatcircle and rhumbline this would have been respectively 1.3, 12.7 and 7.5 hours. This means that on an average the advised route had much better wave conditions than greatcircle and rhumbline. Also in the summer season the wave conditions on the advised route were better than on the greatcircle and the rhumbline.

In figure 16 the mean number of hours per voyage with adverse waves $\geqslant$ 6 metres are given for the months August - April both for the advised routes and for the greatcircle.

The largest number of hours with adverse waves ≥ 6 metres again occurred in January with a mean of 18.2 hours on the advised routes and of 54.4 hours on the greatcircle.

4. Europe - Eastcoast of United States south of Cape Hatteras (ports of Brunswick, Savannah, Charleston, Wilmington, Morehead City), vice versa.

The shortest route from the English Channel or more norherly situated ports is a greatcircle route via Cape Race on New Foundland. This route has the advantage of the lee, offered by the America continent, for westerly, northwesterly and northerly waves. Moreover by sailing under the American coast advantage can be taken of following currents. The rhumbline on the contrary has the disadvantage of the Gulfstream. Moreover the rhumbline passes through the area between Nova Scotia and Bermuda with a relative high storm frequency.

Eastbound advantage can be taken of the Gulfstream. Here the route via the axis of the Gulfstream and 42°N, 50°W (on the C-track) has been considered as the shortest route. Teh results have been compared with this route.

4.1. Mean time differences and detours with respect to the greatcircle (westbound) of the Gulfstream, combined with the C-track (eastbound).

Distinction has been made (table 4.1) between the results obtained with conventional freighters and with the lash-ship "Bilderdijk". The time gains on westbound routes are not so large as for the routes to the Caribbean Sea and the Gulf of Mexico. This is partly caused by the fact that the possible time gains (on the least-time tracks) are smaller. Deviations to the North are limited by the fact that one always has to pass south of Cape Race and in the case of southerly deviations to avoid the area with the higher storm frequency between Nova Scotia and Bermuda one often has to make a too large detour to make a large gain of time possible. On the other hand especially in the case of the new type of ship as the lash-ship "Bilderdijk" the routeing officers have been a little bit too cautious in their routeing advices, which is shown by the fact that the detour of the advised route is on an average considerable larger than that of the least-time track.

Compared to the rhumbline the advised route gives a much better result. That the rhumbline, which passes through the area with a relative high storm frequency between Nova Scotia and the Bermudas is also less favourable from a climatological point of view is shown by the fact that, contrary to the routes to the Caribbean Sea and the Gulf of Mexico, the always following of the rhumbline would have resulted in a mean time loss of a few hours with respect to the greatcircle.

The eastbound results in winter time are comparable with those on the route from the Gulf of Mexico. During the summer season on an average on westbound voyages 0.1 hour was gained and on eastbound voyages 0.1 hour was lost by routeing.

The graphs in figures 17 (westbound) and 18 (eastbound) are showing the results per month. The good result for westbound voyages in February is caused by the fact that two from the six routeings in that month were very successful with time gains of 34 and 41 hours with respect to the greatcircle route.

Of a total of 52 westbound voyages in the winter season about 48% had a positive result and about 21% a negative result, with respect to the greatcircle route. In about 31% of the cases there was neither gain nor loss of time. In 6 of the 8 possible cases a gain of 10 hours or more was realized. The maximum gain of time realized in one crossing was 41 hours.

Of a total of 83 eastbound voyages in the winter season about 34% had a positive and about 16% a negative result. In about 50% there was neither gain nor loss of time. In 8 of the possible 11 cases a gain of 10 hours or more was realized, while the maximum gain of time realized in one crossing was 28 hours.

4.2. Mean duration of voyages and the standard deviation with respect to this mean duration.

The standard deviations in table 4.2 show that also on this route routeing has resulted in a more regular sailing than when always the greatcircle would have been followed.

4.3. Time spent in higher waves.

On westbound routes (table 4.3) both in winter and summer routeing has resulted in better wave conditions. Although in the summer season the time gains were neglectable this did not mean that routeing had no profit at all. The number of hours in adverse waves with a height $\geq$ 4 metres is much less on the advised routes than along greatcircle and rhumbline.

The mean numbers of hours per westbound voyage with adverse waves $\geqslant$ 6 metres for the months August - April in figure 19 show that on this more northern route the possibility to avoid the higher wave-fields is less than on the foregoing more southern routes. In January for example the mean time spent in adverse waves $\geqslant$ 6 metres was 22.6 hours, while on the greatcircle this would have been 31.3 hours.

5. Europe - Eastcoast of United States and Canada from Cape Hatteras to Nova Scotia (ports of Baltimore, Norfolk, Philadelphia, New York, Boston, Saint John, Halifax), vice versa.

The shortest route from the English Channel or more northern ports is a greatcircle route via Cape Race. However during the ice season the routeing advice takes into account the New Foundland ice limit in such a way that the ship will pass 30 nautical miles south of it. In this case that greatcircle route which passes 30 nautical miles south of the ice limit is considered as the shortest route, to which the results have been compared.

When ships were coming from or bound to the English Channel the results have not been compared with the rhumbline, but with the C-track (via 43°N, 50°W if westbound and via 42°N, 50°W if eastbound). For more northern ports the results have been compared with the rhumbline via Cape Race or a point 30 nautical miles south of the ice limit.

From a climatological point of view the route lies within the ocean area where the frequency of high waves from directions between South and Northwest is high. It is often seen that, although on the first part of the crossing (when westbound) a deviation to the south is desirable, on the last days of the crossing the best speed can be made by sailing under the cover of the American coast. In general the C-track is then a less favourable route to follow.

Because of its position with respect to the general weather circulation this route is as routeing is concerned a difficult one.

In figure 20 a survey is given of the routes advised to westbound container-ships during the winter season 1973-1974. It shows a spreading of the routes over a wide area of the ocean on both sides of the greatcircle. Except for the few cases in which the greatcircle could be advised, every route is different from the others due to the ever changing weather situation.

More than on the routes to southern ports a choice must be made between a route north or south of the depression paths. Also it occurs more that the route intersects with the depression paths. In such cases it is always difficult to determine the best place and time of intersection, especially when a series of fast depressions is moving over the ocean.

5.1. Mean time differences and detours with respect to the greatcircle.

In table 5.1 distinction has been made between conventional freighters, tankers and container-ships, while for the container ships also distinction has been made between different speed classes. Moreover it was possible to give the results for the container-ships not only for all ports of sailing and destination together, but also separately for the routes Liverpool-Nantucket, Liverpool-Halifax, Bishop Rock - Nantucket, Bishop Rock - Halifax and Pentland Firth - Nantucket.

The results in table 5.1 confirm that qua routeing this route is not such an easy one. There is quite a difference between the actual and the possible gain in time with respect to the greatcircle. In general along the advised route a gain of time has been realised. For the 150 container-ships and the 39 tankers on all westbound routes this was on an average 1.6 hours. For the 72 freighters it was even 3.0 hours. In an earlier publication (K.N.M.I., 1969) results are given for the winter seasons of the years 1965-1969. In this publication mean time losses with respect to the greatcircle of 0.2 hours for freighters and 0.7 hours for container-ships are mentioned. From this one can draw the conclusion that in the course of time the routeing results have been improved.

The freighters (speed varying from 11 to 17 knots) are considerable slower than the container-ships. The better results (in an absolute sense) with the freighters can be ascribed to the fact that because their mean voyage duration is much longer a larger gain is possible. In a relative sense, if one considers the percentage of the time gained from the possible time gain, the results of the 150 container-ships are slightly better than those of the 72 freighters.

One of the conclusions which can be drawn from table 5.1 is that the C-track which ships used to follow in the past is very unfavourable. In almost all cases the following of the C-track would have resulted in a mean loss of several hours with respect to the greatcircle. If one wants to follow a standard route the greatcircle is preferable above the C-track.

On eastbound voyages and in the summer season the time differences between the advised routes and the greatcircle are negligible. So if one is only interested in time one could just as well always follow the greatcircle route.

Table 5.1 gives the mean results for five years. From year to year they vary, but not so much as for the route to the Caribbean Sea. For example the 150 winter routeings of container-ships show an average gain of time with respect to the greatcircle of 1.6 hours, while for the individual years (for the seasons 1969-1970 up to 1973-1974) these results were respectively 1.7, 2.0, 2.8, 1.0 and 0.8 hours. The possible gains were respectively 2.8, 3.4, 4.0, 2.8 and 4.2 hours. In contrast with the route to the Caribbean Sea, where 1973-1974 was the best winter season, here the results were smallest in this season. The good results for the route to the Caribbean Sea were determined by a period with a continuous southern west circulation in January and the first half of February. For the route to New York, etc. during this period the least time route was mostly situated north or extremely north of the greatcircle. In some cases a northerly route was advised with success, but unfortunately for one voyage a southerly route was tried, which resulted in a loss of 24 hours with respect to the greatcircle, while on the northerly least time route a gain of 25 hours had been possible. Without this route the result in this season would have been close to normal,

The best results on the route to New York, etc. were obtained in the season 1971-1972. In a great part of January 1972 the general circulation was characterized by a northern west circulation with a continuous series of deep depressions, while in the area between Ireland and Labrador wave fields with maximum heights from 8 - 11 metres occurred. The three routed container-ships during this period were all advised to sail well south of these high wave fields which resulted in a total time gain of 66 hours. Without these three routes the average gain in that season would have been only 0.4 hours.

The graphs in figures 21 and 22 are showing the results per month for westbound voyages of respectively container-ships and conventional freighters.

As for nearly all routes it appears that routeing is most successful in January.

Of a total of 150 westbound voyages of container-ships in the winter season about 38% had a positive result and about 20% a negative result with respect to the greatcircle. In about 42% of the cases there was neither gain nor loss of time. For the 145 eastbound voyages these percentages were respectively 15, 16 and 69. In 13 of the 20 possible westbound cases a gain of ten hours or more was realized. The maximum gain of time realized in one crossing was 35 hours. In 2 of the 4 possible eastbound cases a gain of 10 hours or more was realized with a maximum gain of time in one crossing of 15 hours.

Of a total of 73 Westbound voyages of conventional freighters in the winter season about 44% had a positive result and about 24% a negative result with respect to the greatcircle. In about 32% of the cases there was neither gain nor loss of time. For the 40 eastbound voyages these percentages were respectively 20, 27 and 53. In 19 of the 25 possible Westbound cases a gain of 10 hours or more was realized, while the maximum gain realized in one crossing was 42 hours. In 1 of the 3 possible eastbound cases a time gain of more than 10 hours was realized.

During the summer season the maximum time gain realized in one crossing was 9 hours for container-ships and 4 hours for conventional freighters.

5.2. Mean duration of voyages and the standard deviation with respect to this mean duration.

When all ports of sailing and destination and ships with different speeds are taken together a part of the standard deviation with respect to the mean voyage duration is due to the differences in distance, another part is due to the differences in speed, while the remaining part can be ascribed to weather and wave conditions. To get an idea of the last part a subdivision has been made in table 5.2 for the routes of the container-ships between Liverpool-Nantucket (only ships with speeds of 21 knots), Liverpool - Halifax (only ships with speeds of 21 knots), Bishop Rock - Nantucket (only ships with speeds of 21 knots), Bishop Rock - Nantucket (only ships with speeds of 23 knots), Bishop Rock - Halifax (only ships with speeds of 23 knots) and Pentland Firth - Nantucket (only ships with speeds of 21 knots). Also the results of 150 routeings on all legs together have been given. Here the standard deviation for example on the greatcircle route is 24 hours. The figures for the individual routes show that about half of the standard deviation is caused by differences in speed and distance and half of it is caused by weather and wave conditions, which must be an important parameter when considering sailing schedules.

5.3. Time spent in higher waves.

On westbound voyages (table 5.3) both in winter and summer routeing has resulted in better wave conditions than would have been met on the greatcircle and the C-track.

The mean numbers of hours for westbound voyages with adverse waves equal to or higher than 6 metres for the months August - April in figure 23 (container-ships) and in figure 24 (conventional freighters and tankers) show that the higher waves have been avoided more succesfully by the faster container-ships.

6. Europe - St. Lawrence River, vice versa.

The shortest route from the English Channel or more northern ports is a greatcircle via the Strait of Belle Isle between Labrador and Newfoundland. Because of the ice season only a few routeings occurred in the months December, January, February and March. At the beginning and the end of the ice season, when the Strait of Belle Isle is closed already or still closed, the ships had to be routed via Cabot Strait west of Newfoundland. Most ships routed on this stretch were bulkcarriers

On the one hand this route has the advantage of a rather short ocean leg, so a relative great part of the route can be overlooked by the available forecasts at the moment of the issuing of the routeing advice. On the other hand because of the shortness of the route large deviations to the north or the south result in relative large detours with respect to the greatcircle, which are hard to be made good by better wave conditions.

6.1. Mean time differences and detours with respect to the greatcircle.

During the winter season westbound routeing resulted in a mean time gain (table 6.1) of 2.4 hours of the advised route with respect to the greatcircle and of 2.4 + 1.0 = 3.4 hours with respect to the rhumbline. The rhumbline is here a less favourable route than the greatcircle. The slightly better mean wave conditions (table 6.3) are not enough to make good the detour by following the rhumbline.

Remarkable is that the 28 westbound routeings during the summer season resulted in a mean time gain of 1.0 hour with respect to the greatcircle.

On eastbound routeings the mean time gains were small, namely 0.6 hours in the winter season and 0.1 hours in the summer season.

The results by year vary in the same way as for the route to New York, etc., with the best results on westbound routeings the winter season 1971-1972 and the poorest results in the winter season 1973-1974 with mean time gains of 5.8 and 0.9 hours respectively.

The graph in figure 25 shows the monthly results for westbound voyages with the best results in October and November and not as usual in December and January. However, because of the fact that due to the ice season the results for December and January are only based on respectively one and two routeings one cannot attach much statistical value to these results.

Of a total of 37 westbound voyages in the winter season about 54% had a positive result and about 14% a negative result with respect to the greatcircle. In about 32% of the cases there was neither gain nor loss of time. For the 20 eastbound voyages these percentages are 26, 21 and 53, respectively.

In 2 of the 4 possible westbound cases a gain of ten hours or more was realized. The maximum gain of time realised in one crossing was 12 hours. The maximum gain of time on eastbound voyages was 6 hours.

6.2. Mean duration of voyages and the standard deviation with respect to this mean duration.

The durations mentioned in table 6.2 are those from the beginning of the ocean leg of the route (for example Bishop Rock) to the point 49°40'N, 66°W in the entrance of the St. Lawrence River; this because of the fact that the routes north of Newfoundland via the Strait of Belle Isle and south of Newfoundland via Cabot Strait join each other at that point.

The contribution of routeing to a more regular sailing was small. On westbound routes in winter time the standard deviation with respect to the mean voyage duration of the advised route is respectively 2 and 1 hours less than that of the greatcircle and the rhumbline.

6.3. Time spent in higher waves.

On westbound voyages (table 6.3) both in winter and summer routeing has resulted in better wave conditions than on the greatcircle or the rhumbline would have been met. The number of hours spent in adverse waves with a height $\geqslant 6$ metres in the winter season and with a height $\geqslant 4$ metres in the summer season is roughly about the half of the number of hours with those wave conditions on greatcircle and rhumbline.

Some conclusions and remarks.

The results and the experience of the Netherlands routeing office on the North Atlantic are leading to a number of conclusions and remarks:

1. Although not every individual routeing was successful the mean results for the years 1969 - 1974 are justifying the practice of ship routeing.
2. Routeing with the purpose of achieving a least-time ocean crossing has at the same time the effect of less risk on weather damage to ship and cargo. The number of hours in adverse wave conditions are diminished by routeing not only in the winter season but also in the summer season. For passenger - ships this means more comfort for the passengers.
3. The best results are obtained on routes to southern ports such as in the Caribbean Sea and the Gulf of Mexico. For routes to more northern ports the results are not so good but still positive.
4. The best results are obtained during the winter months December, January and February. Because of the fact that during these months the weather conditions on the North Atlantic Ocean are worst the delays in time along a fixed route like the greatcircle are large. By choosing in every individual case the right route to avoid the bad conditions more gain of time with respect to the greatcircle is possible than during the other months.
5. The mean time gains on westbound voyages are larger than those on eastbound voyages due to the fact that following waves, which don't have so much influence on the perfomance of a ship, are dominating on eastbound voyages.
6. During the summer season (15 April - 15 August) one can, if only the duration of a route is of interest, on most routes just as well follow always the greatcircle. Only on the routes to the Caribbean Sea and to the St. Lawrence River routeing resulted in a mean time gain, in the order of one hour with respect to the greatcircle.
7. Unless the range of reliable forecasts becomes of the same order as the time needed for an ocean crossing there always will be an unavoidable margin in time between the advised routes and the least-time route.
8. The results are a little more favourable for slower ships. Although the faster ships are able to perform an advised deviation from the greatcircle route more easily and so avoid unfavourable wave conditions, often the slower ships have obviously longer profit of a once recommended deviation.

9. The quality of the results is determined especially by relative short periods with unfavourable weather conditions on the ocean, in which the general weather situation does not change much.

10. Routeing results in a more regular sailing. The spreading in voyage durations is smaller for the advised routes than it would have been on the greatcircle or the rhumbline.

11. The results vary from year to year. The possible results are determined by the weather on or near the greatcircle route. When the waves are low, such as in summer time, then one cannot do better than by sailing along the greatcircle. During one year the weather conditions near the greatcircle are worse than during the other. For this reason the results with respect to the greatcircle are varying from year to year.

12. An extra service of the Netherlands routeing office is that the routed ships are receiving wave forecasts for two days ahead during the whole voyage. In this way the masters are warned for unfavourable wave conditions in time to take measures as securing the cargo, etc. Moreover it enables masters to estimate the time of arrival of their ships more accurately, which is an important factor in preparing loading and discharging.

13. By constructing speed characteristics routeing contributes to the knowledge about the performance of a ship in different sea conditions

14. The results have been compared with those which would have been obtained along fixed routes such as the greatcircle and the rhumbline. Of cource it would be more interesting to compare them with the results of the same type of ships which did not use routeing advices and where the masters had to choose their own routes.

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Table 1.1.1 Europe - Caribbean. Mean time differences ($\overline{\Delta t}$) and detours ($\overline{\Delta s}$) with respect to the greatcircle route.

	Number of voyages	$\overline{\Delta t}$ in hours			$\overline{\Delta s}$ in nautical miles		
		least time	route	rhumbline	least time	route	rhumbline
Winter.							
1. Bishop Rock - Mona, freighters (speed ≤ 18 knots)	32	+11.5	+ 9.7	+8.7	67	65	51
2. Bishop Rock - Mona, freighters (speed > 18 knots)	62	+ 5.1	+ 4.0	+1.7	45	54	48
3. Glasgow - Mona, freighters (speed 16-18 knots)	16	+10.1	+ 8.4	-0.5	113	125	53
4. Bishop Rock - Mona, fruitschips	20	+12.8	+12.2	+8.2	63	67	51
5. Bishop Rock - Sombrero, tankers (speed 15.5 - 16.4 knots)	56	+ 6.2	+ 5.6	+3.4	44	50	34
6. Bishop Rock - Sombrero, tankers (speed 14.5 - 15.4 knots)	76	+ 5.6	+ 4.8	+3.0	40	44	34
7. Bishop Rock - Sombrero, tankers (speed 13.5 - 14.4 knots)	31	+ 7.2	+ 6.3	+4.9	40	40	35
8. Bishop Rock - Sombrero, tankers (speed 12.5 - 13.4 knots)	23	+ 8.9	+ 7.2	+5.5	45	46	35
9. Fastnet - Sombrero, tankers (speed 15.5 - 16.4 knots)	8	+ 9.3	+ 8.3	+3.3	102	102	36
10. Fastnet - Sombrero, tankers (speed 14.5 - 15.4 knots)	37	+ 6.3	+ 4.5	+2.5	58	57	34
11. Fastnet - Sombrero, tankers (speed 13.5 - 14.4 knots)	15	+ 7.5	+ 6.4	+5.3	51	52	34
12. Fastnet - Sombrero, tankers (speed 12.5 - 13.4 knots)	36	+ 9.6	+ 8.3	+6.7	60	73	38
13. Bishop Rock and Fastnet - Sombrero etc., tankers (all speeds)	307	+ 7.2	+ 6.1	+4.1	50	53	35
14. Pentland Firth - Sombrero, tankers	23	+10.3	+ 9.1	+5.8	64	75	46
15. Skaw - Sombrero, tankers	10	+17.7	+16.6	+3.3	155	187	49
Summer.							
1. Bishop Rock, etc. - Mona, freighters (speed ≤ 18 knots)	14	+ 1.6	+ 1.1	-0.4	32	37	56
2. Bishop Rock, etc. - Mona, freighters (speed > 18 knots)	29	+ 1.2	+ 0.5	-1.2	23	35	48
3. Bishop Rock, etc. - Mona, fruitships	16	+ 1.6	+ 0.7	-1.2	19	26	45

Table 1.1.2 Europe - Caribbean. Mean duration of voyages in hours, standard deviations between brackets.

	Number of voyages	least time	route	greatcircle	rhumbline
Winter.					
1. Bishop Rock - Mona, freighters (speed ≤ 18 knots)	32	224.6(30)	226.4(31)	236.1(36)	227.4(30)
2. Bishop Rock - Mona, freighters (speed > 18 knots)	62	179.6(12)	180.6(13)	184.6(15)	183.0(15)
3. Glasgow - Mona, freighters (speed 16 - 18 knots)	16	218.3(13)	219.9(13)	228.3(20)	228.9(18)
4. Bishop Rock - Mona, fruitships	20	196.1(13)	196.7(12)	208.9(27)	200.7(18)
5. Bishop Rock - Sombrero, tankers (speed 15.5 - 16.4 knots)	56	217.1(16)	217.7(16)	223.3(20)	219.9(17)
6. Bishop Rock - Sombrero, tankers (speed 14.5 - 15.4 knots)	76	224.9(11)	225.8(12)	230.5(15)	227.6(13)
7. Bishop Rock - Sombrero, tankers (speed 13.5 - 14.4 knots)	31	242.1(11)	242.9(12)	249.3(18)	244.4(12)
8. Bishop Rock - Sombrero, tankers (speed 12.5 - 13.4 knots)	23	251.7(13)	253.3(15)	260.5(19)	255.1(14)
9. Fastnet - Sombrero, tankers (speed 15.5 - 16.4 knots)	8	218.5(15)	219.5(14)	228.1(23)	224.5(20)
10. Fastnet - Sombrero, tankers (speed 14.5 - 15.4 knots)	37	226.4(15)	228.2(16)	232.7(22)	230.2(18)
11. Fastnet - Sombrero, tankers (speed 13.5 - 14.4 knots)	15	242.6(23)	243.7(23)	250.1(28)	244.8(23)
12. Fastnet - Sombrero, tankers (speed 12.5 - 13.4 knots)	36	253.9(16)	255.3(17)	263.6(24)	256.8(17)
13. Bishop Rock and Fastnet - Sombrero, etc. tankers (all speeds)	307	234.3(22)	235.4(23)	241.5(27)	237.4(23)
14. Pentland Firth - Sombrero, tankers	23	237.8(23)	239.0(24)	248.2(27)	242.7(26)
15. Skaw - Sombrero, tankers	10	270.3(18)	271.4(18)	288.0(19)	284.7(17)
Summer.					
1. Bishop Rock, etc. - Mona, freighters (speed ≤ 18 knots)	14	204.9(15)	205.4(15)	206.5(16)	206.9(16)
2. Bishop Rock, etc. - Mona, freighters (speed > 18 knots)	29	177.0(12)	177.7(12)	178.2(12)	179.4(13)
3. Bishop Rock, etc. - Mona, fruitships	16	187.7(16)	188.6(17)	189.3(17)	190.4(18)

Table 1.1.3 Europe - Caribbean. Mean number of hours with adverse and following (between brackets) waves ≥ 6 metres (winter) or ≥ 4 metres (summer).

	number of voyages	least time	route	greatcircle	rhumbline
Winter.					
1. Bishop Rock - Mona, freighters (speed ≤ 18 knots)	32	0.8(0.0)	1.6(0.3)	7.0(1.0)	1.5(0.3)
2. Bishop Rock - Mona, freighters (speed > 18 knots)	62	0.3(0.1)	1.2(0.4)	3.6(0.5)	3.3(0.2)
3. Glasgow - Mona, freighters (speed 16 - 18 knots)	16	0.0(0.0)	1.1(0.4)	6.6(0.7)	5.0(0.6)
4. Bishop Rock - Mona, fruitships	20	1.9(0.5)	2.1(0.5)	13.1(1.3)	5.4(0.3)
5. Bishop Rock - Sombrero, tankers (speed 15.5 - 16.4 knots)	56	0.9(0.4)	1.2(0.7)	4.1(0.7)	2.9(0.8)
6. Bishop Rock - Sombrero, tankers (speed 14.5 - 15.4 knots)	76	0.3(1.1)	0.6(1.1)	3.4(1.6)	2.0(1.3)
7. Bishop Rock - Sombrero, tankers (speed 13.5 - 14.4 knots)	31	0.9(0.5)	1.4(0.5)	5.6(0.5)	1.4(0.5)
8. Bishop Rock - Sombrero, tankers (speed 12.5 - 13.4 knots)	23	0.5(0.7)	0.9(0.3)	1.9(1.5)	1.7(1.1)
9. Fastnet - Sombrero, tankers (speed 15.5 - 16.4 knots)	8	0.0(0.0)	0.0(0.0)	8.3(1.3)	8.6(0.9)
10. Fastnet - Sombrero, tankers (speed 14.5 - 15.4 knots)	37	0.3(0.7)	1.1(2.0)	5.4(1.3)	3.9(1.2)
11. Fastnet - Sombrero, tankers (speed 13.5 - 13.4 knots)	15	0.9(0.7)	1.3(0.8)	8.0(0.6)	1.3(0.8)
12. Fastnet - Sombrero, tankers (speed 12.5 - 13.4 knots)	36	3.1(1.0)	3.8(1.1)	6.8(2.4)	5.2(1.0)
13. Bishop Rock and Fastnet - Sombrero, etc., tankers (all speeds)	307	1.1(0.7)	1.5(0.9)	5.3(1.2)	3.2(1.1)
14. Pentland Firth - Sombrero, tankers	23	0.0(0.4)	0.2(0.4)	5.3(1.7)	4.2(0.6)
15. Skaw - Sombrero, tankers	10	0.0(0.0)	0.0(0.0)	17.0(0.0)	7.6(0.0)
Summer.					
1. Bishop Rock, etc. - Mona, freighters (speed ≤ 18 knots)	14	1.9(1.9)	3.0(1.9)	4.3(3.1)	3.6(0.7)
2. Bishop Rock, etc. - Mona, freighters (speed > 18 knots)	29	2.3(0.0)	2.7(0.0)	6.8(1.7)	4.2(1.9)
3. Bishop Rock, etc. - Mona, fruitships	16	2.2(0.4)	4.3(0.8)	5.9(1.1)	2.2(0.4)

Table 1.2.1 Caribbean - Europe. Mean time differences ($\overline{\Delta t}$) and detours ($\overline{\Delta s}$) with respect to the greatcircle route.

	Number of voyages	$\overline{\Delta t}$ in hours			$\overline{\Delta s}$ in nautical miles		
		least time	route	rhumbline	least time	route	rhumbline
Winter.							
1. Mona, etc. - Bishop Rock, etc., freighters (speed ≤ 18 knots)	55	+ 1.8	+0.9	-2.2	17	21	69
2. Mona, etc. - Bishop Rock, etc., freighters (speed > 18 knots)	102	+ 1.0	+0.5	-2.6	13	15	62
3. Mona, Caicos - Fastnet, fruitships	28	+ 1.5	+1.0	-3.3	18	16	78
4. Sombrero - Bishop Rock, tankers (speed 15.5-16.4 knots)	36	+ 2.4	+1.5	-2.0	25	25	63
5. Sombrero - Bishop Rock, tankers (speed 14.5-15.4 knots)	92	+ 1.7	+0.8	-3.1	20	16	64
6. Sombrero - Bishop Rock, tankers (speed 13.5-14.4 knots)	30	+ 0.5	+0.1	-3.7	13	11	62
7. Sombrero - Bishop Rock, tankers (speed 12.5-13.4 knots)	28	+ 0.9	+0.4	-3.2	13	13	63
8. Sombrero - Fastnet, tankers (speed 15.5-16.4 knots)	20	+ 3.3	+2.0	-0.9	23	21	63
9. Sombrero - Fastnet, tankers (speed 14.5-15.4 knots)	26	+ 1.2	+0.7	-3.6	13	13	59
10. Sombrero - Fastnet, tankers (speed 13.5-14.4 knots)	21	+ 1.6	+1.1	-2.3	19	14	58
11. Sombrero - Fastnet, tankers (speed 12.5-13.4 knots)	29	+ 2.0	+0.8	-2.5	19	12	58
12. Sombrero, etc. - Bischop Rock, Fastnet, etc., tankers (all speeds)	340	+ 2.0	+1.0	-2.5	20	18	63
13. Caribbean - Teesport, tankers	10	+10.4	+8.7	-1.6	76	80	75
14. Caribbean - Skaw, tankers	8	+ 4.9	+2.0	-1.9	102	68	81
Summer.							
1. Mona, etc. - Bishop Rock, etc., freighters (speed ≤ 18 knots)	22	+ 0.5	+0.2	-3.6	9	8	71
2. Mona, etc. - Bishop Rock, etc., freighters (speed > 18 knots)	46	+ 0.4	0.0	-3.4	2	1	68
3. Mona, Caicos - Fastnet, fruitships	25	+ 0.4	0.0	-4.0	6	9	84

Table 1.2.2 Caribbean - Europe. Mean duration of voyages in hours, standard deviations between brackets.

	Number of voyages	least time	route	greatcircle	rhumbline
Winter.					
1. Mona, etc. - Bishop Rock, etc., freighters (speed ≤ 18 knots)	55	206.9(16)	207.8(17)	208.7(17)	210.9(18)
2. Mona, etc. - Bishop Rock, etc., freighters (speed > 18 knots)	102	174.8(13)	175.3(13)	175.8(14)	178.4(14)
3. Mona, Caicos - Fastnet, fruitschips	28	189.3(11)	189.8(11)	190.8(12)	194.1(13)
4. Sombrero - Bishop Rock, tankers (speed 15.5-16.4 knots)	36	227.8(10)	228.7(11)	230.2(12)	232.2(10)
5. Sombrero - Bishop Rock, tankers (speed 14.5-15.4 knots)	92	233.2(13)	234.1(14)	234.9(14)	238.0(15)
6. Sombrero - Bishop Rock, tankers (speed 13.5-14.4 knots)	30	251.2(15)	251.6(15)	251.7(15)	255.4(16)
7. Sombrero - Bishop Rock, tankers (speed 12.5-13.4 knots)	28	261.5(14)	262.0(14)	262.4(14)	265.6(14)
8. Sombrero - Fastnet, tankers (speed 15.5-16.4 knots)	20	220.0(17)	221.3(20)	223.3(21)	224.2(22)
9. Sombrero - Fastnet, tankers (speed 14.5-15.4 knots)	26	224.4(10)	224.9(11)	225.6(11)	229.2(12)
10. Sombrero - Fastnet, tankers (speed 13.5-14.4 knots)	21	246.4(20)	246.9(19)	248.0(19)	250.3(19)
11. Sombrero - Fastnet, tankers (speed 12.5-13.4 knots)	29	260.2(13)	261.4(15)	262.2(15)	264.7(14)
12. Sombrero, etc. - Bishop Rock, Fastnet, etc, tankers (all speeds)	340	241.7(22)	242.7(23)	243.7(23)	246.2(23)
13. Caribbean - Teesport, tankers	10	291.8(24)	293.5(25)	302.2(22)	303.8(20)
14. Caribbean - Skaw, tankers	8	291.0(21)	293.9(24)	295.9(24)	297.8(22)
Summer.					
1. Mona, etc. - Bishop Rock, etc.,freighters (speed ≤ 18 knots)	22	204.0(13)	204.3(13)	204.5(13)	208.1(13)
2. Mona, etc. - Bishop Rock, etc.,freighters (speed > 18 knots)	46	169.7(17)	169.7(17)	169.7(17)	173.1(17)
3. Mona, Caicos - Fastnet, fruitships	25	182.1(7)	182.5(7)	182.5(7)	186.5(8)

Table 1.2.3 Caribbean - Europe. Mean number of hours with adverse and following (between brackets) waves ≥ 6 metres (winter) or ≥ 4 metres (summer).

	Number of voyages	least time	route	greatcircle	rhumbline
Winter.					
1. Mona, etc. - Bishop Rock, etc., freighters (speed ≤ 18 knots)	55	0.0(0.3)	0.9(0.4)	1.3(1.3)	1.0(0.3)
2. Mona, etc. - Bishop Rock, freighters (speed > 18 knots)	102	0.0(1.0)	0.1(1.1)	0.1(1.2)	0.2(0.7)
3. Mona, Caicos - Fastnet, fruitships	28	0.0(2.7)	0.0(5.1)	0.0(8.5)	0.0(1.4)
4. Sombrero - Bishop Rock, tankers (speed 15.5-16.4 knots)	36	0.0(2.2)	0.4(3.1)	1.6(5.1)	0.2(2.6)
5. Sombrero - Bishop Rock, tankers (speed 14.5-15.4 knots)	92	0.0(1.5)	0.0(2.0)	0.1(3.3)	0.1(1.8)
6. Sombrero - Bishop Rock, tankers (speed 13.5-14.4 knots)	30	1.7(3.8)	1.7(4.4)	1.7(4.4)	2.0(3.2)
7. Sombrero - Bishop Rock, tankers (speed 12.5-13.4 knots)	28	0.0(2.4)	0.0(2.2)	0.0(3.6)	0.0(2.3)
8. Sombrero - Fastnet, tankers (speed 15.5-16.4 knots)	20	1.6(2.5)	2.1(4.9)	2.5(6.1)	2.7(4.7)
9. Sombrero - Fastnet, tankers (speed 14.5-15.4 knots)	26	0.2(3.6)	0.3(3.6)	0.3(3.9)	0.2(4.0)
10. Sombrero - Fastnet, tankers (speed 13.5-14.4 knots)	21	0.7(4.6)	0.7(4.6)	1.1(4.6)	0.0(3.9)
11. Sombrero - Fastnet, tankers (speed 12.5-13.4 knots)	29	0.0(3.5)	1.1(5.2)	1.1(5.6)	0.0(4.8)
12. Sombrero, etc. - Bishop Rock, Fastnet, etc., tankers (all speeds)	340	0.3(2.4)	0.8(3.0)	1.1(4.0)	0.8(2.6)
13. Caribbean - Teesport, tankers	10	1.8(6.7)	3.5(12.5)	8.1(18.6)	9.8(12.1)
14. Caribbean - Skaw, tankers	8	0.0(0.0)	0.0(9.4)	3.9(5.9)	0.0(9.4)
Summer.					
1. Mona, etc. - Bishop Rock, etc., freighters (speed ≤ 18 knots)	22	0.1(2.3)	1.9(3.0)	2.1(3.8)	2.7(1.3)
2. Mona, etc. - Bishop Rock, etc., freighters (speed > 18 knots)	46	0.6(1.3)	0.6(1.8)	0.7(2.0)	0.7(0.9)
3. Mona, Caicos - Fastnet, fruitships	25	0.7(2.0)	1.3(2.4)	1.3(4.0)	1.3(2.5)

Table 2.1 Europe - Gulf of Mexico, vice versa. Mean time differences ($\overline{\Delta t}$) and detours ($\overline{\Delta s}$) with respect to the K-route (Westbound) and the combined Gulfstream C-track (Eastbound).

	Number of voyages	$\overline{\Delta t}$ in hours			$\overline{\Delta s}$ in nautical miles		
		least time	route	rhumbline	least time	route	rhumbline
Europe - Gulf of Mexico.							
Winter.							
1. Tankers	12	+10.4	+ 8.2	+6.2	137	152	120
2. Freighters	57	+12.9	+10.4	+4.5	136	126	124
Summer.							
1. Freighters	23	+1.5	+ 0.4	-3.9	37	59	124
Gulf of Mexico - Europe.							
Winter.							
1. Tankers	7	+2.0	+ 0.6		44	57	
2. Freighters	73	+3.8	+ 1.7		34	42	
Summer.							
1. Freighters	41	+0.3	0.0		3	8	

Table 2.2 Europe - Gulf of Mexico, vice versa. Mean duration of voyages in hours, standard deviations between brackets.

	Number of voyages	least time	route	K-route	rhumbline
Europe - Gulf of Mexico.					
Winter.					
1. Tankers	12	259.2(20)	261.3(21)	269.9(25)	263.3(20)
2. Freighters	57	242.9(36)	245.4(38)	255.7(47)	251.3(41)
Summer.					
1. Freighters	23	231.0(23)	232.1(23)	232.5(24)	236.4(23)
Gulf of Mexico - Europe.				Gulfstream C-track	
Winter.					
1. Tankers	7	265.4(19)	266.8(20)	267.4(22)	
2. Freighters	73	238.7(31)	240.8(31)	242.5(32)	
Summer.					
1. Freighters	41	229.3(25)	229.6(26)	229.6(25)	

Table 2.3 Europe - Gulf of Mexico, vice versa. Mean number of hours with adverse and following (between brackets) waves ≥ 6 metres (winter or ≥ 4 metres (summer).

	Number of voyages	least time	route	K-route	rhumbline
Europe - Gulf of Mexico.					
Winter.					
1. Tankers	12	0.4(1.7)	1.1(2.6)	8.8(0.4)	2.3(0.0)
2. Freighters	57	0.4(0.7)	2.1(1.7)	15.2(1.3)	4.0(2.2)
Summer.					
1. Freighters	23	1.2(0.0)	1.0(0.8)	4.8(0.2)	0.9(1.7)
Gulf of Mexico - Europe.				Gulfstream C-track	
Winter.					
1. Tankers	7	0.0(1.7)	0.0(2.9)	0.0(4.7)	
2. Freighters	73	0.0(4.9)	0.0(5.5)	1.5(8.8)	
Summer.					
1. Freighters	41	0.3(7.0)	0.3(8.2)	0.3(8.5)	

Table 3.1 Europe - Bermuda. Mean time differences ($\overline{\Delta t}$) and detours ($\overline{\Delta s}$) with respect to the greatcircle route.

	Number of voyages	$\overline{\Delta t}$ in hours			$\overline{\Delta s}$ in nautical miles		
		least time	route	rhumbline	least time	route	rhumbline
1. <u>Winter</u>, freighters	46	+8.4	+5.6	+1.9	96	99	58
2. <u>Summer</u>, freighters	21	+1.2	-0.1	-1.8	18	41	56

Table 3.2 Europe - Bermuda. Mean duration of voyages in hours, standard deviations between brackets.

	Number of voyages	least time	route	greatcircle	rhumbline
1. <u>Winter</u>, freighters	46	186.6(24)	189.4(26)	195.0(30)	193.0(29)
2. <u>Summer</u>, freighters	21	168.9(11)	170.2(12)	170.1(12)	171.9(11)

Table 3.3 Europe - Bermuda. Mean number of hours with adverse and following (between brackets) waves ≥ 6 metres (winter) or ≥ 4 metres (summer).

	Number of voyages	least time	route	greatcircle	rhumbline
1. <u>Winter</u>, freighters	46	1.3(0.0)	3.9(0.3)	12.7(0.0)	7.5(1.1)
2. <u>Summer</u>, freighters	21	1.1(1.7)	1.7(3.2)	3.7(2.4)	2.4(3.8)

Table 4.1 Europe-Charleston, Savannah, etc., vice versa. Mean time differences ($\overline{\Delta t}$) and detours ($\overline{\Delta s}$) with respect to the greatcirlce route.

	Number of voyages	$\overline{\Delta t}$ in hours			$\overline{\Delta s}$ in nautical miles		
		least time	route	rhumbline	least time	route	rhumbline
<u>Europe - Charleston, Savannah, etc.</u>							
<u>Winter.</u>							
1. Freighters	39	+5.4	+3.0	-3.8	100	117	78
2. Lash-ship "Bilderdijk"	13	+4.6	+1.9	-1.5	87	131	90
<u>Summer.</u>							
1. Freighters	24	+1.1	+0.1	-4.9	29	40	79
2. Lash-ship "Bilderdijk"	10	+0.9	+0.1	-2.0	12	32	43
<u>Charleston, Savannah, etc. - Europe.</u>							
<u>Winter.</u>							
1. Freighters	69	+3.8	+2.2		24	38	
2. Lash-ship "Bilderdijk"	14	+1.4	+0.5		10	13	
<u>Summer.</u>							
1. Freighters	29	+0.3	-0.1		3	6	
2. Lash-ship "Bilderdijk"	9	+0.1	-0.1		4	3	

Table 4.2 Europe - Charleston, Savannah, etc. vise versa. Mean duration of voyages in hours, standard deviations between brackets.

	Number of voyages	least time	route	greatcircle	rhumbline
Europe - Charleston, Savannah, etc.					
Winter.					
1. Freighters	39	210.2(28)	212.6(29)	215.6(33)	219.4(32)
2. Lash-ship "Bilderdijk"	13	209.2(21)	211.9(21)	213.8(24)	215.3(21)
Summer.					
1. Freighters	24	189.5(16)	190.5(17)	190.6(17)	195.5(18)
2. Lash-ship "Bilderdijk"	10	202.6(12)	203.4(13)	203.5(13)	205.5(12)
Charleston, Savannah, etc. - Europe.					
Winter.					
1. Freighters	69	211.9(30)	213.5(31)	215.7(34)	
2. Lash-ship "Bilderdijk"	14	194.5(10)	195.4(11)	195.9(11)	
Summer.					
1. Freighters	29	197.9(20)	198.3(20)	198.2(20)	
2. Lash-ship "Bilderdijk"	9	190.3(7)	190.5(8)	190.4(8)	

Table 4.3 Europe - Charleston, Savannah, etc. vice versa. Mean number of hours with adverse and following (between brackets) waves ≥6 metres (winter) or ≥4 metres (summer).

	Number of voyages	least time	route	greatcircle	rhumbline
<u>Europe - Charleston, Savannah, etc.</u>					
<u>Winter</u>.					
1. Freighters	39	1.4(0.5)	3.2(0.5)	7.5(1.8)	6.5(2.5)
2. Lash-ship "Bilderdijk"	13	0.4(1.5)	1.4(1.5)	7.6(1.3)	3.6(1.5)
<u>Summer</u>.					
1. Freighters	24	2.0(2.5)	3.7(2.5)	7.5(2.6)	10.2(0.0)
2. Lash-ship "Bilderdijk"	10	3.9(4.4)	4.4(4.5)	5.5(8.0)	8.0(6.8)
<u>Charleston, Savannah, etc. - Europe</u>.					
<u>Winter</u>.					
1. Freighters	69	0.4(2.1)	0.6(2.7)	1.3(3.0)	
2. Lash-ship "Bilderdijk"	14	0.0(5.8)	0.0(6.1)	0.0(6.4)	
<u>Summer</u>.					
1. Freighters	29	1.7(2.7)	2.4(2.7)	1.7(2.7)	
2. Lash-ship "Bilderdijk"	9	0.0(4.4)	2.6(4.4)	2.2(5.1)	

Table 5.1 Europe - New York, etc., vice versa. Mean time differences ($\overline{\Delta t}$) and detours ($\overline{\Delta s}$) with respect to the greatcircle route.

	Number of voyages	$\overline{\Delta t}$ in hours			$\overline{\Delta s}$ in nautical miles		
		least time	route	C-track or rhumbline	least time	route	C-track or rhumbline
<u>Europe - New York, etc.</u>							
<u>Winter.</u>							
1. Bishop Rock, etc. - New York, Baltimore, etc., freighters	72	+7.6	+3.0	-7.6	99	83	76
2. Bishop Rock, etc. - New York, Baltimore, etc., tankers	39	+4.9	+1.6	-3.5	59	76	60
3. Liverpool - Nantucket, container-ships (speed 21 knots	27	+4.3	+2.3	-3.2	45	59	39
4. Liverpool - Halifax, container-ships (speed 21 knots)	18	+3.9	-1.1	-2.3	51	62	35
5. Bishop Rock - Nantucket, container-ships (speed 21 knots)	18	+1.5	+0.7	-3.0	30	40	59
6. Bishop Rock - Nantucket, container-ships (speed 23 knots)	21	+3.6	+2.0	-4.9	40	58	62
7. Bishop Rock - Halifax, container-ships (speed 23 knots)	6	+3.0	+1.8	-7.7	59	36	114
8. Bishop Rock, Liverpool, etc. - Halifax, New York, etc. container-ships	150	+3.4	+1.6	-3.2	46	56	48
9. Pentland Firth - Nantucket, container-ships (speed 21 knots)	5	+0.8	+0.2	-0.8	13	24	28
<u>Summer.</u>							
1. Freighters	24	+1.3	+0.1	-4.0	18	28	48
2. Container-ships	86	+1.0	+0.2		19	16	
<u>New York, etc. - Europe.</u>							
<u>Winter.</u>							
1. Freighters	40	+2.4	-0.2	-4.0	19	35	68
2. Container-ships	145	+1.0	+0.2	-1.3	13	20	42
<u>Summer.</u>							
1. Container-ships	84	+0.01	-0.05		1	2	

Table 5.2 Europe - New York, etc., vice versa. Mean duration of voyages in hours, standard deviations between brackets.

	Number of voyages	least time	route	greatcircle	C-track or rhumbline
Europe - New York, etc.					
Winter.					
1. Bishop Rock, etc.- New York, Baltimore, etc., freighters	72	233.8(42)	238.4(45)	241.4(45)	249.0(45)
2. Bishop Rock, etc.- New York, Baltimore, etc., tankers	39	220.1(33)	223.4(34)	225.0(36)	228.5(35)
3. Liverpool - Nantucket, container-ships (speed 21 knots)	27	149.8(6)	151.8(7)	154.1(12)	157.3(13)
4. Liverpool - Halifax, container-ships (speed 21 knots)	18	144.5(19)	149.5(29)	148.4(24)	150.7(26)
5. Bishop Rock - Nantucket, container-ships (speed 21 knots)	18	140.5(9)	141.3(11)	142.0(10)	145.0(10)
6. Bishop Rock - Nantucket, container-ships (speed 23 knots)	21	125.0(8)	126.6(10)	128.6(12)	133.5(14)
7. Bishop Rock - Halifax, container-ships (speed 23 knots)	6	110.2(6)	111.4(6)	113.2(10)	120.9(13)
8. Bishop Rock, Liverpool, etc. - Halifax, New York, etc., container-ships	150	141.8(20)	143.6(22)	145.2(24)	148.4(23)
9. Pentland Firth - Nantucket, container-ships (speed 21 knots)	5	141.0(14)	141.6(15)	141.8(14)	142.6(14)
Summer.					
1. Freighters	24	203.9(18)	205.1(18)	205.2(18)	209.2(21)
2. Container-ships	86	132.0(13)	132.8(14)	133.0(14)	
New York, etc. - Europe.					
Winter.					
1. Freighters	40	208.3(20)	210.9(21)	210.7(21)	214.7(25)
2. Container-ships	145	141.1(14)	141.9(14)	142.1(15)	143.4(15)
Summer.					
1. Container-ships	84	138.7(10)	138.7(10)	138.7(10)	

Table 5.3 Europe - New York, etc. vice versa. Mean number of hours with adverse and following (between brackets) waves ≥ 6 metres (winter) or ≥ 4 metres (summer).

	Number of voyages	least time	route	greatcircle	C-track or rhumbline
Europe - New York, etc.					
Winter.					
1. Bishop Rock, etc. - New York, Baltimore, etc., freighters	72	4.4(3.3)	8.7(1.8)	15.4(1.6)	12.7(1.0)
2. Bishop Rock, etc. - New York, Baltimore, etc., tankers	39	2.6(0.6)	4.1(0.6)	7.5(1.0)	7.7(0.4)
3. Liverpool - Nantucket, container-ships (speed 21 knots)	27	0.0(0.0)	2.0(0.1)	7.5(0.2)	8.7(0.5)
4. Liverpool - Halifax, container-ships (speed 21 knots)	18	0.9(0.0)	6.4(0.7)	8.7(0.6)	10.4(0.6)
5. Bishop Rock - Nantucket, container-ships (speed 21 knots)	18	0.7(0.6)	0.7(0.6)	1.9(0.0)	2.9(0.0)
6. Bishop Rock - Nantucket, container-ships (speed 23 knots)	21	1.5(0.5)	2.9(0.8)	5.0(0.5)	7.6(0.8)
7. Bishop Rock - Halifax, container-ships (speed 23 knots)	6	4.2(0.0)	5.8(2.8)	9.7(2.5)	16.3(0.0)
8. Bishop Rock, Liverpool, etc. - Halifax, New York, etc., container-ships	150	1.2(0.2)	2.6(0.4)	7.0(0.3)	8.3(0.3)
9. Pentland Firth - Nantucket, container-ships (speed 21 knots)	5	1.8(0.0)	2.0(0.0)	3.0(0.0)	2.0(0.0)
Summer.					
1. Freighters	24	3.6(1.6)	5.3(1.7)	7.5(1.7)	6.5(2.1)
2. Container-ships	86	2.7(0.3)	4.9(0.2)	6.1(0.2)	
New York, etc. - Europe.					
Winter.					
1. Freighters	40	0.0(2.2)	0.9(4.4)	0.9(6.4)	1.4(6.4)
2. Container-ships	145	0.3(3.6)	0.4(4.5)	0.7(4.8)	0.7(4.2)
Summer.					
1. Container-ships	84	0.4(3.9)	0.4(4.0)	0.5(3.8)	

Table 6.1 Europe - St. Lawrence, vice versa. Mean time differences ($\overline{\Delta t}$) and detours ($\overline{\Delta s}$) with respect to the greatcircle route.

	Number of voyages	$\overline{\Delta t}$ in hours			$\overline{\Delta s}$ in nautical miles		
		least time	route	rhumbline	least time	route	rhumbline
Europe - St. Lawrence.							
1. Winter, bulkcarriers	37	+3.6	+2.4	-1.0	54	43	43
2. Summer, bulkcarriers	28	+2.2	+1.0	-0.4	32	39	32
St. Lawrence - Europe.							
1. Winter, bulkcarriers	20	+1.7	+0.6	-0.3	26	47	43
2. Summer, bulkcarriers	24	+0.3	+0.1	-2.0	1	3	27

Table 6.2 Europe - St. Lawrence, vice versa. Mean duration of voyages in hours, standard deviations between brackets.

	Number of voyages	least time	route	greatcircle	rhumbline
Europe - St. Lawrence.					
1. Winter, bulkcarriers	37	180.2(38)	181.4(39)	183.8(41)	184.8(40)
2. Summer, bulkcarriers	28	175.0(26)	176.2(26)	177.2(26)	177,6(26)
St. Lawrence - Europe.					
1. Winter, bulkcarriers	20	159.6(16)	160.7(16)	161.3(17)	161.6(16)
2. Summer, bulkcarriers	24	173.9(20)	174.1(20)	174.2(20)	176.2(20)

Table 6.3 Europe - St. Lawrence, vice versa. Mean number of hours with adverse and following (between brackets) waves ≥ 6 metres (winter) or ≥ 4 metres (summer).

	Number of voyages	least time	route	greatcircle	rhumbline
Europe - St. Lawrence.					
1. Winter, bulkcarriers	37	1.9(0.0)	3.8(0.0)	8.8(0.0)	7.2(0.0)
2. Summer, bulkcarriers	28	4.6(1.3)	5.5(1.3)	10.6(1.3)	10.7(0.3)
St. Lawrence - Europe.					
1. Winter, bulkcarriers	20	0.3(5.1)	0.3(5.9)	0.0(5.7)	0.3(4.0)
2. Summer, bulkcarriers	24	0.5(2.0)	0.7(2.9)	0.7(4.4)	0.7(4.4)

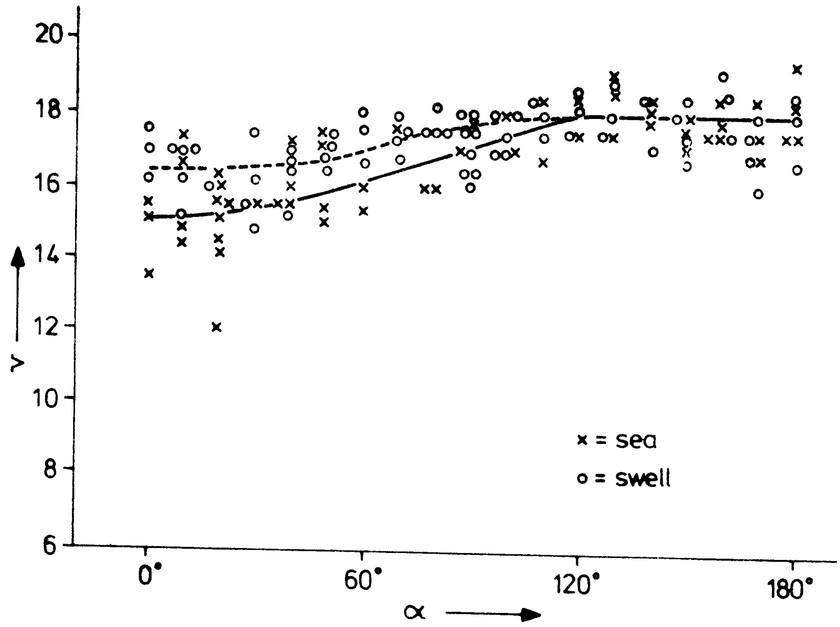

Figure 1. Ship's velocity v (knots) at a wave height of 3 - 3.5 metres in dependence of angle α (degrees) between direction of waves and course of ship (0° = head waves, 180° = following waves).

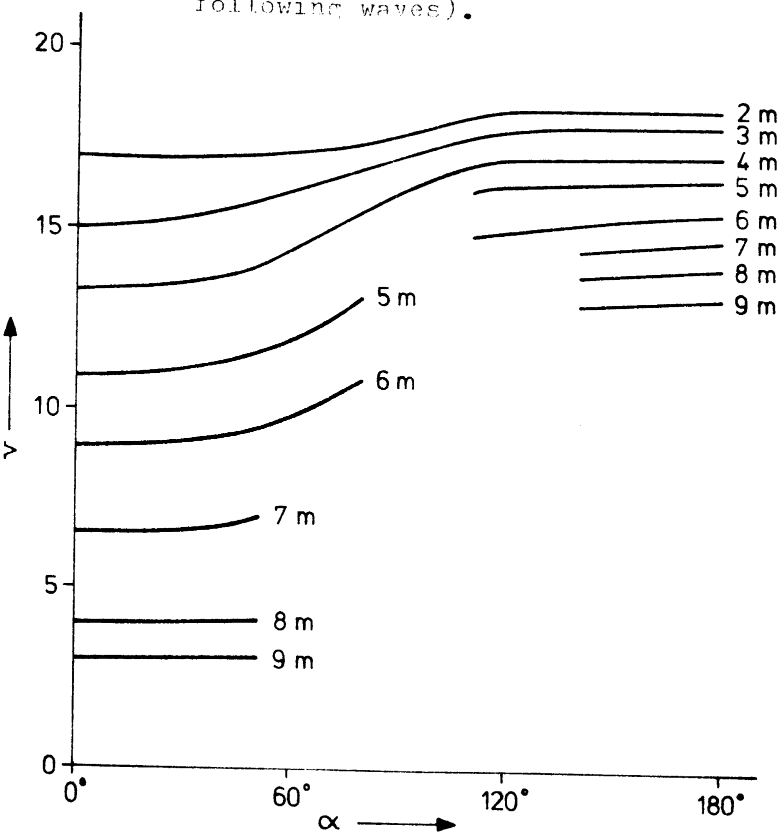

Figure 2. Ship's velocity v (knots) in dependence of height (metres) and angle α (degrees) between direction of waves and cource of ship (0° = head waves, 180° = following waves).

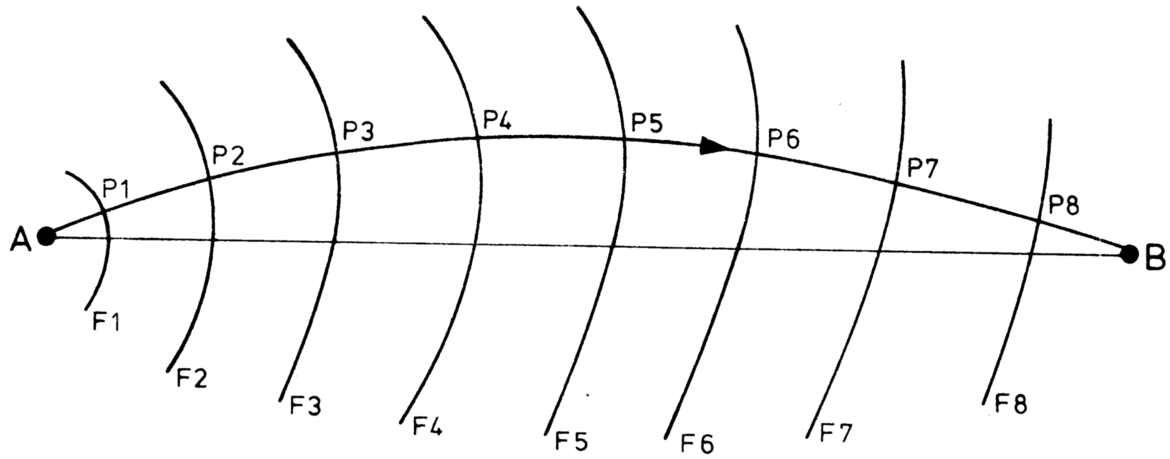

Figure 3. Construction of least time track $AP_1P_2P_3P_4P_5P_6P_7P_8B$ with the help of a series of time fronts F_1, F_2, etc..

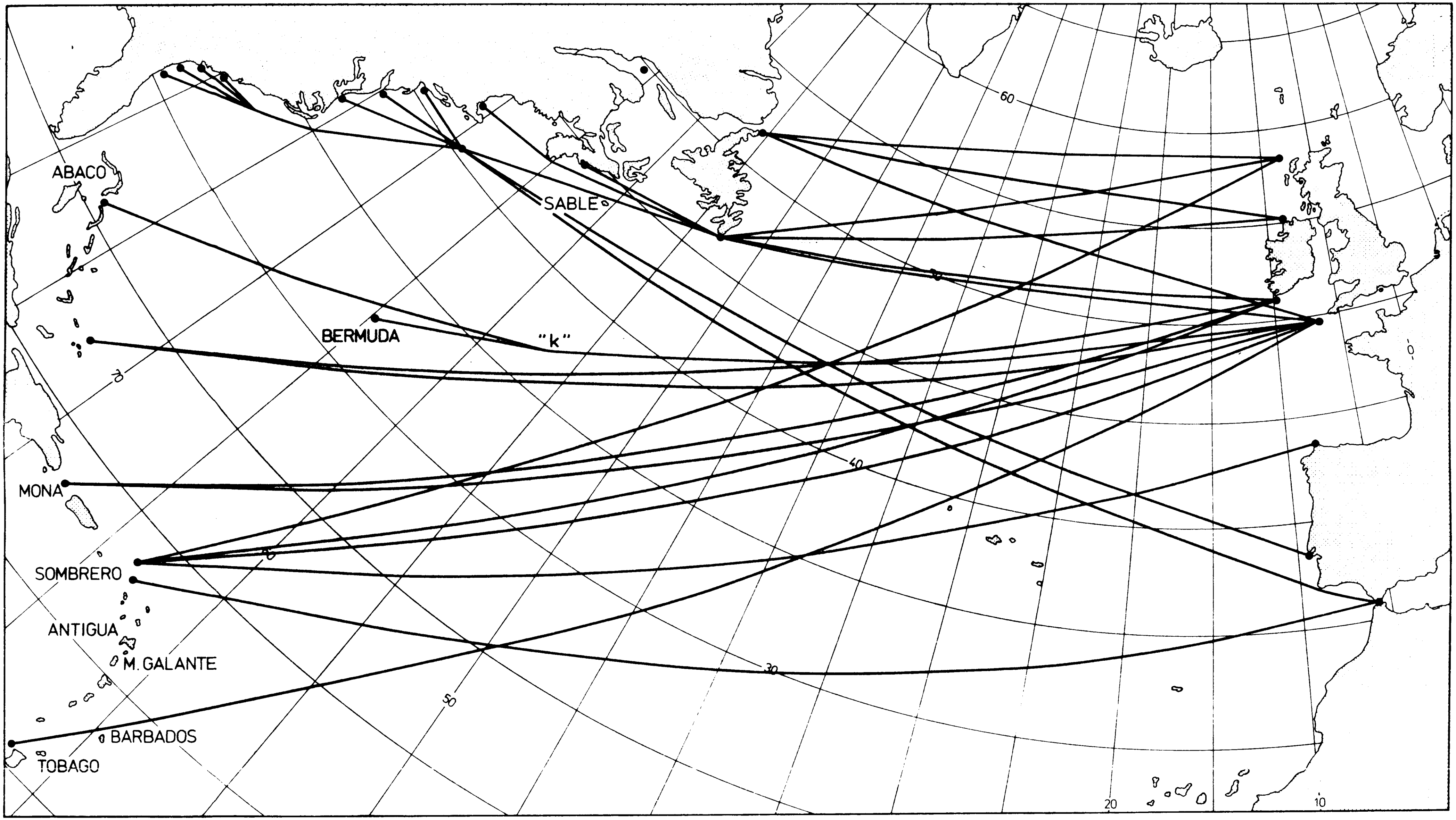

FIGURE 1. A SURVEY OF THE OCEAN LEGS OF THE MOST IMPORTANT ROUTES

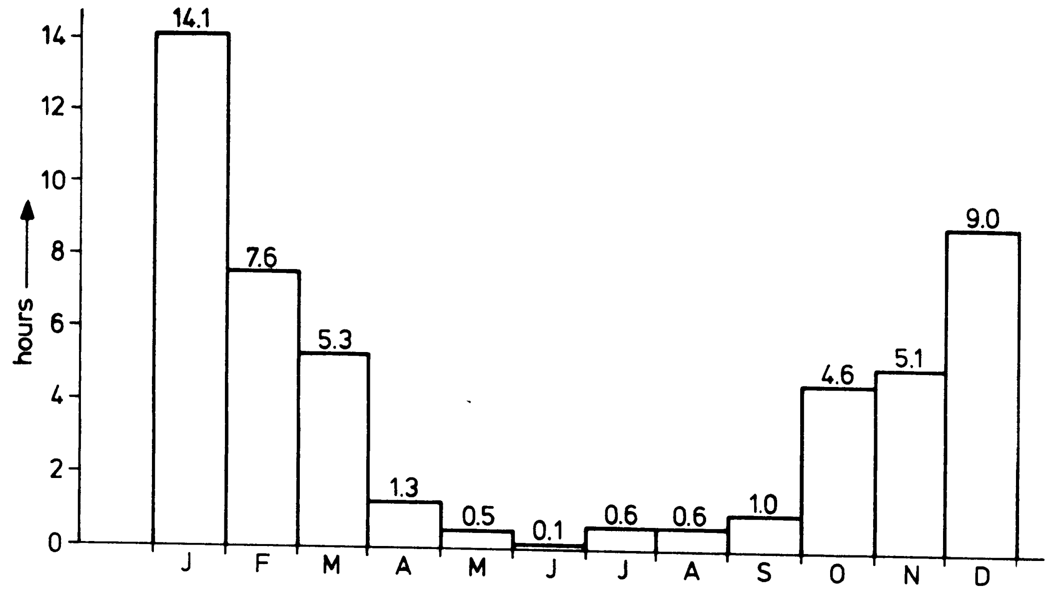

Figure 5. Europe - Caribbean Sea, freighters. Mean time gains per month with respect to the greatcircle.

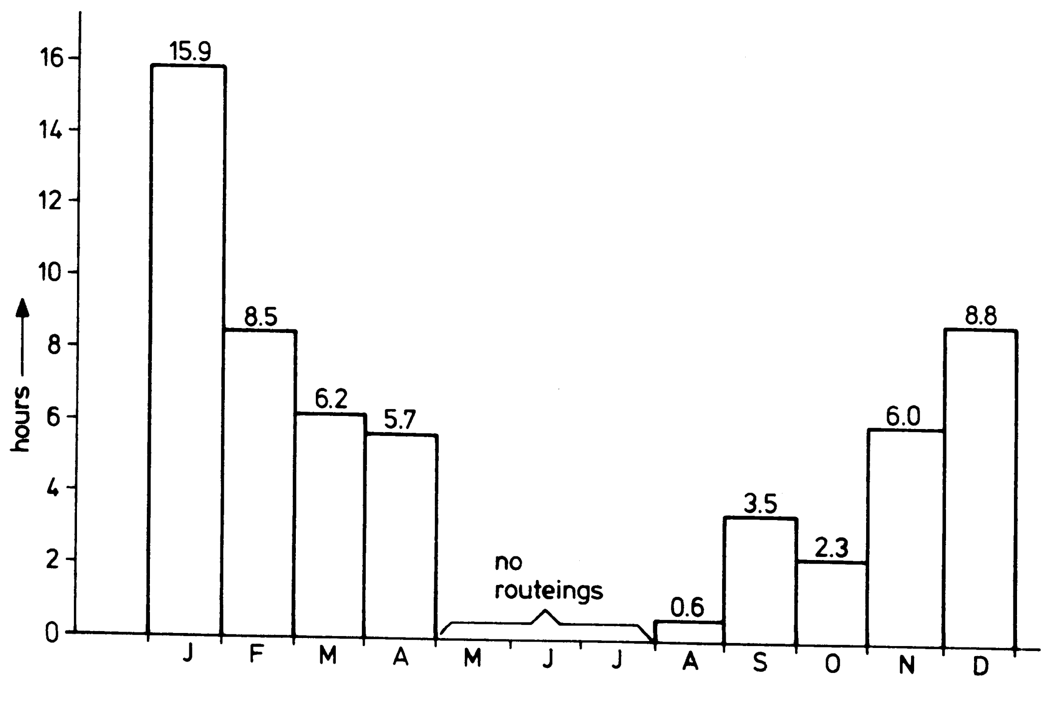

Figure 6. Europe - Caribbean Sea, tankers. Mean time gains per month with respedt to the greatcircle.

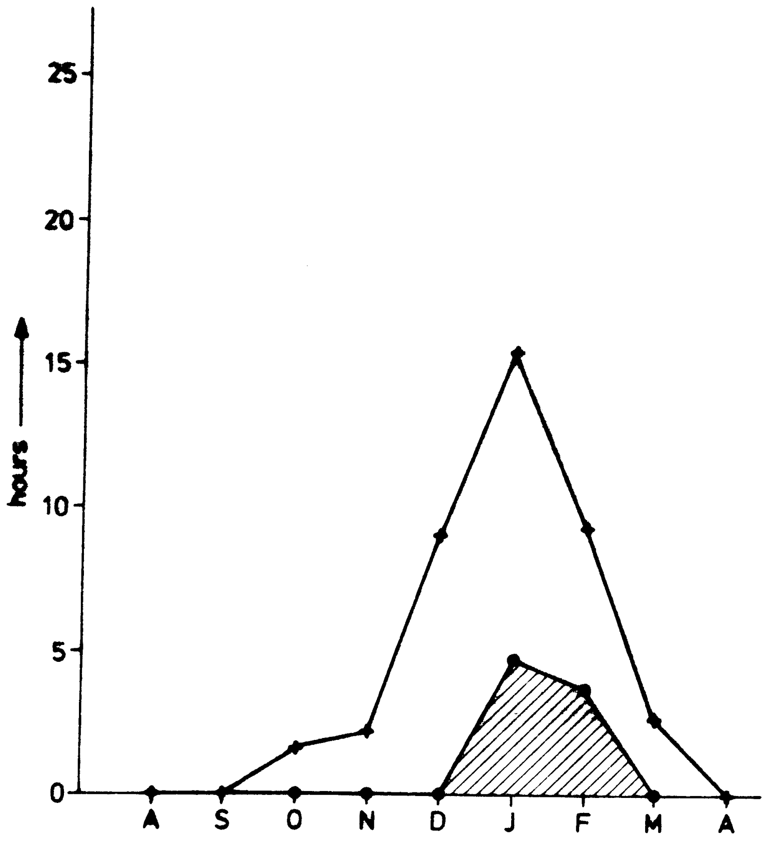

Figure 7. Europe - Caribbean Sea, freighters. Mean monthly numbers of hours with adverse waves ≥ 6 metres on the advised routes (dots) and on the great-circle (crosses).

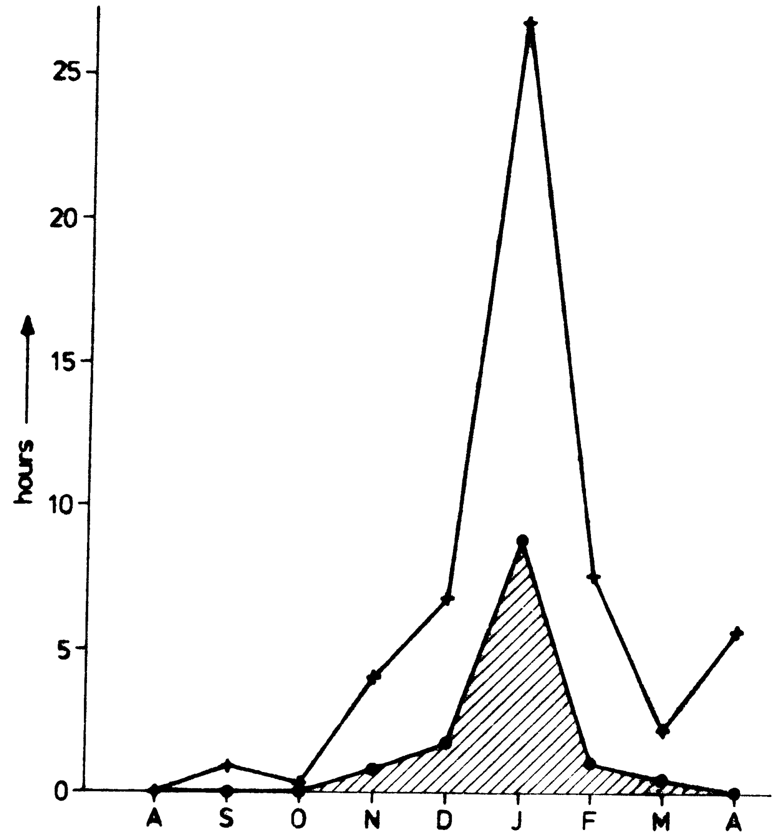

Figure 8. Europe - Caribbean Sea, tankers. Mean monthly numbers of hours with adverse waves ≥ 6 metres on the advised routes (dots) and on the great-circle (crosses).

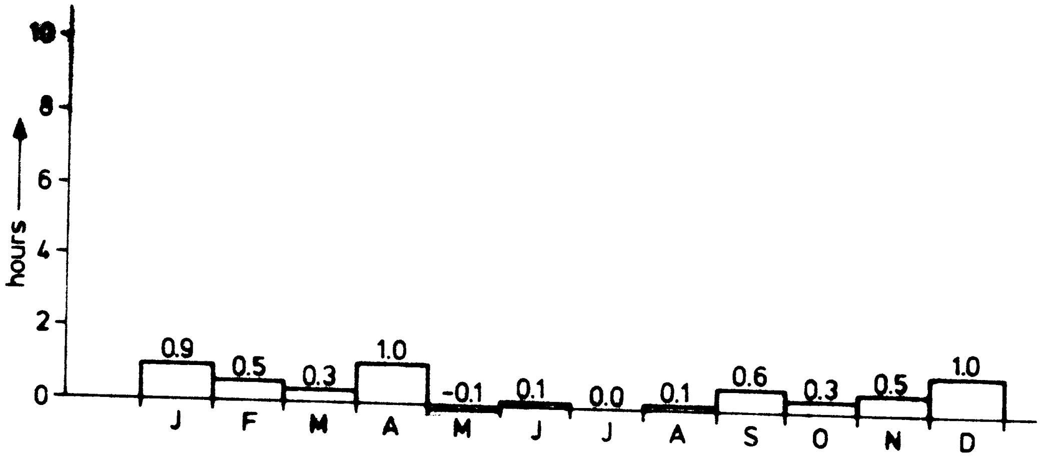

Figure 9. Caribbean Sea - Europe, freighters. Mean time gains per month with respect to the greatcircle.

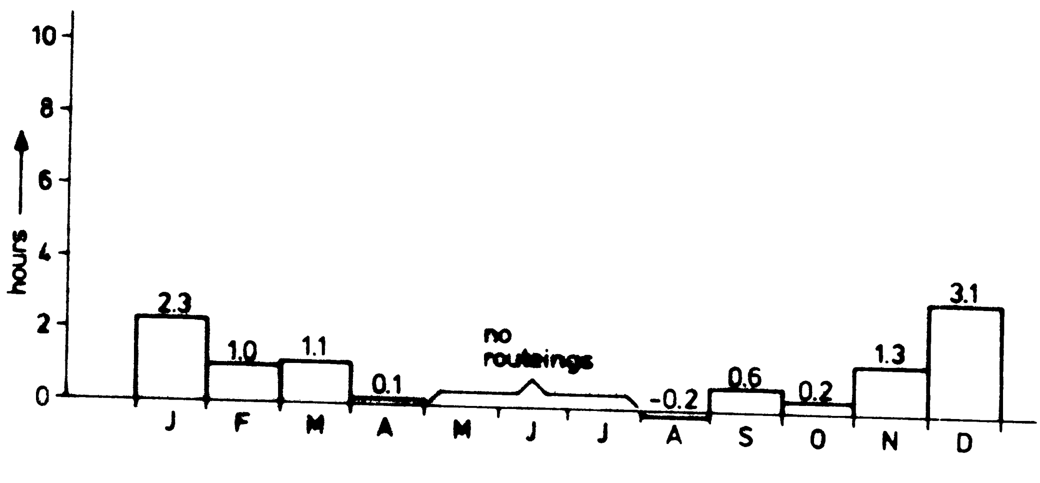

Figure 10. Caribbean Sea - Europe, tankers. Mean time gains per month with respect to the greatcircle.

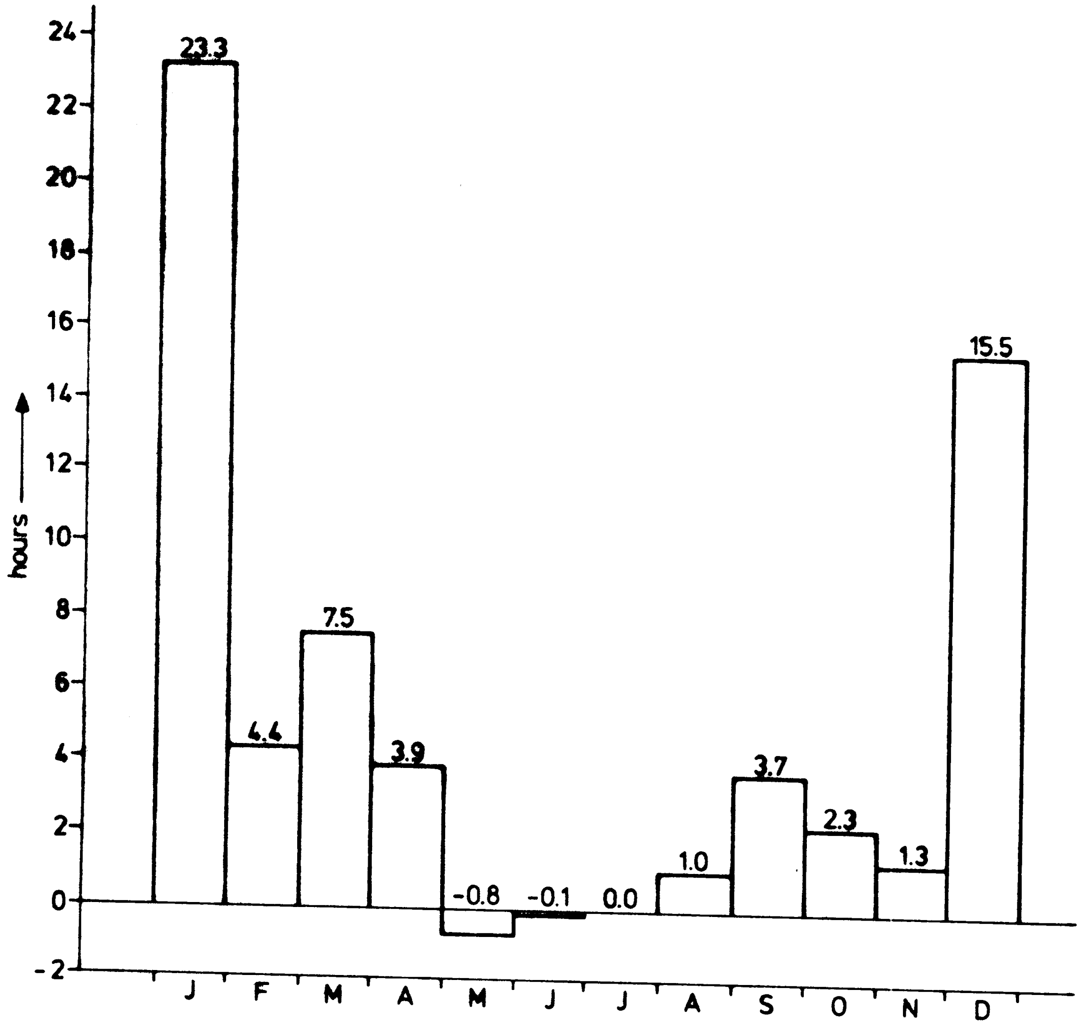

Figure 11. Europe - Gulf of Mexico. Mean time gains per month with respect to the K-route.

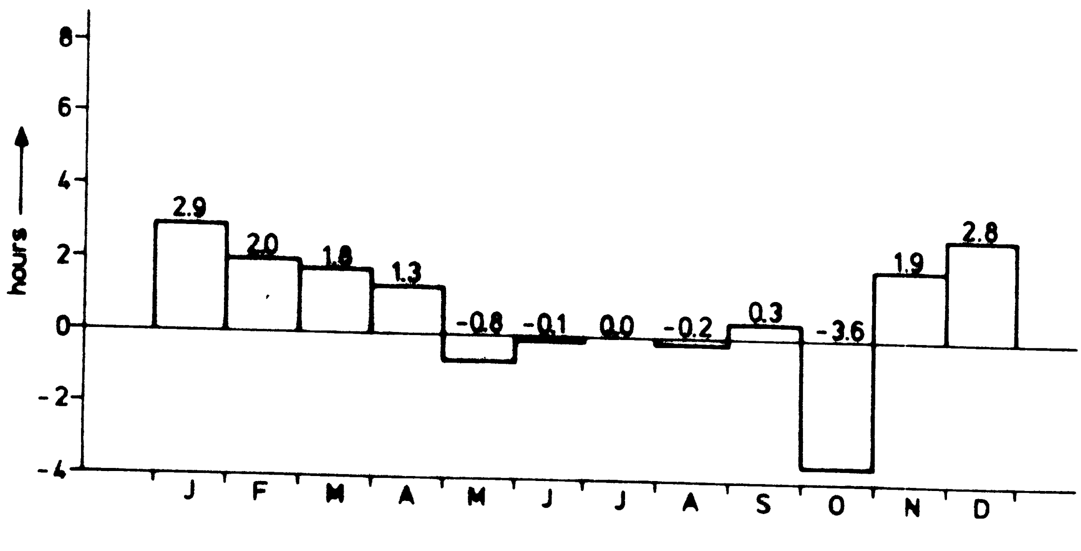

Figure 12. Gulf of Mexico - Europe. Mean time gains per month with respect to the combined Gulfstream C-track.

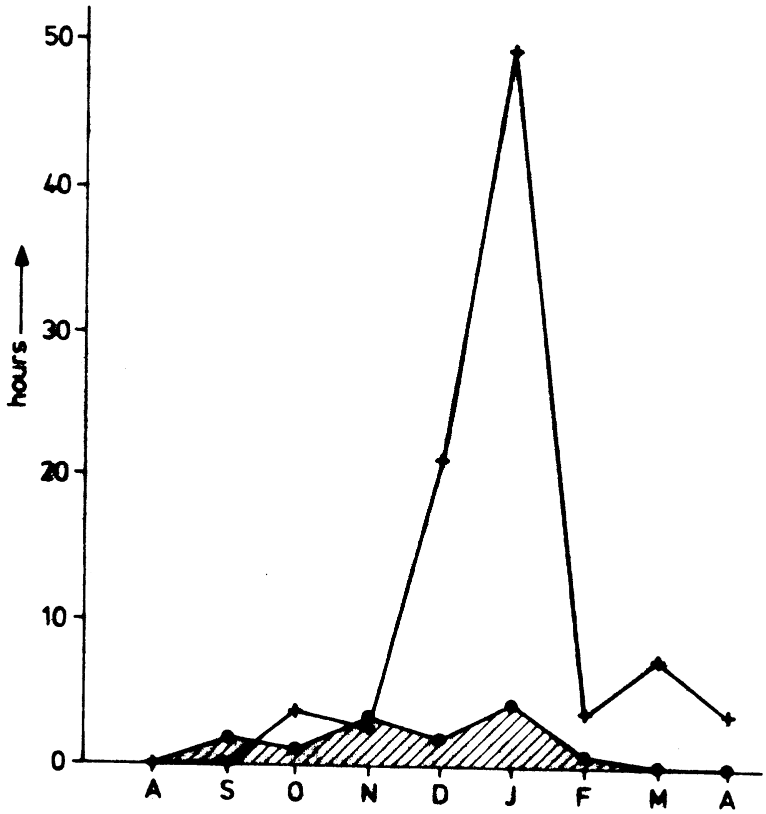

Figure 13. Europe - Gulf of Mexico. Mean monthly number of hours with adverse waves ≥ 6 metres on the advised routes (dots) and on the K-route (crosses).

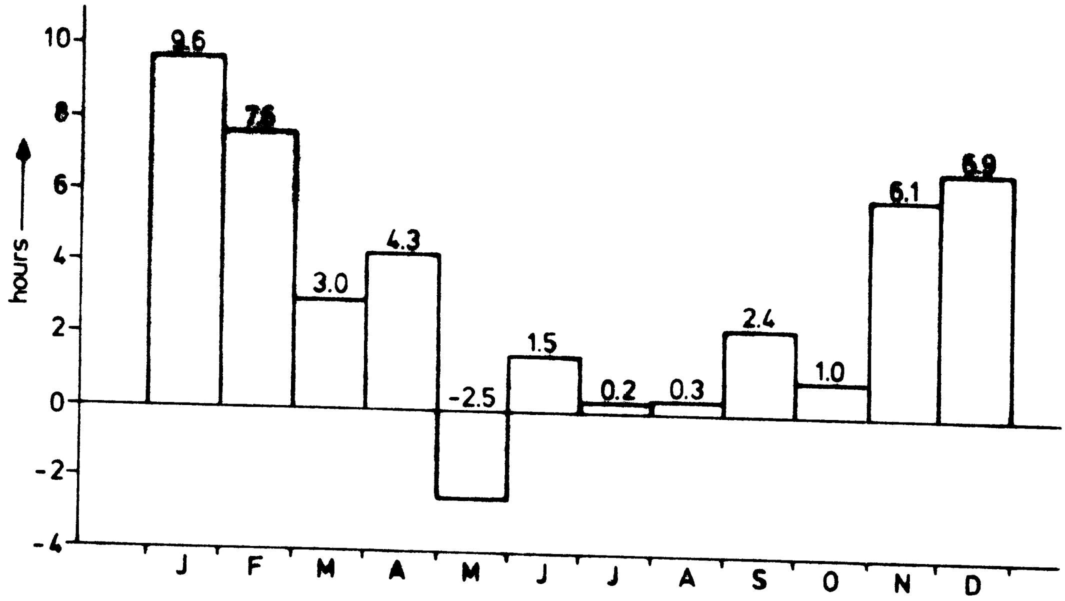

Figure 14. Europe - Bermuda. Mean time gains per month with respect to the greatcircle.

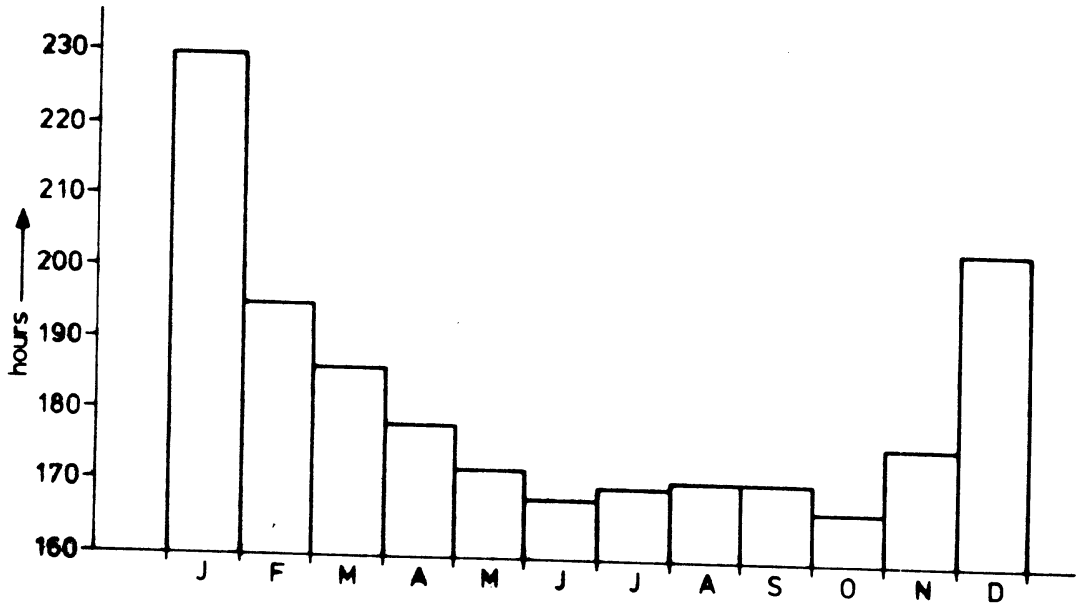

Figure 15. Europe - Bermuda. Mean duration of voyages per month.

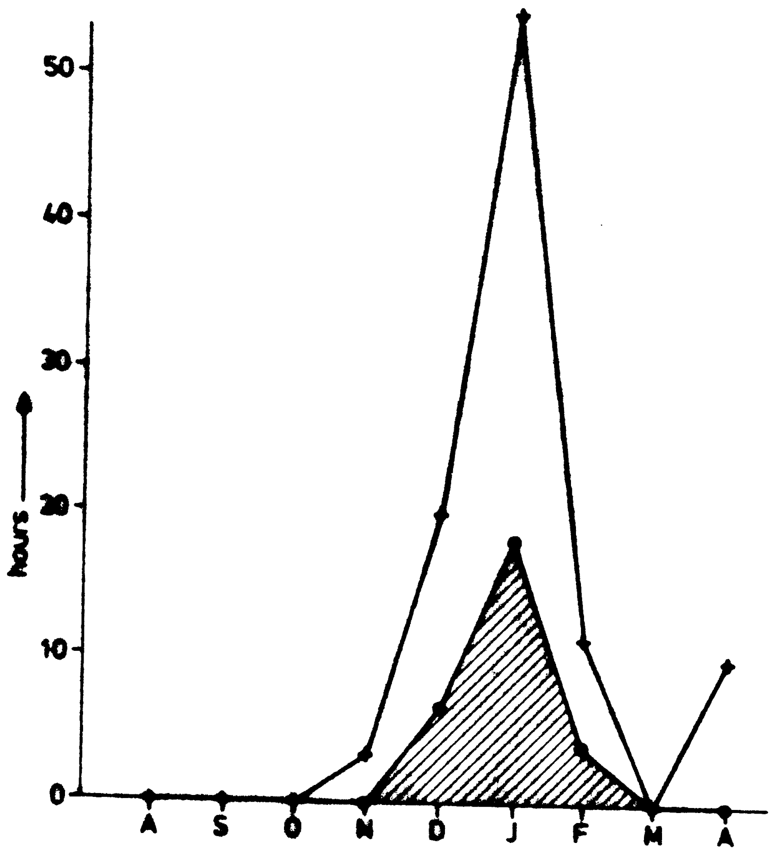

Figure 16. Europe - Bermuda. Mean monthly numbers of hours with adverse waves ≥ 6 metres on the advised routes (dots) and on the greatcircle (crosses).

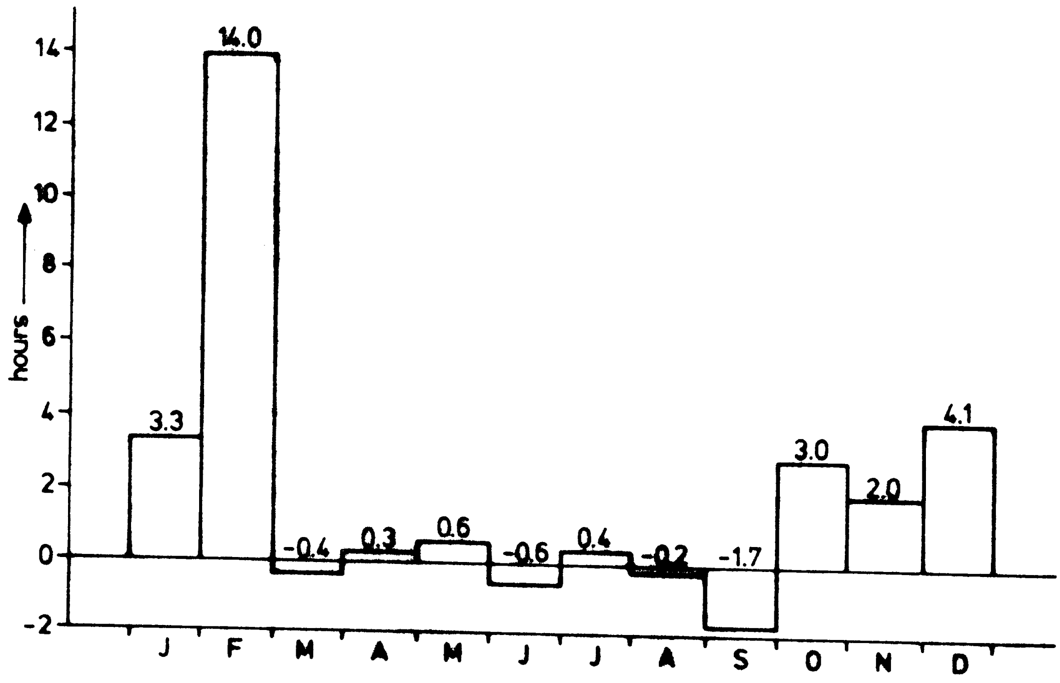

Figure 17. Europe - Charleston, Savannah, etc.. Mean time gains per month with respect to the greatcircle.

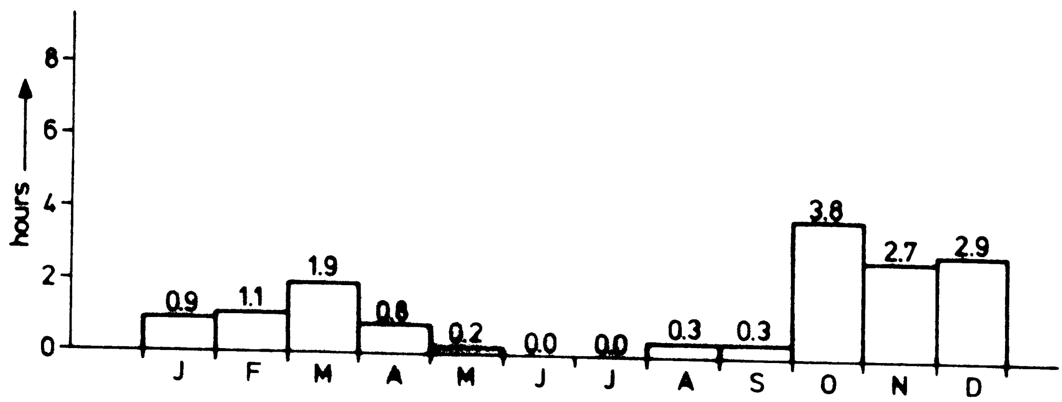

Figure 18. Charleston, Savannah, etc. - Europe. Mean time gains per month with respect to the greatcircle.

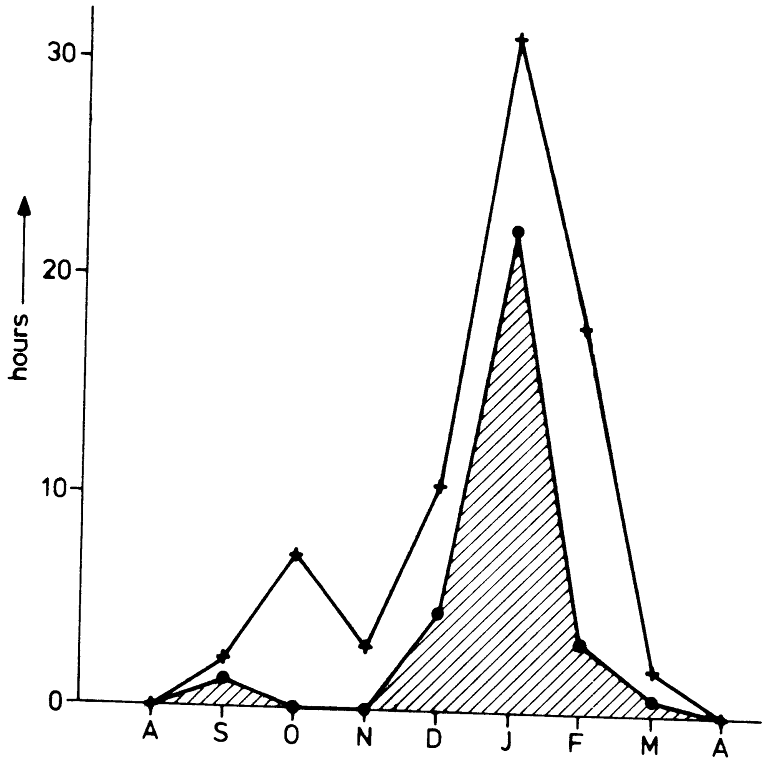

Figure 19. Europe - Charleston, Savannah, etc.. Mean monthly numbers of hours with adverse waves ⩾ 6 metres on the advised routes (dots) and on the greatcircle (crosses).

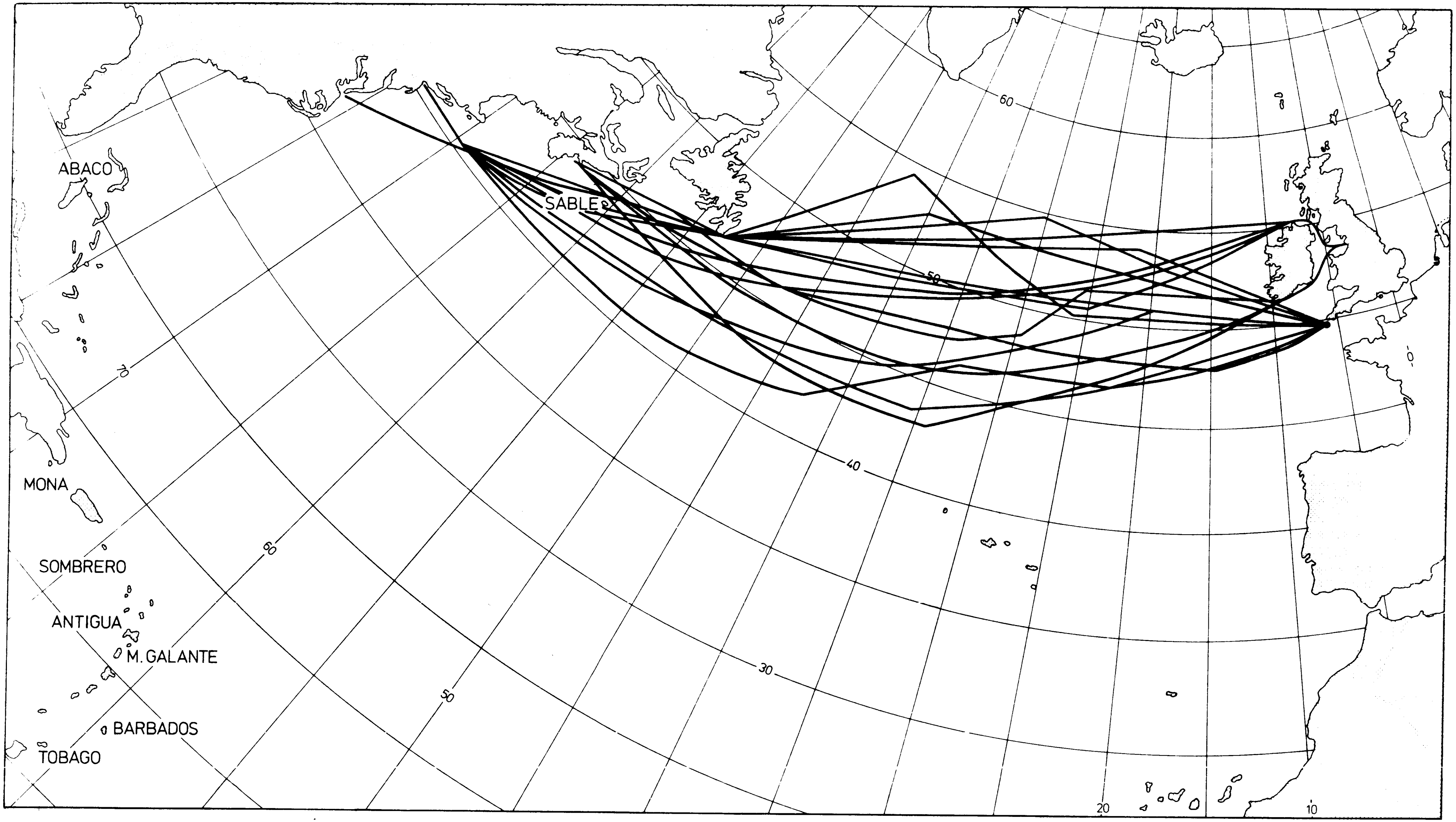

FIGURE 20. AN ASSEMBLY OF THE ROUTES ADVISED TO WESTBOUND CONTAINER SHIPS DURING THE WINTER SEASON 1973 - 1974.

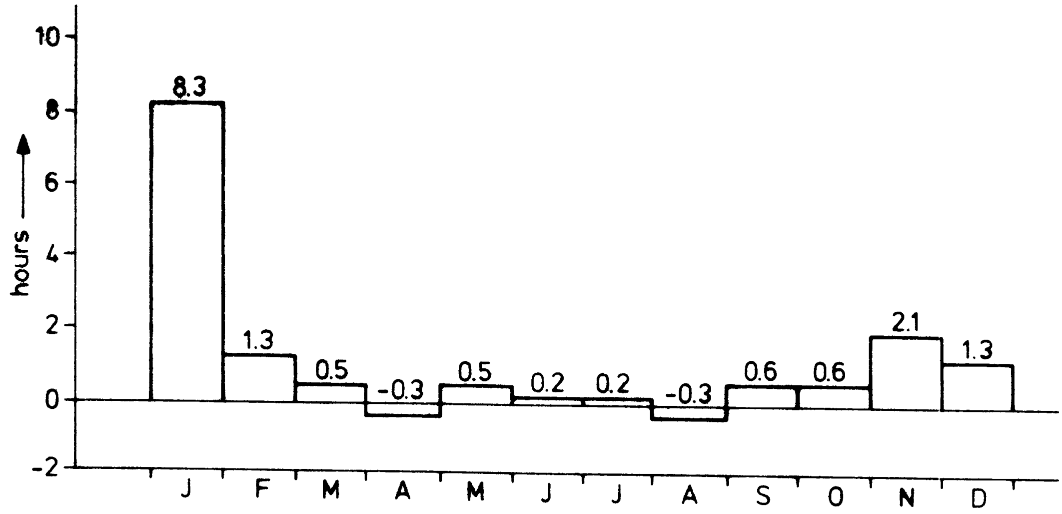

Figure 21. Europe - New York etc., container ships. Mean time gains per month with respect to the greatcircle.

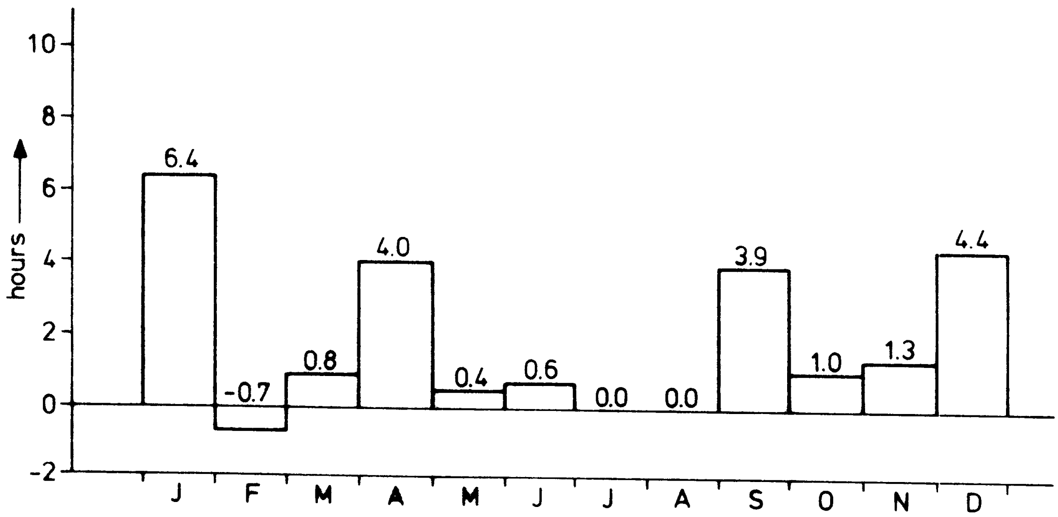

Figure 22. Europe - New York, etc., conventional freighters. Mean time gains per month with respect to the greatcircle.

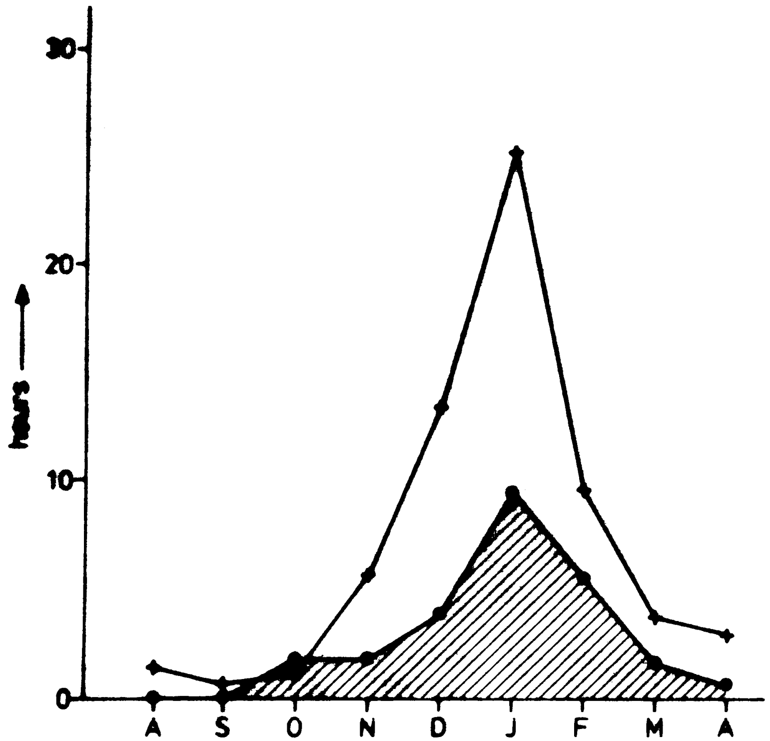

Figure 23. Europe - New York, etc., container ships. Mean monthly numbers of hours with adverse waves ⩾ 6 metres on the advised routes (dots) and on the greatcircle (crosses).

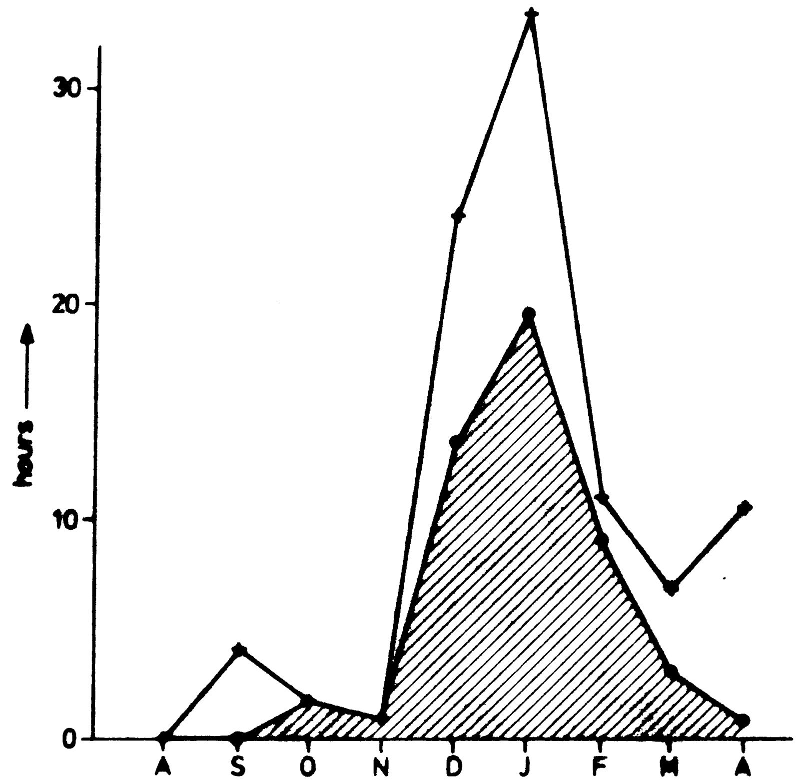

Figure 24. Europe - New York, etc., conventional freighters. Mean monthly numbers of hours with adverse waves ⩾ 6 metres on the advised routes (dots) and on the great-circle (crosses).

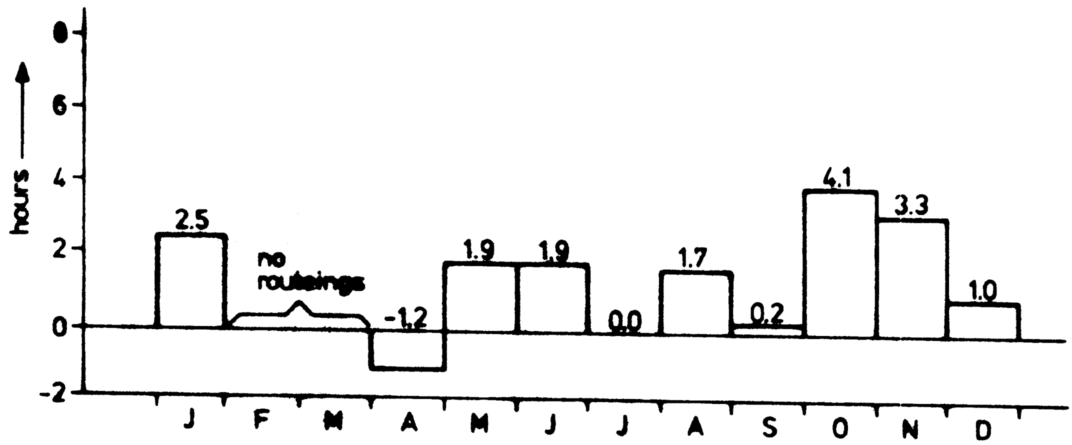

Figure 25. Europe - St. Lawrence. Mean time gains per month with respect to the greatcircle.