Analysis and Selection of Shipping Route in Ocean

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Abstract—This electronic document is a “live” template. Ocean navigation is a long-distance cross ocean navigation. There are three kinds of ocean routes in common use: great circle route, rhumb line route and mixed route. The great circle route is usually used when ships are sailing in the ocean, but sometimes in the mid latitude sea area, the rhumb line route is a choice in the mid latitude sea area. Combined with the calculation of a navigation example, this paper makes some analysis on the selection of ocean routes in mid latitude sea area, illustrates the advantages and disadvantages of these three ocean routes with data, and draws a conclusion on how to choose the routes.

1. Introduction
When a ship is sailing in the ocean, the ocean route can be divided into climatic route and weather route according to the hydrometeorological factors that may be encountered on the route. But usually in ocean navigation, the two places are far away. According to the specific situation, the whole voyage may not use a fixed route, so the commonly used ocean routes can be divided into three kinds of routes: great circle route, rhumb line route and mixed route, each of which has its own advantages and disadvantages[1].

Although the voyage of Great circle route is short, if the ship has been sailing through the sea area with great influence of wind and current, it will not only affect the safety of the ship, but also reduce the operation efficiency; Although the rhumb line route is easy to operate, if the pilot chooses it wantonly, it will certainly lead to the prolongation of the sailing time and greatly reduce the operating efficiency. Therefore, as a ship pilot, he should carefully analyze all kinds of navigation conditions and navigation factors, and get the best route suitable for the navigation environment at that time. On the premise of ensuring safety, the purpose of this paper is to design the shortest and most economical route to guide ships from the port of departure to the port of destination safely and economically.

In order to reduce fuel consumption and save navigation time, the great circle method is often used in ocean navigation, especially in high latitude sea area. But in the middle latitude sea area, sometimes when the rhumb line route is used as the ocean route, although the voyage is longer than the great circle route, the navigation safety of the ship may be higher, and the navigation operation is simpler[2].

The following is an analysis of the three main routes in ocean navigation.
2. Great Circle Route

When sailing in the ocean, especially when the route is east-west, and the route passes through a higher latitude and has a larger cross longitude difference, the great circle voyage will often shorten the distance by hundreds of nautical miles compared with the rhumb line route voyage. Generally, the great circle route will be selected for ocean navigation\[3\].

(1) The formula for calculating the great circle voyage is as follows:

$$\cos S = \sin \phi_1 \cdot \sin \phi_2 + \cos \phi_1 \cdot \cos \phi_2 \cdot \cos D \lambda$$

Where:

$\phi_1$ is the latitude of the starting point of the ship’s sailing;

$\phi_2$ is the latitude of the ship’s sailing arrival point;

$D \lambda$ is the difference between the starting point and the destination of the ship\[4\].

For example, a ship departs from Yokosuka (135°20′N, 114°00′E) in Japan and arrives at Seattle (246°20′N, 2124°30′W) in the United States. First, the longitude difference $D \lambda$ between the two places is calculated to be 102 ° 06 ′ E, then, the latitude $\phi_1$ of Yokosuka port, the latitude $\phi_2$ of Seattle port and the longitude difference $D \lambda$ between the two points are replaced by formula (1).

$$S = \arccos(\sin35°20′\cdot\sin46°20′ + \cos35°20′\cdot\cos46°20′\cdot\cos95°30′)$$

$$= 4118\text{ (n mile)}$$

(2) The starting course $C_1$ of the great circle route: because the course of the great circle route is constantly changing, it is calculated with the starting course.

The starting course $C_1$ of the great circle route is as follows:

$$\tan C_1 = \frac{\sin D \lambda}{\cos \phi_1 \cdot \tan \phi_2 - \sin \phi_1 \cdot \cos D \lambda}$$

In the example, the latitude of Yokosuka port $\phi_1$ 35°20′N, the latitude of Seattle port $\phi_2$ 46°20′N and the longitude difference $D \lambda$ 95°30′E are replaced by (2) to obtain the starting course $C_1$ of the great circle route.

$$C_1 = \arctan[\sin D \lambda/( \cos \phi_1 \cdot \tan \phi_2 - \sin \phi_1 \cdot \cos D \lambda)]$$

$$= 47° 30′\text{ NE}=047° 30′$$

(3) Route vertex: the route vertex is the highest latitude point that the great circle reaches (passes through). By calculating the route vertex, we can judge whether the great circle route exceeds the limit latitude circle.

Vertex latitude $\phi_{\text{max}}$:

$$\cos\phi_{\text{max}} = \cos \phi_1 \cdot \sin C_1$$

Substituting the initial heading $C_1$ calculated in front into equation (3), $\phi_{\text{max}}$:

$$\phi_{\text{max}} = \arccos(\cos \phi_1 \cdot \sin C_1)$$

$$= \arccos(\cos35° \cdot 20′ \cdot \sin47° 30′)$$

$$= 52° 58′ \text{ N}$$

(4) The implementation of the route. Except for the meridian circle and the equator, the intersection angles of the great arc and the meridians are not equal on the earth. In order to strictly implement the great arc navigation, we must constantly change the ship’s course, which is difficult to implement in the actual ship navigation. Generally, there are two ways to navigate along the great circle route: along the chord and along the tangent line. The great arc is divided into several segments, and each segment is still sailing according to the rhumb line route. The whole route is basically close to the great arc, as shown in Figure 1 and Figure 2.
At present, ocean going ships are widely equipped with radio navigators (GPS, etc.), which can not only provide accurate position information, but also have navigation function, special calculation function, high degree of automation and easy operation. Therefore, when the ship is sailing in the ocean, it can make full use of the radio navigator to play its role in ocean navigation.

3. Mixed Line Route

In order to avoid the bad weather conditions or dangerous areas of islands and reefs in the high latitude sea area, the route should not exceed a certain limited latitude. In this case, the shortest distance route combining the great circle route and the isolatitude circle route in the limited latitude is the mixed route.

The mixed navigation method is the combination of the great circle navigation method and the rhumb line route navigation method in the ocean voyage. The great circle route and the rhumb line route used in this method are combined to form a mixed route. For example, take the 50 ° N latitude circle as the limiting latitude circle, use the great circle navigation method when the latitude is higher than 50 ° n, and use the rhumb line route navigation method when the latitude is lower than 50 ° n, as shown in Figure 3.

The first section AM: the great circle route from the departure point A to the tangent point M which is tangent to the restricted latitude, as shown in Figure 3;

The second segment MN: the course of the rhumb line route along the isolatitude circle from the tangent point M to the tangent point N on the restricted latitude circle, as shown in Figure 3;

The third segment NB: the great circle route from the tangent point N tangent to the restricted latitude to the arrival point B, as shown in Figure 3.
(1) The determination of rhumb line route and great circle line. Two intersections (50°N, 170°45′E, 50°N, 136°35′E) between the great circle route and the 50° N latitude circle are taken as the tangent points of the mixed route. From the starting point to the destination of tangent point m and tangent point n, it is located in the middle and low latitude sea area and navigates on the rhumb line route; Between the tangent point M (50°N, 170°45′E) and the tangent point N (50°N, 136°35′E), they are in the high latitude sea area and use the great circle route.

(2) The range of mixed routes. The range of the mixed route consists of two sections of rhumb line route and one section of great circle route.

① The great circle range S1 of tangent point M and tangent point N
\[ S_1 = \arccos(\sin 50° \cdot \sin 50° + \cos 50° \cdot \cos 50° \cdot \cos 52°42′) \]
= 1989 (n mile)

② The rhumb line route S2 from starting point A to tangent point M:
If the earth is regarded as a sphere, according to the formula of latitude increasing rate of Mercator chart:
\[ MP = 7915.70447 \log \left( \frac{\pi}{4} + \frac{1}{2} \left( \frac{1 - e \sin \varphi}{1 + e \sin \varphi} \right) \right)^{e/2} \]
The values of MP_A and MP_M are calculated respectively, and then the difference DMP between the starting point A and the tangent point M is obtained.
DMP = MP_A - MP_M = 1200 NAM
Longitude difference: D_λ = 1845 E, latitude difference: D_δ = 880 N
Course of rhumb line route: TC = \arctan(D_λ / DMP)
= \arctan(1845 E / 1200 N) = 57° NE = 057°
The rhumb line route S_2 from starting point A to tangent point M:
S_2 = D_δ \times \sec TC = 880 \times \sec 057° = 1616 (n mile)
③ Range S3 from tangent point N to arrival point B:
If the earth is regarded as a sphere, according to the formula of latitude increasing rate of Mercator chart:
\[ MP = 7915.70447 \log \left( \frac{\pi}{4} + \frac{1}{2} \left( \frac{1 - e \sin \varphi}{1 + e \sin \varphi} \right) \right)^{e/2} \]
The values of MP_N and MP_B are calculated respectively, and then the difference DMP between the tangent point n and the arrival point B is obtained.
DMP = MP_N - MP_B = 301 S
Longitude difference: D_λ = 725 E, latitude difference: D_δ = 220 S
Course of rhumb line route: TC = \arctan(D_λ / DMP)
= \arctan(725 E / 301 S) = 67°30′ SE = 112°30′
The range from tangent point N to arrival point B S_3:
S_3 = D_δ \times \sec TC = (220 S) \times \sec (112°30′) = (-220 S) \times \sec (112°30′) = 574.9 (n mile)
④ Mixed route S:
S = S_1 + S_2 + S_3 = 1989 + 1616 + 574.9 = 4179.9 (n mile)

(3) The top of the line. The vertex of the mixed route is at the top of the middle great circle route: 52°58′N.

4. Rhumb Line Route
When a ship is always sailing in a rhumb line route, the theoretical trajectory of the ship is called a rhumb line route. A rhumb line route is a curve on the earth's surface. It intersects all meridians at the same angle, so it is also called an equiangular line.

The rhumb line route is a logarithmic spiral curve on the earth, which is not the shortest route. For example, in the previous example, the ordinary rhumb line route navigation method is used, and the
voyage is 4384.8 n miles, which is 205 n miles longer than that of the mixed route. Therefore, the great circle navigation method is generally used in ocean navigation. But when sailing in the middle latitude sea area, using the one-time steering rhumb line route as the ocean route, its voyage is not much more than the great circle navigation method, but its operation is simple, and it can avoid entering the high latitude sea area. The one-time steering rhumb line route method only uses two equal angle routes to connect the starting point and the arrival point. One section is the rhumb line route.

Connecting the starting point, and the other section is parallel to the latitude circle and connected to the destination. The intersection of the two routes is the only turning point.

(1) The starting point is at low latitude. One section is the rhumb line connecting the points at lower latitudes, and the other is parallel to the latitude circle and connecting another point at higher latitudes. The intersection of the two routes is the only turning point.

The key of one turn rhumb line method is to determine the turning point to minimize the sum of the two routes. The voyage from the starting point to the destination D:

$$D = D_\phi \cdot \cos \phi_2 - (D_\lambda - DMP \cdot \tan TC) \cdot \cos \phi_2$$  

Where: $D_\phi$ is the latitude difference between the starting point and the destination, in minutes; $D_\lambda$ is the longitude difference between the starting point and the destination, in minutes; DMP is the difference of latitude increasing rate between the starting point and the destination, in minutes; $\phi_2$ is the latitude of the destination; TC is the heading from low latitude.

In order to find the heading TC with the minimum distance, the right side of formula (4) is used to derive TC and make it 0.

$$D_\phi \cdot \tan TC \cdot \sec TC = DMP \cdot \cos D_\phi \cdot \sec \phi_2$$

After simplification, we get the following conclusions.

$$D_\phi \cdot \tan TC = DMP \cdot \cos \phi_2 \cdot \sec \phi_2 = 0$$

$$TC = \arcsin (DMP \cdot \cos \phi_2 / D_\phi)$$

Calculate the latitude difference of the starting point and destination in the example: $D_\phi = 660.0'N$; The difference of longitude: $D_\lambda = 5730.0'E$; The rate difference of growing latitude is as follows

$$DMP = 7915 \cdot 70447 \times \lg [\tan (\pi/4 + \phi_2 / 2) / \tan (\pi/4 + \phi_1 / 2)]$$

$$= 876.6'$$

By substituting the above data into equation (6), it is concluded that:

$$TC = \arcsin (DMP \cdot \cos \phi_2 / D_\phi)$$

$$= (876.6' \cos 46.20' / 660.0')$$

$$= 66.30'NE = 066°30'$$

By substituting it into equation (4), we get the following result:

$$D = 660' \times \sec 66.30' + (5730 - 876.6' \times \tan 66.30') \times \cos 46.20' = 4219.5$$

The peak of the route is 46°20'N.

(2) The starting point is at high latitude. One section is a rhumb line connecting the points at higher latitudes, and the other section is parallel to the latitude circle and connecting another point at lower latitudes. The calculation process is exactly the same as the starting point at low latitude, but the course of the route is different.

(3) Navigation control. The operation of one turn rhumb line method is relatively simple, and the whole route has only one turn.
5. Comparison of Routes of Great Circle route, Rhumb Line Route and Mixed Route

Table 1 Comparison of Routes

| Port of departure and port of destination          | Three routes | voyage (n mile) | Vertex latitude | Maneuverability                            |
|---------------------------------------------------|--------------|----------------|-----------------|--------------------------------------------|
| Yokosuka, Japan ($\phi 35°20′N, \lambda 140°00′E$) | Great circle route | 4118           | 52°58′N        | It’s not convenient to operate, and it turns at any time, but it has the shortest voyage |
|                                                   | Mixed routes  | 4180           | 52°58′N        | The control is general and the course is sometimes fixed |
| Seattle in the United States ($\phi 46°20′N, \lambda 124°30′W$) | Rhumb Line Route | 4219.5         | 46°20′N        | The range is the longest, but it is easy to operate and the course is fixed |

5.1. Range, Vertex Latitude

It can be seen from table 1 that the great circle route has the shortest voyage, which is 4118 n miles; The range of the mixed route is 4180 n miles, which is shorter than the range of 4219.5 n miles of the one turn rhumb line. However, the vertex latitude of the great circle route or the mixed route is 52°58′N, which is about 6 °38′ higher than that of the one turn rhumb line method. That is to say, the middle section of the great circle route or the mixed route may cross the high latitude sea area, and navigation in the high latitude sea area will often encounter bad weather, especially in the northern hemisphere, which is quite unfavorable to the navigation safety of ships.

5.2. Navigation Maneuverability

On the earth, except for the meridian circle and the equator, the course of each point on the great circle route changes. For the convenience of execution, the large arc is actually divided into several sections, and each section is navigated according to the rhumb line route, and the whole route is basically close to the large arc. But dividing the great circle route into several equal angle routes will not only reduce the effect of the great circle route in saving the voyage, but also make the actual execution inconvenient because of changing the course for many times. The operation of one turn rhumb line method is simple, and the whole route only turns once. The hybrid navigation method is more complicated in calculation and control than the one turn rhumb line route method.

6. Conclusion

In order to avoid the bad weather in the high latitude sea area, the one-time steering rhumb line route method is one of the choices in the mid latitude sea area.

As a ship pilot, he should carefully analyze all kinds of navigation conditions and navigation factors, and get the best route suitable for the navigation environment at that time. On the premise of ensuring safety, the shortest and most economical route is designed to guide ships from the port of departure to the port of destination safely and economically.

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