



*Numerical Modeling Article*

# The Application of Trigonometry in Ship Navigation Direction Determination to Improve Sailing Accuracy

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**Abstract:** This article examines the use of trigonometry in determining ship navigation directions to improve sailing accuracy. The main problem discussed is route deviation caused by inaccurate bearing interpretation, current, wind, and limited manual verification of electronic navigation data. The research used a descriptive qualitative method through literature study and mathematical simulation. Data were analyzed with right-triangle relationships, arctangent, bearing conversion, distance estimation, and simple course-correction procedures. The simulations show that trigonometry helps navigators calculate heading direction, direct distance, lateral deviation, estimated arrival time, and correction angle. A movement of 30 km east and 40 km north produces a bearing of 36.87 degrees with a direct distance of 50 km. A 5 km eastward deviation during a 60 km northward track requires a 4.76-degree correction to the west. The novelty of this article lies in presenting trigonometry as a contextual bridge between mathematical concepts and practical maritime decision making. The implication is that trigonometric literacy supports safer, more efficient, and more accurate navigation, especially when electronic systems need to be checked manually.

**Keywords:** trigonometry; ship navigation; bearing; sailing accuracy; course correction

## 1. Introduction

Ship navigation is the process of determining a vessel's position, direction, route, speed, and movement correction so that voyages at sea can be carried out safely and accurately. In navigation, a ship does not merely move from one point to another, but also faces changing environmental conditions such as currents, waves, wind, limited visibility, and dense maritime traffic [1], [2]. Therefore, the ability to determine direction accurately is an important element in maritime safety.

Indonesia's archipelagic geography makes shipping important for inter-island connectivity, logistics, fisheries, tourism, and port operations [3]. Many routes pass through straits, shallow waters, coral areas, and congested port approaches. In such conditions, a small angular error may become a large positional deviation when accumulated over distance [4], [5]. This makes systematic direction calculation relevant

for both voyage planning and route monitoring

International maritime guidance also emphasizes navigation safety. SOLAS Chapter V addresses safety of navigation and provides the regulatory framework for navigational responsibilities, while bridge procedures and ECDIS guidance emphasize route planning, route monitoring, position verification, and proper use of navigational information [6], [7], [9]. These regulations and guidance documents show that navigation accuracy is not only a mathematical issue, but also a matter of safety management and operational responsibility [10].

A ship's direction is commonly represented by bearing. In this article, bearing is defined as an angle measured clockwise from north [11]. In actual navigation, the north reference may be true north or magnetic north, depending on the instrument and charting context [13], [14]. In this study, the simulation uses an assumed north in a local coordinate system to simplify the educational explanation. This convention must

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be stated clearly because different north references and angle conventions can lead to different interpretations of a heading [15], [16], [17].

Trigonometry studies relationships between angles and sides of triangles. In navigation, the east-west and north-south displacement components can be represented as the sides of a right triangle [8]. The bearing can be calculated using a tangent-based relationship, while the direct distance can be calculated using the Pythagorean theorem. When a vessel deviates from the planned route, the correction angle can also be estimated through the ratio between lateral deviation and forward distance [14], [15].

Modern navigation systems such as GPS, radar, ECDIS, and autopilot can generate position and heading information automatically. Nevertheless, ECDIS is a complex, safety-relevant system that requires appropriate understanding by officers and crews, not passive acceptance of electronic outputs [9], [10]. Trigonometric understanding remains useful for cross-checking instrument readings, interpreting discrepancies between heading and track, and making initial estimates during equipment limitations or signal disturbances [11].

Modern navigation systems such as GPS, radar, CDIS, and autopilot can generate position and heading information automatically. Nevertheless, ECDIS is a complex, safety-relevant system that requires appropriate understanding by officers and crews, not passive acceptance of electronic outputs [23], [24]. Trigonometric understanding remains useful for cross-checking instrument readings, interpreting discrepancies between heading and track, and making initial estimates during equipment limitations or signal disturbances [12], [18], [19].

The novelty of this article does not lie in proposing a new trigonometric formula. Navigation textbooks and nautical manuals already discuss direction, distance, bearings, and position fixing in greater technical detail. The novelty of this article lies in its structured educational simulation: it connects basic trigonometric formulas, calculation steps, navigation interpretation, figure-based visualization, and limitations of the simplified model in one coherent learning-oriented framework. Therefore, the article differs from navigation manuals that focus on professional operational procedures and from mathematics

learning studies that often do not translate calculations into maritime decision. The observation angles toward these objects can then be used to estimate the ship's position through triangulation. Thus, trigonometry functions as a basis for combining visual information and numerical information [21], [22], [23].

Based on the background above, this article aims to explain how trigonometry can support ship navigation direction determination in a simple educational simulation. The scope is limited to bearing calculation, direct distance, heading correction due to deviation, estimated time, and basic interpretation of triangulation. The study is intended for maritime education and introductory navigation training, not as a replacement for official bridge procedures, certified navigation training, or full geodetic navigation calculations.

## 2. Materials and Methods

### 2.1 Research Design

This study uses a descriptive qualitative approach supported by mathematical simulation. The descriptive approach is used to explain the relationship between trigonometric concepts and navigation decisions. The mathematical simulation is used to demonstrate how formulas are applied to a simplified ship movement scenario.

The position of this article is a conceptual and educational simulation study. It is conceptual because it synthesizes ideas from trigonometry and basic navigation. It is educational because the numerical scenarios are designed to clarify calculation mechanisms for learning purposes. The data are hypothetical and are not derived from actual ship track records, onboard observations, or sea trials.

The simulation is not intended to replace complete marine navigation calculations. Instead, it simplifies the situation into a local plane so that the relationship between displacement components, angle, distance, and correction can be observed clearly. This simplification is appropriate for introductory learning before students study geographic coordinates, compass error, set and drift, course to steer, and spherical trigonometry.

## 2.2 Simulation Assumptions and Angle Convention

The coordinate system used in the simulation is a local plane coordinate system. The ship's initial position is represented as point A. The destination or actual ship position is represented as another point on the same coordinate plane. The eastward component is denoted as Delta E ( $\Delta E$ ), while the northward component is denoted as Delta N ( $\Delta N$ ). Positive  $\Delta E$  indicates movement to the east, and positive  $\Delta N$  indicates movement to the north.

All bearing values in this study are measured clockwise from an assumed north in the local coordinate system. This means that  $0^\circ$  or  $360^\circ$  represents east,  $180^\circ$  represents south, and  $270^\circ$  represents west. Because the study uses an assumed local north for educational simplification, the results should not be interpreted directly as true bearings or magnetic bearings in actual navigation. In real operations, the navigator must account for chart reference, compass variation, compass deviation, gyro error, and instrument calibration.

The unit used in the numerical simulation is kilometers. In maritime navigation, nautical miles and knots are more common. Kilometers are used here only to make mathematical relationships easier to follow for students who are beginning to learn trigonometry. The use of kilometers does not change trigonometric principles because the formulas depend on ratios of distances. If needed, the simulated distances can be converted into nautical miles by using the relationship 1 nautical mile = 1.852 km.

## 2.3 Simulation Scenarios

Three simulation scenarios are used. The first scenario determines the ship's bearing and direct distance when the destination is located 30 km east and 40 km north of the initial position. The second scenario estimates heading correction when the ship should move northward but has deviated 5 km to the east after traveling 60 km. The third scenario estimates travel time by dividing distance by average speed.

The scenarios were selected because they represent three basic navigation tasks: planning a heading, monitoring deviation from a planned route, and estimating voyage duration. These tasks are simple, but they provide a useful bridge between mathematical formulas and navigation interpretation.

## 2.4 Instruments and Data Collection

The research instruments consisted of simulation sheets, calculation tables, and coordinate diagrams. The simulation sheets were used to record  $\Delta E$ ,  $\Delta N$ , lateral deviation, distance, speed, bearing, correction angle, and estimated time. The tables were used to organize numerical results, while the diagrams were used to visualize the relationship between the planned route, the actual position, and the required correction.

Data collection was conducted through theoretical documentation and the preparation of hypothetical numerical data. The documentation stage reviewed basic navigation concepts, bearing conventions, ECDIS related guidance, maritime training standards, and the mathematical relationship between angle and distance. The hypothetical data were then processed using formulas that are appropriate for a local-plane educational model.

## 2.5 Data Analysis Technique

Data analysis was conducted by converting ship movement into directional components. The ship's position change was expressed as displacement toward the east–west direction ( $\Delta E$ ) and north–south direction ( $\Delta N$ ). These components were then used to calculate bearing, distance, correction angle, and travel time.

The ship bearing was calculated using the following formula:

$$B = \left[ \left( \text{atan2}(\Delta E, \Delta N) \times \frac{180}{\pi} \right) + 360 \right] \text{mod } 360 \quad (1)$$

where  $B$  is the ship bearing angle measured clockwise from north,  $\Delta E$  is the eastward or westward displacement, and  $\Delta N$  is the northward or southward displacement.

The  $\text{atan2}$  function was used because it can determine the correct directional quadrant based on the signs of  $\Delta E$  and  $\Delta N$ . The direct distance between the ship's initial position and the destination point was calculated as:

$$d = \sqrt{(\Delta E)^2 + (\Delta N)^2} \quad (2)$$

where  $d$  is the direct distance from the initial point to the destination point. The correction angle was calculated to determine the required adjustment when the ship deviated from the planned route:

$$\alpha = \arctan \left( \frac{X}{S} \right) \quad (3)$$

where  $\alpha$  is the correction angle,  $X$  is the lateral deviation from the planned route, and  $S$  is the forward distance already traveled by the ship. Travel time was calculated using:

$$t = \frac{d}{v} \quad (4)$$

where  $t$  is the travel time,  $d$  is the direct distance, and  $v$  is the average ship speed. Overall, these equations were used to simulate ship navigation direction by determining the bearing angle, estimating the distance to the destination,

calculating the correction angle due to route deviation, and estimating the required travel time.

### 3. Results

#### 3.1. Bearing, Direct Distance, and Estimated Time

In the first scenario, the ship moves from point A to point B. The destination is located 30 km to the east and 40 km to the north of the initial position. Because the angle is measured clockwise from the assumed north, the bearing is calculated from the ratio between the eastward and northward components.

Table 2. Simulation results for bearing, direct distance, and estimated time

Scenario	$\Delta E$	$\Delta N$	Formula	Result	Interpretation
Bearing	30 km	40 km	$B = a \tan 2(30,40)$	36,87°	The ship is directed 36,87° east of north.
Direct distance	30 km	40 km	$d = \sqrt{((30)^2 + (40)^2)}$	50 km	The shortest distance from the initial position to the destination is 50 km.
Estimated time	-	-	$t = \frac{50}{20}$	2,5 hours	If the average speed is 20 km/h, the travel time is approximately 2.5 hours.

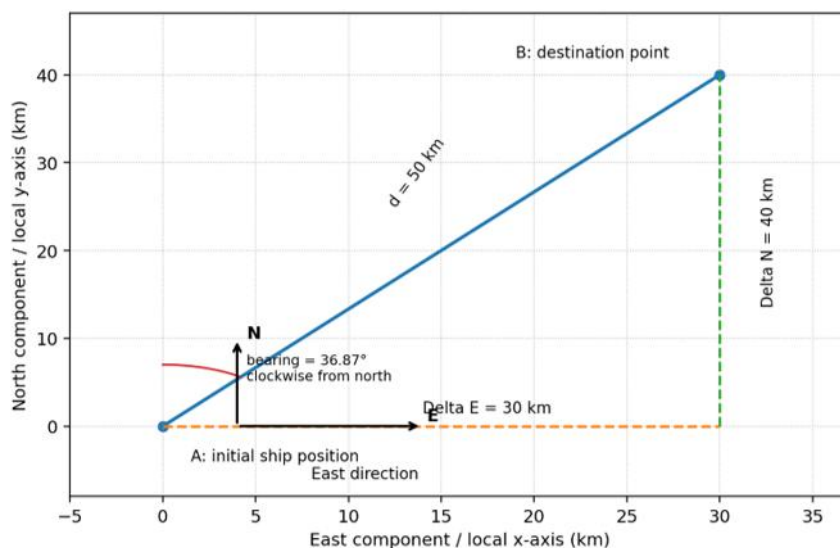


Figure 1. Navigation Triangle showing north, east, initial position, destination, bearing, and direct distance

The calculation produces a bearing of 36.87°. This means that the ship’s direction is 36.87° east of north in the local coordinate system. The direct distance is calculated using the Pythagorean

theorem and produces a result of 50 km. If the average speed is assumed to be 20 km/h, the estimated travel time is 2.5 hours. Figure 1 shows that bearing determination is essentially a

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process of reading the angle in a triangle. The eastern component acts as the opposite side to the angle measured from the north, while the northern component acts as the adjacent side. The ratio between these two sides produces tangent value. When the tangent value is converted through the arctangent function, the navigator obtains an angle that can be used as a heading reference.

### 3.2. Heading Correction Due to Deviation

In the second scenario, the ship is planned to move along a northward route for 60 km. However, the actual position is 5 km to the east of the planned route. The lateral deviation may be caused by current, wind, steering error, or delayed route monitoring. To return toward the planned route, the ship needs a correction angle in the opposite direction of the deviation.

Table 3. Simulation Results of Heading Correction Due to Deviation

Condition	Value	Formula	Result	Navigation Decision
Planned route	60 km to the north	-	-	The ship should be located on the northern route line.
Lateral deviation	5 km to the east	-	-	The actual position is located to the east of the planned route.
Correction angle	5 km and 60 km	$\arctan\left(\frac{5}{60}\right)$	4.76°	The heading is corrected by approximately 4.76° to the west.
Implication	Reduced deviation	Repeated monitoring	More stable route	Sailing accuracy increases.

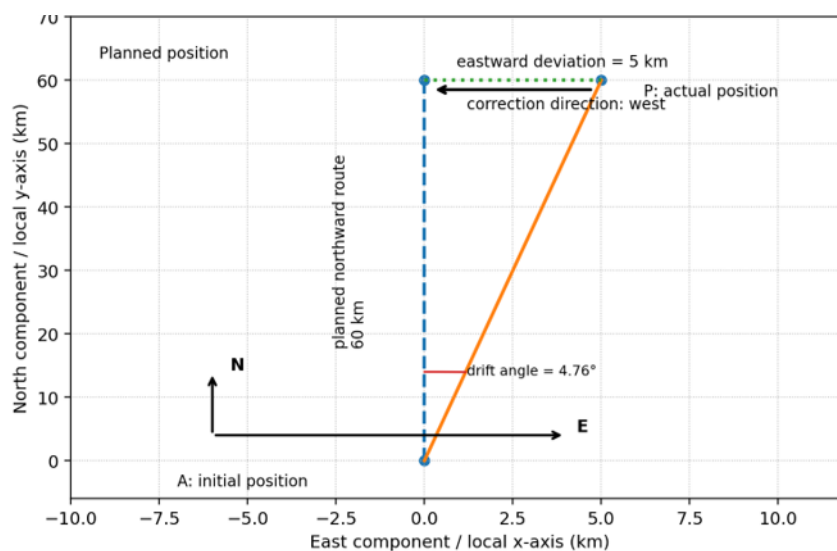


Figure 2. Heading correction scheme showing planned route, actual position, deviation direction, and correction direction

The correction angle is calculated using  $\alpha = \arctan\left(\frac{5}{60}\right)$ . The result is approximately 4.76°. Because the deviation occurs to the east, the correction direction is toward the west. This result shows that a relatively small angular correction can be meaningful when it is calculated and applied at the right time.

### 3.3. Triangulation and Interpretation of Position

In addition to bearing and correction

calculations, trigonometry also supports position interpretation through triangulation. In a simplified navigation learning context, a navigator can observe bearings toward two or more known reference objects, such as lighthouses, buoys, headlands, or coastal marks. When the bearing lines are plotted on a chart or coordinate diagram, their intersection can be used to estimate the vessel's position.

This article does not calculate an actual triangulated fix from field observations, because

the study uses hypothetical data. However, the triangulation principle is included to show that trigonometry is not limited to route planning. It also supports position verification, especially when navigators need to compare observed directions with expected positions.

#### 4. Discussion

The first simulation shows that trigonometry transforms position information into practical navigation instruction. The values of  $\Delta E$  and  $\Delta N$  do not automatically tell the navigator what heading to select. After being processed using the  $\text{atan2}$  function, the two components produce a bearing value that can be interpreted as a heading reference in the local coordinate system.

The result of  $36,87^\circ$  is more precise than the general statement “toward the northeast.” In navigation planning, this precision is important because the ship’s movement must be translated into an angle that can be compared with a compass, chart, ECDIS route, or autopilot setting. The direct distance of 50 km also supports planning because it helps estimate travel time, fuel needs, and route efficiency.

##### 4.1. Route Monitoring and Deviation Correction

The second simulation demonstrates the role of trigonometry in route monitoring. A ship may be aimed northward, but the track over the ground can differ from the intended route because of current, wind, waves, steering response delay, or instrument reading error. In such cases, trigonometry helps quantify the relationship between lateral deviation and forward movement.

The correction value of  $4.76^\circ$  appears small, but small angles can produce significant positional differences when they continue over long distances. Conversely, small corrections can be effective if they are calculated early and applied consistently. Therefore, trigonometry supports sailing accuracy by helping navigators identify how much correction is required and in which direction it must be applied. It does not guarantee accuracy by itself; actual accuracy still depends on monitoring frequency, environmental conditions, vessel handling, and crew decision-making.

##### 4.2. Safety and Operational Implications

From a safety perspective, calculated bearing

and correction values help vessels remain closer to a planned safe route. This is especially important near shallow waters, reefs, narrow channels, traffic separation schemes, or port approaches. A route deviation that is not identified may increase the risk of entering unsafe waters or crossing another vessel’s route.

From an operational perspective, deviation also affects distance, fuel consumption, arrival time, and coordination with ports. A longer route may increase operational cost and delay cargo or passenger movement. Trigonometric calculation contributes to more rational route management because it links direction, distance, deviation, and time in measurable terms.

These calculations should be understood as complementary to official navigation procedures. Modern bridge teams still need to use nautical charts, ECDIS, GPS, radar, visual bearings, compass checks, and bridge resource management. However, trigonometric literacy helps officers understand the logic behind the displayed values and makes cross-checking more meaningful.

##### 4.3. Educational Implications and Novelty

The main educational value of this article is that it presents trigonometry in a maritime context. Students often view sine, cosine, tangent, and arctangent as abstract mathematical formulas. By connecting the formulas to ship direction, distance, deviation, and estimated time, the learning process becomes more contextual and applicable.

This article contributes by organizing the application into an integrated learning model: defining the angle convention, explaining the local-coordinate assumption, showing formulas, providing numerical simulations, visualizing the results, and interpreting the calculations as navigation decisions. This structure can be used by maritime instructors as an introductory exercise before students proceed to more complex topics such as chart work, current correction, magnetic variation, gyro error, and great-circle navigation.

##### 4.4. Limitations of the Flat-Plane Model

The main limitation of this study is the use of a flat-plane model and hypothetical data. The model assumes that the sailing area is small enough for the earth’s curvature to be ignored. This assumption is useful for education, but it is

not sufficient for long-distance navigation or for navigation that requires precise latitude-longitude calculations.

Real navigation involves factors that are not included in the simulation, such as true and magnetic north differences, compass variation, compass deviation, gyro error, current set and drift, wind leeway, wave effects, vessel maneuvering characteristics, speed changes, shallow water effects, and traffic conditions. For longer voyages, navigators also need spherical

trigonometry, great-circle concepts, rhumb-line calculations, geodetic coordinates, and official nautical chart procedures.

Therefore, the results should be interpreted as an educational demonstration rather than as operational navigation instructions. Future studies may improve the model by using actual GPS track data, route plans from ECDIS, current and wind observations, and coordinate-based calculations using nautical miles and knots.

Table 4. Contribution of Trigonometry to Sailing Accuracy

Navigation Aspect	Role of Trigonometry	Impact on Accuracy	Example of Application
Heading determination	Converts position components into bearing.	The ship's direction becomes more measurable.	Bearing of 36.87°.
Distance calculation	Calculates the direct distance from the initial position to the destination.	Time and fuel estimation becomes more accurate.	Distance of 50 km.
Deviation correction	Calculates the correction angle based on lateral deviation.	The ship can return to the safe route.	Correction of 4.76° to the west.
Estimated time	Divides distance by average speed.	Arrival time can be estimated for planning and coordination.	50 km at 20 km/h equals 2,5 hours.
Triangulation	Uses angles toward reference objects.	The ship's position can be verified.	Observation of lighthouses and coastal marks.
Navigation learning	Connects mathematical formulas with real cases.	Conceptual understanding becomes stronger.	Sailing scenario exercises.

## 5. Conclusions

This article shows that trigonometry supports ship navigation direction determination by connecting position data with heading decisions. Through the relationship between eastward and northward components, navigators can calculate bearing in a defined angle convention. Through direct-distance calculation, they can estimate the shortest local-plane distance, travel time, and basic voyage needs. Through deviation correction, they can estimate the magnitude and direction of a heading adjustment when the ship moves away from the planned route.

The educational simulation shows that a displacement of 30 km east and 40 km north produces a bearing of 36.87° and a direct

distance of 50 km. The correction simulation shows that a 5 km eastward deviation after a 60 km northward route requires a correction of approximately 4.76° to the west. These results do not prove that trigonometry directly improves sailing accuracy in all real conditions; rather, they show that trigonometry supports sailing accuracy by helping navigators calculate direction, distance, correction, and time in a systematic way.

The study is limited by its hypothetical data and flat-plane assumption. Future research should use actual sailing data, latitude-longitude coordinates, nautical miles and knots, wind and current observations, compass-error correction, and spherical trigonometric or geodetic models. Such development would allow the relationship

between trigonometry and navigation performance to be tested more closely under real maritime conditions.

**Supplementary Materials:** Not applicable.

**Author contributions:** Conceptualization, article design, main writing, and final manuscript preparation validation of calculation scenario, mathematical formula checking, and data interpretation: Diana Ayu Wulandari; General Review, maritime navigation correction: Abdurrohman; Minor correction: Syahron Al Rosyid

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