Study of the Interceptors Effect on Ship Manoeuvrability Using the Open Free Running Test Method

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Abstract. Interceptors are plates that are attached to the stern of the ship to produce lift that controls the trim angle of the ship. This paper describes the use of interceptors on the fast boat to enhance its ability to perform the turning manoeuvre. The ship model of High-speed crafts (HSCs) with a scale of 1: 26.9 is tested in an open pool with the open free running test method, namely the movement of the model is controlled from the edge of the pool with a remote control. The ship trajectory data is obtained by using the colour object tracking method, that is, the ship trajectory captured by the camera is processed based on colour filters. The main concern is the varying dimensions of the interceptor including 0% (no interceptor), 50% (half length), and 100% (full length) of the design cord length. The initial trim conditions are examined, such as even keel, trim by bow, and trim by stern with a trim angle of 2 degree. The test results show that the interceptor contributed to improve the manoeuvrability of the boat by decreasing the tactical diameter length respectively at half and full length of the cord by 8.8% and 17.9% in even keel, 6.3% and 15% in bow trim, and 12.9% and 14.8% in stern trim.

1. Introduction

Interceptors are rectangular flat plates attached to the transom of the hull mostly used to control trim angle. Basically, the interceptor works by utilizing a pressure gradient and causing lift at the stern that changes the trim angle [3,9]. Although, the additional effect of the interceptor increases the total resistance at low speed, the rate of increasing resistance of the hull with the interceptor at high speed is less than the hull without the interceptor. Then, the hull moves forward faster and provides about 10–15% fuel efficiency compare to the hull without an interceptor [2].

The interceptor systems were studied with an experimental method on a high-speed hull-scale model with various heights and placement locations of interceptor to investigate effects to hull’s resistance. The results show the resistance decrease about 1.50% – 11.30% for Froude number of 0.58 – 1.19, and the trim angle reduced in between 1.60 and 4.70 degrees [1].

Mansoori and Fernandes [5] studied the unwanted movement known as porpoising instability in high speed boat and showed that the interceptor can control trim well so that it can reduce oscillatory pitch motion and avoid the porpoising phenomenon. The interceptor technology further is developed to help maintain the stability of high-speed crafts while manoeuvring in sea way. Since the ship's manoeuvrability can be affected by the magnitude of the ship's trim angle, the interceptor can also be used as a tool in controlling the manoeuvring movements of fast boats.

In this paper, the interceptors are tested experimentally to consider the maneuverability of a high-
speed vessel in a model-scale turning circle test. The open free running test is used in combination with the color object tracking method to retrieve track data. This color object tracking method is almost similar to the image processing method, namely image processing based on image retrieval for every second of the test video [11]. In this study, the trajectory of an object was by filtering the color of the video taken with an RGB and HSV based camera [8]. Image or video processing only intends to display a certain color on the desired object within the scope of the camera frame capture, from that color which indicates the location of the object in the frame. The test is carried out in accordance with IMO (International Maritime Organization) regulations concerning Ship Maneuverability Standards [7], namely turning tests that is studied. Although rudder design has an impact on maneuvering performance [10], this is not studied. The variations in the height of the interceptor plate were 100%, 50%, and 0% of the design height of the interceptor based on [6] which included a flat hull trim, bow trim, and aft trim with a 2 degree of trim angle.

2. Experimental setup

The ship model used in this study is the combat ship type with dimensions scale of 1:26.93 from a full-scale ship. The main dimensions of the full-scaled ship and the model are described in Table 1. The ship model is made using material of fiberglass with an axe bow design as shown in Figure 1. The model is equipped with a rudder which functions to control the direction of the ship as presented in Figure 2, with a submerged rudder area of 22.8 cm², and 2 blades propeller with a diameter of 4.2 cm is used to push the model ship as shown in Figure 3.

| Length o.A. (meter) | Full-scale Ship | Model Ship |
|---------------------|----------------|------------|
| 18.85               | 15.89          | 0.7        |
| Length W.L. (meter) | 15.89          | 0.7        |
| Breadth (meter)     | 4.2            | 0.2        |
| Depth (meter)       | 2.8            | 0.108      |
| Draught (meter)     | 0.98           | 0.043      |
| 85% Max. Eng. Output (m/s) | 15.43 | - |
| Speed Test (m/s)    | 13.89          | 3.72       |

**Table 1.** Main dimensions of the full-scale ship and the model ship.

**Figure 1.** The model ship.
The ship model is equipped with several equipment so that it can move under the control of the operator, including the propulsion system, steering system, ship model, control system, interceptor circuits and sensor circuits, as well as cameras, laptops / PCs, and programs for capturing ship track data. Placement of any equipment needed on the hull must consider the location of the ship's centre of gravity and adjust the hull model space. Figures 4 and 5 illustrate the location of the sensor system equipment such as the sensor module and the battery on the superstructure, and the sensor circuit that takes into account preventing the influence of the DC motor heat and preventing contact with outside water. Electrical equipment is located on the inside of the hull model, the motor is positioned right at the centre of gravity of the ship, and other equipment adjusts its position to maintain the ship's centre of gravity, load, heel conditions and even keel conditions, see Figure 6.

Figure 2. Rudder model.

Figure 3. Propeller model.

Figure 4. The arrangement of the sensor circuit on the superstructure.
2.1. Testing pool
The turning circle test for the ship model is carried out in an open pond where at the time of testing the wind speed conditions are calm, which is below 1 knot and the water conditions during the test are calm like glass. Meanwhile, the water temperature during the test is about 28° - 30° Celsius. The test pool area is large enough so that there is no blockage effect from the pool wall on the ship model, see Figure 7.

The comparison of the pool depth (h) with the ship draft (T) must be sufficient to avoid the influence of shallow water according to ITTC 2002 rules that the minimum allowable value is h / T = 4. The test pool has dimensions of 4 meters deep, 18 meters wide and 20 meters long, see Figure 7.

2.2. Equipment test
Installation of the interceptor system follows the design referred to in reference [5], the size of the interceptor is designed based on the height of the boundary layer with the formula for boundary layer height (h) as follows h = 0.382 x L_WL / (Re x L_WL x 0.2). The height of the interceptor plate (d) must not exceed 60% of the thickness of the boundary layer (h) under the transom, for the height of the interceptor plate is 0.1h to 0.6h. Then calculate the interceptor time span (S) by comparing S/d with d/h as shown in Figure 8, so that the span interceptor (S) can be determined.

Based on Figure 8, it can be seen that the height of the interceptor plate used for 100% (full length) is 9.96 mm, for 50% (half length) it is 4.98 mm, and 0% for without using the interceptor, and the length of the interceptor model used is 66.77 mm. The reference in designing the interceptor model is as shown in Figure 9. The interceptor model used in this study is as described in Figure 10 and its size can be seen in Figure 11.
Figure 7. Maneuver area in testing pool.

Figure 8. Comparison chart of d/h with S/d [5].

Figure 9. Interceptor design model [5].

Figure 10. Interceptor model.

Figure 11. The interceptor model design.
For track tracking, several programs and applications are developed. First, the Mission Logger application, where this application is used as a user interface and records data directly from sensor readings on the ship model. Sensor data is sent over a wireless network connected via a hardware router, and the user interface for this application is shown in Figure 12.

![Figure 12. Display user interfaces application "Mission Logger".](image12)

Second, the Color Range Detector Program, this program is a program that filters the colors in the image captured by the camera that the "Ship Tracking" program wants to read, this program can set the minimum and maximum range of HSV and RGB values for the colors want to be captured with the program "Ship Tracking", for an example of color filtering in the image can be seen in Figure 13.

![Figure 13. Color filter window program "Range Color Detector".](image13)

Third, the Ship Tracking Program, the program functions to read the pattern of ship movement through the pixel coordinates that the ship traversed in the image from the captured camera. This program reads the object's location based on the object's color, where previously the object's color was determined using the "Color Range Detector program", the program will track the object and determine the object's center point as the pixel coordinates that the program reads, then when the object moves, the program will record the object by tracking the coordinates of the pixels that the object traverses.

Fourth, Drafting Application, basically this application aims to plot the actual coordinate points of the ship's movement to form a ship's movement trajectory.
2.3. Testing procedures
The test procedure can be briefly described as follows, first, prepare for the test by measuring wind speed; second, ships must be in a calm water condition and first reset the sensor; third, run the ship model and start recording the model's movements with video and sensors; fourth, the ship enters the buoy area by moving forward in a straight line, and when rotate the rudder marks the start of the rotating motion of the model ship; sixth, the ship rotates in a circle in two rounds and then the ship exits the buoy area, data collection is complete.

2.4. Data Processing
In processing data taken from testing, the steps taken are first, matching camera data with sensor data at the same second of data collection, this is necessary because there are differences in the two data at the same second. This procedure is done by calibrating the time from the sensor data with the time on the test video.

![Figure 14. Comparison of the path of the pixel coordinate data with the actual coordinate data.](image)

Second, determining the value of the calibration factor based on the reference buoy placed in the test pool, this is because the position of the camera is located sideways from the ship model object, it is necessary to project the data taken from the test so that the actual coordinate data is obtained. So the path data in the form of pixel coordinates on the video recording is transformed into actual coordinates multiplied by the calibration factor, see Figures 14 and 15. The equation used to determine the value of the calibration factor is shown in equation (1) and (2).

\[
\text{Calibration Factor Value at Coordinate X} \quad (1)
\]
\[
\frac{\text{Coordinate } X}{(x_B - x_C)} \times 6
\]

\[
\text{Calibration Factor Value at Coordinate Y} \quad (2)
\]
\[
\frac{\text{Coordinate } Y}{(y_B - y_C)} \times 6
\]
Third, after obtaining the actual coordinates, filtering or data normalization is carried out in order to obtain a fair turning test trajectory, as shown in Figure 16 for the turning circle results of the model in case of without interceptor device.

![Buoy as a reference for track data calibration.](image)

**Figure 15.** Buoy as a reference for track data calibration.

![Turning test result of the model without interceptor (0%).](image)

**Figure 16.** Turning test result of the model without interceptor (0%).

3. Results and discussion

3.1. Verification of test results

Verification of the test results with this technique is carried out by comparing the results with the test results for the type of patrol boat that has a length of 27 meters and 9.5 meters that have been tested at the Indonesian Hydrodynamics Laboratory. The model length of the 27-meter and 9.5-meter Patrol boat models are 3 meters and 1.80 meters respectively, with initial velocities of 22 knots and 10 knots, respectively, and the same rudder angle of 35 degrees. The data being compared are the test results of the ship model without using an interceptor, and the comparison of the results for the three ships is described in Table 2 in term of non-dimensional.
From the turning circle test data in Table 2, the tactical diameter of the model without interceptors produces a very close to the test result of a 27 m patrol boat and slightly different from a vessel of 9.5 m by 8.8%. Likewise, the test results in the form of advance length are also close to the results of the patrol boat test of 27 m and 9.5 m, with differences of 36.8% and 6.7%, respectively. The test results of the model ship without interceptors in the form of transfer length have a difference with the results of the 27 m and 9.5 m patrol tests of 24% and 30.5%, respectively. The difference occurred in the test results of a turning diameter between the model ship and the 9.5 m patrol, amounting to 2.9 %, while the difference with 27 m patrol was 6.8%. In general, the model test results are close to both results of the 27 m and 9.5 m patrol boats for all parameters except a length of transfer. The standards for ship manoeuvrability according IMO Resolution MSC 137(76) 2002 are only parameters of advance and tactical diameter so that the method of model test are satisfied.

### Table 2. Comparison results of the Turning Circle Test for Model Ships 0% Interceptor with the Results of LHI Testing for 27 m Patrol Ships and 9.5 m Patrol Ships.

| Parameter               | Advance | Transfer | Tactical Diameter | Turning Diameter |
|-------------------------|---------|----------|-------------------|------------------|
| Non-Dimensional (x Lpp)| 0% Interceptor Model | 2.37     | 1.71              | 3.29             |
|                         | 9.5 m Patrol Boat   | 2.39     | 1.19              | 3.09             |
| 27 m Patrol Boat        | 3.75     | 1.29     | 3.29              | 3.22             |
| 9.5 m Patrol Boat       | 2.37     | 1.71     | 3.29              | 3                |

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#### 3.2. Test results and discussion

Following are the test results with the free running method on a model scale of 26.93, for testing at an initial speed of 27 knots, with the steering angle for turning circle testing is port side 35 degrees. The ship model was tested with interceptor height variations of 9.96 mm (100%), 4.98 mm (50%), and without interceptor (0%), which has the same span length of the interceptor model, namely 66.77 mm. The method of collecting data on this test track is by tracking color objects and wind speed conditions below 1 knot. Table 2 describes the results of the model testing in the early even keel conditions. Tables 3 and 4 describe the results of the tests when the conditions are trim by bow and trim by stern, respectively.

### Table 3. Test results for model at even keel condition.

| Even Keel Condition | Parameter       | Advance | Transfer | Tactical Diameter | Turning Diameter |
|---------------------|-----------------|---------|----------|-------------------|------------------|
| **Dimensional (meter)** | 0% Interceptor Model | 1.66    | 1.2      | 2.3               | 2.1              |
|                     | 50% Interceptor Model | 1.48    | 1.03     | 2.1               | 2.09             |
|                     | 100% Interceptor Model | 1.36    | 0.75     | 1.89              | 1.86             |
| **Non-Dimensional (x Lpp)** | 0% Interceptor Model | 2.37    | 1.71     | 3.29              | 3                |
|                     | 50% Interceptor Model | 2.11    | 1.47     | 3                 | 2.99             |
|                     | 100% Interceptor Model | 1.94    | 1.07     | 2.70              | 2.66             |
Table 3 explains that in the initial conditions of the keel event, the interceptors of 100% and 50% provide a reduction in the tactical diameter size of 17.9% and 8.8% respectively on the results of the model test without interceptor.

At trim by bow conditions as shown in Table 3, the test result in term of tactical diameter for the model with 100% interceptor decrease about 15% from model without interceptor (0%), and the model with 50% interceptor give a tactical diameter 6.3% less than model without interceptor.

Table 4. Test results for model at trim by bow.

| Bow Trim Condition | Parameter | Advance | Transfer | Tactical Diameter | Turning Diameter |
|--------------------|-----------|---------|----------|-------------------|------------------|
| Dimensional (meter) | 0% Interceptor Model | 1.57 | 0.7 | 1.99 | 1.88 |
| 50% Interceptor Model | 1.39 | 0.62 | 1.86 | 1.78 |
| 100% Interceptor Model | 1.28 | 0.65 | 1.69 | 1.64 |
| Non-Dimensional (x Lpp) | 0% Interceptor Model | 2.24 | 1 | 2.84 | 2.69 |
| 50% Interceptor Model | 1.99 | 0.89 | 2.66 | 2.54 |
| 100% Interceptor Model | 1.83 | 0.93 | 2.41 | 2.34 |

At trim by stern conditions as shown in Table 3, the test result in term of tactical diameter for the model with 100% interceptor decrease about 14.8% and 12.9% less than the model without interceptor results, respectively.

Table 5. Test Results for model at trim by stern.

| Stern Trim Condition | Parameter | Advance | Transfer | Tactical Diameter | Turning Diameter |
|----------------------|-----------|---------|----------|-------------------|------------------|
| Dimensional (meter) | 0% Interceptor Model | 1.83 | 1.17 | 2.6 | 2.57 |
| 50% Interceptor Model | 1.93 | 0.95 | 2.26 | 2.18 |
| 100% Interceptor Model | 1.5 | 0.95 | 2.21 | 2.16 |
| Non-Dimensional (x Lpp) | 0% Interceptor Model | 2.61 | 1.67 | 3.71 | 3.67 |
| 50% Interceptor Model | 2.76 | 1.36 | 3.23 | 3.11 |
| 100% Interceptor Model | 2.14 | 1.36 | 3.16 | 3.09 |

Table 4 show the result test for model at stern trim condition that the model test with 100% and 50% interceptor give about 14.8% and 12.9% less than the model without interceptor results, respectively.

From the results of the test model described in Tables 3, 4, and 5, it is explained that the addition of an interceptor can increase the maneuverability of the ship at high speed, where the interceptor design limit refers to [5], where the d / h value is between 0.1 - 0.6. Besides, the initial condition of the ship trim angle of 2 degrees affects the ability of the ship's turning circle maneuver, namely the trim by bow condition shows the best rotating performance followed by the keel and trim by bow event conditions,
respectively. This happens because the location of the LCG point at the time of trim by bow is ahead of the other two trim conditions, so that the yaw force is greater.

However, the addition of interceptors has the most significant effect on the maneuverability of the ship during the initial conditions of the keel event and then the trim by bow and trim by stern conditions are followed, respectively.

4. Conclusions

The accuracy of the fast boat test results using the open free running test method combined with the color object tracking technique in taking the turning circle maneuver data is quite reliable after verification of the similar test results on a patrol boat at the Indonesian Hydrodynamics Laboratory with a difference of 0% in tactical diameter and 6.8% in the turning diameter. In general, the addition of an interceptor in the transom area of the ship improves the ability of the ship's rotary maneuver, where the size of the interceptor of 100% of the design size provides a reduction in tactical diameter length of 14.8% to 17.9% for ships without interceptors (0%) in all initial trim conditions of 2 degrees whereas on ships with an interceptor of 50% of the design size, it provides a reduction in tactical diameter length of 6.3% to 12.9%.

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