EMAIL KORESPONDENSI

[IJTech] Manuscript Submission Confirmation for : ME-2852

External

Inbox

dparoka@g.unhas.ac.id

IJTech <noreply@ijtech.eng.ui.ac.id>

Wed, Feb 6, 2019, 3:51 PM

to me

Manuscript Submission Confirmation

Dear Dr. Daeng Paroka,

Your manuscript entitled **"Yaw Motion Stability of an Indonesian Ro-Ro Ferry in Adverse Weather Conditions"** has been successfully submitted to International Journal of Technology (IJTech) Online System.
Your manuscript ID #: **ME-2852.**
Please quote the above manuscript ID in all future correspondence. If there are any changes in your postal or e-mail address, please log into IJTech Online System at http://ijtech.eng.ui.ac.id/ and edit your contact and/or personal information as appropriate.
You can also view the status of your manuscript at any time by checking your Author Account after logging in to http://ijtech.eng.ui.ac.id/dashboard.
Thank you for submitting your manuscript to International Journal of Technology (IJTech) Online System.

Yours sincerely,

Editorial System
International Journal of Technology (IJTech)
p-ISSN: 2086-9614
e-ISSN: 2087-2100

http://ijtech.eng.ui.ac.id/

[IJTech] Editor Decision

External
Inbox
dparoka@g.unhas.ac.id

IJTech <noreply@ijtech.eng.ui.ac.id> Wed, May 13, 2020, 1:43 PM

to me

Decision Result : Revise

Dear **Dr. Daeng Paroka**
We have finished the review and made decision on your manuscript entitled **[Yaw Motion Stability of an Indonesian Ro-Ro Ferry in Adverse Weather Conditions]** which was submitted to International Journal of Technology.
We have decided that your manuscript **Need to be Revised**
We also send you the review result from the reviewers. Here is the detail review result:

Notes from Editor:
Please revise according to the reviewer's comment and it is suggested to include at least 3 relevant IJTech articles as references

Reviewer (1)

Introduction:
Please see attached file.

Methodology:
Please see attached file.

Results and Discussion:
Please see attached file.

References:
Please see attached file.

Other:
Please see attached file.

Originality	3 *(average)*
Technical	2 *(fair)*
Methodology	3 *(average)*
Readability	2 *(fair)*
Practicability	4 *(above average)*
Organization	3 *(average)*
Importance	3 *(average)*

Additional Comment:
See attached file.

Attachment File:
Review Attachment

Reviewer (2)

Introduction:
Description of previous work and the focus of the current paper is adequate. However, authors should mention the typical difference of ro-ro vessel compared to other and not just said it has a low draught. Ro-ro vessel in Indonesia is unique and it does not described at all in this Introduction.

Methodology:
Authors do not show the complete mathematical formulation used in the paper. It is OK for a conference paper, but not for a journal one. Authors must also show the body-plan and typical figure or photograph of the Indonesian ro-ro used in the current work.

Results and Discussion:
Authors said that they used a 3-DOF approach and also said that Spyrou et al. (2007) used a 4-DOF (plus rolling item, which is usually used in seakeeping analysis. This is not discussed at all here as well as not clear if the work done by Spyrou is also tested for the Indonesian ro-ro vessel. Also, the effects of typical Indonesian ro-ro type of vessel (such as a lot if openings) are not explained and discussed at all.

References:
Numbers and recent papers are

properly used. However, there is no paper or information about ro-ro vessel and particularly, Indonesian ro-ro vessel.

Other:

Conclusion is too general and applied to any kind of ships. Special conclusion which is only for Indonesian ro-ro ships must be given so as correlate to the title of paper.

Originality	3 *(average)*
Technical	3 *(average)*
Methodology	3 *(average)*
Readability	3 *(average)*
Practicability	3 *(average)*
Organization	3 *(average)*
Importance	4 *(above average)*

Additional Comment:

There are a number of mistakes of written English and some have been noticed with green light.

Attachment File:

Review Attachment

Please login into application https://ijtech.eng.ui.ac.id/login

You must respond to this revise and resubmit request before **20 May 2020**, after which point we will presume that you have withdrawn your submission from International Journal of Technology (IJTech) Online System.

Yours sincerely,

Dr. Nyoman Suwartha
nsuwartha@eng.ui.ac.id
Managing Editor
International Journal of Technology (IJTech)
p-ISSN : 2086-9614
e-ISSN 2087-2100
https://ijtech.eng.ui.ac.id/

[IJTech] Editor Decision

External

Inbox

IJTech <noreply@ijtech.eng.ui.ac.id>

Fri, Jul 3, 2020,
2:16 PM

to me

Decision Result : Revise

Dear **Dr. Daeng Paroka**
We have finished the review and made decision on your manuscript entitled **[Yaw Motion Stability of an Indonesian Ro-Ro Ferry in Adverse Weather Conditions]** which was submitted to International Journal of Technology.
We have decided that your manuscript **Need to be Revised**
We also send you the review result from the reviewers. Here is the detail review result:

Notes from Editor:
Please revise according to the reviewer's comment

Reviewer (1)

Introduction:
Abstract has not explained yet the gap from previous research, i.e. need to state that none of the previous/existing research has done simulation in the area of yaw motion and wind. The novelty of the paper should be reflected explicitly in the paper. Since this is a scientific and numerical simulation work, I highly suggest to include NOMENCLATURE consisting symbol, description, and unit. In the introduction section, the paper has given the background setting of the paper. However, is there any incidents/collision happen due to wind effect so far? Need to provide a reference to support the background setting. Again, regarding the originality, the work by Fujiwara, et al, 2006 has

exposed similar issue on the maximum rudder angle which may imply the work in the paper is less important / not new. Therefore, what is the novelty of the paper can offer to the existing research / what is the significance of the paper? Why this issue has not been done in the previous research? There is no reasoning as to why the paper use Indonesian ro-ro ferry, why not any other geographical area of a ro-ro ferry which may be more crowded than Indonesia sea traffic? Please add more background setting as to why the author(s) chose the Indonesian ro-ro ferry. In the introduction, there are some qualitative statements such as "small draught...." and "small ships with large windage areas...." in the second paragraph. Please provide a numerical range.

Methodology:

. Mathematical model Equation 1 and 6, if the equation is not new, put in the appendix, together with the empirical formulae used in the paper by Yoshimura, et al, 2012, Carlton... Fujiwara, et al, 2006 (paragraph after equation 1) H, P, R, and A which stands for appendage? Please provide nomenclature. Typo "enought" "th" Double-check if the Rawson-Newton method, Taylor expansion, Runga-Kutta methods can be classified as "common knowledge"? Otherwise, please provide relevant references. 2. Ship data Please provide the reference on the caption of Table 1 also Table 2, otherwise, it is plagiarism. Since this is not a novel work, put this in the appendix. Typo "as follow" vs "as follows" Figure 2 is far from the paragraph where it is mentioned, please rearrange the layout of the paper. Also, CAX, CAY, 10xCAN are not explained in the text. Again, the nomenclature is important.

Results and Discussion:

3. Results and discussion first paragraph " ... of ship velocity or larger." larger than what? be specific. Paragraph three, "or 0.34 of ship velocity" should be in percentage form

(34 %). Typo "phenomena" and overused, consider another word. The last paragraph in the discussion is too crowded for explaining multiple diagrams. Consider rearranging the layout and provide the discussion adjacent to the plot.

References:

4.Conclusion Overall, the paper needs to discuss the validation of the results, including, but not limited to how accurate the results compared to the experimental results/ real-world situation. Additionally, the paper should identify what are the future works/aspects that have not considered in the simulation, .e.g. effect of underwater current, change rudder characteristics, etc.

Other:

In addition to the comments, I suggest adding more independent variables to be considered in the paper, e.g. to find out what necessary rudder characteristics need to be improved for course keeping, not just changing the input of ship data and varying the wind velocities. This would add more significance to the paper.

Originality	1 *(poor)*
Technical	2 *(fair)*
Methodology	2 *(fair)*
Readability	1 *(poor)*
Practicability	3 *(average)*
Organization	1 *(poor)*
Importance	3 *(average)*

Additional Comment:

Indonesia as the largest archipelago country in the world should have many publications in the domain of the ocean science, and therefore, I would like to appreciate author(s) for their contribution to the field. The paper starts by introducing the motivation behind the work and then provides the approach including, but not limited to algorithms used in the simulation. The results suggest when the wind velocity is beyond 24 m/s, it exceeds the available rudder angle (which was assumed to be +- 35 deg) for course keeping.

Attachment File:
-

Reviewer (2)

Introduction:
Ok

Methodology:
Ok

Results and Discussion:
Ok

References:
The integrity of Reference 1 (Asri et al. 2014), which is published in International Journal of Engineering Research and Technology (IJERT) with Initial Review Acceptance: within 4 – 6 days after submission, is questionable and should be checked/verified.

Other:
Ok

Originality	3 *(average)*
Technical	3 *(average)*
Methodology	3 *(average)*
Readability	3 *(average)*
Practicability	4 *(above average)*
Organization	3 *(average)*
Importance	4 *(above average)*

Additional Comment:

Attachment File:
-

Reviewer (3)

Introduction:
Authors gave some further information about ro-ro vessel in Indonesia, e.g. it has a small draught and large windage area. Ro-ro vessel in Indonesia is unique and the explanation is not adequate. Indonesian ro-ro has more openig areas than that (say) in Japan or Italy.

Methodology:
Authors reject to show the complete mathematical formulation and propose to see their previous paper. This is a journal and not a conference paper; readers do not have enough time to see that paper. Thus, authors must show the complete mathematical

formulation hence readers can easily understand the paper. Further, authors must show the body-plan and typical figure or photograph of the Indonesian ro-ro used in the current work. It has been asked previously but authors neglected it.

Results and Discussion:

Comment with the work done by Spyro (1995) is given but not enough and clear. Authors should show it in a graph/curve and give appropriate comment on the agreement and disagreement of their results and Spyro's results.

References:

N/A

Other:

Conclusion is too general and can be applied to any kind of ships. Special conclusion which is only for Indonesian ro-ro ships must be given hencde correlate to the title of paper. For example, what is the correlation between B/H (breadth / height of superstructure) which is typical for ro-ro vessel. It has been asked before, but no comment from authors.

Originality	3 *(average)*
Technical	3 *(average)*
Methodology	3 *(average)*
Readability	3 *(average)*
Practicability	3 *(average)*
Organization	3 *(average)*
Importance	4 *(above average)*

Additional Comment:

Authors did not answer the entire notes. They just replied a few. In general, the paper is lacking of adequate comparative analyses, despite it has 18 references.

Attachment File:

-

Please login into application https://ijtech.eng.ui.ac.id/login for more detail.
You must respond to this revise and resubmit request before **10 Jul 2020**, after which point we will presume that you have withdrawn your submission

from International Journal of Technology (IJTech) Online System.

Yours sincerely,

Dr. Nyoman Suwartha
nsuwartha@eng.ui.ac.id
Managing Editor
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p-ISSN : 2086-9614
e-ISSN 2087-2100
https://ijtech.eng.ui.ac.id/

IJTech] Editor Decision

Inbox

IJTech <noreply@ijtech.eng.ui.ac.id>
Thu, Jul 16, 2020, 2:41 PM

to me

Editor Decision on #R1-ME-2852 : Accepted

Ms ID **#R1-ME-2852**
Title : Yaw Motion Stability of an Indonesian Ro-Ro Ferry in Adverse Weather Conditions
Author(s) : Daeng Paroka, Daeng Paroka

Dear **Dr. Daeng Paroka** ,

Greetings from Depok,

The editorial board is delighted to inform you that your paper entitled "Yaw Motion Stability of an Indonesian Ro-Ro Ferry in Adverse Weather Conditions" has been accepted to be published on IJTech. **Congratulation!**
In order to ensure the readability and the quality of the journal, Starting from 1st of January 2020, all accepted articles to publish will be subjected to article processing charge (APC) of US$ 550 for Regular Publication or US$ 650 for Special Edition Publication, as announced in IJTech's website. This fee covers the review process, line editing, layouting, DOI deposit, printing, and shipping cost.
You can make a payment via bank transfer (please noted that transfer fees may be additionally charged and become the responsibility of the sender) addressed to :

Bank Name: **Bank BNI**
Branch: **Kantor Cabang UI Depok**
Swift Code: **BNINIDJAXXX**
Acc. Number: **1273000411**
Acc. Name: **UNIVERSITAS INDONESIA-FT NON BP**

We appreciate if you can confirm your payment (along with the receipt of transfer) no later than 3 days after this email is received, otherwise your paper is assumed to be withdrawn. Any payment confirmation can be submitted by email to ijtech@eng.ui.ac.id. We look forward to receiving your confirmation at your earliest convenience.

Warmest regards,

Dr. Mohammed Ali Berawi
maberawi@eng.ui.ac.id
Editor in Chief
International Journal of Technology (IJTech)
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e-ISSN: 2087-2100
https://ijtech.eng.ui.ac.id/

[IJTech-ME-2852] Result of Line-editing of the Paper

Inbox

IJTech <ijtech@eng.ui.ac.id> Tue, Sep 15, 2020, 7:56 PM

to me

Dear Dr. Daeng Paroka,

We have conducted line editing for your paper as part of the publication process in IJTech. Enclosed, please find the comments from the line editor indicated by the character in color besides black.
We would like to ask you to complete the following:

1. Please make necessary revise the paper accordingly to the line editor comments.
2. Please complete detail information for the name of the author(s), and affiliation of each author(s). Please refer to Guideline for Author to write the affiliation section (https://ijtech.eng.ui.ac.id/about/3/online-submission)

After the revision complete, please send it back to ijtech@eng.ui.ac.id or by reply to this email, no later than **September 17, 2020**
We will proceed to the next step (Layouting, Final proof & Copyright) of the revised paper before printing.

We are looking forward to receiving your revised paper soon.

--
Kind regards,
Secretariat IJTech
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[IJTech-ME-2852] Result of Line-editing of the Paper

Inbox

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Dear Dr. Daeng Paroka,

We have conducted line editing for your paper as part of the publication process in IJTech. Enclosed, please find the comments from the line editor indicated by the character in color besides black.
We would like to ask you to complete the following:

1. Please make necessary revise the paper accordingly to the line editor comments.
2. Please complete detail information for the name of the author(s), and affiliation of each author(s). Please refer to Guideline for Author to write the affiliation section (https://ijtech.eng.ui.ac.id/about/3/online-submission)

After the revision complete, please send it back to ijtech@eng.ui.ac.id or by reply to this email, no later than **September 17, 2020**
We will proceed to the next step (Layouting, Final proof & Copyright) of the revised paper before printing.

We are looking forward to receiving your revised paper soon.

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Kind regards,
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International Journal of Technology (IJTech)
ISSN : 2086-9614
http://www.ijtech.eng.ui.ac.id

2 Attachments

[IJTech-ME-2852] Acknowledgement of Receipt of Your Line Editing Revised Manuscript

Inbox

IJTech <ijtech@eng.ui.ac.id>

Fri, Sep 18, 2020, 9:59 PM

to me

Dear Dr. Daeng Paroka,

Herewith, we confirm that we have received your revised manuscript based on the line-editing comments.

The editorial board will conduct the last process of editing on your paper and preparation for publication.

Soon, after the process finish, IJTech secretariat will send you an email for proofreading and copyright confirmation.

--
Kind regards,
Secretariat IJTech
International Journal of Technology (IJTech)
ISSN : 2086-9614
http://www.ijtech.eng.ui.ac.id

[IJTech-ME-2852] Final Proof reading & Copyright form

Inbox

IJTech <ijtech@eng.ui.ac.id>

Mon, Oct 5, 2020, 10:36 AM

to me

Dear Dr. Daeng Paroka,

The editorial boards delighted to inform you that your paper has been accepted to be published in IJTech next Volume 11 issue 4, October 2020.

Congratulations!

We have carried out necessary layouting and editing of your manuscript. Prior to publication we need your final proof and copyright of the paper. Here is the note from editor:

1. **Please provide both the corresponding author's telephone and fax number (if any)**

Enclosed please find the copyright form and the paper for a final check and please confirm that the article ready for printing.
Any confirmation of the final check should be submitted on **October 07, 2020.**
Copyright form can be printed, signed, scanned and
send by email to ijtech@eng.ui.ac.id.

On behalf of editorial boards, we want to express you and your collaborators our deep appreciation for your contribution to IJTech.

We look forward to receiving the copyright form and proofs at your earliest convenience.

Yours sincerely,

Dr. Mohammed Ali Berawi
maberawi@eng.ui.ac.id
Editor in Chief
International Journal of Technology (IJTech)
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http://ijtech.eng.ui.ac.id/

2 Attachments

[IJTech] Acknowledgement of Receiving Final Proof reading & Copyright form

Inbox

IJTech <ijtech@eng.ui.ac.id> Thu, Oct 15, 2020, 10:54 AM

to me

Dear Dr. Daeng Paroka,

We confirmed that the editorial board has received your final proof and copyright of the paper.
We appreciate your effort to refine your paper to meet the quality
of IJTech publication standard.

Thank you.

--
Kind regards,
Secretariat IJTech
International Journal of Technology (IJTech)
ISSN : 2086-9614
http://www.ijtech.eng.ui.ac.id

Journal Publishing : Volume 11 Issue 4, Oct 2020

Inbox

IJTech <noreply@ijtech.eng.ui.ac.id> Fri, Oct 16, 2020, 7:36 PM

to me

Journal Publishing

Dear Dr. Daeng Paroka,

Greetings from Depok!

On behalf of the Editorial Board, I am pleased to inform you that your article entitled **Yaw Motion Stability of an Indonesian Ro-Ro Ferry in Adverse Weather Conditions** has been published online in *Volume 11 Issue 4, Oct 2020*. You can check the online version at: https://ijtech.eng.ui.ac.id/issue/64 The articles are available to be accessed and downloaded free of charge. The hardcopy version is being printed and one copy will be delivered to the corresponding author.

Thank you for your contribution to IJTech and we look forward to a good collaboration in the next future.

Yours sincerely,

Dr. Mohammed Ali Berawi
maberawi@eng.ui.ac.id
Editor in Chief
International Journal of Technology (IJTech)
p-ISSN: 2086-9614
e-ISSN: 2087-2100
https://ijtech.eng.ui.ac.id/

Reviewer's Guide

PART A: ***Editorial Office Only***

SECTION I

Reviewer's Name:	
E-Mail:	
Manuscript Number:	IJTech-07-140
Title:	PREDICTION OF SHIP TURNING MANEUVERING IN CONSTANT WIND AND REGULAR WAVES

PART B: ***Reviewer Only***

SECTION II: Comments per Section of Manuscript

General comment:	OK
Introduction:	OK
Methodology:	OK
Results:	OK
Discussion:	OK
Bibliography/References:	OK
Others:	A ship usually perform maneuvering under influence of external forces and moments such as wind, waves and current. Therefore, the maneuvering behaviour of ships under action of the external forces becomes important to understand. This paper discusses turning maneuvering of an Indonesian ro-ro ferry under influence of combined constant wind and regular waves by using MMG model. The ship position relative to the wave through is added to the original MMG model in order to estimate the exciting forces and moment induced by waves. The results of numerical simulation show that effect of wave height on turning ability is more significant in small wave

	length and this effect decreases as the wave length increases. Effect of wave length on the sway force and yaw moment is more significant compared with its effect on surge force. The ship initial position relative to the wave through does not have significant effect on turning characteristic and it can be neglected in case of the present subject ship. Overall, the results of the present work compare well with published data. The word ‘its’ on the blue colour should be ‘it’

SECTION III - Please rate the following: *(1 = Poor) (2 = Fair) (3 = Average) (4 = Above Average) (5 = Excellent)*

Originality:	2
Technical Quality:	3
Methodology :	3
Readability :	3
Practicability:	2
Organization:	3
Importance:	3

SECTION IV - Recommendation: (*Kindly Mark with an X*)

Accept As Is:	**X**
Requires Moderate Revision:	
Reject On Grounds of (Please Be Specific):	

SECTION V: Additional Comments

Please add additional comments, if any:

RETURN OF COMMENTS

Thank you for contributing to International Journal of Technology by completing this review. Please return your comments to:

Dr. Nyoman Suwartha
Managing Editor
International Journal of Technology (IJTech)
Faculty of Engineering
Universitas Indonesia,

Kampus UI Depok 16424
T: +62 (0) 21 78849052
F: +62 (0) 21 7863506
E: ijtech@eng.ui.ac.id atau ijtech.eng.ui@gmail.com

International Journal of Technology 11(4)167-177 (2020)
Received February 2019 / Revised May 2020 / Accepted July 2020

International Journal of Technology

http://ijtech.eng.ui.ac.id

Yaw Motion Stability of an Indonesian Ro-Ro Ferry in Adverse Weather Conditions

Daeng Paroka[1]*

[1]*Department of Ocean Engineering, Faculty of Engineering, Hasanuddin University, Gowa Campus, Jl. Poros Malino Km. 6, South Sulawesi 92171, Indonesia*

Abstract. The yaw motion stability and course-keeping ability of ships are important factors with regard to collision danger, particularly for ships operating in narrow channels, crowded routes, or port areas. Yaw motion may become unstable due to external forces, such as wind. To investigate yaw stability and course-keeping ability, this study developed a nonlinear dynamic system of a three-degree-of-freedom mathematical model to determine steady state equilibrium. Yaw motion behavior was then analyzed using the eigenvalue characteristic of the obtained equilibrium points. The numerical results for an Indonesian ro-ro ferry showed that the rudder angle required to maintain the ship's course tended to increase as wind velocity increased. In beam wind, the necessary rudder angle was larger than the maximum possible rudder angle when the wind velocity was 24 m/s or more. The ship could be controlled by the rudder during operation, but its yaw motion tended to be unstable in following wind. The stable oscillation of yaw motion occurs when the wind velocity is higher than 11 m/s, and the range of heading and rudder angles increases as wind velocity increases.

Keywords: Limit cycles; Maneuvering; Ro-ro ferry;Yaw motion

1. Introduction

The maneuvering performance of a ship is indicated by its turning ability, zig-zag maneuverability, course-keeping ability, and stopping ability, which are considered as maneuvering criteria by the International Maritime Organization (IMO; 2002). During the initial design of a ship, its maneuvering performance is evaluated through numerical simulation or free-running model experiments. After a ship is launched, tests are conducted in a sea trial to guarantee the maneuverability of the vessel. External disturbances, such as wind and waves, are not considered in the aforementioned criteria, although some studies have shown that these factors have significant effects on the maneuvering performance of a ship (Paroka et al., 2017; Shigunov, 2018). The rudder angle required to maintain a ship's course increases if wind velocity and wave height increase. In severe weather, the rudder may not control the ship's direction because the required rudder angle is larger than the maximum possible rudder angle (Fujiwara et al., 2006).

When a ship operates in a narrow channel, river, or port area, yaw motion stability becomes highly important for the avoidance of collisions during operation. Several studies regarding yaw stability have been conducted. Spyrou (1995) investigated the yaw motion

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doi: 10.14716/ijtech.v11i4.2852

of four different ship types under wind action and found that yaw motion tends to be unstable in following wind and stable in headwind. It was also found that a ship's direction is significantly influenced by yaw motion stability. In addition, limit cycles of yaw oscillation were identified within a certain range of heading and rudder angles for specified wind velocities and directions. A ship's heading angle oscillates at constant amplitude under a constant rudder angle. Detailed information regarding the effect of wind on the behavior of yaw motion is necessary to safely and effectively control a ship during operation. For this purpose, Spyrou et al. (2005, 2007) investigated this area in relation to rudder angle. In these studies, Spyrou et al. (2005, 2007) found that limit cycles of oscillation occur at small rudder angles with low wind velocities, but they did not provide any explanations of yaw motion stability at higher wind velocities. Further investigation of yaw behavior under wind action was undertaken by Yasukawa et al. (2012), who specifically studied the effects of wind velocity and wind direction on yaw, including the oscillation of yaw motion. These studies used a three-degree-of-freedom (3-DOF) mathematical model of ship maneuverability under the assumption that the ship's forward speed does not significantly change due to wind and that the drift motion is small. This method is easy to use because the maneuvering equations can be analytically solved under these assumptions. However, ships with small draught may experience a large amount of drift motion in headwinds, meaning that their forward speed cannot be assumed to be the same as their surge velocity due to significant sway. In addition, the added resistance of the wind may significantly decrease forward speed, especially for small ships with large windage areas.

A ship master should have accurate information regarding alterations in yaw stability according to wind velocity and wind direction relative to their ship. A ship can be controlled by making changes to the rudder angle and propulsion in order to avoid dangerous situations, such as potential collisions (Spyrou et al., 2005). Course-keeping ability failures due to yaw instability depend on wind velocity and direction as well as the geometric characteristics of the windage area (Liu et al., 2018). In high wind velocities, the heading angle cannot be controlled by the rudder, and thus the ship cannot maintain her trajectory (Aung & Umeda, 2018). Indonesian ro-ro ferries have small draught and large windage areas relative to their overall dimensions (Asri et al., 2014), and wind-induced drift could significantly affect their maneuverability with regard to yaw stability and course-keeping ability. Muhammad et al. (2015) used azimuthing podded propulsion to improve the maneuverability of an Indonesian ro-ro ferry, but this was only advantageous for turning maneuvers. Therefore, the effect of wind on yaw motion and the related course-keeping ability is an important factor in the minimization of collision risk during the operation of ro-ro ferries. A numerical simulation incorporating variations in wind velocity and direction is a useful method of verifying the yaw characteristics of a ship in different wind conditions.

This paper discusses the yaw motion characteristics and course-keeping ability of an Indonesian ro-ro ferry under the action of steady wind. In this study, the rudder angles required to maintain the heading angle and the yaw stability were measured at specific wind velocities and directions. This information is important for the avoidance of collision dangers. Therefore, the yaw characteristics obtained in this study can be used as guidance for ship masters to safely operate their ships. This information should also be considered in the development of traffic separation schemes to prevent accidents, as proposed by Sunaryo et al. (2015). Finally, these results may be used for the future design of Indonesian ro-ro ferries.

2. Methods

2.1. Mathematical Model

Numerical simulations of ship maneuvering usually use 3-DOF mathematical models consisting of surge, sway, and yaw motions. A 4-DOF mathematical model including a roll equation has also been used to investigate the effect of maneuvering on ship stability (Spyrou et al., 2007). Both 3-DOF and 4-DOF mathematical models of ship maneuvering under the action of wind are developed based on the local and global coordinate system shown in Figure 1. The local coordinates originate in the midship section with the axis indicated by x and the ordinate indicated by y. The surge velocity, sway velocity, and yaw rate are indicated by u, v, and r, respectively. The drift angle is indicated by β, and the ship velocity (U) is resultant of the surge and sway velocities. The axis of the global coordinate is designated as x_0, and its ordinate is indicated by y_0. The heading angle (ψ) and the wind direction (ψ_A) are determined from the global coordinate system. Here, δ is the rudder angle. This system demonstrates that the wind direction relative to the ship depends on both the heading angle and the wind direction.

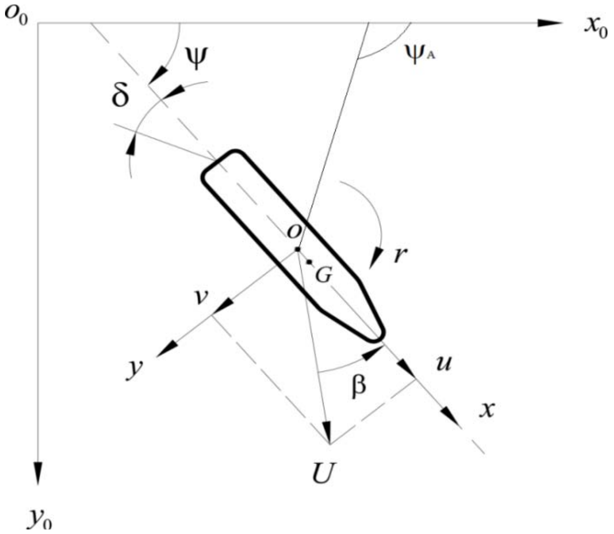

Figure 1 Coordinate system

A well-established mathematical model for the purpose of numerical simulations is the mathematical modelling group (MMG), in which the 3-DOF approach can be expressed as follows (Fujiwara et al., 2006):

$$
\begin{gathered}
m(\dot{u} - vr) = X_H + X_P + X_R + X_A \\
m(\dot{v} - ur) = Y_H + Y_R + Y_A \\
I_{zz}\dot{r} = N_H + N_R + N_A - x_G(Y_H + Y_R + Y_A)
\end{gathered} \tag{1}
$$

here, m is the ship mass and I_{zz} is its inertia in yaw motion. The acceleration of surge, sway, and yaw are $\dot{u}$, $\dot{v}$, and $\dot{r}$, respectively. Surge, sway, and yaw rate are designated by u, v, and r, respectively. The longitudinal position of the ship's center of gravity in the local coordinate system is designated by x_G. The subscripts H, P, R, and A indicate the hydrodynamic forces and moments induced by the ship's hull, propeller thrust, rudder forces, and moment, respectively, as well as those forces and moments induced by the wind.

In Equation 1, the hydrodynamic forces and moments of the ship hull are estimated using the empirical formulae proposed by Yoshimura and Matsumoto (2012), the propeller thrust is estimated using the regression equation obtained from open water test data for B-series propeller (Carlton, 2007) the rudder forces and moment are estimated using the formula proposed by Kijima et al. (1990) and those forces induced by the wind are estimated using Fujiwara's formula (Fujiwara et al., 2006). The formulae used to calculate the hull, propeller, rudder, and wind-induced forces and moments have been reported by Paroka et al. (2015).

Equation 1 can be written as a first-order differential equation of a dynamical system with the rudder angle as a control variable, as follows:

$$\dot{z} = F(z(\delta), \delta) \tag{2}$$

The state vector, z, consists of the surge and sway velocities, the yaw rate, and the heading angle; thus, $z = (u, v, r, \psi)^T$. The steady state equilibrium of the dynamical system of Equation 2 was determined to investigate yaw motion characteristics under steady wind. Under equilibrium conditions, the dynamical system in Equation 2 can be written as follows:

$$F(z(\delta), \delta) = 0 \tag{3}$$

Then, the Newton-Raphson method is used to solve Equation 3 for a specified rudder angle to obtain the surge and sway velocities as well the heading angle. The yaw rate vanishes in the equilibrium condition. Here, the rudder angle ranges between -35° and +35°, the maximum rudder angle of the ship.

Yaw stability is subsequently analyzed by calculating the eigenvalues of the system in the equilibrium condition. By applying perturbation (ξ) to the equilibrium point and expanding the right-hand side of Equation 2 using Taylor expansion, the equation for steady state equilibrium can be written as follows:

$$\dot{z}_E + \dot{\xi} = F(z_E) + F_z(z_E)\xi + \frac{1}{2}F_{zz}(z_E)\xi^2 + \frac{1}{6}F_{zzz}(z_E)\xi^3 + \cdots \tag{4}$$

The time derivative of the vector state ($\dot{z}_E$) and the resultant forces and moments ($F(z_E)$) in equilibrium are equivalent to zero, as defined in Equation 3. If the applied perturbation is small enough, the high-order terms of Equation 4 can be neglected to find a linear first-order differential equation as follows:

$$\dot{\xi} = F_z(z_E)\xi \tag{5}$$

Here, $F_z(z_E)$ is the partial derivative of the forces and moments to the variable vector state in the equilibrium point z_E. This equation shows that the stability of steady state equilibrium depends on the eigenvalues of the matrix $F_z(z_E)$. If the real parts of all the eigenvalues are negative, the equilibrium point is stable. This means that the ship course (heading angle) can be maintained with a constant rudder angle. However, if one eigenvalue has a positive real part, the equilibrium point is unstable. In this case, the heading angle increases with time for a constant rudder angle if a small disturbance is applied to the equilibrium condition toward a stable equilibrium point. The transition between stable and unstable yaw motion can be observed in a change from negative to positive real eigenvalue parts. Additionally, yaw oscillation occurs if the imaginer part of at least one eigenvalue is not zero. This oscillation can be a stable or unstable limit cycle depending on the characteristics of the real parts of the eigenvalues (Somieski, 2001). If the real parts of the eigenvalues change from positive to negative, the limit cycles are stable in the region of variable state smaller than this transition point. The ship's heading angle and yaw rate oscillate at a constant amplitude under a constant rudder angle. The limit cycles are unstable in the region of variable state larger than the transition point if the real part of the eigenvalue changes from negative to positive. The oscillation amplitude of the heading angle and yaw rate may increase or decrease in response to a small disturbance when the rudder angle is kept constant. As a result, the heading angle moves to a stable equilibrium point. Stable oscillation can also occur in a variable state region if the first derivative of the real part of the eigenvalue to the variable state is negative. In contrast, oscillation is unstable if this derivative is positive.

To verify the yaw motion characteristics, a simulation of ship maneuvering was conducted by solving Equation 1 through numerical integration using Runga-Kutta method with the obtained equilibrium point as the initial condition. Alteration of the heading angle from unstable to stable conditions and yaw oscillation in the region of stable and unstable limit cycles can be obtained from the results of this numerical simulation.

2.2. Ship Data

The mathematical models outlined here in were applied to investigate the yaw characteristics of an Indonesian ro-ro ferry with the principle dimensions shown in Table 1 and the propeller and rudder characteristics shown in Table 2.

Table 1 Principle dimension of the ro-ro ferry

Parameter	Value
Length, overall (L_{OA})	56.70 m
Length, between perpendicular (L_{BP})	50.50 m
Breadth (B)	14.00 m
Height (H)	3.80 m
Draught (T)	2.70 m
Ship speed (V_S)	11.0 knot
Lateral projected windage area (A_L)	355.35 m^2
Transverse projected windage area (A_F)	156.07 m^2
Lateral projected area of superstructure (A_{OD})	45.44 m^2
Center of windage area from midship (C)	-0.471 m
Vertical center of A_L (H_C)	3.598 m
Vertical center of A_{OD} (H_L)	9.948 m
Height of transverse projected area (H_{BR})	11.148 m

Table 2 Propeller and rudder characteristics

Items	Value
Number of propellers	2
Propeller blade (Z)	4
Propeller diameter (D_P)	1.40 m
Propeller revolution (n)	9.55 rps
Transverse position propeller (y_P)	±2.55 m
Longitudinal position propeller (x_P)	24.38 m
Rudder area (A_R)	2.81 m^2
Transverse rudder position (y_R)	±2.55 m
Longitudinal rudder position (x_R)	25.50 m

To identify the wind velocity up to which the rudder angle will not exceed its maximum, the simulated velocity was increased from 1 m/s to 25 m/s. The wind direction relative to the ship varies according to the heading angle, which ranges from 0° to 360°. The wind coefficients in the surge (CAX), sway (CAY), and yaw (CAN) directions of the local coordinate system are shown in Figure 2. Although the wind effect was symmetrically applied to the starboard and portside, the maneuvering motion naturally occurred in opposite directions, meaning that changes to the heading angle or ship motion would occur in different directions depending on the wind direction relative to the ship.

The thrust coefficient of the propeller described in the Table 2 was calculated for different advance coefficients using the following equation (Carlton, 2007):

$$K_T = \sum_{n=1}^{39} C_n (J)^{S_n} (P/D)^{t_n} (A_E/A_0)^{u_n} (Z)^{v_n} \tag{6}$$

Here, $C_n, S_n, t_n, u_n,$ and v_n are based on open water test data for B-series propeller (Carlton, 2007) with the assumption of a constant propeller revolution. To take into account the alteration of ship velocity during the numerical simulation, the thrust coefficient is represented as a function of the advance coefficient in a polynomial regression equation, as shown in Equation 7. This polynomial equation was developed based on the thrust coefficients obtained with Equation 6. The thrust coefficient (K_T), torque coefficient (K_Q), and efficiency (η) of the propeller are presented in Figure 3.

$$K_T(J) = 0.3128 - 0.3406J - 0.1094J^2 \tag{7}$$

where J is the advance coefficient of the propeller.

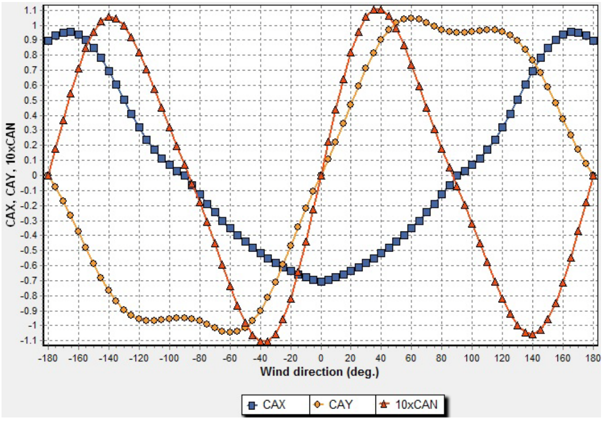

Figure 2 Coefficients for wind forces and moments

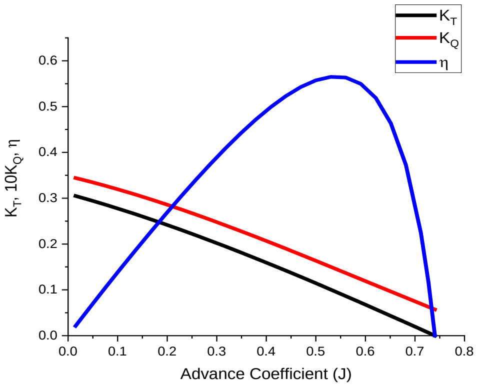

Figure 3 Thrust coefficient of the propeller

3. Results and Discussion

The steady state equilibrium of the ship is shown in Figure 4 for wind velocities (U_w) of 10 m/s, 15 m/s, 20 m/s, and 25 m/s; the horizontal and vertical axes indicate the rudder angle and the heading angle, respectively. The rudder angle required to maintain the ship's direction increased as wind velocity increased, and the heading angle with the largest required rudder angle tended to decrease as wind velocity increased. This is because the wind force and moment coefficients shown in Figure 2 alternated with the wind direction relative to the ship. The required rudder angle exceeded the maximum available rudder angle (±35°) under a wind velocity of 24 m/s (4.24 of ship velocity) or greater.

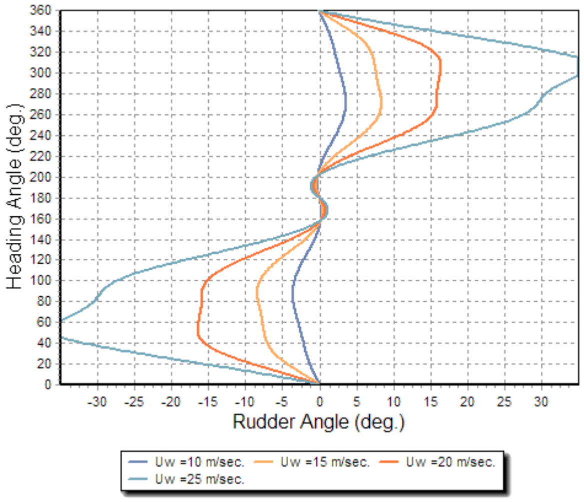

Figure 4 Steady state equilibrium points

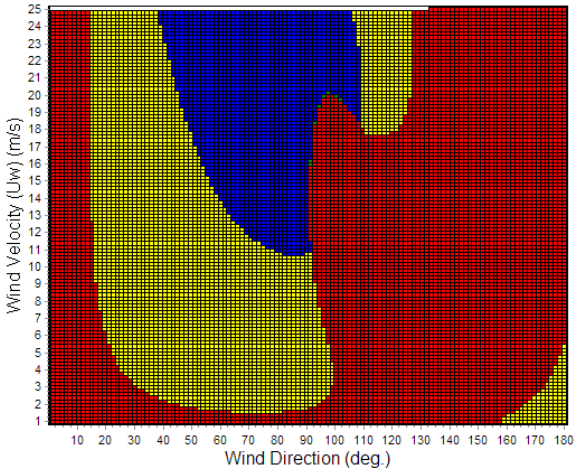

Figure 5 Stability of yaw motion

The equilibrium point exists at two heading angles for each rudder angle. In contrast, equilibrium may occur at four different heading angles for small rudder angles. This means that even when the rudder angle is constant, the heading angle may change from one equilibrium point to another depending on the yaw stability of each point. If a small disturbance is applied to the unstable equilibrium point, the yaw rate will gradually increase with time. As a result, the heading angle increases with time toward the stable equilibrium point. Figure 5 shows the stability characteristics of the yaw motion at steady state equilibrium for different wind velocities and directions. The red area indicates the equilibrium point with unstable yaw at which the eigenvalues are real and at least one eigenvalue is positive. The yellow area indicates unstable yaw motion with one (or pairs of) complex eigenvalue(s) with a positive real part; here, the yaw motion oscillates with increasing amplitude over time. As a result, the heading angle also oscillates with increasing amplitude over time toward a heading angle with a stable equilibrium. The blue area indicates the equilibrium point with stable yaw oscillation. Here, the eigenvalues are complex and all real parts are negative; the yaw oscillation decays, while the yaw rate and the heading angle become constant after a certain period of time.

The yaw motion was unstable for all wind directions at wind velocities smaller than 2 m/s or 0.34 of ship velocity. This meant that the ship would perform a turning maneuver because all the equilibrium points within this range of wind velocity were unstable. Unstable yaw with oscillation was found for wind directions between 160° and 180° or in the following wind indicated by the yellow area. The range of heading angles decreased as wind velocity increased and disappeared in wind velocities larger than 5 m/s. Unstable yaw motion was also found in wind directions of 20° or smaller for all wind velocities. These cases of unstable yaw occurred due to the hysteresis of steady state equilibrium for heading angles between 150° and 210°, as shown in Figure 4. A similar phenomenon was found by Yasukawa et al. (2012), even though the hysteresic characteristic does not typically exist for high wind velocities. Instead, this instability may have been due to an increase in the ship's forward speed induced by the wind, which caused the hydrodynamic forces and moments of the hull to dominate those induced by the rudder. Unstable equilibrium with yaw oscillation occurred for wind directions between 20° and 100° with wind velocities larger than 2 m/s and up to 11 m/s or 1.95 of ship velocity. For wind velocities larger than 11 m/s, oscillating yaw motion was found up to a wind direction of 125°. This region of yaw oscillation is similar to that obtained by Yasukawa et al. (2012), albeit with a different range of wind velocities because of differences in ship and windage area dimensions. Liu et al. (2018) found that the effect of wind load on course-keeping failure depends on the geometric configuration of the windage area.

Stable yaw motion was found in wind velocities greater than 11 m/s within a range of wind directions that increased as wind velocity increased. For example, the range of wind directions with stable yaw motion in a wind velocity of 24 m/s was 40° to 110°. The ship's heading angle could be maintained by the rudder because yaw motion decays and the heading angle becomes constant over time to infinity. An unstable equilibrium with yaw oscillation was also found in wind angles smaller than the lower boundary of the stable regions as well as wind angles larger than the upper boundary of the stable yaw motion. Here, the ship heading angle changed toward a heading angle with stable yaw oscillation, as indicated by the blue area in Figure 5. Stable limit cycle oscillation occurred at the lower boundary of the stable region in which the real part of the eigenvalue changed from positive to negative. The yaw motion and the heading angle oscillated at a certain amplitude with a constant rudder angle. Unstable limit cycle oscillation was found in the upper boundary of the stable region. Here, the amplitude of the yaw rate increased with time so that heading angle oscillation also increased with time until it reached the heading angle with stable conditions. For a wind velocity of 24 m/s, as table limit cycle region was found to range from 20° to 35° in terms of wind direction, while unstable yaw motion occurred in wind directions between 105° and 135°.

Figure 5 also shows that equilibrium points with unstable yaw motion occurred for heading angles smaller than that achieved at the maximum rudder angle. If the heading angle was larger than that achieved at the maximum rudder angle, the equilibrium points behaved as in stable yaw motion or unstable yaw motion with a stable limit cycle when the wind velocity was larger than 11 m/s. Similar results were found by Spyrou (1995) across four different ship types. The present results also showed that the range of the heading angle with oscillating yaw motion increased when the wind velocity was greater than 18 m/s because the heading angle with the maximum rudder angle significantly decreased under these conditions. Therefore, the range of wind directions with limit cycles or stable yaw motion also increased as wind velocity increased for wind velocity larger than 18 m/s, as shown in Figure 5.

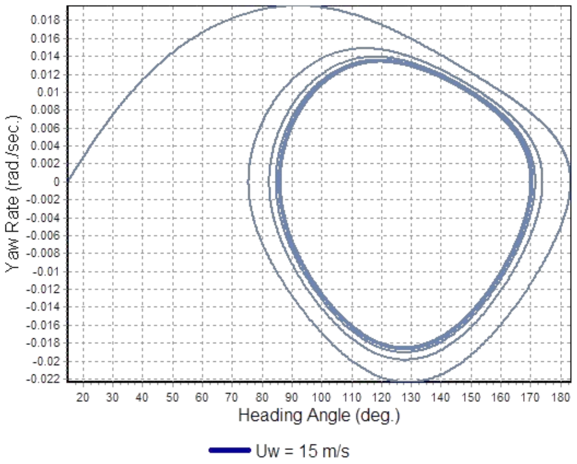

Figure 6 Transition of yaw motion from unstable equilibrium to stable limit cycles

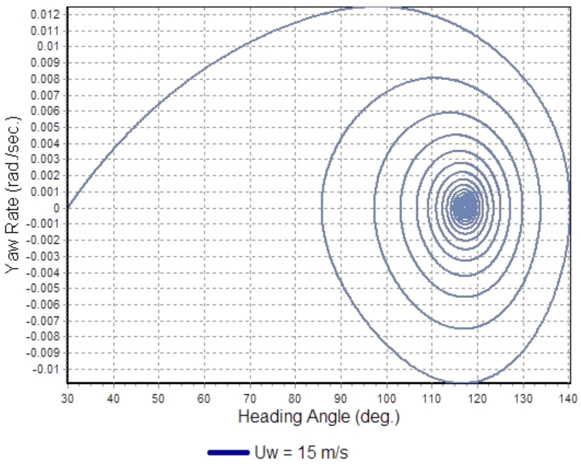

Figure 7 Transition of yaw motion from unstable equilibrium to a stable fixed point

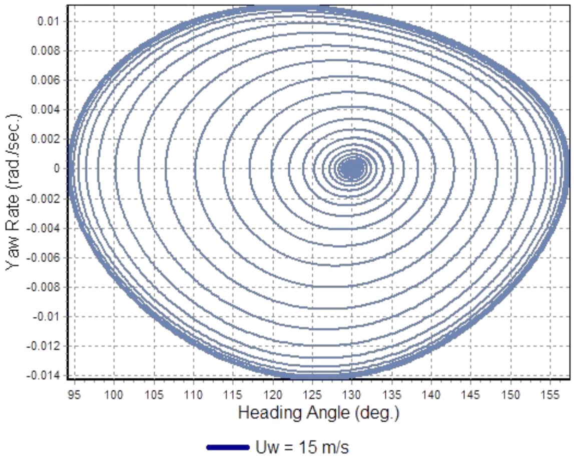

Figure 8 Limit cycle oscillation with a rudder angle of 3.76°

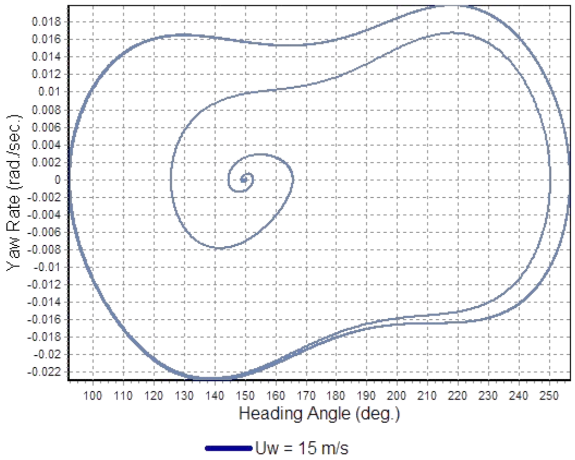

Figure 9 Limit cycle oscillation with a rudder angle of 0.55°

To identify the yaw motion characteristics at the equilibrium points with both stable and unstable yaw, particularly the existence of limit cycle oscillations, a numerical simulation was conducted by solving Equation 1 using the Runga-Kutta integration method with the respective equilibrium points as initial conditions. Figure 6 presents the results of this simulation with an initial condition of unstable equilibrium, a heading angle of 15°, a rudder angle of 3.25° toward the starboard, and a wind velocity (U_w) of 15 m/s. The initial heading angle corresponds to a wind direction of 165° or a following wind and increases toward a stable limit cycle. Here, the heading angle oscillates between 85° and 170°, and the yaw rate alternates between -0.018 and 0.014 rad/s. The same phenomenon was observed for an initial heading angle of 30°, corresponding to a wind direction of 150° and a rudder angle of 6.04° toward the starboard, as shown in Figure 7. In this case, however, the final heading angle is stable so that the yaw rate decreases with time and ultimately vanishes to infinity. The center of the limit cycles in Figure 6 is unstable, as indicated by one eigenvalue with a positive real part. This instability can be further investigated using a mathematical simulation with an initial heading angle at the center of the limit cycles. As such, Figure 8 shows the evolution of yaw motion, starting from an initial heading angle of 130° at the cycle center and a rudder angle of 3.76°. Here, the heading angle increases due to the increase in yaw rate, approaches the limit cycle boundary, and oscillates there with a constant amplitude. Figure 9 presents another equilibrium point with limit cycle oscillation, in which the initial heading and rudder angles are 150° and 0.55° toward the starboard, respectively. This demonstrates that both the amplitude of the yaw rate and the heading angle in oscillating limit cycles tend to decrease when the rudder angle increases.

4. Conclusions

The yaw motion stability and course-keeping ability of an Indonesian ro-ro ferry were investigated under the action of steady wind through an analysis of the characteristic alteration of the eigenvalues obtained in a steady state maneuvering equilibrium. The results of the numerical simulation showed that a heading angle with the maximum rudder angle may significantly change in response to increases in wind velocity. The rudder angle required to maintain the ship's course was equivalent to the maximum possible rudder angle at a wind velocity of 24 m/s. The yaw motion at the equilibrium point was unstable when the heading angle was smaller than that obtained with the maximum rudder angle. Where heading angles are larger than that obtained with the maximum rudder angle, the equilibrium point may be stable or unstable with stable limit cycles, especially for wind velocities larger than the ship velocity. The effect of wind on the stability of yaw motion can be neglected if the wind velocity is smaller than 0.34 of ship velocity. Unstable equilibrium with stable limit cycles appeared when the wind velocity was larger than 0.34 of ship velocity, and stable yaw motion occurred when the wind velocity was larger than 1.95 of ship velocity. The limit cycles were stable for wind velocities between 0.34 and 1.95 of the ship velocity. Different characteristics of limit cycle oscillation were obtained for wind velocities larger than 1.95 of ship velocity; specifically, limit cycle oscillation was stable in headwinds and unstable in quartering winds.

Acknowledgements

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List of Changes

Manuscript:

Response and Revision made by Author(s)

Reviewer #1: #2886

No	Comments	Revision/Changes
1	In equation (1), does the yaw rate *r* depend on *u* and *v* to make the system of equations nonlinear?	An explanation about *u, v* and *r* has been added just after the equation (1)
2	Please describe better with what the authors mean by: “Limit cycles of yaw motion?”	Physical interpretation about limit cycles oscillation of yaw motion has been added in the last paragraph of page 1.
3	Reference about Indonesian ro-ro ferry should be included	A reference explained about geometry characteristics of Indonesian ro-ro ferry has been added in the second paragraph of page 2
4	2.1 Spelling error (Mathmeatical Model)	The spelling error has been revised
5	The following statements, if possible should be accompanied by physical interpretations, otherwise the reader would ask “why are they so?”	The physical interpretations about stability characteristics of yaw motion have been added in the paragraph just after equation (5) in the page 4
6	The labels of Figure 2 are too small, they cannot be read.	Figure 2 has been revised as shown in page 6
7	In Equation (6), the usual symbol for the coefficient of propeller thrust in the naval architecture is K_T not C_T. (C_T is usually used for the ship’s total resistance coefficient	The equation (6) has been changed to be Equation (7). The symbol for propeller thrust coefficient has been changed to be K_T as shown in 6
8	Referring to Figure 3, the analysis of the open water test data of B series propeller should be explained more (how was the analysis done?). What is the difference between “Calculate” and “Polynomial” in the legend of Figure 3? To make Figure 3 complete, the coefficient of torque K_Q and propeller effeciency η should also be shown	Figure 3 has been revised as shonw in page 6. The explanation about analysis of open water test data of B series propeller has been included in the last paragraph of page 5 and thev first paragraph of page 6. The difference of “Calculate” and “Polynomial” is explained in the first paragraph of page 6
9	The results presented in Figures 4 and 5 should be explained better	Explanations correspond to Figures 4 and 5 are added in the last paragraph of page 6, the first and the second paragraphs of page 7.
10	The following paragraph is very difficult to undestand, in particular, how should one interpret them physically!	Some explanation and physical interpretations have been added in the last paragraph of page 7.
11	Check the word “Constrastingly”; do you mean “In contrast”?	The word has been changed as suggested in the first paragraph of page 6.

Reviewer #2: #2874

No	Comments	Revision/Changes
1	Equation (1) firstly appeared in Fujiwara et al (2006) and Paroka et al (2015) just repeated it thus this reference should be neglected.	Paroka et al (2015) has been removed from the text as shown in page 3
2	Please provide with details of the mathematical formulation!	Detail formulation of hull, propeller, rudder and wind forces and moments has been published at Paroka, et al (2015). Additional explanation regarding detail of those formula has been added at the last sentence of pagraph just after Equation (1) in page 3.
3		
4		
5		
6		

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List of Changes

Manuscript:

Response and Revision made by Author(s)

Reviewer #1:

No	Comments	Revision/Changes
1	Abstract has not explained yet the gap from previous research, i.e. need to state that none of the previous/existing research has done simulation in the area of yaw motion and wind. The novelty of the paper should be reflected explicitly in the paper.	Additional explanation to state the novelty and area of research have been added on the thirt sentence of abstract.
2	Since this is a scientific and numerical simulation work, I highly suggest to include NOMENCLATURE consisting symbol, description, and unit.	The nomenclature has been added before the introduction
3	In the introduction section, the paper has given the background setting of the paper. However, is there any incidents/collision happen due to wind effect so far? Need to provide a reference to support the background setting.	Background has been re-arrange by including an accident due to uncontrolof yaw motion. It has been added in the third paragraph of page 3. Some additional relevant references has also been added in the third paragraph of page 3.
4	Again, regarding the originality, the work by Fujiwara, et al, 2006 has exposed similar issue on the maximum rudder angle which may imply the work in the paper is less important / not new. Therefore, what is the novelty of the paper can offer to the existing research / what is the significance of the paper? Why this issue has not been done in the previous research? There is no reasoning as to why the paper use Indonesian ro-ro ferry, why not any other geographical area of a ro-ro ferry which may be more crowded than Indonesia sea traffic? Please add more background setting as to why the author(s) chose the Indonesian ro-ro ferry.	Additional explanation about the difference with Fujiwara's work has been added in the first paragraph of page 2. The novelty and the significance of the paper as well as the reasoning to use Indonesia ro-ro ferry have been added in the third paragraph of page 3 and the first paragraph of page 4
5	In the introduction, there are some qualitative statements such as "small draught...." and "small ships with large windage areas...." in the second paragraph. Please provide a numerical range.	The sentence has been changes to be the ratio of breadth and draught as well as length and breadth as the parameter has siginificant veffect on maneuvering. The range of breadth-to-draught ratio and length-to-breadth ratio have been added in the third paragraph of page 3.
6	Mathematical model Equation 1 and 6, if the equation is not new, put in the appendix, together with the empirical formulae used in the paper by Yoshimura, et al, 2012, Carlton...	The mathatical model has been moved to Appendix A at page 12.
7	Fujiwara, et al, 2006 (paragraph after equation 1) H, P, R, and A which stands for appendage? Please provide nomenclature.	Subscript H, P, R and A correspond to hull, propeller, rudder and wind. Its have been added in the nomenclature.

8	Typo "enought" "th" Double-check if the Rawson-Newton method, Taylor expansion, Runga-Kutta methods can be classified as "common knowledge"? Otherwise, please provide relevant references.	Typo “enought” has been revised. The Newton-Rhapson and the Runga-Kutta methods are common knowledge to solve differential equation. Reference corresponds to Taylor expansion has been added in the third paragraph of page 5.
9	Ship data Please provide the reference on the caption of Table 1 also Table 2, otherwise, it is plagiarism. Since this is not a novel work, put this in the appendix.	Table 1 and Table 2 have been moved to Appendix B at page 14 to 15.
10	Typo "as follow" vs "as follows"	as follows has been changed to be as follow in the equation 1 – 4.
11	Figure 2 is far from the paragraph where it is mentioned, please rearrange the layout of the paper. Also, CAX, CAY, 10xCAN are not explained in the text. Again, the nomenclature is important.	The paragraph has been re-arranged at page 6 and page 7. CAX, CAY and 10xCAN has been explained in the nomenclature.
12	Results and discussion first paragraph " ... of ship velocity or larger." larger than what? be specific.	The sentence has been revised at page 7.
13	Paragraph three, "or 0.34 of ship velocity" should be in percentage form (34 %).	It has been revised to be 34% of ship velocity at second paragraph of page 8.
14	Typo "phenomena" and overused, consider another word.	The sentence has been revised as shown in the second paragraph of page 8.
15	The last paragraph in the discussion is too crowded for explaining multiple diagrams. Consider rearranging the layout and provide the discussion adjacent to the plot.	The paragraphs and graphs have been re-arranged at page 9 and page 10.
16	the paper needs to discuss the validation of the results, including, but not limited to how accurate the results compared to the experimental results/ real-world situation.	Comparation with the real situation has been added in the second paragraph of page 7. Additional explanation has also been added in the thirt sentence of conclusion. Experimental has not been conducted and it would be performed in the next step.
17	Additionally, the paper should identify what are the future works/aspects that have not considered in the simulation, .e.g. effect of underwater current, change rudder characteristics, etc.	The aspects shouldbe considered in the future work have been added at the second paragraph of conclusion.
18	In addition to the comments, I suggest adding more independent variables to be considered in the paper, e.g. to find out what necessary rudder characteristics need to be improved for course keeping, not just changing the input of ship data and varying the wind velocities. This would add more significance to the paper.	The paper regarding rudder configuration and its effecton maneuveringof Indonesian ro-ro ferry under action of wind has been submitted to journal as well.

Reviewer #2:

No	Comments	Revision/Changes
1	The integrity of Reference 1 (Asri et al. 2014), which is published in International Journal of Engineering Research and Technology (IJERT) with Initial Review Acceptance: within 4 – 6 days after submission, is questionable and should be checked/verified.	The reference has been chaged to another relevant paper as shonw in the reference.
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Reviewer #3:

No	Comments	Revision/Changes
1	Authors gave some further information about ro-ro vessel in Indonesia, e.g. it has a small draught and large windage area. Ro-ro vessel in Indonesia is unique and the explanation is not adequate. Indonesian ro-ro has more openig areas than that (say) in Japan or Italy.	The geometry characteristics such as B/T and L/B which have significant effect on maneuvering has been added in the third paragraph of page 3.
2	Authors reject to show the complete mathematical formulation and propose to see their previous paper. This is a journal and not a conference paper; readers do not have enough time to see that paper. Thus, authors must show the complete mathematical formulation hence readers can easily understand the paper.	Detail of mathematical model has been added in the appendix A at page 12.
3	Further, authors must show the body-plan and typical figure or photograph of the Indonesian ro-ro used in the current work. It has been asked previously but authors neglected it.	The bodyplan and the general arrangement have been added as Figure 2 and Figure 3 at page 6.
4	Comment with the work done by Spyro (1995) is given but not enough and clear. Authors should show it in a graph/curve and give appropriate comment on the agreement and disagreement of their results and Spyro's results.	The sentence is moved to the last sentence of the second paragraph of page 7. Spyrou results correspond to steady state equilibrium shown in the Figure 6. It has been added in the figure as black square legend. Some explanation correspond to the present results and Spyrou results has been added in the second paragraph of page 7.
5	Conclusion is too general and can be applied to any kind of ships. Special conclusion which is only for Indonesian ro-ro ships must be given hencde correlate to the title of paper. For example, what is the correlation between B/H (breadth / height of superstructure) which is typical for ro-ro vessel. It has been asked before, but no comment from authors	Additional explanation correspond to the subject ship has been added in the conclution. Effect of superstructures correspond to geometry characteristics of windage are will be investigated in the future works. It has been added in the second paragraph of conclusion
6		

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YAW MOTION STABILITY OF AN INDONESIAN RO-RO FERRY IN ADVERSE WEATHER CONDITIONS

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(Received: Month Year / Revised: Month Year / Accepted: Month Year)

ABSTRACT

Stability of yaw motion and course keeping ability of ships are important factors regarding collision danger particularly for those operating in narrow channel, crowded route or in port areas. The yaw motion may become unstable from external forces such as wind. To investigate yaw stability or course keeping ability, this study develops a nonlinear dynamic system of a three-degree-of-freedom mathematical model to determine the steady state equilibrium; yaw motion behavior is then analysized using the eigenvalue characteristic of the obtained equilibrium points. Numerical results for an Indonesian ro-ro ferry show that the required rudder angle to maintain the ship's course tend to increase as wind velocity increases. In beam wind the necessary rudder angle is larger than the possible maximum when the wind velocity is 25.0 m/s or more. In addition, yaw motion is found to be stable in headwind and unstable in following wind. The yaw motion behaves as an oscillation in headwinds and with small rudder angle when the wind velocity is higher than 11.0 m/s. The range of heading and rudder angles with yaw oscillation increases as the wind velocity increases.

Keywords: Yaw motion; limit cycles; maneuvering; ro-ro ferry

1. INTRODUCTION

The maneuvering performance of ship is indicated by turning ability, zig-zag maneuverability, course keeping ability as well as stopping ability which are decided as maneuvering criteria by the International Maritime Organization (IMO) (International Matirime Organization, 2002). During initial design, the maneuvering performance is evaluated through numerical simulation or free running model experiments. After a ship is launched, tests are conducted in sea trail to guarantee the maneuverability of the vessel. In these criteria, external disturbances such as wind and waves were not considered, although some researches have shown that these factors have a significant effect on the maneuvering performance of a ship (Paroka, et al, 2017; Shigunov, 2017)). The required rudder angle to maintain the ship course increases if wind velocity and wave height increase. In severe weather, the rudder may not control the ship direction because the required rudder angle is larger than the maximum possible rudder angle (Fujiwara, et al, 2006).

When a ship operates in narrow channel, river and port area, yaw motion stability become highly important in order to avoid collision during operation. Several studies regarding yaw stability have been conducted. Spyrou (1995) investigated yaw motion of four different ships types under wind action and found that it tends to be unstable in following wind and stable in headwind. It was also found that the ship direction is significantly influenced by yaw motion stability. In addition, limit cycles of yaw oscillation were identified within a certain range of heading and rudder angles for sepcified wind velocities and directions. Detail information regarding the effect of wind on behaviour of yaw motion is necessary for safely and effectively control the ship during operation. For this purpose, Spyrou, et al (2005; 2007) investigated this area in relation to rudder angle. These studies found that the limit cylces oscilation occurs at small rudder angles with low wind velocities but did not provide explanation about yaw motion stability for higher wind velocities. Further investigation of yaw behavior under wind action was undertaken by Yasukawa, et al (2012) who specifically studied the effects of wind velocity and wind direction on yaw including oscillation of the yaw motion. These studies used a three-degree-of-freedom (3-DOF) mathematical model of ship maneuverability under the assumption that the ship forward speed does not significantly change due to the wind and the drift motion is small. This method seems to be easily used because the maneuvering equations can be analitically solved under these assumptions. However, ships with small draught may experience a large drift motion in headwinds meaning that their forward speed cannot be assumed to be the same as the surge velocity because of the significant sway. In addition, the added resistance caused by the wind may significantly decrease forward speed especially for small ships with large windage areas.

Ship master should have accurate information regarding alteration in yaw stability according to wind velocity and wind direction relative to the ship. A ship can be controlled by changes to rudder angle and propulsion in order to avoid dangerous situation such as potential collision (Spyrou, et al, 2005). Failure of course keeping ability due to instability of yaw depends on wind velocity and direction, as well as geometry characteristic of windage area (Liu, et al, 2018). The heading angle cannot be controlled by rudder in high wind velocity so that the ship cannot maintain her trajectory (Aung and Umeda, 2018). The Indonesian ro-ro ferries have small draught and large windage areas compared to their overall dimensions and wind-induced drift could significantly affect their maneuverability regarding yaw stability and course keeping ability. Therefore, the effect of wind on yaw motion and the related course keeping ability becomes an important factor to minimize collision risk during operation. In order verify yaw characteristics of a ship in different wind conditions, numerical simulation that incorporates variations of wind velocity and direction is an important approach.

This paper discusses the yaw motion characteristics and course keeping ability of an Indonesian ro-ro ferry under action of steady wind. As a result, the required rudder angle to maintain heading angle as well as its stability for specific wind velocities and directions are obtained. This information is important for avoiding collision dangers and the yaw characteristics obtained in this study can therefore be used as guidance for ship masters to safely operate the ship. The results may also be used as additional information for the design of Indonesian ro-ro ferries in the future.

2. METHODS

2.1. Mathmeatical Model

Numerical simulation of ship maneuvering is usually conducted using 3-DOF mathematical models consisting of surge, sway and yaw motions. In order to investigate the effect of maneuvering on ship stability, 4-DOF mathematical model has also been used that includes roll equation (Spyrou, et al, 2007). The mathematical model for both 3-DOF and 4-DOF of ship maneuvering under action of wind is developed based on the local and the global coordinate system shown in Figure 1. The local coordinate originate in the midship section with the axis indicated by x and the ordinate by y. u, v and r are the surge velocity, the sway velocity and the yaw rate, respectively. The drift angle is indicated by β and the ship velocity (U) is resultant of the surge and the sway velocities. The axis of the global coordinate is designated as x_0 and its ordinate is indicated by y_0. The heading angle (ψ) and the wind direction (ψ_A) are determined from the global coordinate system. Here, δ is the rudder angle. The system demonstrate that the wind direction relative to the ship depends on both the heading angle and the wind direction.

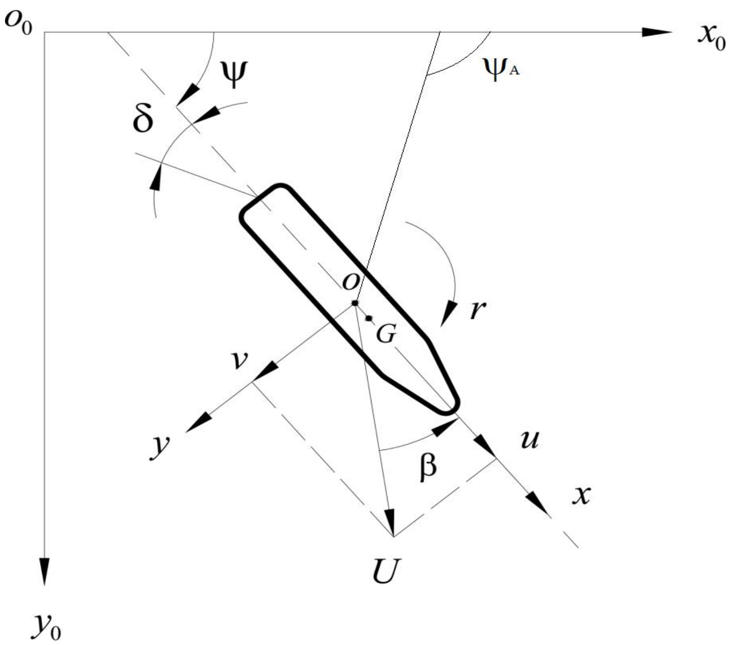

Figure 1 Coordinate system

A well-established mathematical model used for numerical simulation is mathematical modelling group (MMG) in which the 3-DOF approach can be expressed as follows (Fujiwara, et al, 2006; Paroka, et al, 2015):

$$\begin{aligned} m(\dot{u} - vr) &= X_H + X_P + X_R + X_A \\ m(\dot{v} - ur) &= Y_H + Y_R + Y_A \\ I_{zz}\dot{r} &= N_H + N_R + N_A - x_G(Y_H + Y_R + Y_A) \end{aligned} \tag{1}$$

Here, m is the ship mass and I_{zz} is its inertia in yaw motion. $\dot{u}$, $\dot{v}$ and $\dot{r}$ are the acceleration of surge, sway and yaw, respectively. x_G is the longitudinal position of ship's center of gravity in local coordinate system. The subscripts H, P, R and A indicate the hydrodynamics forces and moments induced by the ship's hull, the propeller thrust, the rudder forces and moment as well as the forces and moment induced by the wind, respectively. The hydrodynamics forces and moments of ship hull in the equation (1) are estimated by using empirical formulae proposed by Yoshimura, et al (2012); the propeller thrust is estimated by using regression equation obtained from open water test data for B series propeller (Carlton, 2007); the rudder forces and moment are estimated using formula proposed by Kijima, et al (1990) and those by the wind are estimated using Fujiwara's formula (Fujiwara, et al, 2006).

Equation (1) can be written as a first order differential equation of dynamical system with control variable of rudder angle as:

$$\dot{z} = F(z(\delta), \delta) \tag{2}$$

The state vector, z, consists of the surge and the sway velocities, the yaw rate and the heading angle, thus $z = (u, v, r, \psi)^T$. In order to investigate yaw motion characteristics under steady wind, the steady state equilibrium of the dynamical system of Equation (2) is determined. In equilibrium condition, the dynamical system in the Equation (2) can be written as follows:

$$F(z(\delta), \delta) = 0 \tag{3}$$

Then, the Newton-Raphson method is used to solve the Equation (3) for a specified rudder angle to obtain the surge and the sway velocities as well the heading angle. The yaw rate vanishes in the equilibrium condition. Here the rudder angle varies in a range between -35.0 degrees and +35.0 degrees, the maximum rudder angle of the ship.

Yaw stability is subsequently analyzed by calculating the eigenvalues of the system in the equilibrium condition. By applying perturbation, ξ, to the equilibrium point and expanding the right-handside of Equation (1) using Taylor expansion, the equation for steady state equilibirum can be written as follows:

$$\dot{z}_E + \dot{\xi} = F(z_E) + F_z(z_E)\xi + \frac{1}{2}F_{zz}(z_E)\xi^2 + \frac{1}{6}F_{zzz}(z_E)\xi^3 + \cdots .. \tag{4}$$

The time derivative of vector state ($\dot{z}_E$) as well as the resultant forces and moments ($F(z_E)$) in equilibrium are equivalent zero as defined in the Equation (3). If the applied perturabation is small enought, the high order terms of Equation (4) can be neglected to find linear first order differential equation as follows:

$$\dot{\xi} = F_z(z_E)\xi \tag{5}$$

Here, $F_z(z_E)$ is the partial derivative of the forces and moments to the variable vector state in the equilibrium point, z_E. This equation shows that the stability of steady state equilibrium depends on eigenvalues of matrix $F_z(z_E)$. If the real part of all eigenvalues are negative, the equilibrium point is stable. However, if one eigenvalue has a positif real part, the equilibrium point is unstable. The transition between stable and unstable yaw motion can be observed in a change from negative to positive eigenvalue real parts. Additionally, yaw oscillation occurs if the imaginer part of at least one eigenvalue are not zero. This oscillation can be a stable or unstable limit cycles depending on the characteristics of real part of eigenvalues (Somieski, 2001). If the real part of eigenvalues changes from positive to negative, the limit cycles is stable in the region of variable state smaller than this transition point. The limit cycles is unstable in the region of variable state larger than the transition point if the real part of eigenvalue changes from negative to positive. Stable oscillation can also occur in a variable state region with first derivative of the real part of eigen value to the variable state is negative. In constrast, oscillation is unstable if that derivative is positive.

In order to verify the yaw motion characteristics, simulation of ship maneuvering is conducted by solving the Equation (1) through numerical integration using Runga-Kutta methods with initial condition of the obtained equilibrium point. Alteration of heading angle from unstable to stable conditions and yaw oscillation in region of stable and unstable limit cycles can be obtained from the results of this numerical simulation.

2.2. Ship Data

The mathematical models here outlined will be applied to investigate the yaw characteritics of an Indonesian ro-ro ferry with principle dimensions as shown in Table 1 and propeller and rudder characteristics shown in the Table 2. To identify the wind velocity up to which the rudder angle will not exceed its maximum, the simulated velocity is increased from 1.0 m/s to 25.0 m/s. The wind direction relative to the ship is varied according to the heading angle which itself ranges from 0.0 degree to 360.0 degrees. The wind coefficients in the surge, sway and yaw directions of the local coordinate system are shown in Figure 2. Although the wind effect is symetry applied the starboard and portsides, the maneuvering motion will naturally occur in opposite directions meaning that changes to the heading angle or ship motion will occur in different directions depending on the wind direction relative to the ship.

Tabel 1 Principle dimension of the ro-ro ferry

	Value
Length overall (L_{OA})	56.70 m
Length between perpendicular (L_{BP})	50.50 m
Breadth (B)	14.00 m
Height (H)	3.80 m
Draught (T)	2.70 m
Ship speed (V_S)	11.0 knot
Lateral projected windage area (A_L)	355.35 m^2
Transverse projected windage area (A_F)	156.07 m^2
Lateral projected area of superstructure (A_{OD})	45.44 m^2
Center of windage are from midship (C)	-0.471 m
Vertical center of A_L (H_C)	3.598 m
Vertical center of A_{OD} (H_L)	9.948 m
Height of transverse projected area (H_{BR})	11.148 m

Table 2 Propeller and rudder characteristics

Items	Value
Number of propeller	2
Propeller blade (Z)	4
Propeller diameter (D_P)	1.40 m
Propeller revolution (n)	9.55 rps
Transverse position propeller (y_P)	±2.55 m
Longitudinal position propeller (x_P)	24.38 m
Rudder area (A_R)	2.81 m^2
Transverse rudder position (y_R)	±2.55 m
Longitudinal rudder position (x_R)	25.50 m

The thrust coefficient of the propeller described in the Table 2 is presented in Figure 3 as a function of the advance coefficient, and this can be decribed as the following polynomial equation:

$$C_T(J) = 0.3128J - 0.3406J^2 - 0.1094J^3 \qquad (6)$$

where J is the advance coefficient of the propeller. Here, the thrust coefficients are estimated from open water test data of B series propeller (Carlton, 2007) with assumtion that the propeller revolution is constant.

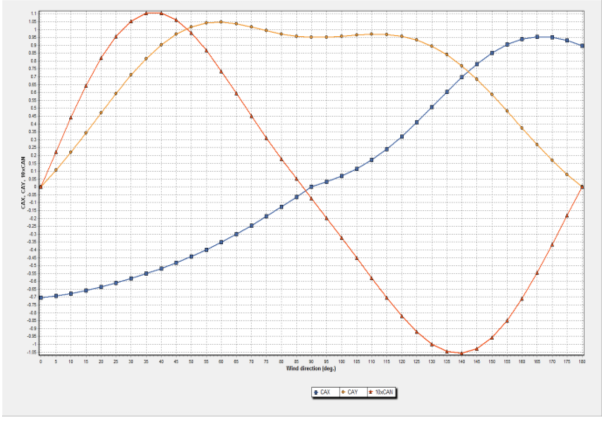

Figure 2 Coefficients for wind forces and moments

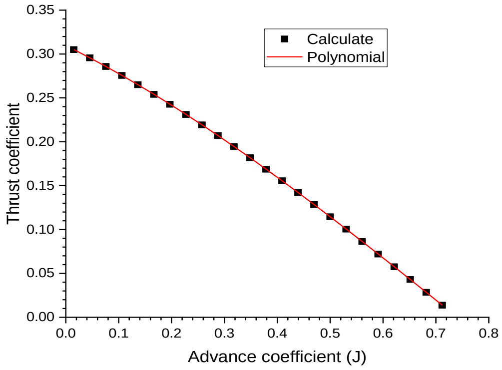

Figure 3 Thrust coefficient of the propeller

3. RESULTS AND DISCUSSION

The steady state equilibrium of the ship for wind velocities of 10 m/s, 15 m/s, 20 m/s and 25 m/s are shown in Figure 4; the horizontal and the vertical axes indicate the rudder angle and the heading angle, respectively. The rudder angle required to maintain the ship direction increases as the wind velocity increases, and the heading angle with maximum rudder angle depends on both geometry of windage area and wind velocity. As such, the heading angle with maximum rudder angle tends to decreases as wind velocity increases. The rudder angle exceed the maximum value in wind velocity of 24.0 m/s or 4.24 of ship velocity.

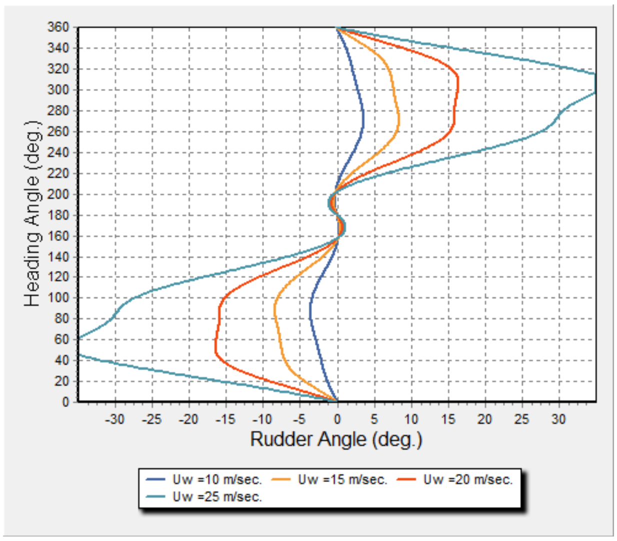

Figure 4 Steady state equilibrium points

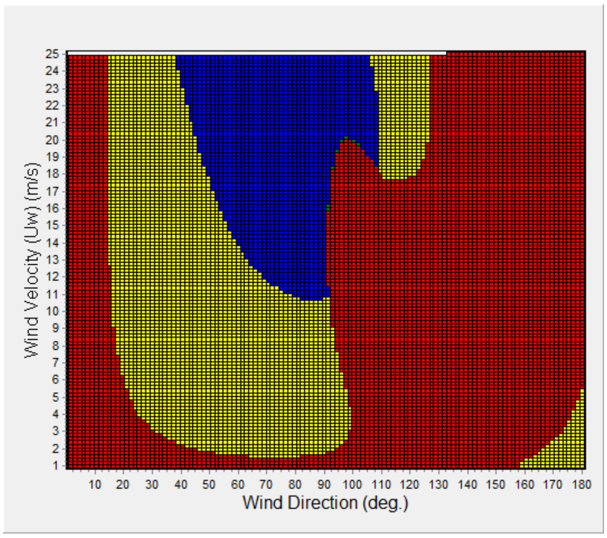

Figure 5 Stability of yaw motion

The equilibrium point exsists at two heading angles for each rudder angle. Constrastingly, for small rudder angles, equilibrium may occur at four different heading angles. This means that even when the rudder angle is constant, the heading angle may change from one equilibrium point to another depending on yaw stability of each point. Figure 5 above presents the stability characteristics of the yaw motion at steady state equilibrium for different wind velocities and directions. The red area indicates the equilibrium point with unstable yaw in which the eigenvalues are real and at least one is positive. The yellow area presents unstable yaw motion with one (or pairs of) complex eigenvalue with a positive real part; here, the yaw motion oscillates with increasing amplitude over time. As result, the heading angle also oscillates with increasing amplitude over time. Both the yaw and heading angle oscillations may behave as limit cycles in a certain respective amplitudes, and the limit cycles itself can be stable or unstable depending on real part of related eigen value(s). The blue area indicates the equilibrium point with stable yaw oscillation. Here, the eigen values are complex and all real parts are negative. The yaw oscillation decays while the yaw rate and heading angle become constant after a certain period of time.

The yaw motion is unstable for all wind directions for wind velocities smaller than 2.0 m/s or 0.34 of ship velocity, and unstable yaw with oscillation was found for wind directions between 160.0 to 180.0 degrees or in a following wind. The rudder angle for steady state equilibrium for these velocities is smaller than 1.0 degree for all wind direction. The moment induced by the rudder becomes larger than that by the wind when the heading angle changes due to yaw motion. Unstable yaw motion was also found in 20.0 degrees or smaller wind directions for all wind velocities. These cases of unstable yaw occur due to the hysteresis of steady state equilibrium for heading angle between 150.0 and 210.0 degrees. For high wind velocities, unstable yaw motion occurs for wind direction between 150.0 and 210.0 degrees even though the hysteresic characteristic does not exist, as found by Yasukawa, et al (2012). Instead, instability may be due to an increase in the ship forward speed induced by wind so that the hydrodynamic forces and moments of the hull dominate compared to those induced by the rudder. Unstable equilibrium with yaw oscillation occurs for wind directions between 20.0 and 100.0 degrees with wind velocities larger than 2.0 m/s and up to the wind velocity of 11.0 m/s, or 1.95 of ship velocity. For wind velocities larger than 11.0 m/s, an oscillating yaw motion was found up to a wind direction of 125.0 degrees. This region of yaw oscillation is similar to that obtained by Yasukawa, et al (2012) but with a different range of wind velocities because of different ship and windage area dimensions. In this way, Liu, et al (2018) found that effect of wind load on failure of course keeping depends on geometric configuration of windage area.

A stable yaw motion was found in wind velocities larger than 11.0 m/s within a range of wind directions that increases as wind velocity increases. For example, the range of wind directions with stable yaw motion in a wind velocity of 24.0 m/s is 40.0 to 110.0 degrees. The yaw motion decays and the heading angle becomes contant over time to infinity, and yaw oscillation occurs because the imaginary parts of eigenvalues are not zero in this range of wind directions. Unstable equilibrium with yaw oscillation was also found in wind angles smaller than the lower boundary of the stable regions as well as in angles larger than the upper boundary of the stable yaw motion. A stable limit cycle oscillation occurs at the equilibrium points for wind angles smaller than the lower boundary of the stable region in which the real part of eigenvalue changes from positive to negative; limit cycle oscillation was not found in the range of wind direction with angles larger than upper boundary of the stable region. Here, the real parts of eigenvalues change from negative to positive as the wind direction increases. For a wind velocity of 24.0 m/s, a stable limit cycle region was found to range from 20.0 to 35.0 degrees in term of wind direction while unstable yaw motion occurs in wind direction of between 105.0 and 135.0 degrees. Here, the real parts of eigenvalues change from negative to be positive if the angle of wind direction increases in relation to the ship.

Figure 5 also shows that equilibrium points with unstable yaw motion occur for heading angles smaller than that achieved at maximum rudder angle. If the heading angle is larger than that achieved at maximum rudder angle, the equilibrium points behave as in stable yaw motion or in unstable yaw with a stable limit cycle when the wind velocity is larger than 11.0 m/s. Similiar results were found by Spyrou (1995) across four different ship types. The yaw oscillation becomes unstable for wind velocities smaller than 11.0 m/s. The stable limit cycles occur only for equlibrium points with rudder angle smaller than 1.0 degree at which the rudder forces and moments become dominant campared to those of the wind in certain heading angles. The range of heading angle with oscillating yaw motion increases when the wind velocity is larger than 18.0 m/s, and this is because the heading angle with maximum rudder angle significantly decreases if the wind velocity larger than 18.0 m/s. Therefore the range of wind directions with limit cycles or stable yaw motion also increases when the wind velocity increases for values larger than 18.0 m/s as shown in Figure 5.

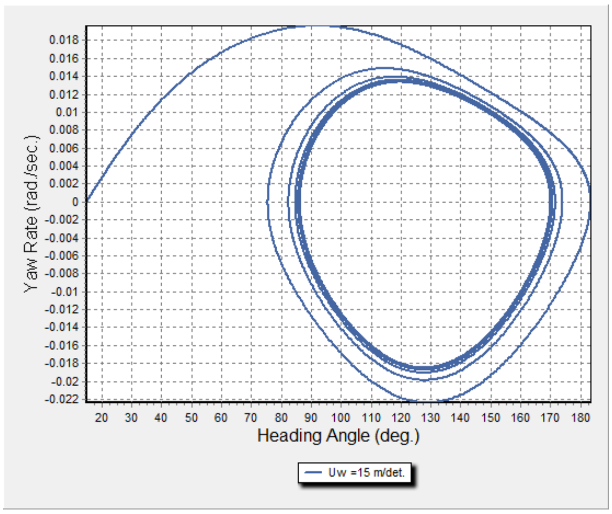

Figure 6 Transition of yaw motion from ustable equilibrium toward stable limit cycles

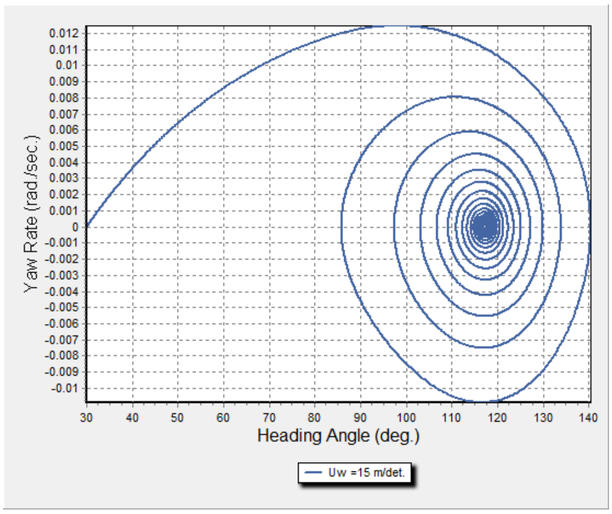

Figure 7 Transition of yaw motion from ustable equilibrium toward stable fixed point

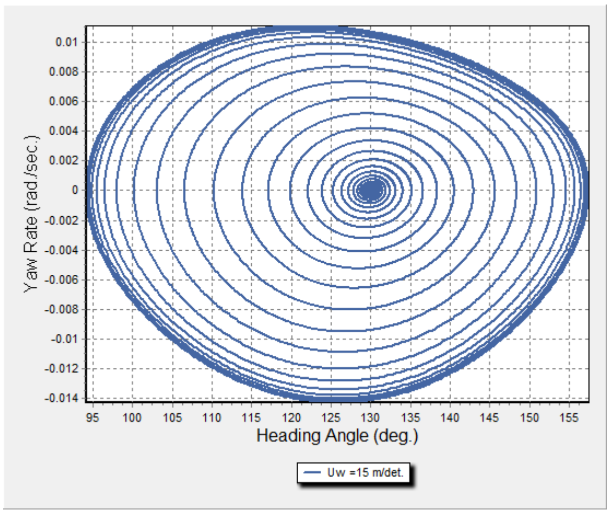

Figure 8 Limit cycles oscillation with rudder angle of 3.76 degrees

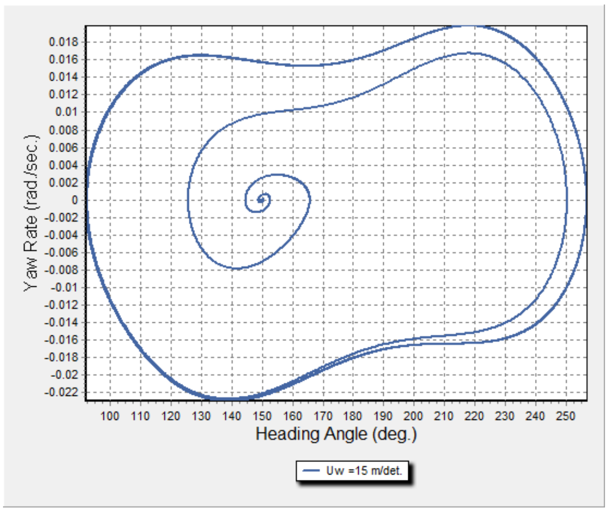

Figure 9 Limit cycles oscillation with rudder angle of 0.55 degrees

To identify the yaw motion characteristics at the equilibrium points with both stable and unstable yaw particularly existence of limit cycle oscillations, numerical simulation using initial condititon the respective equilibrium points was conducted by solving Equation (1) using Runga-Kutta integration method. Figure 6 presents the results of this simulation with the initial condition of unstable equilibrium using a heading angle of 15.0 degrees, a rudder angle of 3.25 degrees to starboard and a wind velocity of 15.0 m/s. The initial heading angle corresponds to a wind direction of 165.0 degrees or a following wind and increases toward a stable limit cycle. Here, the heading angle ocsillates between 85.0 and 170.0 degrees, and the yaw rate alternates between -0.018 and 0.014 rad/s. The same phenomenom was observed for an initial heading angle of 30.0 degrees corresponds to wind direction of 150.0 degrees and the rudder angle of

6.04 degrees toward starboard as shown in Figure 7. In this case, however, the final heading angle is stable so that the yaw rate decreases with time and ultimately vanishes to infinity. The center of limit cycles in Figure 6 is unstable as indicated by one eigenvalue with positive real part. This instability can be further investigated using mathematical simulation with an initial heading angle at the center of limit cycles. As such, Figure 8 shows evolution of yaw motion that starts from an initial heading angle of 130.0 degrees at the cycle center and a rudder angle of 3.76 degrees. Here, the heading angle increases due to the increase in yaw rate and upprocahes the limit cycle boundary, oscillating there with a constant amplitude. Figure 9 presents another equilibrium point with limit cycle oscillation in which the initial heading and rudder angles are 150.0 degrees and 0.55 degrees toward starboard, respectively. This demonstrates that the amplitude of the yaw rate as well as the heading angle in oscillating limit cycles tends to decreases when the rudder angle increases.

4. CONCLUSION

The yaw motion stability and course keeping ability of an Indonesian ro-ro ferry under action of steady wind was investigated through analysis of the characteristic alteration of the eigenvalues obtained in a steady state equilibrium of maneuvering. The results of the numerical simulation show that the heading angle with maximum rudder angle may significantly changes due to increases in wind velocity. The rudder angle required to maintain the ship course is equivalent to the maximum possible rudder angle in wind velocity of 24.0 m/s. The yaw motion at the equilibrium point is unstable when the heading angle is smaller than that obtained with the maximum rudder angle. Where heading angles are larger than that obtained with maximum rudder angle, the equilibrium point may be stable, or unstable with stable limit cycles, epsecially for wind velocities larger than the ship velocity. The effect of wind on the stability of yaw motion can be neglected if the wind velocity is smaller than 0.18 of ship velocity. Unstable equilibrium with stable limit cycles appears when the wind velocity is larger than 0.18 of ship velocity, and stable yaw motion occurs when the wind velocity is larger than the ship velocity. The limit cycles for wind velocities are between 0.18 and 1.00 of the ship velocity are stable. Different characteristics of limit cycles oscillation are obtained for wind velocities larger than ship velocity: stable for headwinds and unstable for quartering winds.

5. ACKNOWLEDGEMENT

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- **Maximum of the paper length: 10 pages (or about 4,000 to 6,000 words)** reviewer_attachment_2886

YAW MOTION STABILITY OF AN INDONESIAN RO-RO FERRY IN ADVERSE WEATHER CONDITIONS

General comments:

A case study on yaw stability of an Indonesian Roro ferry in an adverse weather is carried out. As a case study, I do not find general conclusions that add to the existing knowledge. However, the study is interesting enough. Regarding the results, the discussions/explanations when considering Figures 4 and 5 are rather difficult to understand. In contrast, Figures (6-9) are interesting when the authors identify the characteristics of the yaw motion at the equilibrium points with both stable and unstable yaw. A major revision is required.

Abstract

In the abstract the authors write "To investigate yaw stability or course keeping ability, this study develops a **nonlinear** dynamic system of a three-degree-of-freedom mathematical model to determine the steady state equilibrium; yaw motion behavior is then analysized using the eigenvalue characteristic of the obtained equilibrium points." Comment: In Equation (1), does the yaw rate r depend on u or v to make the system of equations nonlinear?

Introduction

Some notes:

Used maneuvering criteria are in accordance to IMO (2002).

Please describe better with what the authors mean by: "Limit cycles of yaw motion?"

In this study, yaw motion stability for higher wind velocities [which is in contrast to Spyrou et al. (2005, 2007)] and the influence of drift are investigated in the analysis of yaw stability of an Indonesian roro ferry.

The importance of the study: The Indonesian ro-ro ferries have small draught and large windage areas compared to their overall dimensions (references are required) and wind-induced drift could significantly affect their maneuverability regarding yaw stability and course keeping ability. Therefore, the effect of wind on yaw motion and the related course keeping ability becomes an important factor to minimize collision risk during operation.

Methodology

Some notes:

2.1. Spelling error (Mathmeatical Model).

A 3-DOF mathematical model was used to predict the ship motion, with variables surge, sway and yaw angle [Equation (1)].

In Equation (1), make sure that $\dot{u}$ and vr (and $\dot{v}$ and ur) have the same dimension, namely that of acceleration (u is the surge velocity, v is the sway velocity and r is the yaw angle). I see that they do not have the same dimension, because $\dot{u}$ (and $\dot{v}$) has the dimension of acceleration while vr (and ur) has the dimension of velocity (r is dimensionless). (After finishing reading the manuscript, I see that r is the yaw rate with unit rad/s. Equation (1) should be OK.)

The exciting forces due to hydrodynamics, propeller, rudder and wind were calculated from references.

The equations of motion (1) were written as a first order differential equation of dynamical system with control variable of rudder angle as $\dot{z} = F[z(\delta), \delta]$, where δ is the rudder angle and the solution to $F = 0$ representing an equilibrium was calculated using Newton-Raphson method.

Yaw stability is subsequently analyzed by calculating the eigenvalues of the system in the equilibrium condition, $\dot{\xi} = F_z(z_E)\xi$.

Comment: The following statements, if possible, should be accompanied by physical interpretations, otherwise the reader would ask “why are they so?”

“If the real part of all eigenvalues are negative, the equilibrium point is stable. However, if one eigenvalue has a positif real part, the equilibrium point is unstable. The transition between stable and unstable yaw motion can be observed in a change from negative to positive eigenvalue real parts. Additionally, yaw oscillation occurs if the imaginer part of at least one eigenvalue are not zero. This oscillation can be a stable or unstable limit cycles depending on the characteristics of real part of eigenvalues (Somieski, 2001). If the real part of eigenvalues changes from positive to negative, the limit cycles is stable in the region of variable state smaller than this transition point. The limit cycles is unstable in the region of variable state larger than the transition point if the real part of eigenvalue changes from negative to positive. Stable oscillation can also occur in a variable state region with first derivative of the real part of eigen value to the variable state is negative. In constrast, oscillation is unstable if that derivative is positive.”

The labels of Figure 2 are too small, they cannot be read.

In Equation (6), the usual symbol for the coefficient of propeller thrust in the naval architecture is K_T not C_T (C_T is usually used for the ship's total resistance coefficient).

Referring to Figure 3, the analysis of the open water test data of B series propeller should be explained more (how was the analysis done?). What is the difference between "Calculate" and "Polynomial" in the legend of Figure 3? To make Figure 3 complete, the coefficient of torque K_Q and propeller efficiency η should also be shown.

Results and Discussion

The results presented in Figures 4 and 5 should be explained better. My comments are as follows:

The rudder angle required to maintain the ship direction increases as the wind velocity increases (Comment: I understand this), and the heading angle with maximum rudder angle depends on both geometry of windage area and wind velocity (Comment: I cannot see this, the authors should explain this; only one geometry and one windage area are considered!). As such, the heading angle with maximum rudder angle tends to decreases as wind velocity increases (Comment: I cannot understand this). The rudder angle exceed the maximum value in wind velocity of 24.0 m/s or 4.24 of ship velocity (Comment: I cannot understand this; How can the rudder angle exceed its maximum value?).

The equilibrium point exsists at two heading angles for each rudder angle (Comment: OK, for relatively large rudder angle). Constrastingly, for small rudder angles, equilibrium may occur at four different heading angles (Comment: OK). This means that even when the rudder angle is constant, the heading angle may change from one equilibrium point to another depending on yaw stability of each point (Comment: Is it possible physically? The difference in heading angle is relatively large for the different equilibrium points).

Figure 5 above presents the stability characteristics of the yaw motion at steady state equilibrium for different wind velocities and directions. The red area indicates the equilibrium point with unstable yaw in which the eigenvalues are real and at least one is positive (Comment: red = unstable). The yellow area presents unstable yaw motion with one (or pairs of) complex eigenvalue with a positive real part; here, the yaw motion oscillates with increasing amplitude over time (Comment: yellow = unstable). As result, the heading angle also oscillates with increasing amplitude over time. Both the yaw and heading angle oscillations may behave aslimit cycles in a certain respective amplitudes, and the limit cycles itself can be stable or unstable depending on real part of related eigen value(s) (Comment: I cannot understand this). The blue area indicates the equilibrium point with stable yaw oscillation. Here, the eigen values are complex and all real parts are negative. The yaw oscillation decays while the yaw rate and heading angle become constant after a certain period of time (Comment: blue =

stable; I understand this).

The yaw motion is unstable for all wind directions for wind velocities smaller than 2.0 m/s or 0.34 of ship velocity (Comment: I can see this from Figure 5; but what does this mean phisically? The yaw motion is always unstable for very low wind velocity, $v_w < 2.0$ m/s and for all wind directions), and unstable yaw with oscillation was found for wind directions between 160.0 to 180.0 degrees or in a following wind (Comment: I cannot see this from Figure 5). The rudder angle for steady state equilibrium for these velocities is smaller than 1.0 degree for all wind direction (Comment: How can I see this?). The moment induced by the rudder becomes larger than that by the wind when the heading angle changes due to yaw motion (Comment: How can I see this?). Unstable yaw motion was also found in 20.0 degrees or smaller wind directions for all wind velocities (Comment: I can see this from Figure 5). These cases of unstable yaw occur due to the hysteresis of steady state equilibrium for heading angle between 150.0 and 210.0 degrees (Comment: Is it possible to see this from Figure 5?).

For high wind velocities, unstable yaw motion occurs for wind direction between 150.0 and 210.0 degrees (Comment: I cannot see this from Figure 5) even though the hysteresic characteristic does not exist, as found by Yasukawa, et al (2012). Instead, instability may be due to an increase in the ship forward speed induced by wind so that the hydrodynamic forces and moments of the hull dominate compared to those induced by the rudder (Comment: OK). Unstable equilibrium with yaw oscillation occurs for wind directions between 20.0 and 100.0 degrees with wind velocities larger than 2.0 m/s and up to the wind velocity of 11.0 m/s, or 1.95 of ship velocity (Comment: OK from Figure 5). For wind velocities larger than 11.0 m/s, an oscillating yaw motion was found up to a wind direction of 125.0 degrees. This region of yaw oscillation is similar to that obtained by Yasukawa, et al (2012) but with a different range of wind velocities because of different ship and windage area dimensions. In this way, Liu, et al (2018) found that effect of wind load on failure of course keeping depends on geometric configuration of windage area.

Comment: The following pharagraph is very difficult to understand, in particular, how should one interpret them physically! A stable yaw motion was found in wind velocities larger than 11.0 m/s within a range of wind directions that increases as wind velocity increases. For example, the range of wind directions with stable yaw motion in a wind velocity of 24.0 m/s is 40.0 to 110.0 degrees. The yaw motion decays and the heading angle becomes contant over time to infinity, and yaw oscillation occurs because the imaginary parts of eigenvalues are not zero in this range of wind directions. Unstable equilibrium with yaw oscillation was also found in wind angles smaller than the lower boundary of the stable regions as well as in angles larger than the upper boundary of the stable yaw motion. A stable limit cycle oscillation occurs at the equilibrium points for wind angles smaller than the lower boundary of the stable region in which the real part of eigenvalue changes from positive to negative; limit cycle oscillation was not found in the range of wind direction with angles larger than upper boundary of the stable region. Here, the real parts of eigenvalues change from negative to positive as the wind direction increases. For a wind velocity of 24.0 m/s, a stable limit cycle region was found to range from 20.0 to 35.0 degrees in term of wind direction while unstable yaw motion occurs in wind direction of between 105.0 and 135.0 degrees. Here, the real parts of eigenvalues change from negative to be positive if the angle of wind direction increases in relation to the ship.

Figures (6-9) are interesting to identify the yaw motion characteristics at the equilibrium points with both stable and unstable yaw.

Bibliography/references

References on Indonesian roro ferry should be included.

Other comments

Check the word “Constrastingly”; do you mean “In contrast”?