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Seakeeping and Operability Analysis of the Arctic Offshore Patrol Ship with Deployed Stabilizer Fins

Kevin McTaggart

Defence R&D Canada – Atlantic

Technical Memorandum
DRDC Atlantic TM 2012-214
October 2012

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Abstract

The Canadian Navy is planning to procure several Arctic Offshore Patrol Ships (AOPS), for which a design has been developed based on the Norwegian ship Svalbard. This report presents a seakeeping analysis performed using ShipMo3D and an operability analysis performed using SHIPOP2. To facilitate operations in ice, the AOPS design has no bilge keels; thus, roll stabilization using active stabilizer fins or internal tanks is being considered. The present analysis considers stabilizer fins deployed in passive and active modes. Seakeeping computations indicate that roll motions are largest in stern quartering seas at higher ship speeds, and that active stabilizer fins would provide significant roll reduction. Roll stabilization using active pumping between heeling tanks has been examined by modelling the tank system as a ShipMo3D U-tube tank. The results indicate that active fins would be more effective than stabilization using heeling tanks; however, a higher fidelity model of the heeling tank system could yield different results. The present computations and Norwegian experience with Svalbard indicate that inclusion of active stabilizer fins would be warranted.

Résumé

La Marine canadienne projette l'achat de plusieurs Navires de patrouille extracôtiers de l'Arctique (NPEA), pour lesquels un modèle a été conçu sur la base du navire norvégien Svalbard. Le présent rapport fournit une analyse de tenue de mer effectuée à l'aide de ShipMo3D et une analyse d'opérabilité effectuée à l'aide de SHIPOP2. Afin de faciliter les opérations dans les glaces, le modèle du NPEA ne comporte pas de quilles de roulis ; c'est pourquoi on songe à utiliser des ailerons stabilisateurs actifs ou des réservoirs internes pour obtenir la stabilité en roulis. L'analyse présente traite des ailerons stabilisateurs déployés en modes passif et actif. Les calculs de tenue de mer indiquent que les mouvements de roulis sont les plus grands dans les mers obliques arrière à des vitesses de navire plus élevées, et que des ailerons stabilisateurs actifs diminueraient le roulis de façon importante. La stabilité en roulis au moyen de pompage actif entre les caisses d'inclinaison a été examinée en modélisant le système de réservoirs en tant que réservoir à tube en U ShipMo3D. Les résultats indiquent que des ailerons actifs seraient plus efficaces que la stabilisation par caisses d'inclinaison ; cependant, un modèle plus fidèle du système de caisses d'inclinaison pourrait donner des résultats différents. Les calculs actuels et l'expérience norvégienne avec le Svalbard indiquent que l'intégration d'ailerons stabilisateurs actifs serait justifiée.

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Executive summary

Seakeeping and Operability Analysis of the Arctic Offshore Patrol Ship with Deployed Stabilizer Fins

Kevin McTaggart; DRDC Atlantic TM 2012-214; Defence Research and Development Canada – Atlantic; October 2012.

Introduction: The Canadian Navy is planning to procure several Arctic Offshore Patrol Ships (AOPS), for which a design has been developed based on the Norwegian ship Svalbard. This report presents a seakeeping analysis performed using ShipMo3D and an operability analysis performed using SHIPOP2. The analysis considers the ship with stabilizer fins deployed in passive and active modes, and also considers roll stabilization using active pumping between heeling tanks.

Principal Results: Roll motions are greatest in stern quartering seas at higher ship speeds. Roll stabilization using active fins provides significant roll reduction, and increases operability from 87 percent to 90 percent for operations in the North Atlantic. Roll stabilization using active pumping between heeling tanks has been examined by modelling the tank system as a ShipMo3D U-tube tank. The present results indicate that stabilization using heeling tanks is less effective than active fins. If stabilization using heeling tanks were to be seriously considered, then it is recommended that a more sophisticated model of the heeling tank system be developed.

Significance of Results: The analysis suggests that AOPS should include active stabilizer fins. This finding is consistent with Norwegian experience with the Svalbard, which was retrofitted with stabilizer fins. The predicted 3 percent increase in ship operability could be used to support an economic argument for including stabilizer fins.

Future Plans: Implementation of active tank stabilization systems will be considered for future releases of ShipMo3D.

Sommaire

Seakeeping and Operability Analysis of the Arctic Offshore Patrol Ship with Deployed Stabilizer Fins

Kevin McTaggart ; DRDC Atlantic TM 2012-214 ; Recherche et développement pour la défense Canada – Atlantique ; octobre 2012.

Introduction : La Marine canadienne projette l'achat de plusieurs Navires de patrouille extracôtiers de l'Arctique (NPEA), pour lesquels un modèle a été conçu sur la base du navire norvégien Svalbard. Le présent rapport fournit une analyse de tenue de mer effectuée à l'aide de ShipMo3D et une analyse d'opérabilité effectuée à l'aide de SHIPOP2. L'analyse présente traite des ailerons stabilisateurs déployés en modes passif et actif, et examine également la stabilité en roulis au moyen de pompage actif entre les caisses d'inclinaison.

Résultats principaux : Les mouvements de roulis sont les plus grands dans les mers obliques arrière à des vitesses de navire plus élevées. La stabilité en roulis à l'aide d'ailerons stabilisateurs actifs diminue le roulis de façon importante, et augmente l'exploitabilité de 87 à 90 pourcent pour les opérations dans l'Atlantique Nord. La stabilité en roulis au moyen de pompage actif entre les caisses d'inclinaison a également été examinée en modélisant le système de réservoirs en tant que réservoir à tube en U ShipMo3D. Les résultats actuels indiquent que la stabilisation par caisses d'inclinaison est moins efficace que la stabilisation par ailerons actifs. Si on devait considérer sérieusement la stabilisation à l'aide de caisses d'inclinaison, on recommande alors d'élaborer un modèle plus sophistiqué de système de caisses d'inclinaison.

Importance des résultats : L'analyse suggère que le NPEA devrait avoir des ailerons stabilisateurs actifs. Cette constatation correspond aux constatations issues de l'expérience norvégienne avec le Svalbard, qui a été modifié pour intégrer des ailerons stabilisateurs. L'augmentation prévue de 3 pourcent de la capacité opérationnelle des navires pourrait servir en guise d'argument économique en vue de l'intégration d'ailerons stabilisateurs.

Travaux ultérieurs prévus : L'intégration de systèmes de stabilisation de réservoirs actifs sera envisagée pour les prochaines versions du ShipMo3D.

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1 Introduction

The Canadian Navy is planning to procure several Arctic Offshore Patrol Ships (AOPS). The AOPS design is based on the Norwegian icebreaker and patrol ship Svalbard, and has a displacement of approximately 5300 tonnes.

In response to a request from the AOPS Project Management Office (PMO), DRDC Atlantic has performed a seakeeping and operability analysis using the ShipMo3D ship motion suite [1, 2] and the ship operability program SHIPOP [3]. Section 2 describes development of the AOPS ShipMo3D model, with predicted roll and pitch motions shown in Section 3 for stabilizer fins in passive and active modes. Section 4 examines utilization of heeling tanks for roll stabilization. An operability analysis for the ship with passive and active stabilizer fins is given in Section 5. Section 6 discusses general results, and is followed by final conclusions in Section 7.

2 ShipMo3D Model for Seakeeping Analysis

The program SHIPMO7 [4] and applications within the ShipMo3D suite [1, 2] are routinely used for seakeeping analysis of ships within the Canadian Navy. SHIPMO7 is based on strip theory, which is most suited for slender vessels (e.g., length to beam ratio $L/B > 6$). In contrast, ShipMo3D is based on three-dimensional hydrodynamic computations and can be used for non-slender vessels. Given that AOPS is a non-slender vessel ($L/B = 4.4$), ShipMo3D is used for the present analysis. Version 2 [1, 2] is the current release version of ShipMo3D; however, it was decided to use a pre-release version of ShipMo3D 3 because it includes the following capabilities:

- modelling of U-tube tanks, which could be used to model roll stabilization using heeling tanks,
- writing of response amplitude operators (RAOs) to a post-processing file that can be used for operability analysis by SHIPOP2 [3].

The ShipMo3D model was developed from design data produced by STX Canada Marine. Figure 1 shows the general arrangement of the ship. Figures 2 and 3 show profile and lower aft views of the hull geometry model as shown by the 3D geometric modelling program Rhinoceros, also known as Rhino3D [5]. Rhino3D is widely used within the field of naval architecture design.

Table 1 gives dimensions for AOPS, including the load condition used for the present study. The light operating condition at beginning of service life was used for the present study because it is considered representative of a lighter operational condition, which could have somewhat greater motions than for a heavier operational condition.

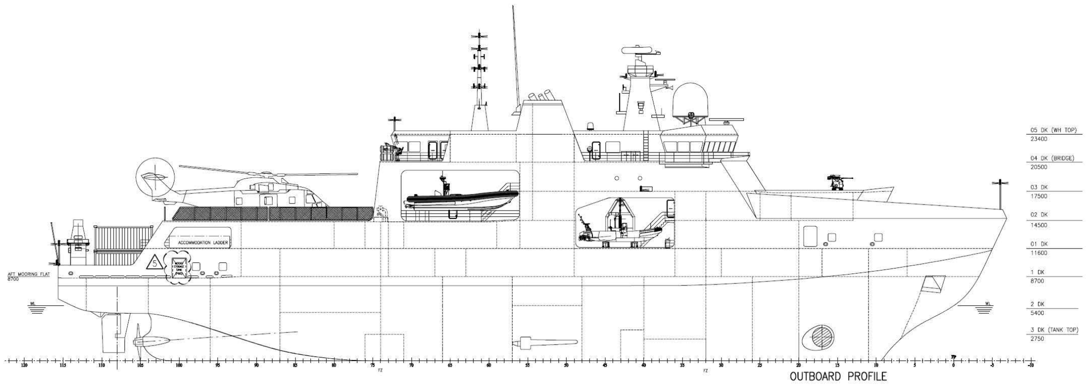

Figure 1: *General Arrangement of Arctic Offshore Patrol Ship*

Table 1: *Arctic Offshore Patrol Ship Dimensions, Light Operating Departure Condition at Beginning of Service Life*

Length between perpendiculars, L	86.4 m
Beam, B	19.5 m
Draft at midships, T_{mid}	5.349 m
Trim by stern, t_{stern}	0.060 m
Displacement, $\triangle$	5,340 tonnes
Height of CG above baseline, $\overline{KG}$	8.593 m
Metacentric height, including fluid effects $\overline{GM}_{fluid}$	1.080 m

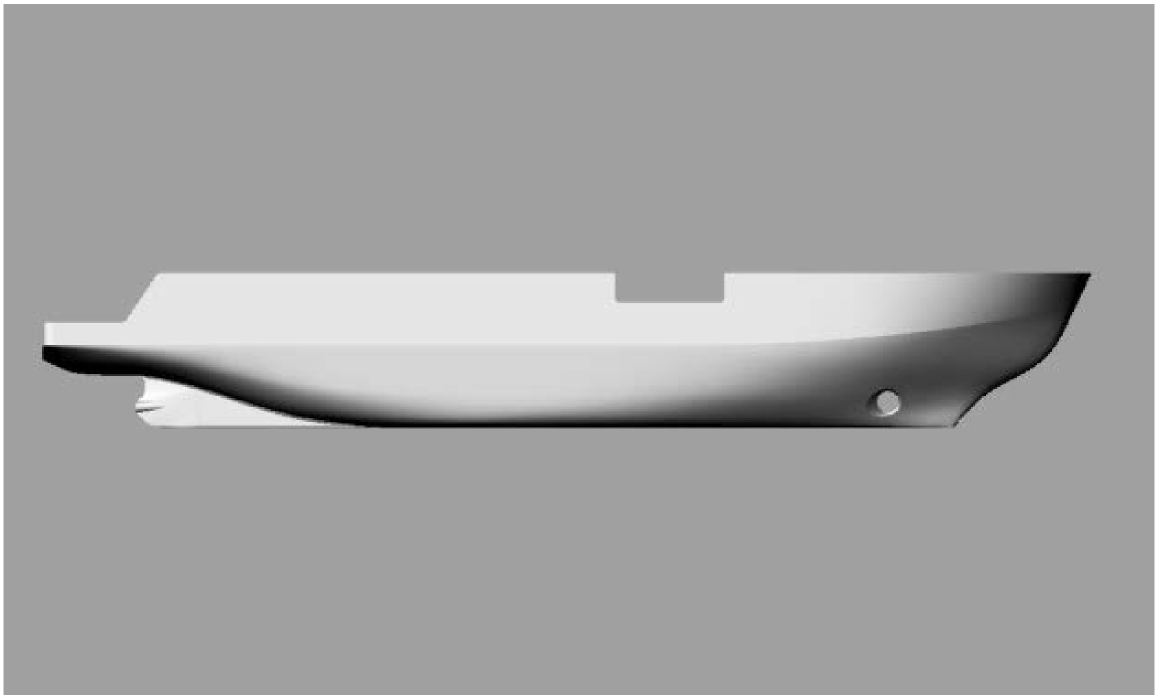

Figure 2: *Profile View of Rhino3D Hull Form Model of Arctic Offshore Patrol Ship*

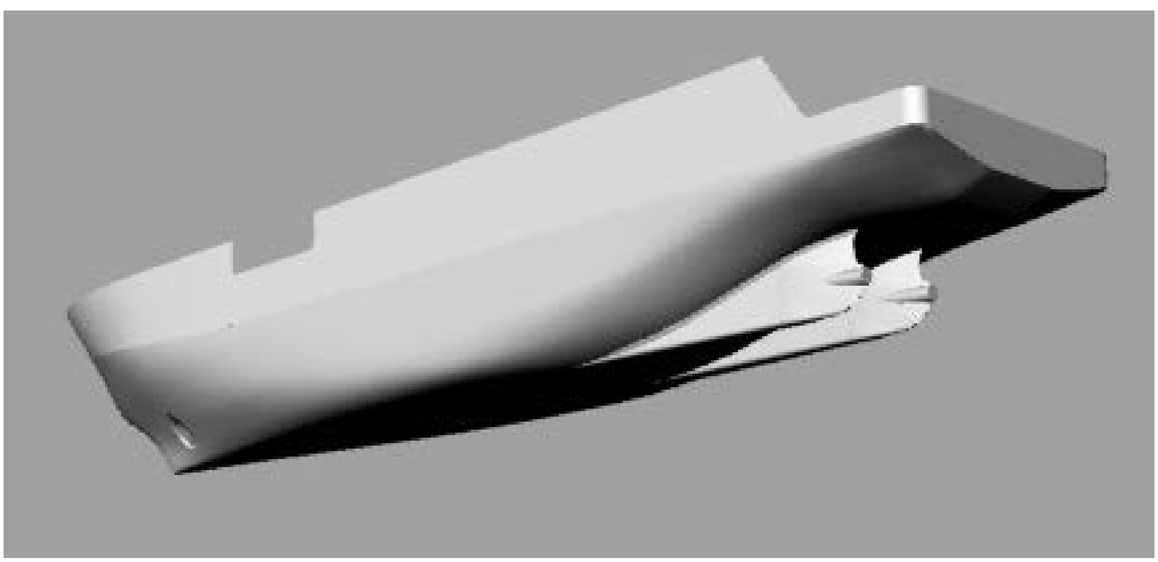

Figure 3: *Profile View of Rhino3D Hull Form Model of Arctic Offshore Patrol Ship*

When preparing a ShipMo3D ship model, the most time consuming part is usually the preparation of the input hull lines. A new computer program SM3DRhinoToPatchHull was developed to determine input ShipMo3D hull lines from the AOPS Rhino3D model. SM3DRhinoToPatchHull uses the Rhino_DotNET software library, which comes with the Rhino3D application software. The Grasshopper Primer [6] provided useful Rhino3D reference information when using the Rhino_DotNET software library. Grass-hopper is one of several applications available based on Rhino3D.

Figure 4 shows the ShipMo3D model of the ship. The ShipMo3D model includes the wet hull, dry hull, rudders, propellers, skegs, and stabilizer fins. To simplify modelling of the hull, the molded skegs are modelled as appended skegs. To facilitate operations in ice, the AOPS design has no bilge keels.

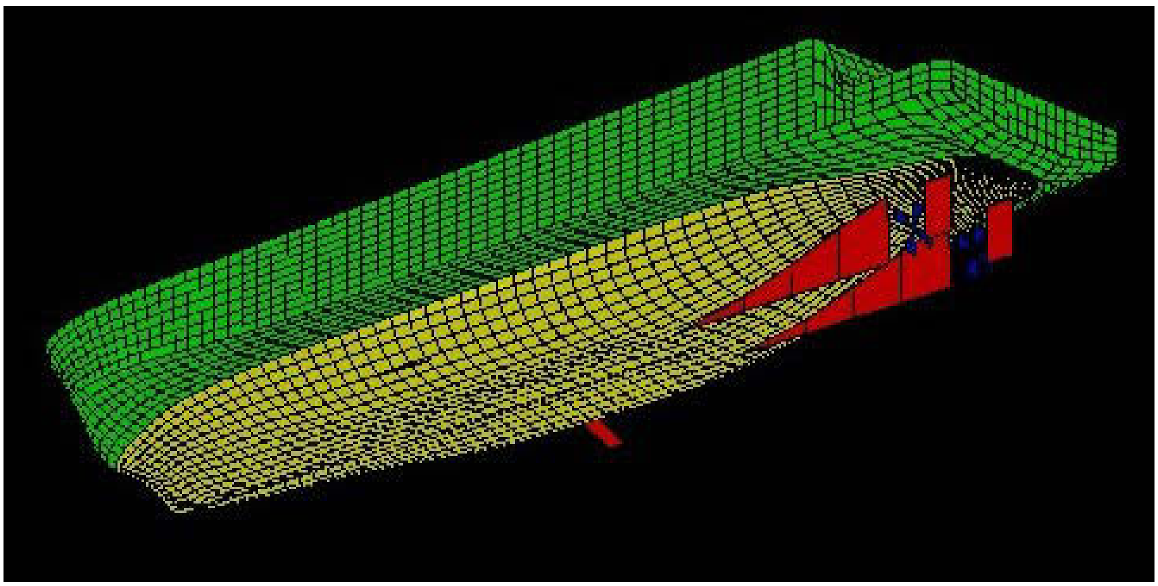

Figure 4: *Lower Aft View of ShipMo3D AOPS Model*

The ShipMo3D model includes roll stabilizer fins, which can be in passive or active modes for ship motion computations. When active, the stabilizer fins respond to an input command deflection angle as follows:

$$\ddot{\delta}^{fin} \ + \ 2 \, \zeta_\delta \, \omega_\delta \, \dot{\delta}^{fin} \ + \ \omega_\delta^2 \, \delta^{fin} \ = \ \omega_\delta^2 \, \delta_C^{fin} \tag{1}$$

where $\ddot{\delta}^{fin}$ is deflection acceleration, ζ_δ is deflection damping, ω_δ is deflection natural frequency, $\dot{\delta}^{fin}$ is deflection velocity, and δ^{fin} is deflection angle. The command fin angle δ_C^{fin} is dependent upon input gains as follows:

$$\delta_C^{fin} \ = \ \sum_{j=1}^{6} \left[k_{\delta j}^P \left(\eta_j^f - \eta_{Cj}^f \right) \ + \ k_{\delta j}^I \int_0^{\tau_{max}^{fin}} \left(\eta_j^f (t-\tau) - \eta_{Cj}^f \right) d\tau \ + \ k_{\delta j}^D \dot{\eta}_j^f \right] \tag{2}$$

where $k_{\delta j}^{P}$ is proportional gain for motion mode j, η_j^f is ship motion displacement in earth-fixed coordinates for mode j, $k_{\delta j}^{I}$ is integral gain, τ_{max}^{fin} is maximum delay time for evaluating integral gain response, η_{Cj}^{f} is command displacement for mode j, and $k_{\delta j}^{D}$ is velocity gain. Table 2 shows the stabilizer fin control parameters. The roll velocity gain value of -10 s causes the stabilizer fins to supplement the roll damping of the ship. The magnitude of the gain was selected such that RMS deflection of the stabilizer fins would typically be less than 10 degrees, with maximum deflection angles less than the 35 degree limits of the fins. To obtain improved roll stabilization, the roll velocity gain could be adjusted for each combination of seaway, ship speed, and ship heading.

Table 2: *Stabilizer Fin Control Parameters*

Maximum deflection angle, δ_{max}^{fin}	35 deg
Maximum deflection rate, $\dot{\delta}_{max}^{fin}$	10 deg/s
Deflection natural frequency, ω_δ	3 rad/s
Deflection damping (fraction of critical) ζ_δ	0.85
Roll velocity gain (when active), $k_{\delta 4}^{P}$	-10 s

3 Roll and Pitch Motions in Waves

Figures 5 to 10 show roll and pitch motions in sea states 5, 6, and 7 for ship speeds of 6 and 12 knots. The roll results include values for both passive and active roll stabilizer fins. The most noticeable feature of the ship motions is the high roll response in stern quartering seas when travelling at 12 knots with passive fins. Under these conditions, the wave encounter period approximates the ship natural roll period of 15.6 s. Due to the higher ship speed associated with large roll motions, active stabilizer fins can be very effective in suppressing roll motions. The pitch motions are typical for a vessel of its size.

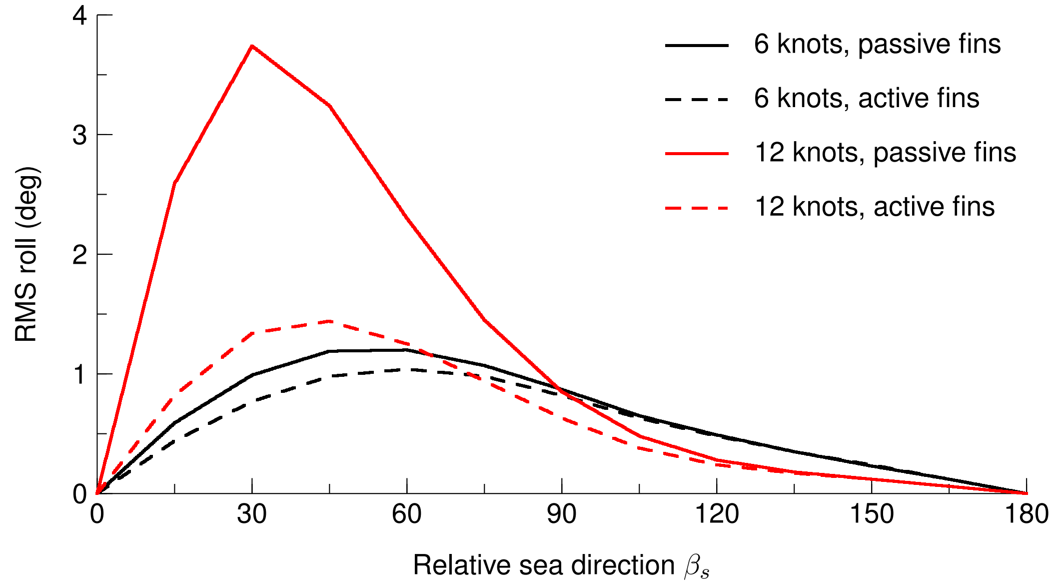

Figure 5: *RMS Roll Motions in Sea State 5, Significant Wave Height H_s = 3.25 m, Peak Wave Period T_p = 9.7 s, Passive and Active Stabilizer Fins*

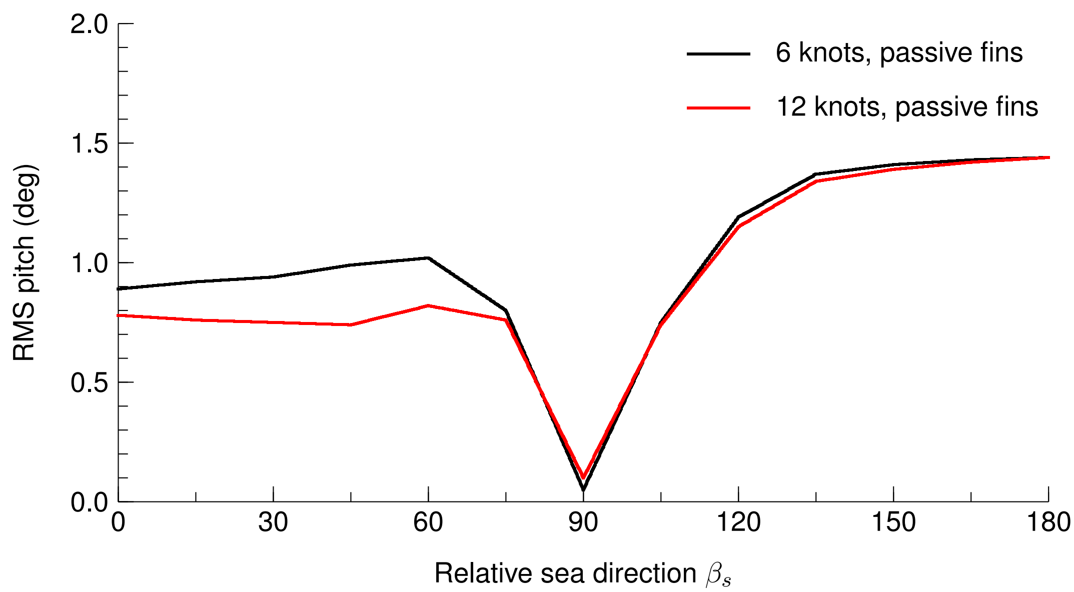

Figure 6: *RMS Pitch Motions in Sea State 5, Significant Wave Height H_s = 3.25 m, Peak Wave Period T_p = 9.7 s*

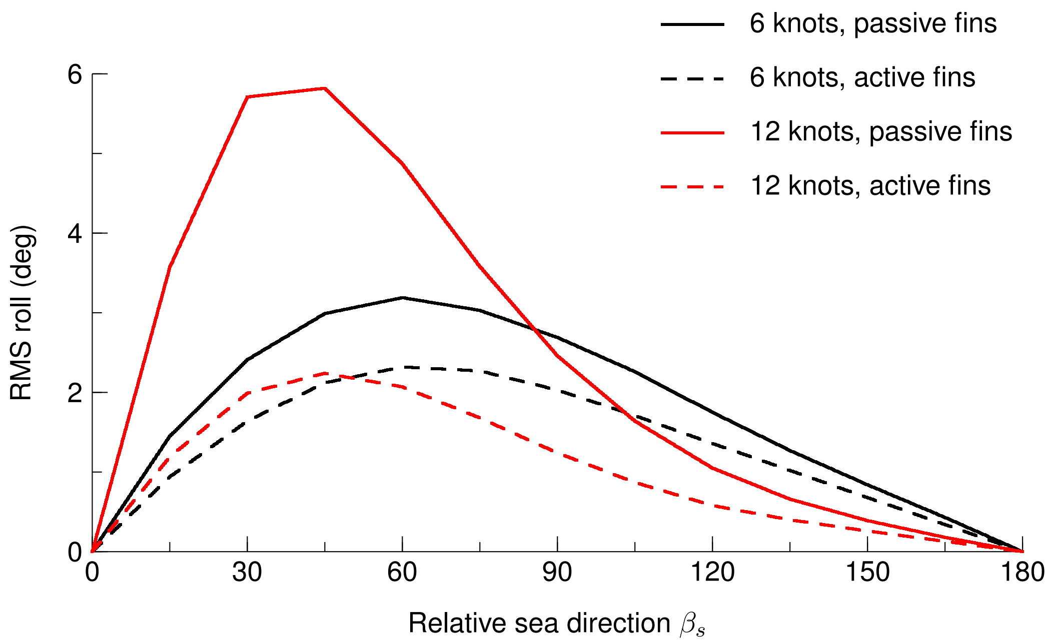

Figure 7: *RMS Roll Motions in Sea State 6, Significant Wave Height $H_s = 5.0$ m, Peak Wave Period $T_p = 12.4$ s, Passive and Active Stabilizer Fins*

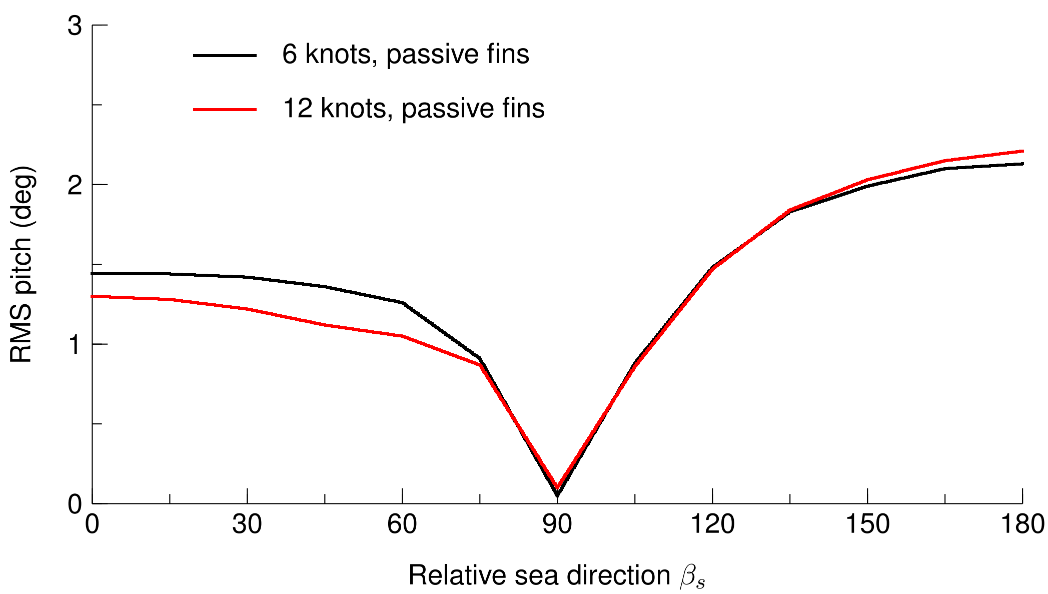

Figure 8: *RMS Pitch Motions in Sea State 6, Significant Wave Height $H_s = 5.0$ m, Peak Wave Period $T_p = 12.4$ s*

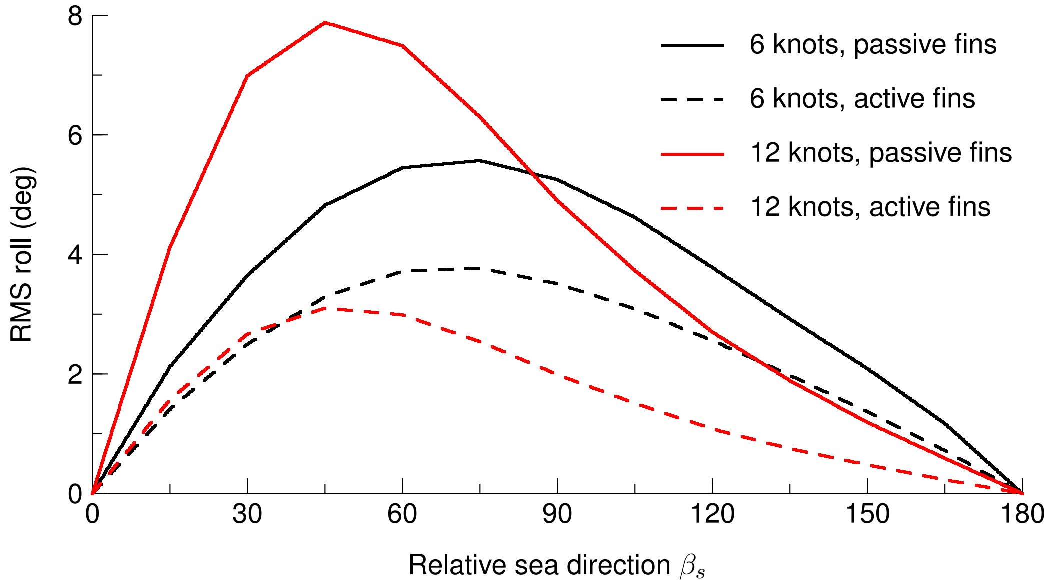

Figure 9: *RMS Roll Motions in Sea State 7, Significant Wave Height H_s = 7.5 m, Peak Wave Period T_p = 15.0 s, Passive and Active Stabilizer Fins*

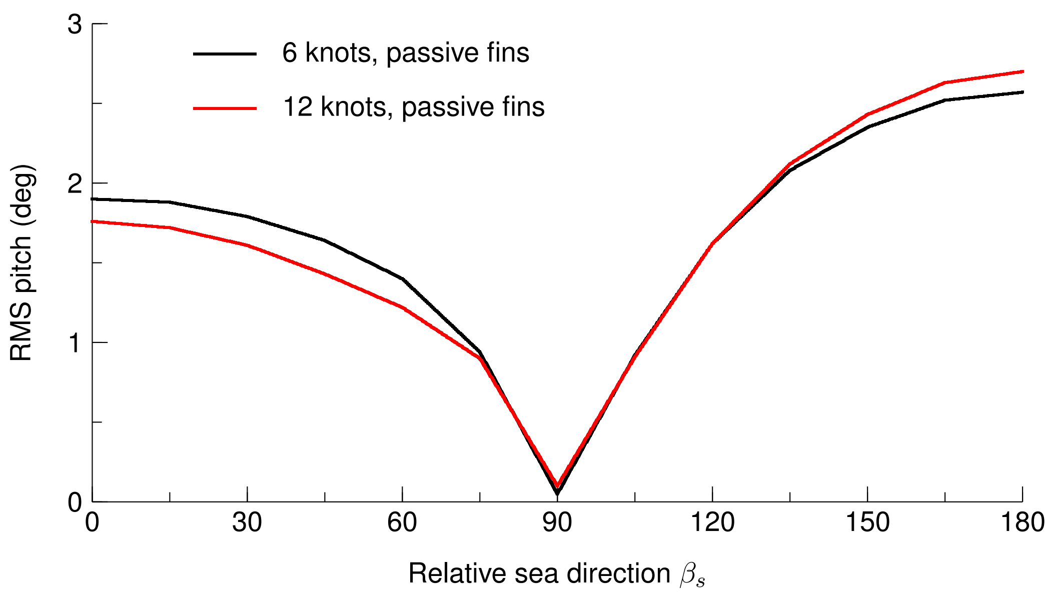

Figure 10: *RMS Pitch Motions in Sea State 7, Significant Wave Height H_s = 7.5 m, Peak Wave Period T_p = 15.0 s*

4 Roll Stabilization Using Active Control of Heeling Tanks

The AOPS design includes heeling tanks, which are intended for producing roll moments when required during operations in ice. The heeling tanks could possibly be used for roll stabilization in waves through active pumping of water between tanks. ShipMo3D has no capability for modelling active pumping of water between tanks; however, a new capability within ShipMo3D for simulating U-tube tanks was used to model roll stabilization using the heeling tanks. Figure 11 shows the heeling tanks, which are located at station 6.67 and have lengths of 6.4 m along the ship longitudinal axis. Each tank has a volume of 87.8 m^3. Figure 12 shows the equivalent U-tube tank model of the heeling tanks. Simulation of U-tube tanks within ShipMo3D is based on the work of Lloyd [7]. The U-tube tank model has the same total volume as the heeling tanks, and the fluid displacement natural frequency is set approximately equal to the ship roll natural frequency to provide optimal damping of roll resonance. The U-tube tank dimensions were determined using the following steps:

- The length of the U-tube tank along the ship longitudinal axis was set to 6.4 m, matching the length of the heeling tanks.
- The height of each reservoir was set to 6 m, the same as the total height of each heeling tank.
- The width of each reservoir was set to 2.28 m based on total volume of each heeling tank.
- The lateral distance between reservoir centres was set to 14 m based on the heeling tank spacing.
- The height of the duct between reservoirs was set to 0.21 m to obtain a fluid motion natural frequency of 0.35 rad/s, approximating the ship roll natural frequency.

Figures 13 to 15 show roll motions without stabilization and with stabilization using the heeling tanks modelled as a U-tube tank. The stabilizer fins are passive in all cases. In most cases, tank stabilization gives some reduction of roll motions, with motion reductions typically being greatest when roll motions are large. Overall, the roll motion reductions predicted using tank stabilization are relatively modest. If tank stabilization were to be seriously considered, then it is recommended that a model of active tank stabilization using pumps be developed. The limited predicted effectiveness using the heeling tanks might be partly due to the low vertical elevation of the tanks within the ship. For U-tube tanks, effectiveness typically increases with vertical elevation, and this might also be applicable for active stabilization using the heeling tanks.

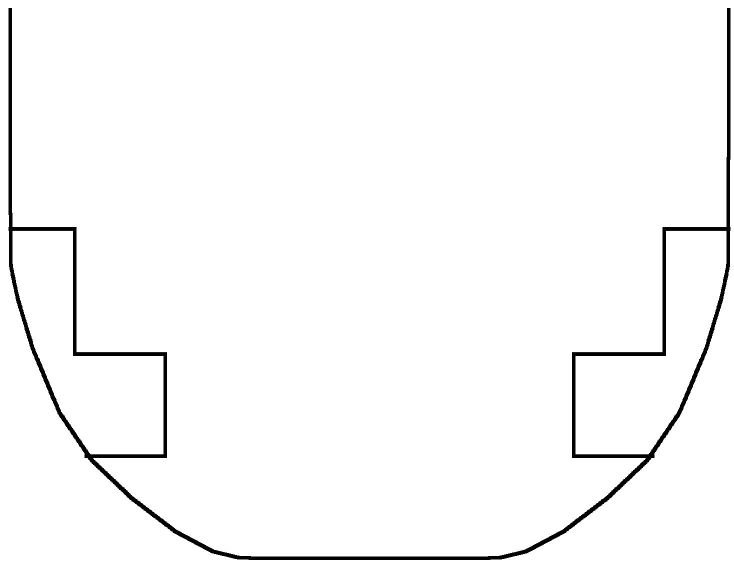

Figure 11: *Heeling Tanks*

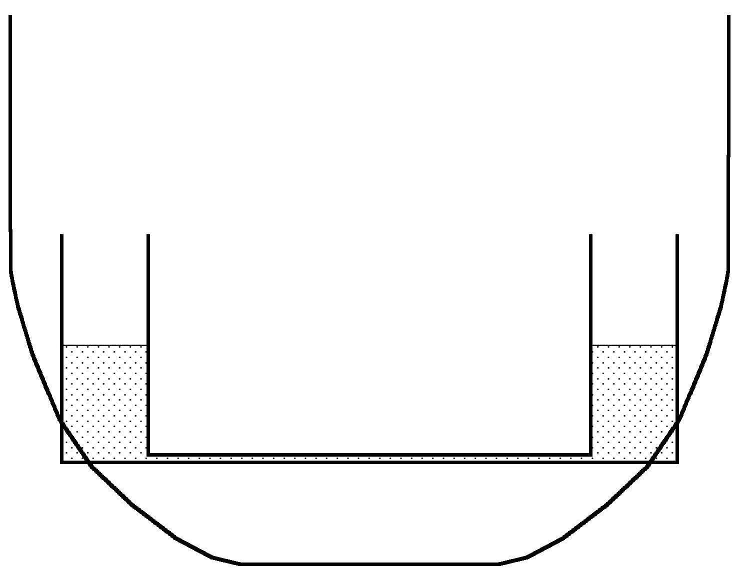

Figure 12: *U-tube Tank Model of Heeling Tanks for Roll Stabilization*

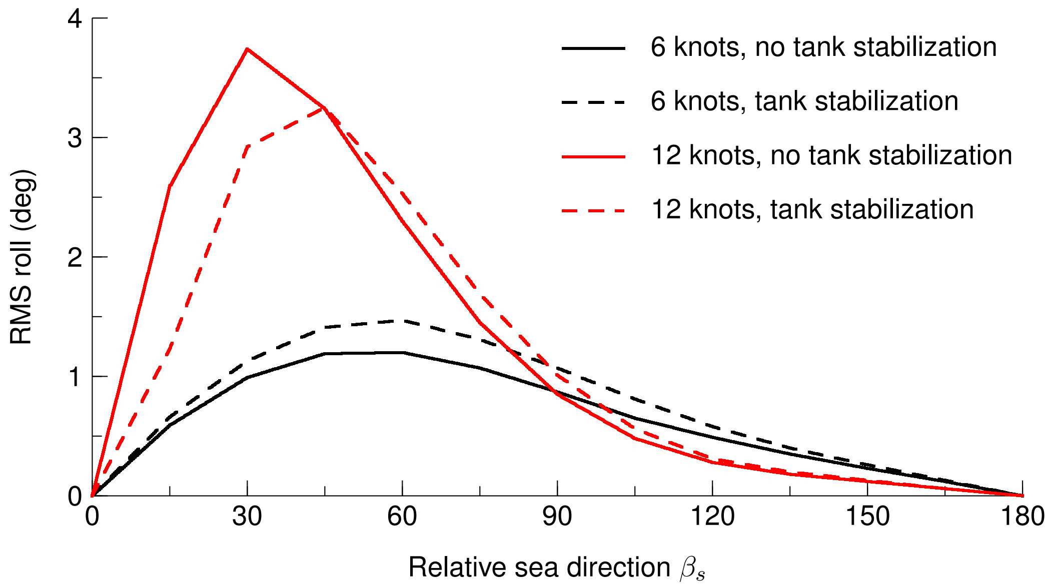

Figure 13: *RMS Roll Motions in Sea State 5, Significant Wave Height H_s = 3.25 m, Peak Wave Period T_p = 9.7 s, Passive Fins, Influence of Active Heeling Tanks*

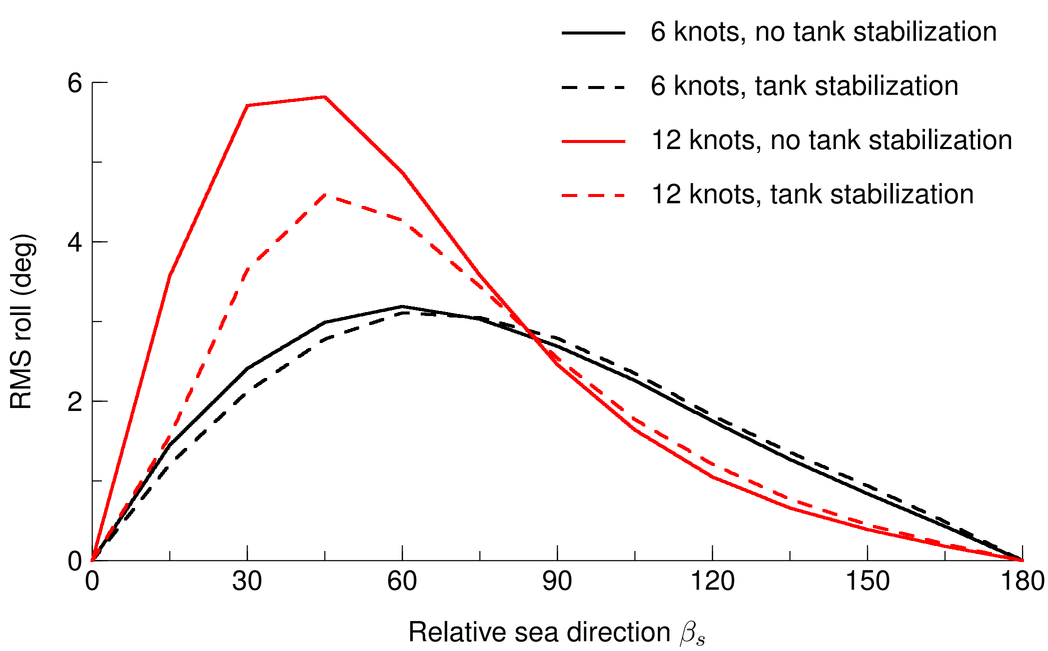

Figure 14: *RMS Roll Motions in Sea State 6, Significant Wave Height H_s = 5.0 m, Peak Wave Period T_p = 12.4 s, Passive Fins, Influence of Active Heeling Tanks*

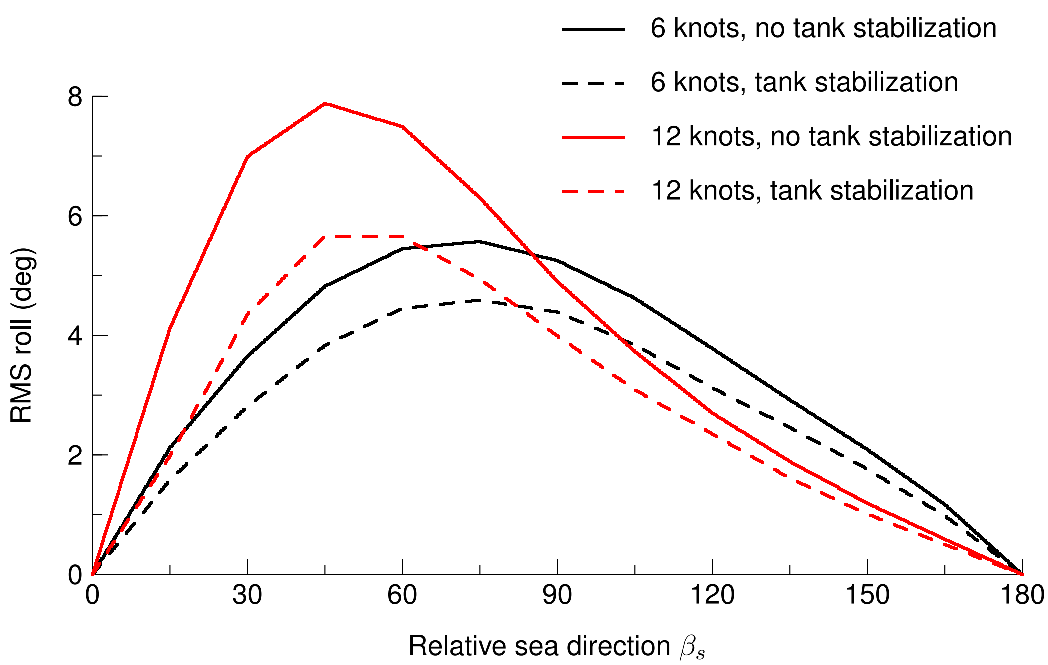

Figure 15: *RMS Roll Motions in Sea State 7, Significant Wave Height H_s = 7.5 m, Peak Wave Period T_p = 15.0 s, Passive Fins, Influence of Active Heeling Tanks*

5 Operability Analysis

An operability analysis was performed using SHIPOP2 [3] to examine percent time operable (PTO) for ship operations in the North Atlantic. An operability analysis evaluates the percentage of time that a ship meets specified operability criteria when operating in a given environment. Table 3 gives the operability criteria, which are based on recommended values for a transit mission in the NATO seakeeping standard [8]. The ship is assumed to operate in the annual North Atlantic wave environment from Bales, Lee, and Voelker [9], which is used by NATO [10]. The distribution of speeds in Figure 16 is based on data provided by the AOPS Project Management Office. Relative sea directions are assumed to have a uniform distribution, and are discretized as shown in Table 17. A relative sea direction β_s of 180 degrees represents head seas.

Table 3: *Operability Criteria for Transit Mission*

RMS roll	4.0°
RMS pitch	1.5°
RMS vertical acceleration at bridge	0.2 g
RMS lateral acceleration at bridge	0.1 g
Tipping motion-induced interruptions at bridge	1.0 per minute
RMS vertical acceleration at flight deck	0.2 g
RMS lateral acceleration at flight deck	0.1 g
Tipping motion-induced interruptions at flight deck	1.0 per minute
Wetness rate at fore deck	30 per hour
Slamming rate at station 3	20 per hour
Emergence rate for top quarter of propellers	90 per hour

Table 4 and Figures 18 to 20 give results of the operability analysis. The ship has high operability, as would be expected for a vessel of its size. Activation of stabilizer fins increases operability from 87 percent to 90 percent. The increase in operability due to active fins could be enhanced by optimization of fin gains for each combination of wave conditions, ship speed, and relative sea direction. Figure 18 illustrates that active fins have a greater influence at higher ship speeds, which is due to both higher roll motions and higher fin stabilization forces at higher speeds. Figures 19 and 20 show variation of percent time operable with relative sea direction for ship speeds of

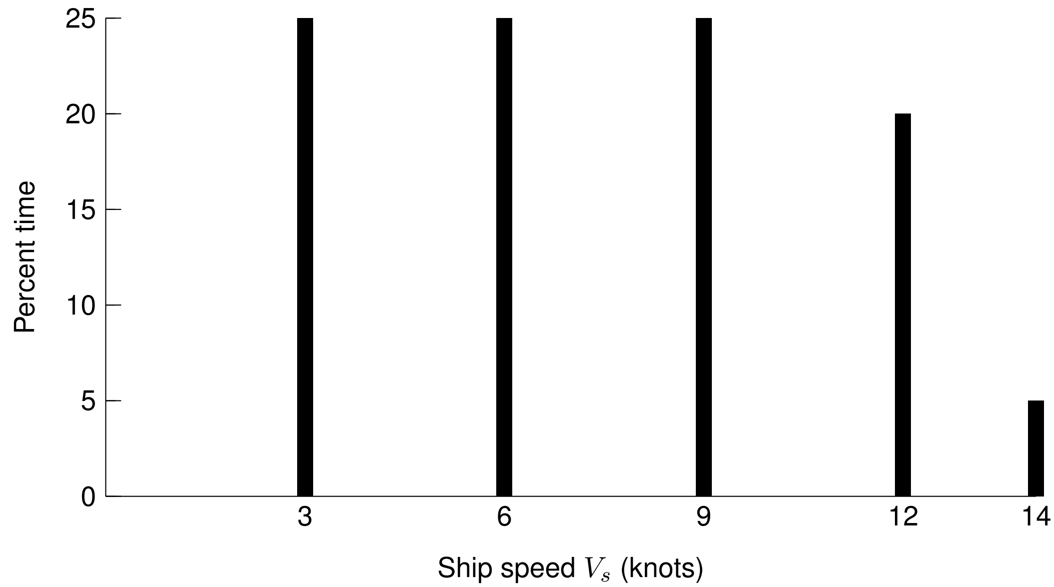

Figure 16: *Speed Distribution for Operability Analysis*

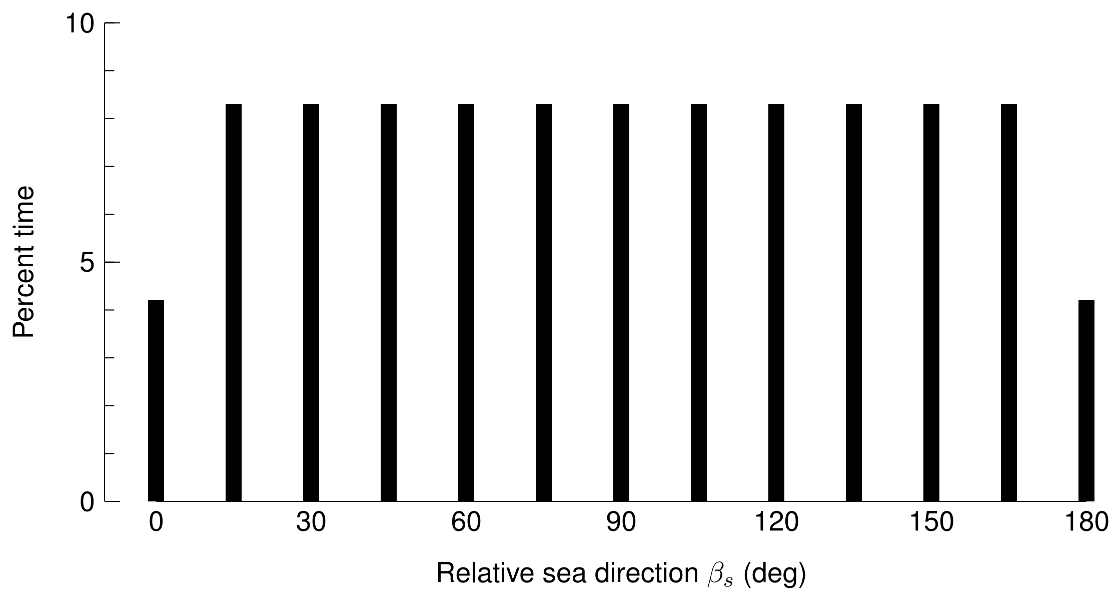

Figure 17: *Relative Sea Direction Distribution for Operability Analysis*

6 and 12 knots. Active fins give a significant increase in operability at higher speeds in stern quartering seas. Lower operability in head and bow quartering seas is caused mostly be pitch motions and motion-induced interruptions at the bridge.

Table 4: *Percent Time Operable for Transit Mission in North Atlantic*

Passive stabilizer fins	87 percent
Active stabilizer fins	90 percent

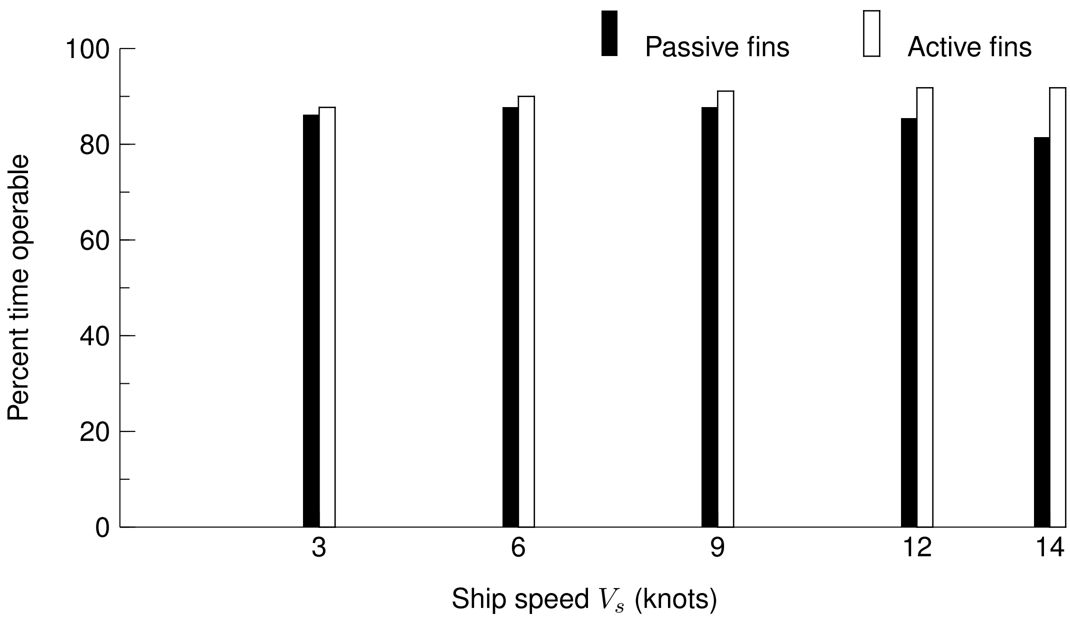

Figure 18: *Percent Time Operable Versus Ship Speed for Transit Mission in North Atlantic*

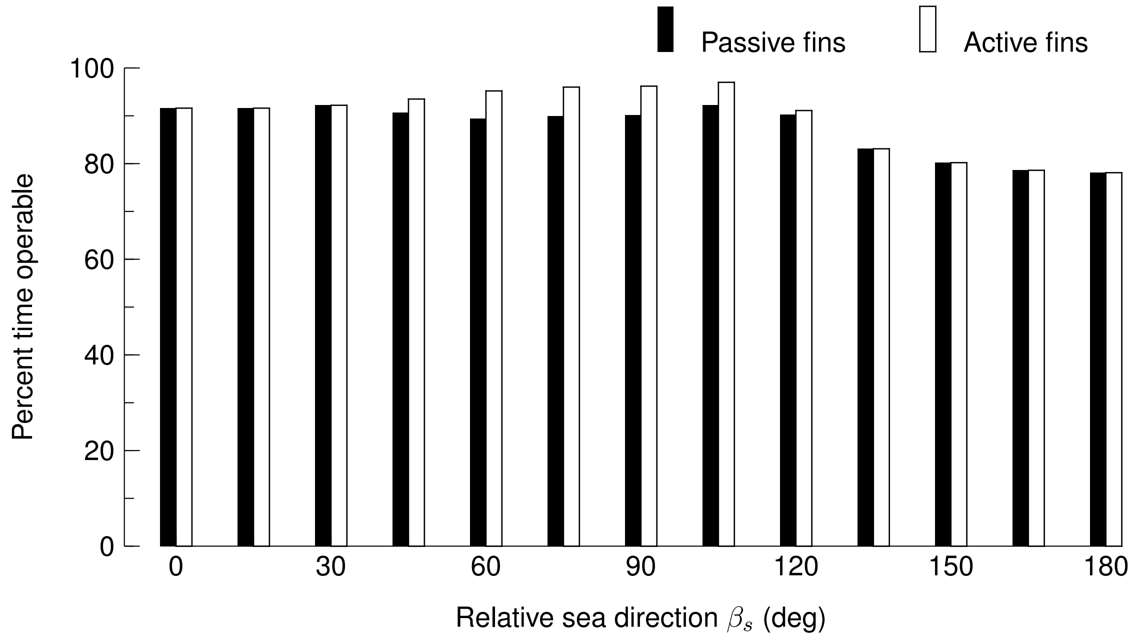

Figure 19: *Percent Time Operable Versus Relative Sea Direction for Transit Mission in North Atlantic, Ship Speed 6 knots*

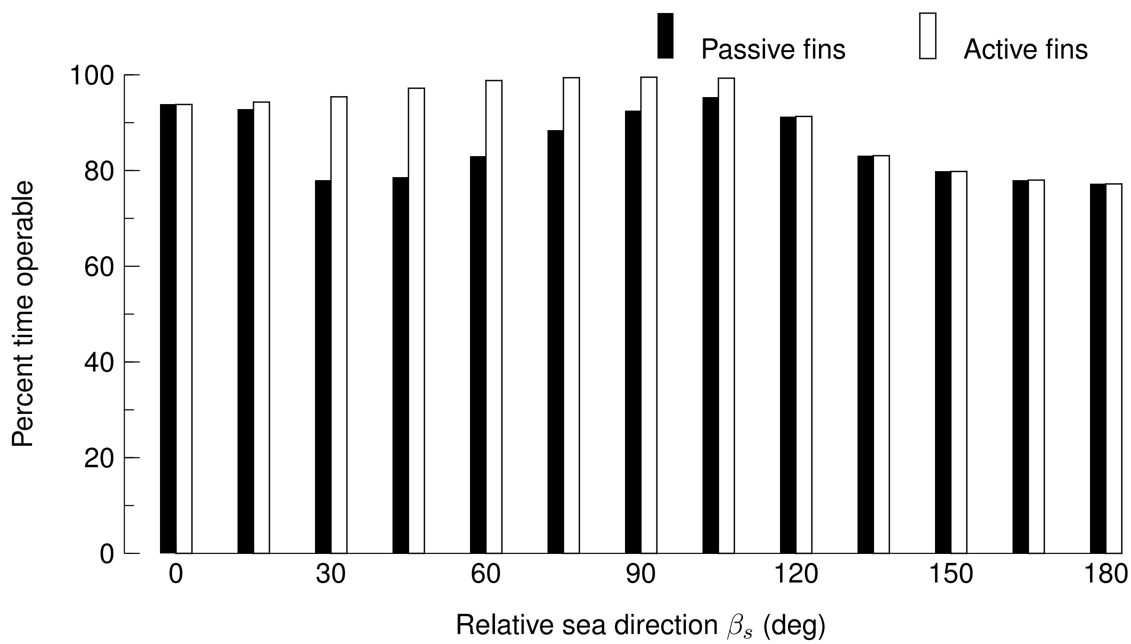

Figure 20: *Percent Time Operable Versus Relative Sea Direction for Transit Mission in North Atlantic, Ship Speed 12 knots*

6 Discussion

The design is based on the existing Norwegian ship Svalbard, which mitigates risk regarding seakeeping performance. For the Canadian Navy, the primary decisions influencing AOPS seakeeping performance will be related to roll stabilization. The present seakeeping and operability analysis indicates that active stabilizer fins would significantly enhance performance. When considering economic benefit, it could be argued that a 3 percent increase in operability could justify spending on active stabilizer fins, which would be less than 3 percent of total ship cost. For the Norwegian ship Svalbard, stabilizer fins were retrofitted after initial operation without fins. Incorporation of stabilizer fins into the original design and construction for AOPS would be more cost effective than a subsequent retrofit.

Active pumping between heel tanks is another option that could be used for roll stabilization. For the present study this option has been approximated using a U-tube tank model. A more rigourous analysis could be performed by developing a detailed model of active pumping between heel tanks. An advantage of tank stabilization relative to fin stabilization is that it is effective at low speeds, including zero speed. For the AOPS design, this is not a major advantage because the natural roll period of the ship is relatively large (15.6 s), and large roll motions tend to be limited to when the ship is travelling at higher speeds in stern quartering seas.

7 Conclusions

A seakeeping and operability analysis for the Arctic Offshore Patrol Ship has been performed for the ship with stabilizer fins deployed in passive and active modes. Roll motions are greatest in stern quartering seas when travelling at higher speeds, and could be significantly reduced by active stabilizer fins. Active roll stabilization by pumping water between heeling tanks has been modelled by approximating the system as a U-tube tank. Predictions indicate that stabilizer fins would be more effective than active pumping between heeling tanks. If roll stabilization using pumping between heeling tanks were to be considered further, then it is recommended that a more sophisticated model of the system physics be developed.

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Symbols and Abbreviations

B	beam
CG	centre of gravity
$\overline{GM}_{fluid}$	ship metacentric height including fluid effects
H_s	significant wave height
$k_{\delta j}^{D}$	derivative gain for motion mode j
$k_{\delta j}^{I}$	integral gain for motion mode j
$k_{\delta j}^{P}$	proportional gain for motion mode j
L	ship length between perpendiculars
PTO	percent time operable
RMS	root mean square
T_p	peak wave period
t_{stern}	ship trim by stern
β_s	relative sea direction
δ^{fin}	fin deflection angle
$\dot{\delta}^{fin}$	fin deflection velocity
$\ddot{\delta}^{fin}$	fin deflection acceleration
δ_C^{fin}	fin command angle
ζ_δ	fin deflection damping
η_j^f	ship motion displacement in earth-fixed coordinates for mode j
τ_{max}^{fin}	maximum delay time for evaluating integral gain response
ω_δ	fin deflection natural frequency
$\triangle$	ship mass displacement

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The Canadian Navy is planning to procure several Arctic Offshore Patrol Ships (AOPS), for which a design has been developed based on the Norwegian ship Svalbard. This report presents a seakeeping analysis performed using ShipMo3D and an operability analysis performed using SHIPOP2. To facilitate operations in ice, the AOPS design has no bilge keels; thus, roll stabilization using active stabilizer fins or internal tanks is being considered. The present analysis considers stabilizer fins deployed in passive and active modes. Seakeeping computations indicate that roll motions are largest in stern quartering seas at higher ship speeds, and that active stabilizer fins would provide significant roll reduction. Roll stabilization using active pumping between heeling tanks has been examined by modelling the tank system as a ShipMo3D U-tube tank. The results indicate that active fins would be more effective than stabilization using heeling tanks; however, a higher fidelity model of the heeling tank system could yield different results. The present computations and Norwegian experience with Svalbard indicate that inclusion of active stabilizer fins would be warranted.

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operability
pitch
roll
seakeeping
ship motions

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