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FREDYN SIMULATIONS IN SUPPORT OF THE MARITIME HELICOPTER PROJECT

K.A. McTaggart

Defence R&D Canada

Technical Memorandum
DREA TM 2001-102
August 2001

National Defence Défense nationale

Canada

FREDYN Simulations in Support of the Maritime Helicopter Project

McTaggart, Kevin A.

Defence Research Establishment Atlantic

Technical Memorandum

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Abstract

This report describes simulations of ship motions in support of the Maritime Helicopter Project. The time domain program FREDYN has been used to simulate the HALIFAX class during coursekeeping and maneuvering. The coursekeeping simulations model the ship travelling in severe seas for a wide range of speeds and headings. The maneuvering simulations model the ship completing a 180 degree turn for a variety of ship speeds, headings, rudder angles, and sea states. Among all simulations, the highest roll angle was 32 degrees. For some cases with low ship speeds and waves, the ship was unable maintain course or complete its maneuver. Second order drift forces are very difficult to predict accurately; thus, the predictions of coursekeeping and maneuvering at low speed in higher sea states have a high degree of uncertainty.

Résumé

Ce rapport décrit les simulations de mouvements de navires effectuées dans le cadre du Projet d'hélicoptère maritime. Le programme de domaine temporel FREDYN a été utilisé pour simuler un navire de classe HALIFAX lors du maintien du cap et de manoeuvres. Les simulations de maintien du cap ont permis de modéliser le navire se déplaçant par mer forte à diverses vitesses et sur différents caps. Les simulations de manoeuvres ont permis de modéliser le navire effectuant une giration de 180 degrés à diverses vitesses, sur différents caps, à différents angles de barre et dans différents états de mer. Pour toutes les simulations, l'angle de roulis le plus élevé noté a été de 32 degrés. Dans certaines situations où le navire se déplaçait à basse vitesse dans des vagues, il a été incapable de conserver le cap ou de terminer la manoeuvre. Les forces de dérive de deuxième ordre sont très difficiles à prédire avec précision et c'est pourquoi les prédictions de maintien de cap et de manoeuvres à basse vitesse dans des états de mer plus élevés ont un haut degré d'incertitude.

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Executive summary

Introduction

The Maritime Helicopter Project tasked DREA to perform motion simulations for the HALIFAX class. The simulation results will be used to assess design loads for securing a helicopter to the ship. The program FREDYN was used to obtain time domain predictions of motions for the HALIFAX class during coursekeeping and maneuvering in calm water and waves.

Principal Results

For simulations in sea state 8, HALIFAX was able to maintain course for all headings when travelling at 10 and 15 knots, but had difficulty maintaining oblique headings at a speed of 5 knots. Additional simulations modelled HALIFAX completing 180 degree turns in calm water and in waves. The ship was unable to complete turns in some conditions with waves combined with low ship speed and/or small rudder angle. Among all simulations of coursekeeping and maneuvering, the highest observed roll angle was 32 degrees.

Significance of Results

FREDYN proved to be a useful tool for modelling of coursekeeping and maneuvering in waves. It should be noted that FREDYN has been extensively validated for frigates travelling at moderate to high speeds in waves. Minimal validation has been performed for a ship travelling at low speed subject to large wave drift forces. Wave drift forces influencing ship maneuvering are a second order effect, and are difficult to predict accurately. Uncertainty exists regarding the ability of FREDYN to predict drift motions of a ship at low speed in waves.

Future Plans

The FREDYN code is currently being updated, and will include an enhanced maneuvering model. Validation of the updated code will include maneuvering of the ship at low speed in waves.

McTaggart, Kevin A.; 2001; FREDYN Simulations in Support of the Maritime Helicopter Project; DREA TM 2001-102; Defence Research Establishment Atlantic.

Sommaire

Introduction

Dans le cadre du Projet d'hélicoptère maritime, le CRDA a été chargé d'effectuer des simulations de mouvements pour les navires de classe HALIFAX. Les résultats des simulations serviront à évaluer les charges admissibles pour l'arrimage d'un hélicoptère au navire. Le programme FREDYN a été utilisé pour obtenir des prédictions dans le domaine temporel des mouvements des navires de classe HALIFAX lors du maintien du cap et de manoeuvres en eaux calmes et dans les vagues.

Principaux résultats

Lors des simulations dans un état de mer 8, le navire de classe HALIFAX a été capable de conserver tous les caps en navigant à 10 et 15 noeuds, mais a eu de la difficulté à conserver un cap oblique à une vitesse de 5 noeuds. D'autres simulations ont permis de modéliser le navire effectuant une giration de 180 degrés en eaux calmes et dans les vagues. Le navire a été incapable d'effectuer des girations dans certaines conditions comme par exemple lorsqu'il se déplaçait à basse vitesse ou avec un faible angle de barre dans des vagues. Pour toutes les simulations de maintien du cap et de manoeuvres, l'angle de roulis le plus élevé observé a été de 32 degrés.

Importance des résultats

FREDYN s'est avéré un outil utile pour la modélisation du maintien du cap et des manoeuvres dans des vagues. Il est à noter que FREDYN a été soumis à une validation poussée pour les frégates navigant à des vitesses de modérées à élevées dans des vagues mais à une validation minimale pour un navire se déplaçant à basse vitesse soumis à d'importantes forces de dérive des vagues. Les forces de dérive des vagues qui influent sur les manoeuvres du navire sont un effet de deuxième ordre et sont difficiles à prédire avec précision. Il n'est pas certain que le programme FREDYN soit capable de prédire les mouvements de dérive d'un navire à basse vitesse dans des vagues.

Plans futurs

Le code FREDYN est actuellement mis à jour et comprendra un modèle de manoeuvres amélioré. La validation du code mis à jour comprendra des manoeuvres de navire à basse vitesse dans des vagues.

McTaggart, Kevin A.; 2001; Simulations au moyen du programme FREDYN effectuées dans le cadre du Projet d'hélicoptère maritime; DREA TM 2001-102; Centre de Recherches pour la Défense Atlantique.

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Notation

B	ship beam
CG	centre of gravity
D	turn diameter
D_s	simulation duration
G	location of ship centre of gravity
$\overline{GM}_{fluid}$	metacentric height, corrected for free surface effects
H_s	significant wave height
$\overline{KG}$	height of centre of gravity above baseline
L	ship length between perpendiculars
p, q, r	ship angular velocity components in ship-fixed axis system
T_{mid}	ship draft at midships
T_p	peak wave period
T_{wa}	average wave period
T_ϕ	ship natural roll period
TD	tactical diameter
U	ship speed
x_e, y_e, z_e	earth-based axes
x_g, y_g, z_g	ship-based axes
θ	pitch angle
ϕ	roll angle
$\|\phi\|_{max}$	maximum absolute roll angle
ψ	ship heading relative to waves (180 degrees for head seas)
$\triangle$	ship mass displacement

1 Introduction

This report describes a series of ship motion simulations in support of the Maritime Helicopter Project. DREA was tasked to perform the simulations and provide the results to a contractor examining securing requirements for new helicopters. The program FREDYN was selected for the simulations because it has a unique capability within DND for predicting maneuvering of a ship in waves. Section 2 gives a brief description of the program FREDYN, and is followed by a description in Section 3 of a program developed for viewing FREDYN results. Section 4 describes the FREDYN simulations for the HALIFAX class in waves. Section 5 discusses some of the results from the present work, and is followed by conclusions in Section 6.

2 Description of FREDYN

The program FREDYN computes motions of a ship maneuvering in waves and wind. The Cooperative Research Navies Dynamic Stability Project, of which DND is a participant, has sponsored the code development by Maritime Research Institute Netherlands (MARIN). FREDYN uses a nonlinear strip theory approach, which gives good results for large amplitude motions of slender vessels such as frigates. This study uses Version 7.7 of FREDYN, which is described in detail in proprietary References 1 and 2. McTaggart and de Kat [3] give an overview of FREDYN in the open literature.

FREDYN uses an earth-fixed axis system (x_e, y_e, z_e) and a ship-fixed axis system (x_g, y_g, z_g), as shown in Figure 1. The plane $x_e - y_e$ lies in the still waterplane, with the z_e axis pointing downward. The ship-fixed system (x_g, y_g, z_g), which has its origin at the ship center of gravity, rotates and translates as the ship moves. When the ship is at rest in a calm water, the z_g axis points downward.

Table 1 gives some of the main FREDYN output parameters. Note that the output value for ZE, the vertical displacement of the ship CG, is given relative to its value when the ship is at rest in calm water. Application of FREDYN output often requires transformation of results from earth-fixed to ship-fixed axis systems. The output rotational parameters are based on the following sequence of rotations:

1. yaw rotation ψ about vertical axis, parallel to z_e axis, with respect to x_e axis,

2. pitch rotation θ about y axis of yawed coordinate system,

3. roll rotation ϕ about x axis of yawed and pitched coordinate system.

***Figure 1:** Plan View of FREDYN Axes (z_e and z_g axes point downward)*

Transformations of translational and angular velocity components are as follows:

$$\begin{Bmatrix} \dot{x}_e \\ \dot{y}_e \\ \dot{z}_e \end{Bmatrix} = [T_{3f}]^{-1} \begin{Bmatrix} \dot{x}_g \\ \dot{y}_g \\ \dot{z}_g \end{Bmatrix} \tag{1}$$

$$\begin{Bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{Bmatrix} = [T_{3v}]^{-1} \begin{Bmatrix} p \\ q \\ r \end{Bmatrix} \tag{2}$$

where p, q, and r are the ship angular velocity components in the ship-fixed coordinate system. The transformation matrices are:

$$[T_{3f}]^{-1} = \tag{3}$$
$$\begin{bmatrix} \cos\psi\cos\theta & -\sin\psi\cos\phi + \cos\psi\sin\theta\sin\phi & \sin\psi\sin\phi + \cos\psi\sin\theta\cos\phi \\ \sin\psi\cos\theta & \cos\psi\cos\phi + \sin\psi\sin\theta\sin\phi & -\cos\psi\sin\phi + \sin\psi\sin\theta\cos\phi \\ -\sin\theta & \cos\theta\sin\phi & \cos\phi\cos\theta \end{bmatrix}$$

$$[T_{3v}]^{-1} = \tag{4}$$
$$\begin{bmatrix} 1 & \sin\phi\tan\theta & \cos\phi\tan\theta \\ 0 & \cos\phi & -\sin\phi \\ 0 & \frac{\sin\phi}{\cos\theta} & \frac{\cos\phi}{\cos\theta} \end{bmatrix}$$

Table 1: *FREDYN Output Parameters*

Time (s)	Time relative to beginning of simulation
Wave ZETAG (m)	Wave elevation at ship CG
Wave slope ALFAY (deg)	Beamwise component of wave slope at ship CG
XE (m)	x_e displacement of ship CG
YE (m)	y_e displacement of ship CG
ZE (m)	z_e displacement (+ down) of ship CG relative to calm water value
Roll PHI (deg)	Ship roll angle (starboard down)
Pitch THETA (deg)	Ship pitch angle (stern down)
Heading PSI (deg)	Ship heading relative to x_e axis
Heading PSI-PSI0 (deg)	Ship heading relative to initial heading
Forward speed UG (m/s)	Speed of ship CG in direction x_g
Transverse velocity VG (m/s)	Speed of ship CG in direction y_g (+ starboard)
Vertical velocity WG (m/s)	Speed of ship CG in direction z_g (+ down)
Rudder angle DEL (deg)	Rudder angle (+ port)

3 FREDYN Time Series Viewer

To assist with analysis of results from FREDYN simulations, a program was developed to view output maneuvers and time series of roll angle, wave slope, yaw angle, ship speed, and rudder angle. The FREDYN time series viewer was developed using the Java programming language with the Borland JBuilder Foundation 4.0 integrated development environment [4]. Plotting of FREDYN time series was facilitated with the JFreeChart package [5]. Both JBuilder Foundation and JFreeChart are available at no cost from their cited web sites.

Figure 2 shows a FREDYN maneuver from the time series viewer. The viewer also produces time series plots of various parameters such as roll and ship speed. The time series viewer was very useful for examining run results.

The time series viewer consisted of approximately 800 lines of Java source code, some of which was generated automatically by Borland JBuilder. As an alternative to the relatively long Java code, a second version of the time series viewer was developed using the Python computer language [6]. Python is a higher level language than Java, with the resulting code typically being more concise and easier to understand. The development of the viewer in both Java and Python permitted evaluation

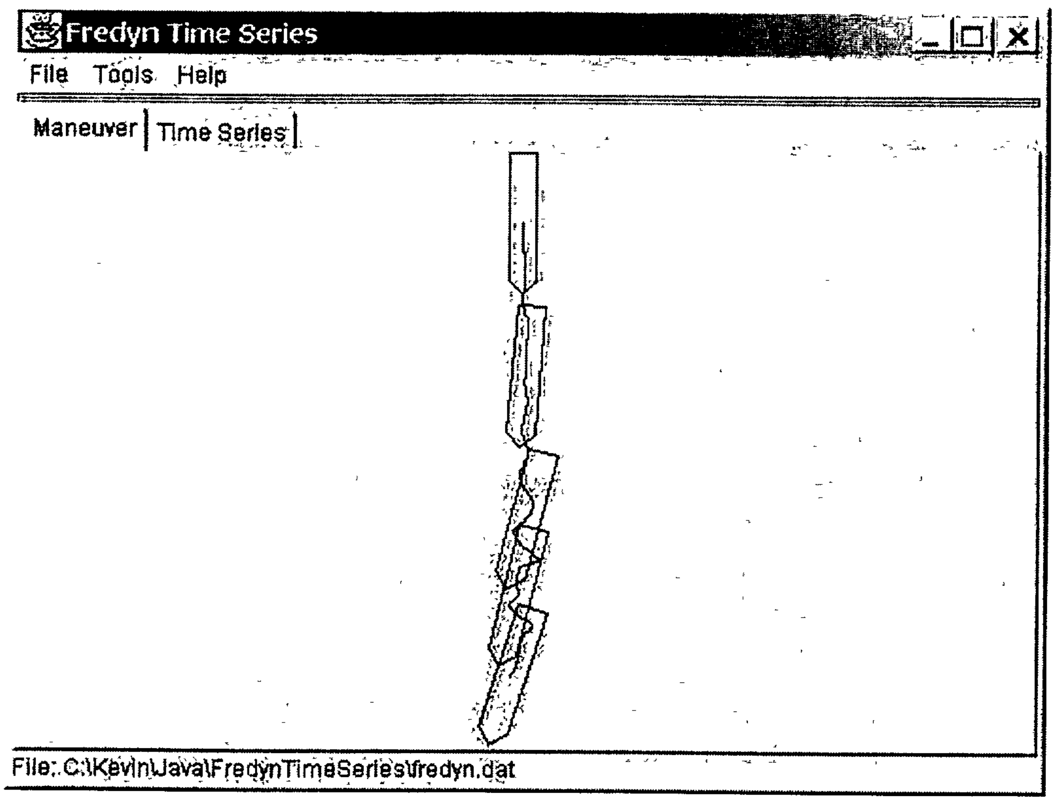

Figure 2: *View of Maneuver with FREDYN Time Series Viewer*

of both languages for long-term usage.

The Python code was developed using the ActivePython integrated development environment, using the Tkinter GUI package and the PMW.BLT plotting package. The required software was installed on a Windows 2000 PC in the following sequence:

1. ActivePython was installed from:
http://www.activestate.com/Products/ActivePython/Download.html

2. Tcl/Tk 8.3 was installed from:
http://dev.scriptics.com

3. the BLT plotting package was installed from:
http://www.tcltk.com/blt

4. the Python Megawidgits (PMW) package was installed from:
http://www.dscpl.com.au/pmw

The source code for the Python version of the viewer was approximately 200 lines, compared to 800 lines for the Java version. To open and display a FREDYN time series of 36,200 time steps, the Python viewer required 20 s, less than half the time required for the Java viewer. In summary, Python is an effective programming language for long-term use.

4 Simulations of HALIFAX Class Motions

In support of the Maritime Helicopter Project, simulations were performed for the HALIFAX class performing coursekeeping and semi-circle maneuvers in various sea states. All simulations were performed using version 7.7 of FREDYN, which has been used for capsize risk analysis studies [3, 7]. The ship condition for the present simulations is given in Table 2, and is the same as for References 3 and 7. It should be noted that the ship typically operates at a displacement closer to 4800 tonnes, with the resulting motions likely less than those predicted here. At the request of the Maritime Helicopter Project contractor, the simulations had an output time step of 0.1 s.

For simulations representing a nominal ship speed, the propeller RPM was set to the value such that FREDYN would give the desired ship speed in calm water. The propeller RPM used to give a desired ship speed from FREDYN will differ from the actual propeller RPM for the HALIFAX class due to assumptions made in numerical modelling. It should be noted that FREDYN does not model variable pitch propellers, and that the present results are for the HALIFAX propellers set to a specified pitch value.

Table 2: Main Particulars for HALIFAX Class Frigate

Length, L	124.5 m
Beam, B	14.7 m
Midships draft, T_{mid}	4.64 m
Trim by stern, t_s	0.0 m
Displacement, Δ	4179 tonnes
Vertical centre of gravity, $\overline{KG}$	6.44 m
Height of CG above waterline	1.80 m
Metacentric height, $\overline{GM}_{fluid}$ (corrected for free-surface)	1.224 m
Natural roll period, T_ϕ	11.7 s

For simulations with waves, random long-crested seaways were simulated using linear superposition of 20 sinusoidal components. Bretschneider spectra were used for all cases. The program FREDYN requires average wave period T_{wa} as an input parameter, which is related to the peak wave period T_p as follows:

$$T_{wa} = 0.772\, T_p \tag{5}$$

No wind effects were included in the simulations because of uncertainties regarding the response of a drifting ship to wind. Annex A gives sample input and output files.

4.1 Helicopter Securing Simulations

The helicopter securing simulations modelled the ship trying to maintain heading using its autopilot in severe wave conditions. Motions from these simulations are intended for determination of design loads for securing the helicopter inside the hangar. Tables 3 and 4 summarize the simulation conditions. The tabulated ship speeds represent calm water values, which were generally close to observed values in waves. In sea state 8 at a ship speed of 5 knots, simulations were limited to head seas due to problems with coursekeeping at other headings. All simulations were of one hour duration.

For each simulation, there are three main FREDYN files:

- the input file with extension ".inp",
- the output summary file with extension ".out",

Table 3: *Helicopter Securing Simulations in Sea State 8*

Significant wave height, H_s	11.5 m
Peak wave period, T_p	16.4 s
Average wave period, T_{wa}	12.7 s
Ship headings, ψ	0, 30, 60, 90, 120, 150, 180 degrees
Ship speeds, U	5, 10, 15 knots

Table 4: *Helicopter Securing Simulations in Ship Survivability Limit*

Significant wave height, H_s	15.0 m
Peak wave period, T_p	18.0 s
Average wave period, T_{wa}	13.9 s
Ship headings, ψ	180 degrees
Ship speeds, U	5 knots

- the output time series file with extension ".dat".

The main portion of each file name is designated by the ship speed, heading, and nominal significant wave height. For example, file "10k120d11m.inp" is the input file for a ship speed of 10 knots, heading of 120 degrees, and significant wave height of 11.5 m. The resulting output files for all helicopter securing simulations occupy approximately 180 MB of disk space.

Figure 3 gives maximum absolute roll angles for simulations in sea state 8. Roll angle is presented here because it is typically the dominant term influencing helicopter securing forces.

4.2 Maneuvering Simulations

The maneuvering simulations model the ship initially heading into the waves and then attempting to execute a 180 degree turn with a fixed rudder angle. Table 5 gives a summary of the simulations. Note that each significant wave height was associated with only one peak wave period. The relative turn diameter D/TD denotes the turn diameter D in calm water for the specified rudder angle divided by the tactical diameter TD, which is based on the maximum rudder angle of 35 degrees. Figure 4 shows the predicted tactical diameters in calm water for the various ship speeds. The rudder angles for different relative turn diameters were determined us-

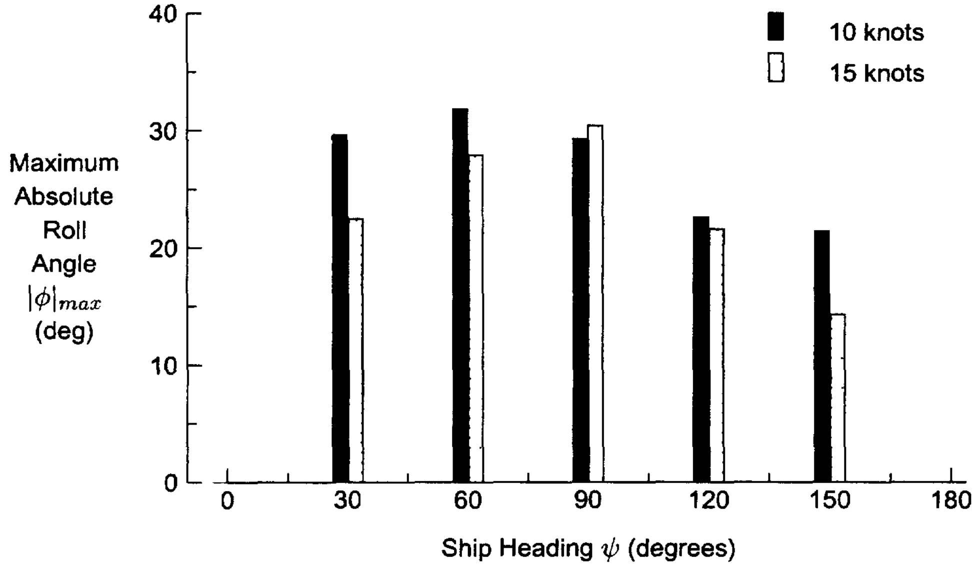

Figure 3: *Maximum Absolute Roll Angle for Helicopter Securing Simulations in Sea State 8*

ing simulations at the mid-range ship speed, 15 knots. Figure 5 shows the variation of relative diameter with rudder angle at 15 knots, and Table 6 shows the rudder angles used for turn maneuvers at all ship speeds.

Table 5: *Maneuvering Simulations*

Significant wave height, H_s	0, 2.5, 4.0, and 6.0 m
Peak wave period, T_p	-, 8.8, 11.0, and 13.6 s
Average wave period, T_{wa}	-, 6.8, 8.5, and 10.5 s
Ship speeds, U	5, 10, 15, 20, and 25 knots
Relative turn diameter D/TD	1, 3, 5, 10

Table 7 gives durations for the maneuvering simulations. Simulation durations were set to ensure that there was sufficient time for the maneuver to be completed, with the exception of some cases in waves where the ship would never be able to complete the maneuver. Table 8 gives limiting wave heights for successful completion of the maneuver. It should be stressed that accurate prediction of wave effects on maneuvering is difficult because the time-averaged wave drift forces are a second order effect. For a ship travelling at low speed and/or having small rudder angle, the inaccuracies in the wave drift forces lead to incorrect maneuvering predictions.

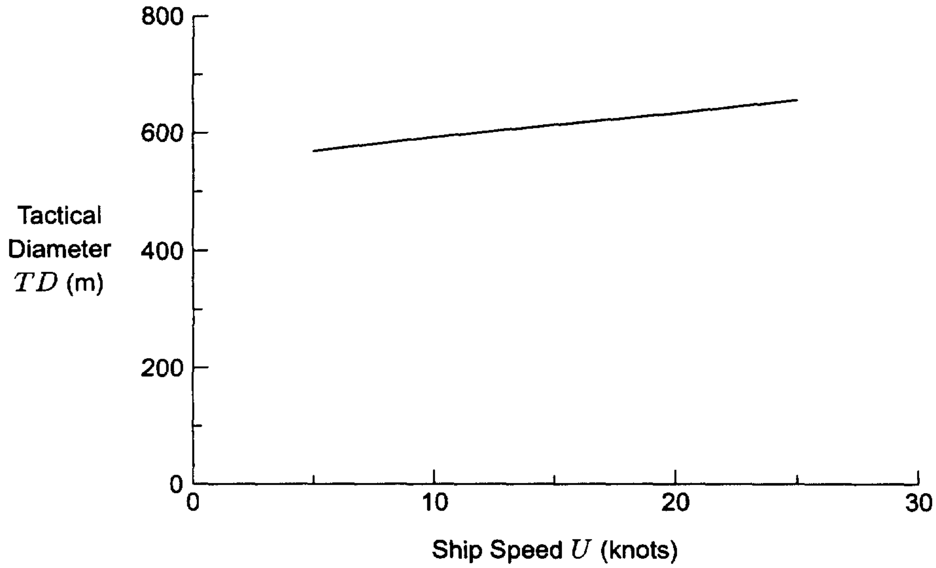

***Figure 4:** Tactical Diameter in Calm Water Versus Ship Speed*

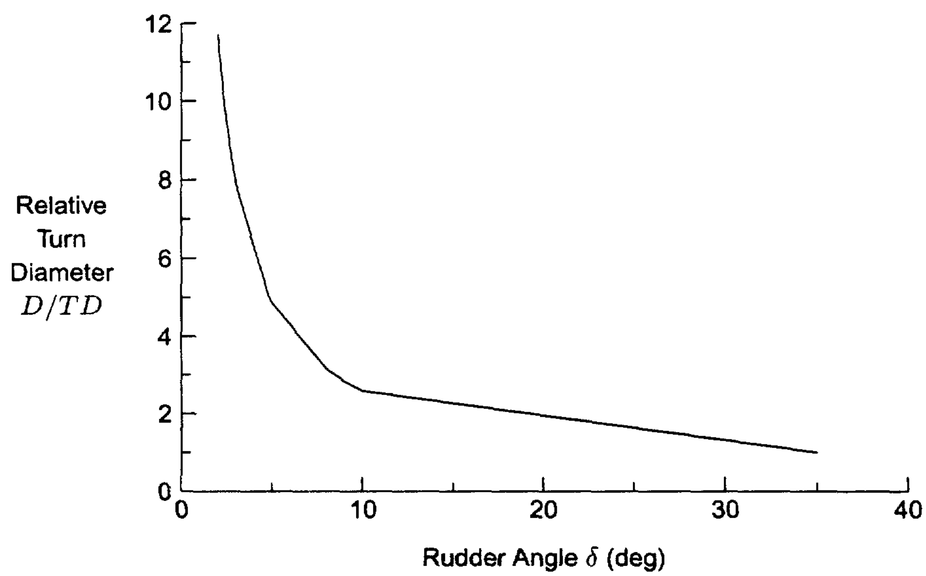

***Figure 5:** Relative Turn Diameter in Calm Water Versus Rudder Angle, 15 knots*

Table 6: *Relative Turn Diameters in Calm Water and Rudder Angles*

Relative Turn Diameter D/TD	Rudder Angle (deg)
1	35
3	8.5
5	4.9
10	2.4

Table 7: *Durations of Maneuvering Simulations*

Speed	Relative turn diameter D/TD			
	1	3	5	10
5 knots	600 s	2000 s	3000 s	5000 s
10 knots	400 s	800 s	1500 s	2500 s
15 knots	300 s	600 s	1000 s	2000 s
20 knots	200 s	500 s	800 s	2000 s
25 knots	200 s	400 s	500 s	1500 s

Table 8: *Maximum Significant Wave Height for Successful Completion of Turn (Blank cell indicates turn completed for all wave heights)*

Speed	Relative turn diameter D/TD			
	1	3	5	10
5 knots	0 m	0 m	0 m	0 m
10 knots		0 m	0 m	0 m
15 knots			2.5 m	0 m
20 knots				2.5 m
25 knots				

The file names for maneuvering simulations are denoted by ship speed, relative turn diameter, and nominal wave height. For example, "10k10td2m.inp" is the input file for a ship speed of 10 knots, turn diameter of 10 tactical diameters, and significant wave height of 2.5 m.

Figures 6 to 9 give maximum absolute roll angles from the maneuvering simulations. The presented results include conditions for which maneuvers were not completed, as indicated in Table 8. The output files from the maneuvering simulations occupy approximately 320 MB of disk space.

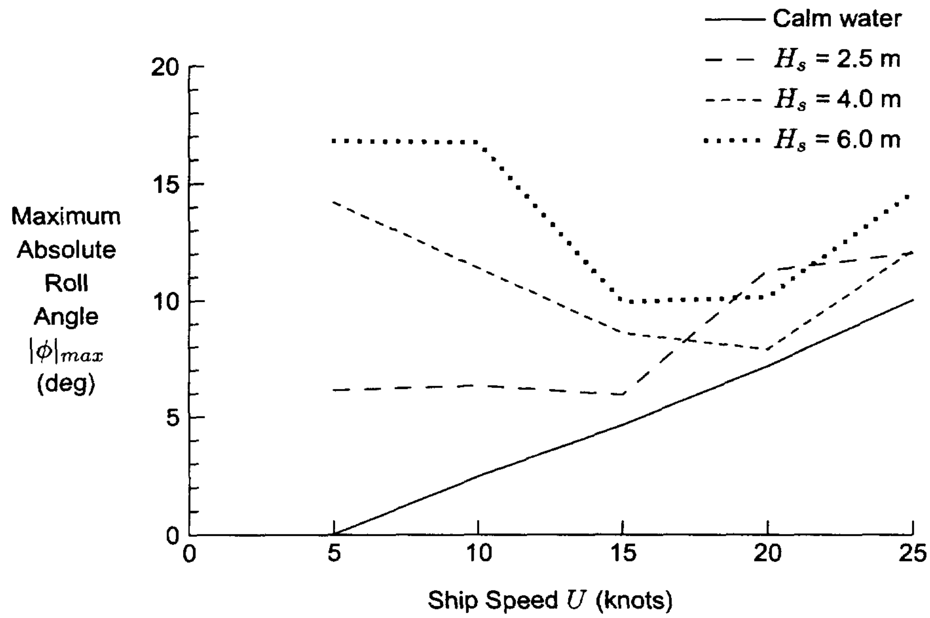

***Figure 6:** Maximum Absolute Roll Versus Ship Speed, 1 Tactical Diameter*

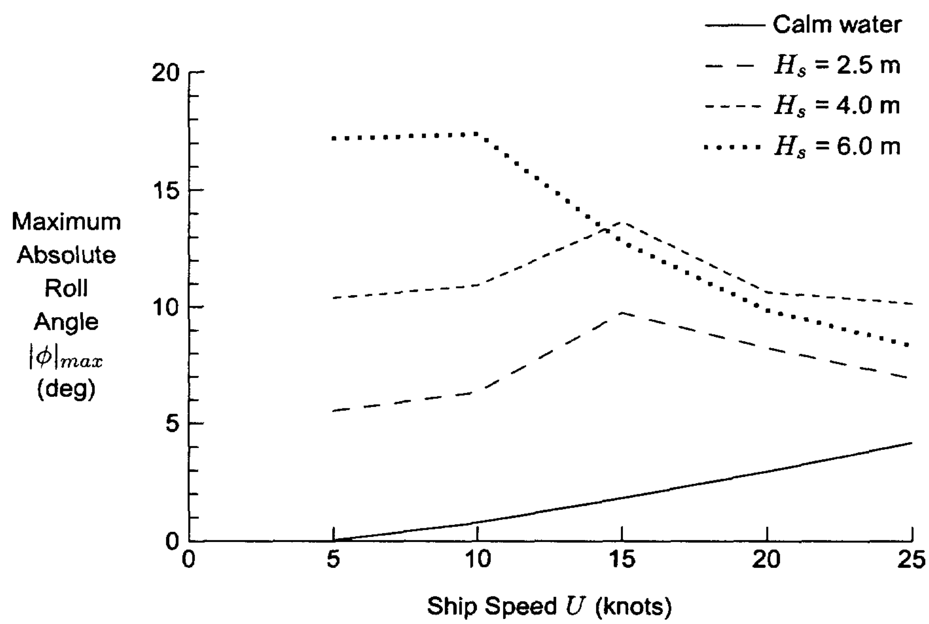

***Figure 7:** Maximum Absolute Roll Versus Ship Speed, 3 Tactical Diameters*

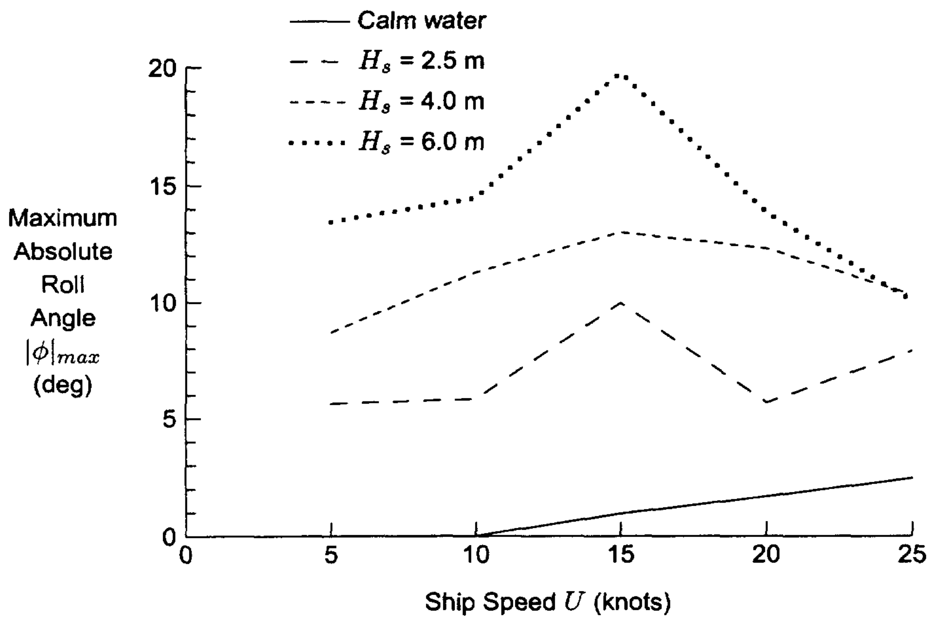

__Figure 8:__ Maximum Absolute Roll Versus Ship Speed, 5 Tactical Diameters

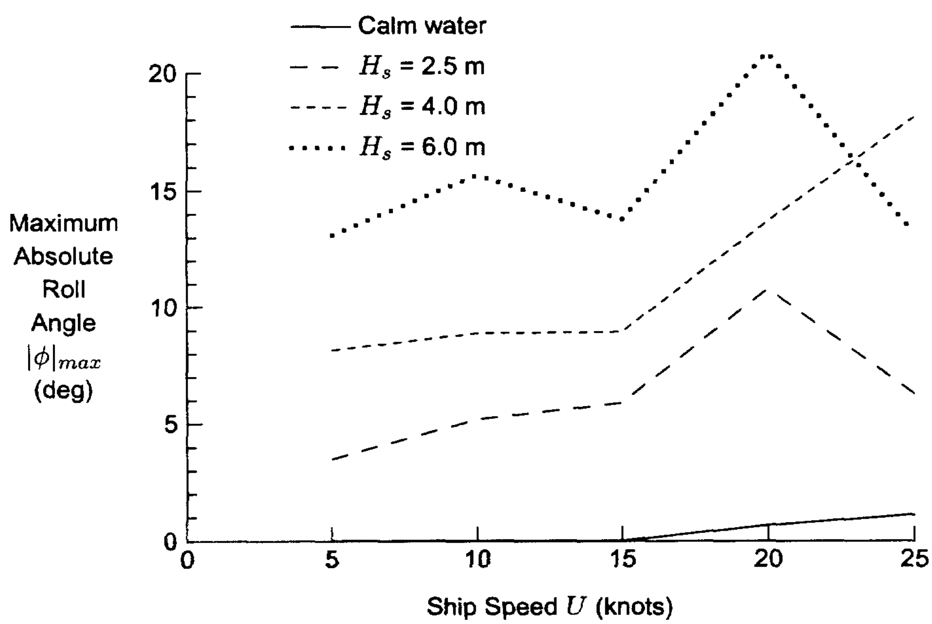

__Figure 9:__ Maximum Absolute Roll Versus Ship Speed, 10 Tactical Diameters

5 Discussion

During the present simulation study, several observations were made regarding the capabilities of FREDYN. These observations are intended to assist with the interpretation of the present results and with future improvements to FREDYN.

The FREDYN output data file "fredyn.dat" gives time series of ship motion values, which are given in scientific notion format with 4 significant figures. For the present study, the FREDYN code had to be modified such that time and horizontal plane coordinates XE and YE had 9 significant figures.

The majority of validation for the FREDYN code has been focused on oscillatory motions and capsize in waves. Less effort has been devoted to validating maneuvering predictions in waves and wind. For a ship maneuvering in waves, second-order wave drift forces will influence ship motions. Wave drift forces are difficult to predict accurately, and can significantly influence ship maneuvering at lower speeds. Future work is required to address the ability of FREDYN to predict maneuvering at low speed in waves and wind.

For several of the maneuvering simulations in waves, the ship was unable to complete the turn using the prescribed rudder angle. In a realistic scenario, the ship captain would likely increase the rudder angle to enable the ship to complete the maneuver.

6 Conclusions

FREDYN simulations of the HALIFAX class have been completed in support of the Maritime Helicopter Project. The simulations represent coursekeeping during severe sea states and maneuvering during a variety of sea states. The maximum roll angle from all simulated conditions is 32 degrees.

For several of the simulations in waves, the ship was unable to maintain course or complete the prescribed turn. Due to the difficulty in predicting wave drift forces, there is uncertainty regarding the accuracy of FREDYN maneuvering simulations for a ship at low speed in larger waves. This deficiency will be addressed in ongoing development of FREDYN.

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Annex A
Sample FREDYN Files

The following files are FREDYN input and output for the HALIFAX class completing a 180 degree turn at a speed of 25 knots in a sea state with a wave height of 6 m. The FREDYN input files utilize the "INCLUDE" feature for input to ensure consisting among simulations. For brevity, the output time series file has been truncated at both the right and the bottom.

A.1 Master Input File "25k1td6m.inp"

```
COMMENT   CPF - MHP maneuvering, November 2000
COMMENT   25knots 1 tactical diameters
COMMENT   Hs = 6.0 m, Tp = 13.6 s
INCLUDE   maneuver.inp
INCLUDE   25k1td.inp
INCLUDE   wave6m.inp
```

A.2 Maneuver Input File "maneuver.inp"

```
COMMENT    CPF - MHP maneuvering, DREA, November 2000
COMMENT    Main control file
COMMENT    Analysis Conditions
SIMPAR    .001      1         20.00     150       0.1
EXC.ON.OFF
OPTION     PRIWAVE  NOLIST
```

A.3 Speed and Rudder Input File "25k1td.inp"

```
COMMENT   Maneuvering 25 knots, 1 tactical diameter
SIMTIME   200.0     0.00
INITPOS   0.0       0.        0.        0.0       0.        180.00    180.
INITVEL   12.9      0.        0.        0.        0.        0.
RPMPROP   168.5
DEL0      0.        0
DELDC     4.5
MAN       2
DEL0      0.0
DELG0     -35.0
PSI1M     360.0
DEADBAND
C0D
C1D       -3.81
C2D       -8.5
C3D
C4D
C5D
C6D
C7D
A1D       1         1         1
A2D
DELM      35.       35.       0.0
```

A.4 Wave Condition Input File "wave6m.inp"

```
COMMENT   HSIGN     TWA       NWA       ISPEC     GAMMA
COMMENT   [m]       [m]       [-]       [1...6]   [~3.3]
WAVE1     6.0       10.5      20        1
RANSEED   111       0         1001      111
```

A.5 Main Output File "25k1td6m.out"

```
                              F R E D Y N                 DATE · 05/12/2000
                              ===========                 TIME . 11:57·10

                              Revision 7.7

SIMULATION OF THE BEHAVIOR OF A STEERED SHIP IN WIND AND WAVES WITH
(OPTIONAL) DAMAGED COMPARTMENTS
-----------------------------------------------------------------------------------------------




 **** N O T I C E ****

 This program has been developed by the Maritime Research Institute Netherlands (MARIN)
 MARIN does not assume any responsibility for the validity, accuracy or applicability of
 any results obtained from this computer program.
 For a detailed description reference is made to:

           * FREDYN 6 0 User's Guide *



 Suggestions and comments on the program and documentation are welcome.
 Any errors encountered should be brought to our attention.

 May 1996              MARIN, P.O. BOX 28 , 6700 AA WAGENINGEN
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                       TELEFAX +31 317 493245
```

```
                              Summary of input records
*******************************************************************************************
 Record no   *          *          *          *          *          *          *          *
*******************************************************************************************

  0         COMMENT   |CPF - MHP |maneuverin|g, Novembe|r 2000    |          |          |
  1         COMMENT   |25knots 1 |tactical d|iameters  |          |          |          |
  2         COMMENT   |Hs = 6.0 m|, Tp = 13 |6 s       |          |          |          |
  3         INCLUDE   |maneuver.i|np        |          |          |          |          |
--- BEGIN INCLUDE SECTION ------------
  3         COMMENT   | CPF - MHP| maneuveri|ng, DREA, |November 2|000       |          |
  4         COMMENT   | Main cont|rol file  |          |          |          |          |
  5         COMMENT   | Analysis |Conditions|          |          |          |          |
  6         SIMPAR    |.001      |1         |20 00     |150       |0.1       |          |
  7         EXC.ON.OFF|          |          |          |          |          |          |
  8         OPTION    | PRIWAVE  |NOLIST    |          |          |          |          |
--- END OF INCLUDE SECTION -----------
  9         INCLUDE   |25kltd.inp|          |          |          |          |          |
--- BEGIN INCLUDE SECTION ------------
  9         COMMENT   |Maneuverin|g 25 knots|, 1 tactic|al diamete|r         |          |
 10         SIMTIME   |200.0     |0.00      |          |          |          |          |
 11         INITPOS   |0 0       |0.        |0         |0.0       |0.        |180.00    |180.00
 12         INITVEL   |12 9      |0.        |0.        |0.        |0.        |0         |
 13         RPMPROP   |168 5     |          |          |          |          |          |
 14         DEL0      |0.        |0         |          |          |          |          |
 15         DELDC     |4 5       |          |          |          |          |          |
 16         MAN       |2         |          |          |          |          |          |
 17         DEL0      |0.0       |          |          |          |          |          |
 18         DELG0     |-35 0     |          |          |          |          |          |
 19         PSI1M     |360 0     |          |          |          |          |          |
 20         DEADBAND  |          |          |          |          |          |          |
 21         C0D       |          |          |          |          |          |          |
 22         C1D       |-3.81     |          |          |          |          |          |
 23         C2D       |-8.5      |          |          |          |          |          |
 24         C3D       |          |          |          |          |          |          |
 25         C4D       |          |          |          |          |          |          |
 26         C5D       |          |          |          |          |          |          |
 27         C6D       |          |          |          |          |          |          |
 28         C7D       |          |          |          |          |          |          |
 29         A1D       |1         |1         |1         |          |          |          |
 30         A2D       |          |          |          |          |          |          |
 31         DELM      |35        |35.       |0.0       |          |          |          |
--- END OF INCLUDE SECTION -----------
 32         INCLUDE   |wave6m.inp|          |          |          |          |          |
--- BEGIN INCLUDE SECTION ------------
 32         COMMENT   |HSIGN     |TWA       |NWA       |ISPEC     |GAMMA     |          |
 33         COMMENT   |[m]       |[m]       |[-]       |[1.. 6]   |[~3.3]    |          |
 34         WAVE1     |6.0       |10 5      |20        |1         |          |          |
 35         RANSEED   |111       |0         |1001      |111       |          |          |
--- END OF INCLUDE SECTION -----------

******************************************************************************************


          Input data read from file ·  freinp.dat
          Based on the geometry file.  wspl.dat
          Loading condition ·
                      KG   =           6.440 [m]
                      MASS =        4178.807 [tonnes]
```

Wave spectrum used in the simulations

Frequency [rad/s]	S.dens. [m^2-s]	Ampl. [m]	Phase [deg]
0.305	0.274	0 105	326.891
0.325	0.874	0 191	296.315
0.347	1.998	0.298	69.047
0.370	3.525	0.408	327.199
0.394	5.091	0.506	35.272
0 420	6.299	0 582	230.901
0 448	6.911	0.629	83 776
0 477	6.910	0.649	33 541
0.509	6.429	0 647	245.726
0 542	5.658	0.626	118.333
0 578	4 768	0 594	87.718
0 616	3.886	0 553	320.046
0 657	3.086	0.509	172 119
0.700	2.402	0.464	1.010
0.746	1.841	0.419	82.055
0 795	1 394	0.377	234 410
0.848	1.046	0.337	222.481
0.904	0.779	0.300	50.127
0 963	0 577	0 267	113 352
1.027	0 426	0 233	23 213

Spectrum characteristics

Sign wave height 5 867 [m] Mean period 11.208[sec]

Wave data generated from a Pierson Moskowitz spectrum·

Sign. wave height. 6.000 [m] Mean period 10.5 [sec]
Peak period 14.0 [sec]

Program FREDYN MARITIME RESEARCH INSTITUTE NETHERLANDS

Sample rate of output signals 0.100 s

Statistical Analysis of simulation results

notation	units	mean	st dev	maximum	minimum	no.samp.
ZETAg1+2	(m)	-0 06	1.48	4.19	-3.83	2000
ALFAy	(deg)	-0.22	1.79	7.32	-6.78	2000
Xe	(m)	182.94	496 97	1215.05	-375.80	2000
Ye	(m)	-370.91	191 43	0.12	-610.70	2000
Ze	(m)	-0.06	1.04	3.81	-3.44	2000
PHI	(deg)	2 54	4.46	14.61	-4.43	2000
THETA	(deg)	-0 16	0 97	4.03	-3.99	2000
PSI	(deg)	326.33	65.68	382.71	180.00	2000
PSI-PSI0	(deg)	146.33	65.68	202 71	0.00	2000
Ug	(m/s)	11.91	1.15	14 46	10.12	2000
Vg	(m/s)	-0.31	0.46	1 25	-1.87	2000
Wg	(m/s)	-0.03	0.58	2.21	-2.27	2000
P	(deg/s)	0 00	1.43	5.77	-4.63	2000
Q	(deg/s)	0 09	0.74	3.36	-3.25	2000
R	(deg/s)	0.99	0 99	4 01	-0.28	2000
DELTA1	(deg)	-16 76	17.02	0.00	-35.00	2000

A.6 Truncated Time Series Output File "25k1td6m.dat"

```
"FREDYN version 7 7       . Data generated on 05/12/2000 at 11:57:12 from datafile freinp.dat  "
   0
    26      "TIME"     "ZETAG"     "ALFAY"            "XE"             "YE"         "ZE"       "Phi"
"Step" 0.000000000E+00 0 0000E+00 0.0000E+00 0.000000000E+00 0.000000000E+00 0.0000E+00 0.0000E+00
"Step" 0.100000001E+00 0.8884E-04 -.9495E-10 -.128999043E+01 0.125718007E-04 0.4149E-02 0.4587E-03
"Step" 0.200000003E+00 0.3633E-03 0.5289E-09 -.257996273E+01 0.954644638E-04 0.1701E-01 0.1212E-02
"Step" 0.300000012E+00 0 8193E-03 0 8133E-08 - 386991787E+01 0.312053628E-03 0.3904E-01 0 1894E-02
"Step" 0.400000006E+00 0.1432E-02 0.5724E-07 -.515985441E+01 0.719314616E-03 0.7038E-01 0 3048E-02
"Step" 0.500000000E+00 0.2160E-02 0.2175E-06 -.644976997E+01 0.136656931E-02 0.1109E+00 0.5205E-02
"Step" 0.600000024E+00 0.2948E-02 0.6278E-06 -.773966026E+01 0.229538092E-02 0 1600E+00 0.8879E-02
"Step" 0.700000048E+00 0.3734E-02 0.1486E-05 -.902951622E+01 0.353985792E-02 0.2172E+00 0.1453E-01
"Step" 0.800000072E+00 0.4458E-02 0.2996E-05 -.103193264E+02 0.512753893E-02 0.2813E+00 0.2271E-01
"Step" 0 900000095E+00 0.5068E-02 0 5315E-05 -.116090746E+02 0.707896613E-02 0.3512E+00 0.3398E-01
"Step" 0.100000012E+01 0.5527E-02 0.8477E-05 -.128987408E+02 0.940803532E-02 0.4255E+00 0.4889E-01
"Step" 0.110000014E+01 0.5823E-02 0.1225E-04 -.141883011E+02 0.121219521E-01 0.5025E+00 0.6800E-01
"Step" 0.120000017E+01 0.5968E-02 0.1603E-04 -.154777260E+02 0.152217373E-01 0.5805E+00 0.9190E-01
"Step" 0.130000019E+01 0.6001E-02 0 1882E-04 -.167669830E+02 0.187024008E-01 0.6578E+00 0.1212E+00
"Step" 0.140000021E+01 0 5988E-02 0 1927E-04 -.180560360E+02 0.225527585E-01 0.7325E+00 0.1562E+00
"Step" 0.150000024E+01 0 6019E-02 0.1573E-04 -.193448486E+02 0.267559905E-01 0.8026E+00 0.1974E+00
"Step" 0.160000026E+01 0.6196E-02 0.6558E-05 -.206333809E+02 0.312897824E-01 0.8665E+00 0.2448E+00
"Step" 0.170000029E+01 0.6627E-02 -.9535E-05 -.219215984E+02 0.361270942E-01 0.9223E+00 0.2987E+00
"Step" 0 180000031E+01 0.7411E-02 -.3318E-04 - 232094650E+02 0.412365347E-01 0.9684E+00 0.3593E+00
"Step" 0 190000033E+01 0.8629E-02 -.6342E-04 -.244969540E+02 0.465822406E-01 0.1003E+01 0.4267E+00
"Step" 0.200000024E+01 0.1033E-01 -.9791E-04 -.257840385E+02 0.521245301E-01 0.1026E+01 0 5011E+00
"Step" 0.210000014E+01 0 1250E-01 -.1319E-03 -.270707035E+02 0.578199625E-01 0 1036E+01 0.5826E+00
"Step" 0.220000005E+01 0.1511E-01 - 1585E-03 - 283569393E+02 0 636218488E-01 0.1032E+01 0.6712E+00
"Step" 0.229999995E+01 0 1803E-01 -.1683E-03 - 296427479E+02 0.694800615E-01 0.1014E+01 0.7668E+00
"Step" 0.239999986E+01 0.2110E-01 -.1493E-03 - 309281330E+02 0.753417164E-01 0.9818E+00 0.8695E+00
"Step" 0 249999976E+01 0 2408E-01 -.8819E-04 -.322131119E+02 0 811518580E-01 0.9360E+00 0.9790E+00
"Step" 0 259999967E+01 0.2669E-01 0.2953E-04 -.334977036E+02 0.868527740E-01 0.8771E+00 0 1095E+01
"Step" 0.269999957E+01 0.2862E-01 0.2180E-03 -.347819290E+02 0 923838094E-01 0.8062E+00 0.1218E+01
"Step" 0.279999948E+01 0.2955E-01 0 4898E-03 - 360658188E+02 0.976823568E-01 0.7243E+00 0.1347E+01
"Step" 0.289999938E+01 0 2915E-01 0.8532E-03 -.373493958E+02 0.102682270E+00 0.6329E+00 0.1481E+01
"Step" 0.299999928E+01 0 2715E-01 0 1310E-02 - 386326790E+02 0 107315443E+00 0.5337E+00 0.1622E+01
"Step" 0 309999919E+01 0.2332E-01 0.1853E-02 -.399156876E+02 0.111510932E+00 0.4285E+00 0.1767E+01
"Step" 0.319999909E+01 0.1752E-01 0.2462E-02 -.411984329E+02 0.115195431E+00 0.3192E+00 0.1918E+01
"Step" 0.329999900E+01 0.9727E-02 0.3103E-02 - 424809151E+02 0.118293233E+00 0 2080E+00 0 2073E+01
"Step" 0.339999890E+01 0.4425E-04 0 3724E-02 -.437631302E+02 0.120726794E+00 0.9686E-01 0 2232E+01
"Step" 0.349999881E+01 -.1129E-01 0 4257E-02 -.450450592E+02 0.122416362E+00 -.1198E-01 0.2395E+01
"Step" 0.359999871E+01 -.2388E-01 0.4617E-02 -.463266792E+02 0.123281062E+00 - 1164E+00 0.2561E+01
"Step" 0.369999862E+01 -.3721E-01 0.4707E-02 -.476079559E+02 0.123238832E+00 -.2144E+00 0.2729E+01
"Step" 0.379999852E+01 - 5063E-01 0 4425E-02 -.488888512E+02 0 122207537E+00 -.3041E+00 0.2901E+01
"Step" 0.389999843E+01 -.6340E-01 0.3675E-02 -.501693268E+02 0 120105311E+00 -.3838E+00 0.3074E+01
"Step" 0.399999833E+01 - 7469E-01 0.2375E-02 - 514493332E+02 0.116851635E+00 -.4518E+00 0 3250E+01
"Step" 0.409999847E+01 -.8367E-01 0 4752E-03 - 527288322E+02 0.112368666E+00 -.5068E+00 0 3427E+01
```

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This report describes simulations of ship motions in support of the Maritime Helicopter Project. The time domain program FREDYN has been used to simulate the HALIFAX class during coursekeeping and maneuvering. The coursekeeping simulations model the ship travelling in severe seas for a wide range of speeds and headings. The maneuvering simulations model the ship completing a 180 degree turn for a variety of ship speeds, headings, rudder angles, and sea states. Among all simulations, the highest roll angle was 32 degrees. For some cases with low ship speeds and waves, the ship was unable maintain course or complete its maneuver. Second order drift forces are very difficult to predict accurately; thus, the predictions of coursekeeping and maneuvering at low speed in higher sea states have a high degree of uncertainty.

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