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FREDYN Simulations of HALIFAX in 6 m Seas

Kevin McTaggart

Defence R&D Canada

Technical Memorandum

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Abstract

In support of procurement of new maritime helicopters, DRDC Atlantic was tasked to simulate motions of the HALIFAX class during air operations in seaways with significant wave height of 6.0 m. Ship motions were simulated using FREDYN, a time domain strip theory program. For a peak wave period of 13.6 s and combinations of speed and heading within the allowable envelope for air operations, maximum motions during 30 minute simulations were 4.8 m for heave, 15.6 degrees for roll, and 6.2 degrees for pitch. For a steeper seaway with peak wave period of 8.9 s, there was no increase in maxima for allowable combinations of speed and heading. A single wave realization was used for each test case. A variability analysis indicates that the coefficient of variation in motion maxima due to seaway realization will be approximately 12 percent.

Résumé

En prévision de l'acquisition de nouveaux hélicoptères maritimes, on a demandé à RDDC Atlantique de simuler les mouvements d'une frégate Halifax lors d'opérations aériennes sur une grosse mer dont la houle atteint six mètres. Nous avons calculé les mouvements du navire avec le programme FREDYN, basé sur la théorie des bandes pour faire des calculs dans le domaine temporel. Nous avons effectué une simulation de trente minutes d'un navire dans une houle dont la période maximale atteignait 13,6 s. Nous avons découvert qu'au plus les navires subissaient des montées de 4,8 m, un roulis de 15,6 et un tangage de 6,2 degrés, pour l'ensemble des vitesses et des caps possibles dans les limites autorisées pour les opérations aériennes. Nous n'avons pas trouvé d'augmentation des maximums pour les combinaisons permises de vitesses et de cap dans une houle plus abrupte, dont la période maximale s'élevait à 8,9 s. Nous avons utilisé le même modèle de houle pour tous les cas. L'analyse de la variabilité que nous avons effectuée montre que le coefficient de variation des mouvements maximums se situe autour de 12 pour cent, pour les différentes simulations de houle.

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Executive summary

Introduction

The Department of National Defence intends to procure new helicopters through its Maritime Helicopter Project. During helicopter operations in rough seas, the helicopter is often secured to the flight deck using a landing probe. To assist with development of design loads for the landing probe, DRDC Atlantic was tasked to determine maximum ship motions for the HALIFAX class during helicopter operations in seaways with a significant wave height of 6 m.

Principal Results

Motion simulations were performed using the ship motion program FREDYN. It was assumed that waves and wind were collinear. For operations in a seaway of 30 minute duration, 6 m significant wave height, and peak wave period of 13.6 s, maximum motions for conditions within the limiting relative wind envelope were 4.8 m for heave, 15.6 degrees for roll, and 6.2 degrees for pitch. For a steeper seaway with peak wave period of 8.9 s, there was no increase in maxima for allowable combinations of speed and heading. A single wave realization was used for each test case. A variability analysis for motion maxima indicates that the coefficient of variation due to seaway realization will be approximately 12 percent.

Significance of Results

The simulation results provide a rational basis for determining design loads for the helicopter landing probe. The estimated coefficient of variation for motion maxima is relatively small, suggesting that a single seaway realization is adequate for determining motion maxima.

Future Plans

DRDC Atlantic plans to continue its development of simulation capabilities for ship motions and sea loads in waves, and will be able to support Canadian Forces clients on an ongoing basis.

Kevin McTaggart; 2002; FREDYN Simulations of HALIFAX in 6 m Seas; DRDC Atlantic TM 2002-090; Defence R&D Canada - Atlantic.

Sommaire

Introduction

Le Projet des hélicoptères maritimes du ministère de la Défense nationale a pour objet l'acquisition de nouveaux hélicoptères. Lors d'opérations dans des mers agitées, on fixe souvent l'hélicoptère au pont à l'aide d'une fiche d'appontage. Pour aider à déterminer la charge nominale de la fiche d'appontage, on a demandé à RDDC Atlantique de calculer les mouvements maximaux des frégates Halifax pour des opérations nécessitant des hélicoptères dans une mer agitée dont la houle atteint six mètres.

Principaux résultats

Nous avons utilisé le logiciel de simulation de mouvement de navire FREDYN. Nous avons supposé que la houle et le vent venaient de la même direction. Nous avons effectué une simulation de trente minutes d'un navire dans une houle dont la période maximale était de 13,6 s. Nous avons découvert qu'au plus les navires subissaient des montées de 4,8 m, un roulis de 15,6 et un tangage de 6,2 degrés, pour l'ensemble des vitesses et des caps possibles dans les limites autorisées pour les opérations aériennes. Nous n'avons pas trouvé d'augmentation des maximums pour les combinaisons permises de vitesses et de cap dans une houle plus abrupte, dont la période maximale s'élevait à 8,9 s. Pour chaque cas, nous avons réalisé un modèle unique pour la houle. L'analyse de la variabilité que nous avons effectuée montre que le coefficient de variation des mouvements maximums se situe autour de 12 pour cent, pour les différentes simulations de houle.

Importance des résultats

Les résultats de la simulation nous donnent une base rationnelle pour déterminer les charges nominales pour la fiche d'appontage de l'hélicoptère. Puisque le coefficient de variation estimé du mouvement maximum est plutôt petit, nous croyons qu'une seule simulation de houle en mer permet de déterminer le mouvement maximal.

Plans futurs

RDDC Atlantique veut continuer à améliorer ses compétences dans la simulation des mouvements des navires et des charges de mers dans la houle afin de satisfaire aux demandes des clients des Forces canadiennes.

Kevin McTaggart; 2002; FREDYN Simulations of HALIFAX in 6 m Seas; DRDC Atlantic TM 2002-090; Defence R&D Canada - Atlantic.

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1 Introduction

The Department of National Defence's Maritime Helicopter Project is responsible for procurement of new ship-borne helicopters. During operation in heavy seas, ship-borne helicopters are either secured to the deck using a landing probe or using a combination of the landing probe and chains. The loads required for securing the helicopter are highly dependent upon the motions of the ship. To assist with specification of design loads, the Maritime Helicopter Project tasked DRDC Atlantic to compute motions of the HALIFAX class in conditions with a significant wave height of 6 m, which is the upper limit of sea state for flight operations.

The present report is an extension of earlier work in Reference 1, which considered coursekeeping for significant wave heights of 11.5 m and 15.0 m, and 180 degree turn maneuvers for significant wave heights up to 6.0 m. The present work considers coursekeeping during flying operations at the limits of safe operation. Section 2 gives a brief description of the program FREDYN used for the present simulations. The ship and environmental conditions are discussed in Section 3. Section 4 presents the result of the simulations, and is followed by an analysis in Section 5 of variability of maximum motions due to seaway realization. Section 6 presents final conclusions.

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 8.2 of FREDYN, which is described in detail in proprietary References 2 and 3. McTaggart and de Kat [4] give an overview of FREDYN in the open literature.

FREDYN can model regular waves and long-crested random waves. When modelling a random seaway, FREDYN uses superposition of sinusoidal wave components, with each component having a randomly generated phase. Twenty wave components are typically used for simulating a random seaway.

3 Simulation Conditions

The conditions for the simulations were specified by the Maritime Helicopter Project. The operational light loading condition for HALIFAX (see Table 1) was selected as a likely conservative case because motions tend to become greater as displacement decreases.

Table 1: *Main Particulars for HALIFAX Class Frigate, Operational Light Loading Condition*

Length, L	124.5 m
Beam, B	14.7 m
Midships draft, T_{mid}	4.643 m
Trim by stern, t_s	0.575 m
Displacement, $\triangle$	4316 tonnes
Vertical centre of gravity, $\overline{KG}$	6.70 m
Metacentric height, $\overline{GM}_{fluid}$ (corrected for free-surface)	0.908 m

The specified sea state for the motions has a significant wave height of 6 m, which is considered to be the limit for flying operations from the HALIFAX class. The specified peak wave period of 13.6 s represents the most probable value for the North Atlantic given a significant wave height of 6 m. Specified ship speeds of 10, 15, and 20 knots are realistic values for the specified sea state. Lower ship speeds are considered unlikely because of potential problems with coursekeeping at low speed in a high sea state. It is assumed that waves are collinear to wind, which is a reasonable assumption for higher sea states. Using the convention of 0 degrees for head winds, headings of 0 to 90 degrees were simulated, and simulation results were categorized as to whether or not they were within the allowable relative wind speed envelope given in Figure 1. A mean wind speed of 47 knots was originally specified based on Lee and Bales [5]. It was subsequently found that this wind speed would give only one combination of speed and heading within the allowable relative wind speed envelope. Subsequent simulations were performed using a lower wind speed of 28 knots, which was based on the following regression formula developed by McTaggart [6] using wave and wind data from Bales et al. [7] for the North Atlantic:

$$\overline{U}_a \;=\; H_s \times 1.823/\text{s} \;+\; 3.45\ \text{m/s} \qquad (1)$$

where $\overline{U}_a$ is mean wind speed at an elevation of 19.5 m.

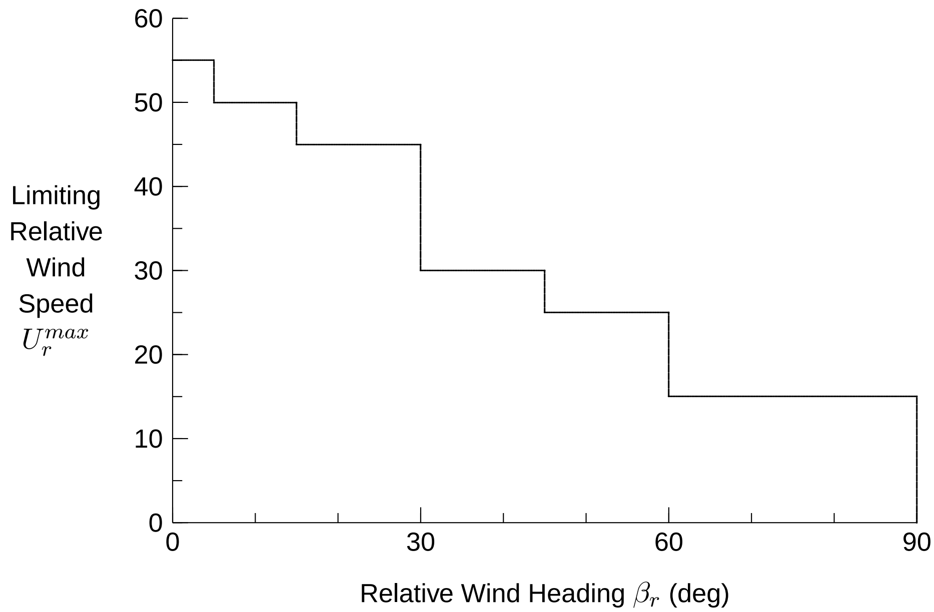

Figure 1: *Limiting Relative Wind Speeds for Air Operations*

Long-crested irregular 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 of a Bretschneider spectrum as follows:

$$T_{wa} = 0.772\, T_p \tag{2}$$

The simulation duration was specified to be 30 minutes, which was considered to be a representative operational duration. Maximum response values were taken as the maximum simulated value during a single 30 minute simulation. The variation of maxima with different wave realizations was not considered. If maximum roll angles are well below the capsize regime, then the maximum response in a 30 minute simulation will not be very sensitive to seaway realization (see Section 5).

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.

4 Simulation Results

Statistics from simulations for a peak wave period of 13.6 s and mean wind speed of 28 knots are presented in Tables 2 and 3. The speed and heading values for relative wind are based on commanded course. Due to wind and wave forces, the actual course varies from the commanded course. Mean speed and heading values for actual course are included in Tables 2 and 3. In the absence of wind restrictions (Table 2), the maximum motions are 5.3 m for heave, 20.9 degrees for roll, and 6.3 degrees for pitch. Table 3 indicates that the maximum roll angle is reduced significantly to 15.6 degrees when relative wind restrictions are considered, while maximum heave and pitch are reduced less significantly to 4.8 m and 6.2 degrees respectively The actual speed and heading statistics given in Tables 2 and 3 indicate that the ship is able to maintain speed and heading under the simulated conditions. The presence of waves causes slight speed reductions for all simulations.

As relative wind speed increases, the range of allowable headings decreases. The Maritime Helicopter Project also requested a simulation at the largest plausible wind speed within the allowable operational envelope. Assuming that a minimum ship speed of 10 knots should be used to maintain coursekeeping, the maximum possible wind speed during air operations is 45 knots, during which the ship must head directly into the wind to utilize a maximum allowable relative wind speed of 55 knots. The maximum motions under these conditions are 3.3 m for heave, 0 degrees for roll, and 6.0 degrees for pitch.

Ship motions can be sensitive to peak wave period for a random seaway. For a given significant wave height, ship motions will often increase as nominal wave steepness increases. To examine this effect, additional simulations were done for a peak wave period of 8.9 s. This wave period was selected based on analysis by Buckley [8], which indicates the following limit on nominal wave steepness in deep water:

$$\frac{2\,\pi\,H_s}{g\,T_p^2} \quad \leq \quad 0.049 \tag{3}$$

Tables 4 and 5 give motion summaries for a peak wave period of 8.9 s. In the absence of wind restrictions (Table 4), the maximum motions are 4.6 m for heave, 34.8 degrees for roll, and 5.8 degrees for pitch. Table 5 indicates that the maximum roll angle is reduced to 14.9 degrees when relative wind restrictions are considered, while maximum heave and pitch are reduced to a lesser extent. When comparing results for the peak wave periods of 13.6 s and 8.9 s, peak wave period has a significant effect on maximum roll angle in the vicinity of beam seas (heading of 90 degrees). In the context of flying operations, this effect is of secondary importance because flying operations will be confined to head and bow quartering seas, for which maximum roll and pitch are less sensitive to peak wave period. Another noticeable difference between the results at peak wave periods of 8.9 s and 13.6 s is that the ship is unable to maintain a course of 90 degrees in steeper waves at the lowest ship speed of 10 knots; however, this heading is outside the allowable relative wind envelope.

Table 2: *Simulation Results, Peak Wave Period* T_p *= 13.6 s, Mean Wind Speed* $\overline{U}_a$ *= 28 knots, All Speed and Heading Combinations*

Commanded course		Relative wind		Actual course		Maximum motion		
Speed (knots)	Heading (deg)	Speed (knots)	Heading (deg)	Speed (knots)	Heading (deg)	Heave (m)	Roll (deg)	Pitch (deg)
10	0	38.0	0.0	9.3	0.0	3.2	0.0	5.1
10	15	37.7	11.1	9.3	15.0	3.4	7.6	5.7
10	30	37.0	22.2	9.3	30.1	3.6	11.7	5.1
10	45	35.8	33.6	9.4	45.2	3.8	16.6	4.8
10	60	34.1	45.3	9.5	59.7	5.0	20.9	4.8
10	75	32.1	57.5	9.7	73.8	4.1	18.1	2.8
10	90	29.7	70.3	9.7	87.8	5.1	19.4	1.2
15	0	43.0	0.0	14.4	0.0	4.5	0.0	6.2
15	15	42.7	9.8	14.4	15.1	4.2	7.5	5.8
15	30	41.7	19.6	14.4	30.2	3.8	11.9	5.3
15	45	40.0	29.6	14.5	45.3	4.1	15.3	4.8
15	60	37.8	39.9	14.6	60.0	4.1	18.3	4.3
15	75	35.0	50.6	14.7	74.5	5.1	20.7	3.4
15	90	31.8	61.8	14.8	89.0	4.9	18.8	1.0
20	0	48.0	0.0	19.5	0.0	4.6	0.0	5.5
20	15	47.6	8.8	19.5	15.1	4.7	7.4	5.7
20	30	46.4	17.6	19.5	30.2	4.8	13.6	6.3
20	45	44.5	26.4	19.6	45.3	4.8	15.6	5.8
20	60	41.8	35.5	19.6	60.1	4.2	19.3	4.3
20	75	38.4	44.8	19.7	74.8	5.3	20.1	3.4
20	90	34.4	54.5	19.8	89.5	4.7	17.9	1.0
Maximum heave, roll and pitch from simulations						5.3	20.9	6.3

Table 3: *Simulation Results, Peak Wave Period T_p = 13.6 s, Mean Wind Speed $\overline{U}_a$ = 28 knots, Speed and Heading Combinations Within Allowable Wind Envelope*

Commanded course		Relative wind		Actual course		Maximum motion		
Speed (knots)	Heading (deg)	Speed (knots)	Heading (deg)	Speed (knots)	Heading (deg)	Heave (m)	Roll (deg)	Pitch (deg)
10	0	38.0	0.0	9.3	0.0	3.2	0.0	5.1
10	15	37.7	11.1	9.3	15.0	3.4	7.6	5.7
10	30	37.0	22.2	9.3	30.1	3.6	11.7	5.1
15	0	43.0	0.0	14.4	0.0	4.5	0.0	6.2
15	15	42.7	9.8	14.4	15.1	4.2	7.5	5.8
15	30	41.7	19.6	14.4	30.2	3.8	11.9	5.3
15	45	40.0	29.6	14.5	45.3	4.1	15.3	4.8
20	0	48.0	0.0	19.5	0.0	4.6	0.0	5.5
20	15	47.6	8.8	19.5	15.1	4.7	7.4	5.7
20	45	44.5	26.4	19.6	45.3	4.8	15.6	5.8
Maximum heave, roll and pitch from simulations						4.8	15.6	6.2

Table 4: *Simulation Results, Peak Wave Period T_p = 8.9 s, Mean Wind Speed $\overline{U}_a$ = 28 knots, All Speed and Heading Combinations*

Commanded course		Relative wind		Actual course		Maximum motion		
Speed (knots)	Heading (deg)	Speed (knots)	Heading (deg)	Speed (knots)	Heading (deg)	Heave (m)	Roll (deg)	Pitch (deg)
10	0	38.0	0.0	9.3	0.0	1.9	0.0	4.0
10	15	37.7	11.1	9.3	15.0	1.8	4.7	4.3
10	30	37.0	22.2	9.2	30.2	2.1	10.0	4.7
10	45	35.8	33.6	9.2	45.3	2.2	13.9	5.0
10	60	34.1	45.3	9.3	59.7	3.4	20.1	5.6
10	75	32.1	57.5	9.5	72.7	3.9	22.1	4.8
10	90	29.7	70.3	8.3	75.0	4.0	24.8	4.2
15	0	43.0	0.0	14.4	0.0	2.1	0.0	4.2
15	15	42.7	9.8	14.4	15.0	2.0	4.1	4.7
15	30	41.7	19.6	14.4	30.1	2.5	8.5	4.7
15	45	40.0	29.6	14.4	45.3	3.0	14.1	5.2
15	60	37.8	39.9	14.5	60.0	3.3	17.5	5.0
15	75	35.0	50.6	14.6	73.8	4.2	25.2	5.8
15	90	31.8	61.8	14.2	86.2	4.5	34.8	4.5
20	0	48.0	0.0	19.6	0.0	2.3	0.0	4.1
20	15	47.6	8.8	19.6	15.0	2.3	4.3	4.5
20	30	46.4	17.6	19.6	30.1	2.8	9.1	5.1
20	45	44.5	26.4	19.6	45.1	3.3	14.9	5.5
20	60	41.8	35.5	19.6	60.0	3.6	22.4	5.2
20	75	38.4	44.8	19.7	74.3	3.8	19.7	4.1
20	90	34.4	54.5	19.5	88.1	4.6	30.7	4.0
Maximum heave, roll and pitch from simulations						4.6	34.8	5.8

Table 5: *Simulation Results, Peak Wave Period T_p = 8.9 s, Mean Wind Speed $\overline{U}_a$ = 28 knots, Speed and Heading Combinations Within Allowable Wind Envelope*

Commanded course		Relative wind		Actual course		Maximum motion		
Speed (knots)	Heading (deg)	Speed (knots)	Heading (deg)	Speed (knots)	Heading (deg)	Heave (m)	Roll (deg)	Pitch (deg)
10	0	38.0	0.0	9.3	0.0	1.9	0.0	4.0
10	15	37.7	11.1	9.3	15.0	1.8	4.7	4.3
10	30	37.0	22.2	9.2	30.2	2.1	10.0	4.7
15	0	43.0	0.0	14.4	0.0	2.1	0.0	4.2
15	15	42.7	9.8	14.4	15.0	2.0	4.1	4.7
15	30	41.7	19.6	14.4	30.1	2.5	8.5	4.7
15	45	40.0	29.6	14.4	45.3	3.0	14.1	5.2
20	0	48.0	0.0	19.6	0.0	2.3	0.0	4.1
20	15	47.6	8.8	19.6	15.0	2.3	4.3	4.5
20	45	44.5	26.4	19.6	45.1	3.3	14.9	5.5
Maximum heave, roll and pitch from simulations						3.3	14.9	5.5

5 Variability of Maximum Responses with Seaway Realization

As mentioned previously, the maximum response in a simulated random seaway will depend on the seaway realization. The present simulations were performed using only one seaway realization. An estimate of the variability in maximum response can be derived from the following equations for a narrow-banded Gaussian process with zero mean (see Reference 9):

$$E(x_{max}) = \sigma_x \left[\sqrt{2 \ln N_{cycle}} + \frac{\gamma}{\sqrt{2 \ln N_{cycle}}} \right] \quad (4)$$

$$\sigma(x_{max}) = \sigma_x \frac{\pi}{\sqrt{6}} \frac{1}{\sqrt{2 \ln N_{cycle}}} \quad (5)$$

where $E(x_{max})$ is the expected maximum of x, σ_x is the RMS value of x, N_{cycle} is the number of cycles of x in a specified period of time, γ is Euler's constant (0.5772...), and $\sigma(x_{max})$ is the standard deviation of the maximum. For the above equations to be valid for ship motions, the motion response has to be approximately linear. For the present simulations with a maximum roll angle less than 35 degrees, the motions can be considered approximately linear because the ship righting arm curve is approximately linear for roll angles less than 35 degrees. Simulations with the HALIFAX class in a previous study [10] confirm that roll response will be approximately linear for roll angles less than 35 degrees. For the present simulations, the duration is 30 minutes and the nominal motion period is 10 seconds, leading to approximately 180 cycles in a simulation. Note that Equations (4) and (5) consider the logarithm of the number of cycles; thus, the equations are not very sensitive to assumptions regarding nominal motion period. Assuming a large number of cycles, the coefficient of variation for the maximum response is given by:

$$\frac{E(x_{max})}{\sigma(x_{max})} = \frac{\pi}{\sqrt{6}} \frac{1}{2 \ln N_{cycle}} \quad (6)$$

For the present simulations, the above equation indicates that the simulated maxima will have a coefficient of variation of 12 percent due to seaway realization (e.g., the maximum roll value of 14.9 degrees in Table 5 will have a standard deviation of 1.8 degrees due to seaway realization).

6 Conclusions

Numerical simulations have been conducted for the HALIFAX class in sea states with significant wave heights of 6.0 m. Winds are assumed to be collinear with waves. When HALIFAX maintains a course within the allowable envelope for air operations, the 30 minute maxima in a peak wave period of 13.6 s are 4.8 m for heave, 15.6 degrees for roll, and 6.2 degrees for pitch. Additional simulations in a steep seaway with peak wave period of 8.9 s give slightly reduced motions when the ship stays within allowable headings for air operations. The above results were obtained using one seaway realization per condition. An analytical treatment indicates that the coefficient of variation for 30 minute maxima will be approximately 12 percent due to seaway realization.

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Symbols

B	ship beam
$E(x_{max})$	mean value of x_{max}
$\overline{GM}_{fluid}$	metacentric height, corrected for free surfaces
H_s	significant wave height
$\overline{KG}$	centre of gravity above baseline
L	ship length between perpendiculars
N_{cycle}	number of cycles
RPM	propeller revolutions per minute
T_{mid}	draft at midships
T_p	peak wave period
T_{wa}	average wave period
t_s	trim by stern
$\overline{U}_a$	mean wind speed
U_r^{max}	limiting relative wind speed
β_r	relative wind heading
γ	Euler's constant (0.5772. . .)
σ_x	RMS value of x
$\sigma(x_{max})$	standard deviation of x_{max}
$\triangle$	ship mass displacement

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FREDYN Simulations of HALIFAX in 6 m Seas

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In support of procurement of new maritime helicopters, DRDC Atlantic was tasked to simulate motions of the HALIFAX class during air operations in seaways with significant wave height of 6.0 m. Ship motions were simulated using FREDYN, a time domain strip theory program. For a peak wave period of 13.6 s and combinations of speed and heading within the allowable envelope for air operations, maximum motions during 30 minute simulations were 4.8 m for heave, 15.6 degrees for roll, and 6.2 degrees for pitch. For a steeper seaway with peak wave period of 8.9 s, there was no increase in maxima for allowable combinations of speed and heading. A single wave realization was used for each test case. A variability analysis indicates that the coefficient of variation in motion maxima due to seaway realization will be approximately 12 percent.

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