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User Manual for HalManeuver: A ShipMo3D Application for Simulating HALIFAX Class Maneuvering

Kevin McTaggart

Defence R&D Canada – Atlantic

Technical Memorandum
DRDC Atlantic TM 2005-070
January 2006

Canada

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Principal Author

Kevin McTaggart

Approved by

Neil Pegg
Head, Warship Performance

Approved for release by

K. Foster
Chair, Document Review Panel

Abstract

This report describes the application HalManeuver for predicting maneuvering of the Canadian Navy's HALIFAX class. HalManeuver was developed using ShipMo3D, an object-oriented library for predicting ship motions in calm water and in waves. Predicted maneuvering motions are determined by evaluating forces acting on the hull, rudder, propeller, and other appendages. Input parameters to HalManeuver include increments to hull maneuvering force coefficients, which can be adjusted to optimize agreement between observed and predicted maneuvering properties. HalManeuver demonstrates the development of an application using the ShipMo3D library. Other applications for ship maneuvering in both calm water and in waves will be developed as requirements arise.

Résumé

Dans ce rapport, nous décrivons le logiciel HalManeuver de prédiction des manœuvres des navires canadiens de la classe Halifax. On a créé HalManeuver à partir de ShipMo3D, une bibliothèque objet conçue pour la prédiction des mouvements des navires, sur une mer calme ou houleuse. Les mouvements prédits sont calculés afin d'évaluer les forces exercées sur la carène, le gouvernail, l'hélice et les autres prolongements de la coque. Les paramètres d'entrée de HalManeuver comprennent des augmentations aux coefficients des forces exercées sur la carène par les manœuvres, qui peuvent être ajustées pour optimiser l'accord entre les caractéristiques observées et prédites de la manœuvre. En outre, la production de HalManeuver démontre la mise au point d'un logiciel à partir de la bibliothèque ShipMo3D. On élaborera d'autres logiciels de simulation des manœuvres en mer calme ou houleuse, en fonction des besoins.

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Executive summary

User Manual for HalManeuver: A ShipMo3D Application for Simulating HALIFAX Class Maneuvering

Kevin McTaggart; DRDC Atlantic TM 2005-070; Defence R&D Canada – Atlantic; January 2006.

Introduction: Predictions of ship maneuvering are often required for assessment of naval ship effectiveness. To meet this requirement, Maritime Forces Atlantic (MARLANT) Operations Research tasked DRDC Atlantic to develop an application for predicting maneuvering of the Canadian Navy's HALIFAX class in calm water.

Principal Results: The program HalManeuver has been developed to simulate maneuvering of the HALIFAX class in calm water. HalManeuver uses components from DRDC Atlantic's ShipMo3D library, which has been developed for simulation of ship motions in calm water and in waves. Maneuvering simulations using HalManeuver run approximately 70 times faster than real time.

Significance of Results: DND now has an in-house capability for predicting ship maneuvering. This capability will advance as ongoing improvements are made to the ShipMo3D library. The high execution speed of maneuvering simulations facilitates examining large numbers of scenarios.

Future Plans: Additional applications using the ShipMo3D library will be developed as requirements arise.

Sommaire

User Manual for HalManeuver: A ShipMo3D Application for Simulating HALIFAX Class Maneuvering

Kevin McTaggart; DRDC Atlantic TM 2005-070; R & D pour la défense Canada – Atlantique; janvier 2006.

Introduction: Pour en évaluer l'efficacité, il est souvent obligatoire de prédire les manœuvres des bâtiments de guerre. Pour satisfaire à cet impératif, le Détachement de recherche opérationnelle des Forces maritimes de l'Atlantique FMAR(A) a chargé RDDC Atlantique de la mise au point d'un logiciel de prédiction des manœuvres en eau calme, des navires de la classe Halifax de la Marine canadienne.

Résultats principaux: Le programme HalManeuver a été conçu pour simuler les manœuvres d'un navire de la classe Halifax dans des eaux calmes. Ce logiciel comprend des éléments tirés de la bibliothèque ShipMo3D créée par RDDC Atlantique pour simuler les mouvements des navires sur une mer calme ou houleuse. Le calcul des simulations de manœuvres avec HalManeuver est 70 fois plus rapide que le temps nécessaire pour les réaliser avec un navire.

Importance des résultats: Le MDN dispose maintenant de son propre outil de prédiction des manœuvres de navires. Cet outil sera perfectionné au fur et à mesure des améliorations qui seront apportées à la bibliothèque ShipMo3D. La grande vitesse d'exécution des simulations de manœuvre facilitera l'étude d'un nombre élevé de scénarios.

Travaux ultérieurs prévus: On élaborera d'autres logiciels, à partir de la bibliothèque ShipMo3D, en fonction des besoins.

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1 Introduction

Predictions of ship maneuvering are often required for assessment of naval ship effectiveness. To meet this requirement, Maritime Forces Atlantic (MARLANT) Operations Research tasked DRDC Atlantic to develop an application for predicting maneuvering of the Canadian Navy's HALIFAX class in calm water. The new application HalManeuver has been developed using components of DRDC Atlantic's ShipMo3D library for prediction of ship motions in waves.

ShipMo3D is an object-oriented library developed to predict ship motions in both the frequency and time domains. The prediction of motions for a ship with nominally steady speed and heading is described in References 1, 2 and 3. The application HalManeuver is based on more recent work in Reference 4 extending ShipMo3D to freely maneuvering ships in waves.

Section 2 of this report gives the axis system used by HalManeuver. Section 3 gives ship properties for HALIFAX within HalManeuver computations. User input is described in Section 4, followed by guidance on installing and running HalManeuver in Section 5. Section 6 describes program output, and final conclusions are given in Section 7.

2 Axis System for HalManeuver Output

The program HalManeuver computes ship motions in the earth fixed coordinate system given in Figure 1. The coordinates x^f, y^f refer to the location of the ship centre of gravity, with x^f being positive north and y^f being positive west. Both x^f and y^f have units of metres.

The ship heading χ is the direction toward which the ship is pointing. The ship velocity can have a different heading due to the presence of a non-zero drift angle.

HalManeuver uses a rudder deflection convention of positive for counter-clockwise motion when looking down at the rudder; thus, a positive rudder deflection causes the ship to turn to starboard.

3 HALIFAX Properties with HalManeuver

The application HalManeuver is intended to be easy to use; thus, representative values for various ship parameters have been selected. Tables 1 and 2 give two loading conditions which are available for simulation with HalManeuver. The loading condition in Table 1 is a deep departure condition that was used for model tests with

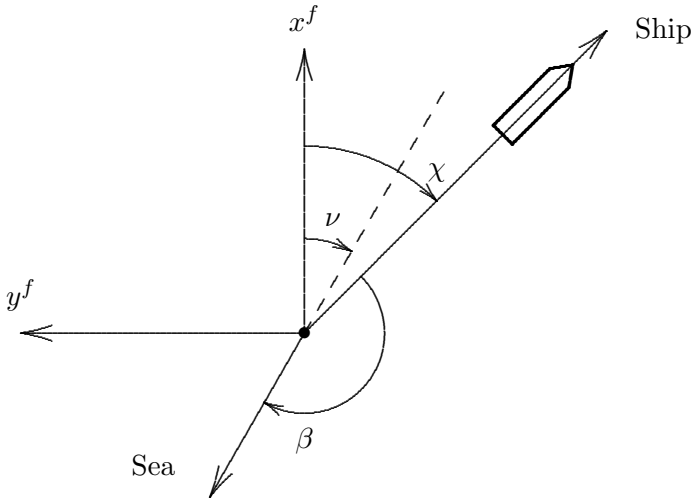

Figure 1: *Earth-Fixed Coordinate System*

the CPF hydroelastic model [5]. The loading condition in Table 2 was used for sea trials with the HALIFAX class.

To avoid using classified data, the ship resistance and propulsion characteristics are modelled using representative values from the open literature. Table 3 shows calm water ship speeds and associated propeller RPM values using the modelled resistance and propulsion characteristics.

When a command rudder angle is issued, the ship rudder responds according to the following:

$$\ddot{\delta}^{rudder} \;=\; \omega_\delta^2 \;\left(\delta_C^{rudder} \;- \delta^{rudder}\right) - \; 2\;\zeta_\delta\;\omega_\delta\;\dot{\delta}^{rudder} \tag{1}$$

where $\ddot{\delta}^{rudder}$ is rudder deflection acceleration, ω_δ is the natural frequency for rudder deflection, δ_C^{rudder} is the command rudder angle, δ^{rudder} is the actual rudder angle, ζ_δ is rudder response damping as a fraction of critical damping, and $\dot{\delta}^{rudder}$ is rudder deflection velocity. Table 4 gives default rudder response values used by HalManeuver.

When simulating motions using HalManeuver, the user can provide an input command rudder angle or can alternatively provide an input ship heading to be used by an autopilot. The autopilot determines the command rudder angle as follows:

$$\delta_C^{rudder} \;=\; k_{\delta\chi}^d\;\left(\chi \;-\; \chi_C\right) \;+\; k_{\delta\chi}^v\;\dot{\chi} \tag{2}$$

where $k_{\delta\chi}^d$ is the yaw displacement gain, χ_C is the command ship heading, and $k_{\delta\chi}^v$ is the yaw velocity gain. Table 5 gives the default autopilot gains for HalManeuver.

Table 1: *Main Particulars for HALIFAX Class Frigate, CPF Hydroelastic Model Deep Departure Condition*

Length, L	124.5 m
Beam, B	14.8 m
Midships draft, T_{mid}	4.97 m
Trim by stern, t_{stern}	-0.04 m
Displacement, $\triangle$	4601 tonnes (salt water)
Vertical centre of gravity, $\overline{KG}$	6.26 m
Dry roll radius of gyration r_{xx}	5.82 m
Dry pitch radius of gyration r_{yy}	28.8 m
Dry yaw radius of gyration r_{zz}	28.8 m

Table 2: *Main Particulars for HALIFAX Class Frigate, Sea Trial Deep Departure Condition*

Length, L	124.5 m
Beam, B	14.8 m
Midships draft, T_{mid}	4.995 m
Trim by stern, t_{stern}	0.236 m
Displacement, $\triangle$	4672 tonnes (salt water)
Vertical centre of gravity, $\overline{KG}$	6.26 m
Dry roll radius of gyration r_{xx}	5.82 m
Dry pitch radius of gyration r_{yy}	28.8 m
Dry yaw radius of gyration r_{zz}	28.8 m

Table 3: *Ship Speeds in Calm Water and Associated Propeller RPM for Unclassified Modelling of HALIFAX Maneuvering*

Speed (knots)	Propeller RPM
5	28.9
10	57.7
15	87.1
20	121.1
25	156.1
30	200.6

Table 4: *Default Rudder Control Properties for HALIFAX*

Maximum rudder deflection δ_{max}^{rudder}	35 degrees
Maximum rudder velocity $\dot{\delta}_{max}^{rudder}$	3 deg/s
Response natural frequency ω_δ	3 rad/s
Response damping ζ_δ	0.85

Table 5: *Default Autopilot Gains for HALIFAX*

Yaw displacement gain $k_{\delta\chi}^{d}$	-4 deg/deg
Yaw velocity gain $k_{\delta\chi}^{v}$	-8 deg/(deg/s)

Table 6: *Predicted HALIFAX Maneuvering Coefficients and Nominal Uncertainties*

Description	Symbol	Predicted	Uncertainty
Linear sway-sway	Y'_v	-0.207	±0.05
Linear sway-yaw	Y'_r	0.062	±0.05
Linear yaw-sway	N'_v	-0.080	±0.02
Linear yaw-yaw	N'_r	-0.037	±0.02
Nonlinear sway-sway	$Y'_{v\|v\|}$	-1.006	±0.2
Nonlinear sway-sway	$Y'_{v\|r\|}$	-0.140	±0.2
Nonlinear sway-yaw	$Y'_{r\|r\|}$	0.000	±0.05
Nonlinear yaw-sway	N'_{vr^2}	0.000	±0.05
Nonlinear yaw-yaw	$N'_{r\|r\|}$	-0.060	±0.02
Nonlinear yaw-yaw	N'_{rv^2}	-0.200	±0.2

It should be noted that there is significant uncertainty regarding hull maneuvering force coefficients for HALIFAX. HalManeuver uses hull maneuvering force coefficients predicted using the method of Inoue et al. [6] as implemented in Reference 4. Table 6 shows predicted maneuvering coefficients for HALIFAX and nominal uncertainties associated with predicted maneuvering coefficients. A sensitivity study in Reference 4 indicates that uncertainty in the predicted linear yaw-yaw coefficient N'_r significantly influences predicted turning circle properties.

There is also significant uncertainty regarding the rudder-propeller interaction coefficient $C^{rudder-prop}$, discussed in Reference 4. For a single screw ship with a large rudder immediately aft of the propeller, this coefficient will have a value close to its limit of 1.0. For a frigate like HALIFAX with twin screws and a single rudder, it is more difficult to estimate the rudder-propeller interaction coefficient. HalManeuver uses a default value of 0.5 for the coefficient $C^{rudder-prop}$.

4 User Input for Program HalManeuver

HalManeuver reads input from an input file "halManeuver.inp" with a format described in Annex A. Annex B gives a sample input file. Each line of the input file begins with a descriptive tag, and is followed by character or numerical input.

The input file starts with a beginning line and a label line, with the following taken from the sample input file of Annex B:

```
begin halManeuver
    label Sample maneuver for HALIFAX
```

Following the above two lines, other optional lines can be inserted to change ship properties from their default values.

The input file has several lines for setting the initial conditions for a simulation, such as the following from the sample input file:

```
    dispsFixed0MDeg 0.0 0.0 0.0 0.0 0.0 0.0
    velsFixed0MDeg 10.3 0.0 0.0 0.0 0.0 0.0
    rudderDeflect0Deg 0.0
    rudderVel0Deg 0.0
    rpmsPropellers0 130.0 130.0
    rpmVelsPropellers0 0.0 0.0
```

Ship initial displacements and velocities for all 6 degrees of freedom are given in the records beginning with "dispsFixed0MDeg" and "velsFixed0MDeg". Initial conditions are also given for the single rudder and twin propellers.

Following the initial conditions, commands are given for setting the rudder and propeller and for executing maneuvers. For example, the following commands set the propeller RPMs according to a calm water speed of 20 knots, set the rudder to 30 degrees (for starboard turn), and tell the simulation to advance until the ship reaches a heading of 90 degrees (i.e., heading east).

```
    setSpeedCalm 20.0
    setRudder 30.0
    turnAbsHeading 90.0
```

All maneuver commands, such as turnAbsHeading, have a default time limit of 3600 s (one hour), which can be over-ridden by user input. The next two lines of sample input tell the ship to switch to autopilot for a course of 120 degrees and to travel a distance of 1000 m:

```
    setCourse 120.0
    straightDistance 1000.0
```

The input file ends with the following:

```
end halManeuver
```

5 Installing and Running Program HalManeuver

The program HalManeuver has been compiled to an executable file "HalManeuver.exe". The directory with "HalManuever.exe" must also include the following dynamically linked libraries:

- _dotblas.pyd
- _numpy.pyd
- dislin.dll
- lapack_lite.pyd
- multiarray.pyd
- python24.dll
- ranlib.pyd
- umath.pyd

Program HalManeuver reads input from file "halManeuver.inp" and writes output to file "halManeuver.out". The following files with data for HALIFAX must also be in the run directory:

- cpfHydroFreeShipTD.pkl
- cpfManTrialFreeShipTD.pkl

Using the default time step size of 0.5 s, HalManeuver runs approximately 70 times faster than real time on a PC with a 1800 MHz Pentium 4 processor running Windows XP Professional.

6 Output from Program HalManeuver

Annex C gives sample output from program HalManeuver. The output begins with user input and default parameters for the simulation. The output then gives a log of start times for execution of maneuvering commands. The final portion of the output is a time series of motions, rudder deflection, and propeller RPMs. Only horizontal plane motions are currently given in the output.

Figure 2 gives the trajectory from the sample output file. From its initial trajectory heading north, the ship makes a 90 degree turn to the east. Upon completion of the initial turn, the ship travels a distance of 1200 m with an autopilot heading of 120 degrees.

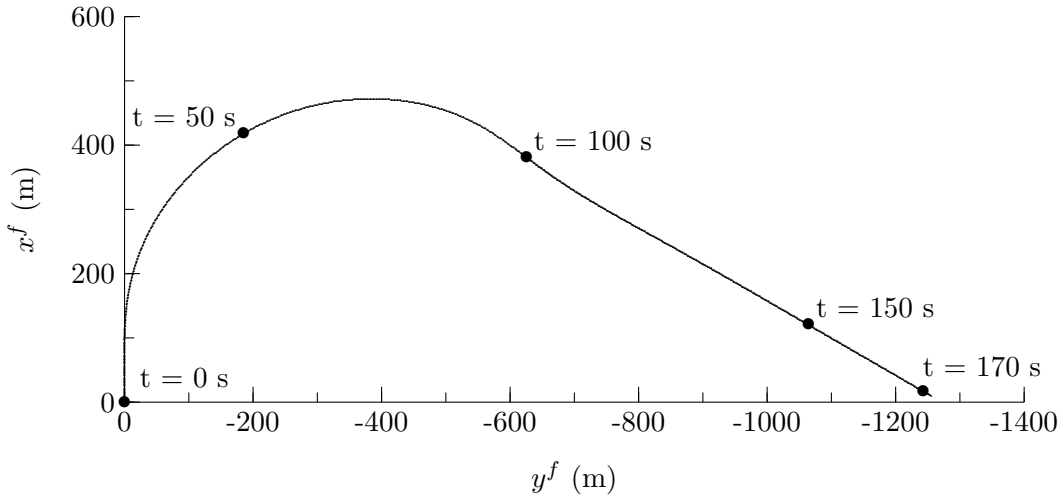

Figure 2: *Trajectory for Sample Output*

7 Conclusions

The ShipMo3D application HalManeuver has been developed to provide maneuvering predictions for the Canadian Navy's HALIFAX class. The applications reads user input commands for ship maneuvering and produces output of times series for ship motions.

HalManeuver demonstrates the development of an application using the ShipMo3D library. Other applications for ship maneuvering in both calm water and in waves will be developed as requirements arise.

References

[1] McTaggart, K.A. (2002). Three Dimensional Ship Hydrodynamic Coefficients Using the Zero Forward Speed Green Function. (DRDC Atlantic TM 2002-059). Defence Research and Development Canada - Atlantic.

[2] McTaggart, K.A. (2003). Hydrodynamic Forces and Motions in the Time Domain for an Unappended Ship Hull. (DRDC Atlantic TM 2003-104). Defence Research and Development Canada - Atlantic.

[3] McTaggart, K.A. (2004). Appendage and Viscous Forces for Ship Motions in Waves. (DRDC Atlantic TM 2004-227). Defence Research and Development Canada - Atlantic.

[4] McTaggart, K.A. (2005). Simulation of Hydrodynamic Forces and Motions for a Freely Maneuvering Ship in a Seaway. (DRDC Atlantic TM 2005-071). Defence Research and Development Canada - Atlantic.

[5] McTaggart, K., Datta, I., Stirling, A., Gibson, S., and Glen, I. (1997). Motions and Loads of a Hydroelastic Frigate Model in Severe Seas. *Transactions, Society of Naval Architects and Marine Engineers*, Vol. 105.

[6] Inoue, S., Hirano, M., and Kijima, K. (1981). Hydrodynamic Derivatives on Ship Manoeuvring. *International Shipbuilding Progress*, **28**, 112–125.

Symbols and Abbreviations

B	beam
$C^{rudder-prop}$	rudder-propeller interaction coefficient
$\overline{KG}$	vertical centre of gravity relative to baseline
$k^d_{\delta\chi}$	rudder heading displacement gain
$k^v_{\delta\chi}$	rudder heading velocity gain
L	ship length between perpendiculars
N'_r	linear yaw-yaw maneuvering force coefficient
$N'_{r\|r\|}$	yaw velocity dependent nonlinear yaw-yaw maneuvering force coefficient
N'_{rv^2}	sway velocity dependent nonlinear yaw-yaw maneuvering force coefficient
N'_v	linear yaw-sway maneuvering force coefficient
N'_{vr^2}	yaw velocity dependent nonlinear yaw-sway maneuvering force coefficient
r_{xx}	roll radius of gyration
r_{yy}	pitch radius of gyration
r_{zz}	yaw radius of gyration
T_{mid}	draft at midships
t_{stern}	trim by stern
x^f, y^f	horizontal plane coordinates in earth-fixed coordinate system
Y'_r	linear sway-yaw maneuvering force coefficient
$Y'_{v\|r\|}$	yaw velocity dependent nonlinear sway-yaw maneuvering force coefficient
Y'_v	linear sway-sway maneuvering force coefficient
$Y'_{v\|r\|}$	yaw velocity dependent nonlinear sway-sway maneuvering force coefficient
$Y'_{v\|v\|}$	sway velocity dependent nonlinear sway-sway maneuvering force coefficient
δ^{rudder}	rudder deflection angle
δ^{rudder}_C	command rudder angle
δ^{rudder}_{max}	maximum rudder deflection
$\dot{\delta}^{rudder}_{max}$	maximum rudder velocity
ζ_δ	rudder nondimensional damping response constant
χ	ship heading (to) in earth-fixed axes
χ_C	command ship heading (to) in earth-fixed axes
ω_δ	rudder response natural frequency
$\triangle$	displacement

Annex A: Input File Format for Application HalManeuver

Detailed descriptions of HalManeuver input records are given below. Each new input record or sub-record corresponds to a new file line. Input records must be given in the order specified below, although optional records can be omitted. Each input record begins with a specified record tag.

The format of the input file may be adjusted by inserting extra blanks between any numerical or character string data. Each input record must be confined to a single file line.

Record (a), Beginning Record

"begin halManeuver"(1 character string with 2 words)

Record (b), Run Title

"label", title (2 character strings)

"label"	Record tag.
title	Title for run. This can include spaces.

Record (c), Record (c), Plot Option

This record is optional.

"plotOption", plotOption (2 character strings)

"plotOption"	Record tag.
plotOption	Set to "plot" for plotting, or "noPlot" for no plotting. If plotting is requested, then plots of ship motions are displayed on the screen at the end of the run.
Note:	If this record is omitted, then no plotting is done.

Record (d), Draft and Trim

This record is optional.

"draftTrim", draftBlMid, trimBlStern (1 character string, 2 floats)

"draftTrim"	Record tag.
draftBlMid	Ship draft at midships (m).
trimBlStern	Trim by stern (m).
Note:	If this record is omitted, then the draft and trim are set to default values of 4.970 m and -0.040 m respectively. If this record is included, then the draft and trim must be set to a valid combination. Current valid combinations are.

- Draft of 4.970 m and trim of -0.040 m,
- Draft of 4.995 m and trim of 0.236 m.

Record (e), Increments to Default Maneuvering Coefficients

This record is optional.

"deltaManCos", deltaYv, deltaYr, deltaNv, deltaNr, deltaYvv, deltaYvr, deltaYrr, deltaNvr2, deltaNrr, deltaNrv2 (1 character string, 10 floats)

"deltaManCos"	Record tag.
deltaYv	Increment to sway-sway maneuvering force coefficient Y'_v.
deltaYr	Increment to sway-yaw maneuvering force coefficient Y'_r.
deltaNv	Increment to yaw-sway maneuvering force coefficient N'_v.
deltaNr	Increment to sway-sway maneuvering force coefficient $N'_{r'}$.
deltaYvv	Increment to nonlinear maneuvering force coefficient $Y'_{v\|v\|}$.
deltaYvr	Increment to nonlinear maneuvering force coefficient $Y'_{v\|r\|}$.
deltaYrr	Increment to nonlinear maneuvering force coefficient $Y'_{r\|r\|}$.
deltaNvr2	Increment to nonlinear maneuvering force coefficient N'_{vr^2}.
deltaNrr	Increment to nonlinear maneuvering force coefficient $N'_{r\|r\|}$.
deltaNrv2	Increment to nonlinear maneuvering force coefficient N'_{rv^2}.
Note:	If this record is omitted, then all of the above values are set to 0.0.

Record (f), Rudder Response Properties

This record is optional.

"rudderProperties", deflectMaxDeg, velMaxDeg, freqResponse, dampResponse, rudderPropCo (1 character string, 5 floats)

"rudderProperties"	Record tag.
deflectMaxDeg	Maximum rudder deflection angle (degrees) (default 35.0).
velMaxDeg	Maximum rudder deflection velocity (degrees/s) (default 3.0).
freqResponse	Rudder natural response frequency (rad/s) (default 3.0).
dampResponse	Rudder response damping ratio as fraction of critical damping (default 0.85).
rudderPropCo	Rudder-propeller interaction coefficient (default 0.5).

Record (g), Auto Pilot Yaw Gains

This record is optional.

"autoPilotGains", headingGain, headingVelGain (1 character string, 2 floats)

"autoPilotGains"	Record tag.
headingGain	Autopilot heading gain (deg/deg) (default -4.0). This value should be less than zero for HALIFAX, which has its rudder pointing downward.
headingVelGain	Autopilot heading velocity gain (deg/(deg/s)) (default -8.0). This value should be less than or equal to zero for HALIFAX, which has its rudder pointing downward.

Record (h), Time Step Size

This record is optional.

"dtMax", dtMax (1 character string, 1 float)

"dtMax"	Record tag.
dtMax	Time step size (default 0.5 s) for motion computations. This value should be $\leq$ 2 seconds.

Record (i), Start Time

"t0", t0 (1 character string, 1 float)

"t0"	Record tag.
t0	Simulation start time (s).

Record (j), Initial Ship Position

"dispsFixed0MDeg", dispsFixed0MDeg[6] (1 character string, 6 floats)

"dispsFixed0MDeg"	Record tag.
dispsFixed0MDeg[0]	Initial x^f position (m, + north).
dispsFixed0MDeg[1]	Initial y^f position (m, + west).
dispsFixed0MDeg[2]	Initial heave η_3^f relative to value in calm water (m, + up).
dispsFixed0MDeg[3]	Initial roll η_4^f relative to value in calm water (deg, + port up).
dispsFixed0MDeg[4]	Initial pitch η_5^f relative to value in calm water (deg, + bow down).
dispsFixed0MDeg[5]	Initial heading χ (deg, + clockwise, 0° for north).

Record (k), Initial Ship Velocity

"velsFixed0MDeg", velsFixed0MDeg[6] (1 character string, 6 floats)

"velsFixed0MDeg"	Record tag.
velsFixed0MDeg[0]	Initial velocity $\dot{x}^f$ (m/s, + north).
velsFixed0MDeg[1]	Initial velocity $\dot{y}^f$ (m/s, + west).
velsFixed0MDeg[2]	Initial heave velocity $\dot{\eta}_3^f$ (m/s, + up).
velsFixed0MDeg[3]	Initial roll velocity $\dot{\eta}_4^f$ (deg/s, + port up).
velsFixed0MDeg[4]	Initial pitch velocity $\dot{\eta}_5^f$ relative to value in calm water (deg/s, + bow down).
velsFixed0MDeg[5]	Initial heading velocity $\dot{\chi}$ (deg/s, + clockwise).

Record (l), Initial Rudder Deflection

"rudderDeflect0Deg", rudderDeflect0Deg (1 character string, 1 float)

"rudderDeflect0Deg"	Record tag.
rudderDeflect0Deg	Initial rudder deflection (deg, + counter-clockwise viewed from above).

Record (m), Initial Rudder Velocity

"rudderVel0Deg", rudderVel0Deg (1 character string, 1 float)

"rudderVel0Deg"	Record tag.
rudderVel0Deg	Initial rudder deflection velocity (deg/s, + counter-clockwise viewed from above).

Record (n), Initial Propeller Velocities

"rpmsPropulsors0", rpmsPropulsors0[2] (1 character string, 2 floats)

"rpmsPropellers0"	Record tag.
rpmsPropellers0[0]	Initial RPM of port propeller (RPM).
rpmsPropellers0[1]	Initial RPM of starboard propeller (RPM).

Record (o), Initial Rate of Change of Propeller Velocities

"rpmVelsPropellers0", rpmVelsPropellers0[2] (1 character string, 2 floats)

"rpmVelsPropellers0"	Record tag.
rpmVelsPropellers0[0]	Initial rate of change of RPM of port propeller (RPM/s).
rpmVelsPropellers0[1]	Initial rate of change of RPM of starboard propeller (RPM/s).

Records (p1) to (p8) given below can be given in any sequence and can be repeated. For many maneuver commands, the input variable tElapsedMax is optional and will have a default of 3600 s if not included.

Record (p1), Propeller RPM Command

This record is optional.

"setRpm", indexPropeller, rpmCommand (1 character string, 2 floats)

"setRpm"	Record tag.
indexPropeller	Index for propeller (0 for port propeller, 1 for starboard propeller, ≤ -1 for both propellers).
rpmCommand	Command propeller RPM (RPM).

Record (p2), Speed Command

This record is optional.

"setSpeedCalm", speedKnots (1 character string, 1 float)

"setSpeedCalm"	Record tag.
speedKnots	Ship speed in calm water (knots) for which RPM of both propellers are set.

Record (p3), Course Command

This record is optional.

"setCourse", shipHeadingToCommandDeg (1 character string, 1 float)

"setCourse"	Record tag.
shipHeadingToCommandDeg	Ship heading χ (deg) to which autopilot is set.

Record (p4), Rudder Deflection Command

This record is optional.

"setRudder", deflectCommandDeg (1 character string, 1 float)

"setRudder"	Record tag.
deflectCommandDeg	Command rudder deflection angle (deg, + counter-clockwise viewed from above). A positive rudder deflection turns the ship to starboard.

Record (p5), Turn to Absolute Heading Maneuver Command

This record is optional.

"turnAbsHeading", finalHeadingDeg, tElapsedMax (optional) (1 character string, 1 or 2 floats)

"turnAbsHeading"	Record tag.
finalHeadingDeg	Ship heading χ (deg, 0 for north) at which the program considers the command completed. To ensure completion of a turn, a setRudder command should normally be made before a turnAbsHeading command.
tElapsedMax	Time limit (s) for attempting to reach heading finalHeadingDeg. If this input is not included, then a default value of 3600 s is used.

Record (p6), Turn Change in Heading Maneuver Command

This record is optional.

"turnDeltaHeading", deltaHeadingDeg, tElapsedMax (optional) (1 character string, 1 or 2 floats)

"turnDeltaHeading"	Record tag.
deltaHeadingDeg	Change from initial heading at which the program considers the turn maneuver completed. To ensure completion of a turn, a setRudder command should normally be made before a turnDeltaHeading command, with the command rudder angle deflectCommandDeg having a sign opposite to that of deltaHeadingDeg.
tElapsedMax	Time limit (s) for attempting to reach change in heading deltaHeadingDeg. If this input is not included, then a default value of 3600 s is used.

Record (p7), Straight Distance Maneuver Command

This record is optional.

"straightDistance", distance, tElapsedMax (optional) (1 character string, 1 or 2 floats)

"straightDistance"	Record tag.
distance	Straight line distance (m) between start and end points at which the program considers the maneuver completed.
tElapsedMax	Time limit (s) for attempting to traverse distance straightDistance. If this input is not included, then a default value of 3600 s is used.

Record (p8), Elapsed Time Maneuver Command

This record is optional.

"elapsedTime", tElapsedMax (1 character string, 1 float)

"elapsedTime"	Record tag.
tElapsedMax	Elapsed time at which the program considers the maneuver completed.

Record (q), End Record

"end halManeuver"(1 character string with 2 words)

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Annex B: Sample HalManeuver Input File

```
begin halManeuver
    label Sample maneuver for HALIFAX
    dispsFixed0MDeg 0.0 0.0 0.0 0.0 0.0 0.0
    velsFixed0MDeg 10.3 0.0 0.0 0.0 0.0 0.0
    rudderDeflect0Deg 0.0
    rudderVel0Deg 0.0
    rpmsPropellers0 130.0 130.0
    rpmVelsPropellers0 0.0 0.0
    setSpeedCalm 20.0
    setRudder 30.0
    turnAbsHeading 90.0
    setCourse 120.0
    straightDistance 1000.0
end halManeuver
```

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Annex C: Sample HalManeuver Output File

```
Program HalManeuver
Time : Tue Dec 13 14:50:44 2005
Run title:
Sample maneuver for HALIFAX

Plot maneuver plotOption:  noPlot
Default draft and trim:
    Draft at midships draftBlMid         4.970 m
    Trim by stern trimBlStern           -0.040 m
Default input maneuvering coefficient terms:
    deltaYAlpha             0.000
    deltaYR                 0.000
    deltaNAlpha             0.000
    deltaNR                 0.000
    deltaYAlphaAlpha        0.000
    deltaYAlphaR            0.000
    deltaYRR                0.000
    deltaNAlphaR2           0.000
    deltaNRR                0.000
    deltaNRAlpha2           0.000

Default rudder motion terms:
    Maximum deflection deflectMaxDeg               35.000 deg
    Maximum deflection velocity velMaxDeg           3.000 deg/s
    Natural frequency freqResponse                  3.000 rad/s
    Damping (fraction of critical)                  0.850
    Rudder-propeller interaction coefficient        0.500

Default autopilot gains:
    Heading gain            -4.000 deg/deg
    Heading gain            -8.000 deg/(deg/s)
```

```
Default time step:
    dtMax             0.500 s
Default start time:
    t0        0.000 s

Initial ship conditions:
   Position dispsFixed0MDeg      0.000 m     0.000 m     0.000 m      0.000 deg     0.000 deg     0.000 deg
   Velocity velsFixed0MDeg     10.300 m/s     0.000 m/s     0.000 m/s      0.000 deg/s     0.000 deg/s     0.000 deg/s
   Rudder deflection rudderDeflect0Deg     0.000 deg
   Rudder deflection velocity rudderVel0Deg     0.000 deg/s
   Propeller rpms rpmsPropellers0   130.000   130.000
   Propeller rpm velocities rpmVelsPropellers0     0.000/s     0.000/s

Maneuvering start times and commands
    0.000 setSpeedCalm 20.0
    0.000 setRudder 30.0
    0.000 turnAbsHeading 90.0
   70.500 setCourse 120.0
   70.500 straightDistance 1000.0
End of maneuvering commands

Time series of motions of ship centre of gravity
       t        xf        yf    Heading       uf        vf   Head vel    Rudder  RPM Port  RPM Star
     (s)       (m)       (m)     (deg)     (m/s)     (m/s)   (deg/s)     (deg)
    0.00       0.0       0.0       0.0    10.300     0.000     0.000      0.00     130.0     130.0
    0.50       5.2      -0.0      -0.0    10.319     0.001     0.003      0.33     122.8     122.8
    1.00      10.3       0.0       0.0    10.321     0.005     0.018      1.32     120.9     120.9
    1.50      15.5       0.0       0.0    10.319     0.013     0.047      2.81     121.0     121.0
    2.00      20.6       0.0       0.1    10.317     0.023     0.091      4.41     121.1     121.1
    2.50      25.8       0.0       0.1    10.314     0.033     0.143      6.00     121.1     121.1
```

3.00	31.0	0.0	0.2	10.311	0.042	0.202	7.60	121.1	121.1
3.50	36.1	0.1	0.3	10.306	0.049	0.266	9.20	121.1	121.1
4.00	41.3	0.1	0.5	10.299	0.052	0.334	10.79	121.1	121.1
4.50	46.4	0.1	0.6	10.291	0.052	0.405	12.39	121.1	121.1
5.00	51.5	0.1	0.9	10.281	0.048	0.479	13.98	121.1	121.1
5.50	56.7	0.2	1.1	10.269	0.040	0.554	15.58	121.1	121.1
6.00	61.8	0.2	1.4	10.254	0.027	0.630	17.18	121.1	121.1
6.50	66.9	0.2	1.8	10.238	0.010	0.707	18.77	121.1	121.1
7.00	72.1	0.2	2.1	10.218	-0.012	0.784	20.37	121.1	121.1
7.50	77.2	0.2	2.5	10.197	-0.040	0.861	21.96	121.1	121.1
8.00	82.3	0.2	3.0	10.172	-0.073	0.938	23.56	121.1	121.1
8.50	87.3	0.1	3.5	10.144	-0.111	1.015	25.15	121.1	121.1
9.00	92.4	0.0	4.0	10.114	-0.155	1.091	26.75	121.1	121.1
9.50	97.4	-0.0	4.6	10.081	-0.205	1.165	28.35	121.1	121.1
10.00	102.5	-0.2	5.2	10.045	-0.263	1.235	29.54	121.1	121.1
10.50	107.5	-0.3	5.8	10.008	-0.331	1.291	29.96	121.1	121.1
11.00	112.5	-0.5	6.5	9.973	-0.408	1.333	30.03	121.1	121.1
11.50	117.5	-0.7	7.1	9.938	-0.494	1.365	30.02	121.1	121.1
12.00	122.4	-1.0	7.8	9.904	-0.586	1.390	30.00	121.1	121.1
12.50	127.4	-1.3	8.5	9.871	-0.684	1.409	30.00	121.1	121.1
13.00	132.3	-1.7	9.2	9.837	-0.788	1.424	30.00	121.1	121.1
13.50	137.2	-2.1	9.9	9.804	-0.895	1.435	30.00	121.1	121.1
14.00	142.1	-2.6	10.7	9.771	-1.006	1.442	30.00	121.1	121.1
14.50	147.0	-3.1	11.4	9.737	-1.121	1.448	30.00	121.1	121.1
15.00	151.8	-3.7	12.1	9.702	-1.240	1.451	30.00	121.1	121.1
15.50	156.7	-4.3	12.8	9.667	-1.361	1.453	30.00	121.1	121.1
16.00	161.5	-5.0	13.6	9.631	-1.484	1.454	30.00	121.1	121.1
16.50	166.3	-5.8	14.3	9.594	-1.610	1.453	30.00	121.1	121.1
17.00	171.1	-6.7	15.0	9.555	-1.736	1.453	30.00	121.1	121.1
17.50	175.9	-7.6	15.7	9.516	-1.865	1.451	30.00	121.1	121.1
18.00	180.6	-8.5	16.5	9.476	-1.993	1.450	30.00	121.1	121.1

18.50	185.3	-9.5	17.2	9.434	-2.122	1.448	30.00	121.1	121.1
19.00	190.0	-10.6	17.9	9.391	-2.252	1.446	30.00	121.1	121.1
19.50	194.7	-11.8	18.6	9.347	-2.381	1.445	30.00	121.1	121.1
20.00	199.4	-13.0	19.4	9.302	-2.510	1.445	30.00	121.1	121.1
20.50	204.0	-14.3	20.1	9.255	-2.639	1.445	30.00	121.1	121.1
21.00	208.6	-15.7	20.8	9.206	-2.767	1.446	30.00	121.1	121.1
21.50	213.2	-17.1	21.5	9.157	-2.894	1.447	30.00	121.1	121.1
22.00	217.8	-18.6	22.3	9.105	-3.022	1.448	30.00	121.1	121.1
22.50	222.3	-20.1	23.0	9.053	-3.148	1.450	30.00	121.1	121.1
23.00	226.9	-21.7	23.7	8.999	-3.274	1.451	30.00	121.1	121.1
23.50	231.3	-23.4	24.4	8.943	-3.400	1.453	30.00	121.1	121.1
24.00	235.8	-25.1	25.2	8.886	-3.525	1.454	30.00	121.1	121.1
24.50	240.2	-26.9	25.9	8.827	-3.649	1.455	30.00	121.1	121.1
25.00	244.6	-28.8	26.6	8.767	-3.773	1.455	30.00	121.1	121.1
25.50	249.0	-30.7	27.3	8.706	-3.896	1.454	30.00	121.1	121.1
26.00	253.3	-32.6	28.1	8.643	-4.018	1.453	30.00	121.1	121.1
26.50	257.6	-34.7	28.8	8.579	-4.140	1.450	30.00	121.1	121.1
27.00	261.9	-36.8	29.5	8.514	-4.260	1.447	30.00	121.1	121.1
27.50	266.2	-38.9	30.2	8.447	-4.379	1.442	30.00	121.1	121.1
28.00	270.4	-41.2	31.0	8.380	-4.497	1.438	30.00	121.1	121.1
28.50	274.5	-43.4	31.7	8.311	-4.614	1.432	30.00	121.1	121.1
29.00	278.7	-45.8	32.4	8.242	-4.728	1.426	30.00	121.1	121.1
29.50	282.8	-48.2	33.1	8.171	-4.841	1.419	30.00	121.1	121.1
30.00	286.8	-50.6	33.8	8.100	-4.952	1.413	30.00	121.1	121.1
30.50	290.9	-53.1	34.5	8.029	-5.060	1.408	30.00	121.1	121.1
31.00	294.9	-55.7	35.2	7.957	-5.167	1.403	30.00	121.1	121.1
31.50	298.8	-58.3	35.9	7.884	-5.271	1.398	30.00	121.1	121.1
32.00	302.8	-61.0	36.6	7.811	-5.373	1.395	30.00	121.1	121.1
32.50	306.6	-63.7	37.3	7.738	-5.473	1.393	30.00	121.1	121.1
33.00	310.5	-66.4	38.0	7.664	-5.570	1.391	30.00	121.1	121.1
33.50	314.3	-69.2	38.7	7.590	-5.666	1.390	30.00	121.1	121.1

34.00	318.1	-72.1	39.4	7.515	-5.761	1.390	30.00	121.1	121.1
34.50	321.8	-75.0	40.1	7.439	-5.853	1.391	30.00	121.1	121.1
35.00	325.5	-77.9	40.8	7.364	-5.944	1.391	30.00	121.1	121.1
35.50	329.2	-80.9	41.5	7.287	-6.034	1.393	30.00	121.1	121.1
36.00	332.8	-84.0	42.2	7.210	-6.122	1.394	30.00	121.1	121.1
36.50	336.4	-87.1	42.9	7.132	-6.209	1.395	30.00	121.1	121.1
37.00	339.9	-90.2	43.6	7.053	-6.296	1.396	30.00	121.1	121.1
37.50	343.4	-93.4	44.3	6.974	-6.381	1.397	30.00	121.1	121.1
38.00	346.9	-96.6	45.0	6.893	-6.465	1.397	30.00	121.1	121.1
38.50	350.3	-99.8	45.7	6.813	-6.548	1.397	30.00	121.1	121.1
39.00	353.7	-103.1	46.4	6.731	-6.630	1.397	30.00	121.1	121.1
39.50	357.1	-106.5	47.1	6.648	-6.710	1.396	30.00	121.1	121.1
40.00	360.4	-109.8	47.8	6.565	-6.790	1.394	30.00	121.1	121.1
40.50	363.6	-113.2	48.5	6.482	-6.869	1.393	30.00	121.1	121.1
41.00	366.9	-116.7	49.2	6.397	-6.946	1.391	30.00	121.1	121.1
41.50	370.0	-120.2	49.9	6.313	-7.022	1.389	30.00	121.1	121.1
42.00	373.2	-123.7	50.5	6.227	-7.096	1.388	30.00	121.1	121.1
42.50	376.3	-127.3	51.2	6.141	-7.170	1.386	30.00	121.1	121.1
43.00	379.3	-130.9	51.9	6.055	-7.242	1.385	30.00	121.1	121.1
43.50	382.3	-134.5	52.6	5.968	-7.312	1.384	30.00	121.1	121.1
44.00	385.3	-138.2	53.3	5.881	-7.382	1.383	30.00	121.1	121.1
44.50	388.2	-141.9	54.0	5.793	-7.450	1.383	30.00	121.1	121.1
45.00	391.1	-145.6	54.7	5.705	-7.517	1.383	30.00	121.1	121.1
45.50	393.9	-149.4	55.4	5.616	-7.583	1.384	30.00	121.1	121.1
46.00	396.7	-153.2	56.1	5.526	-7.647	1.384	30.00	121.1	121.1
46.50	399.4	-157.1	56.8	5.436	-7.711	1.385	30.00	121.1	121.1
47.00	402.1	-160.9	57.5	5.345	-7.773	1.386	30.00	121.1	121.1
47.50	404.8	-164.8	58.2	5.253	-7.835	1.387	30.00	121.1	121.1
48.00	407.4	-168.8	58.9	5.161	-7.895	1.388	30.00	121.1	121.1
48.50	409.9	-172.7	59.6	5.068	-7.955	1.389	30.00	121.1	121.1
49.00	412.4	-176.7	60.2	4.974	-8.014	1.390	30.00	121.1	121.1

49.50	414.9	-180.8	60.9	4.879	-8.071	1.390	30.00	121.1	121.1
50.00	417.3	-184.8	61.6	4.783	-8.128	1.390	30.00	121.1	121.1
50.50	419.7	-188.9	62.3	4.687	-8.184	1.390	30.00	121.1	121.1
51.00	422.0	-193.0	63.0	4.590	-8.239	1.390	30.00	121.1	121.1
51.50	424.3	-197.1	63.7	4.492	-8.292	1.389	30.00	121.1	121.1
52.00	426.5	-201.3	64.4	4.393	-8.345	1.389	30.00	121.1	121.1
52.50	428.7	-205.5	65.1	4.294	-8.396	1.388	30.00	121.1	121.1
53.00	430.8	-209.7	65.8	4.194	-8.447	1.387	30.00	121.1	121.1
53.50	432.9	-213.9	66.5	4.093	-8.496	1.387	30.00	121.1	121.1
54.00	434.9	-218.2	67.2	3.992	-8.544	1.386	30.00	121.1	121.1
54.50	436.9	-222.5	67.9	3.891	-8.590	1.386	30.00	121.1	121.1
55.00	438.8	-226.8	68.6	3.788	-8.636	1.385	30.00	121.1	121.1
55.50	440.7	-231.1	69.3	3.686	-8.680	1.385	30.00	121.1	121.1
56.00	442.5	-235.4	70.0	3.582	-8.723	1.385	30.00	121.1	121.1
56.50	444.2	-239.8	70.7	3.478	-8.765	1.385	30.00	121.1	121.1
57.00	445.9	-244.2	71.3	3.374	-8.806	1.386	30.00	121.1	121.1
57.50	447.6	-248.6	72.0	3.269	-8.845	1.386	30.00	121.1	121.1
58.00	449.2	-253.1	72.7	3.163	-8.883	1.387	30.00	121.1	121.1
58.50	450.8	-257.5	73.4	3.057	-8.921	1.387	30.00	121.1	121.1
59.00	452.3	-262.0	74.1	2.950	-8.956	1.388	30.00	121.1	121.1
59.50	453.7	-266.5	74.8	2.843	-8.991	1.389	30.00	121.1	121.1
60.00	455.1	-271.0	75.5	2.735	-9.024	1.389	30.00	121.1	121.1
60.50	456.5	-275.5	76.2	2.626	-9.056	1.389	30.00	121.1	121.1
61.00	457.7	-280.0	76.9	2.517	-9.087	1.389	30.00	121.1	121.1
61.50	459.0	-284.6	77.6	2.408	-9.117	1.390	30.00	121.1	121.1
62.00	460.1	-289.1	78.3	2.298	-9.146	1.390	30.00	121.1	121.1
62.50	461.3	-293.7	79.0	2.187	-9.173	1.389	30.00	121.1	121.1
63.00	462.3	-298.3	79.7	2.076	-9.198	1.389	30.00	121.1	121.1
63.50	463.3	-302.9	80.4	1.965	-9.223	1.389	30.00	121.1	121.1
64.00	464.3	-307.5	81.1	1.853	-9.246	1.388	30.00	121.1	121.1
64.50	465.2	-312.2	81.8	1.741	-9.268	1.388	30.00	121.1	121.1

65.00	466.0	-316.8	82.5	1.629	-9.288	1.388	30.00	121.1	121.1
65.50	466.8	-321.5	83.1	1.516	-9.308	1.387	30.00	121.1	121.1
66.00	467.6	-326.1	83.8	1.403	-9.325	1.387	30.00	121.1	121.1
66.50	468.2	-330.8	84.5	1.291	-9.342	1.387	30.00	121.1	121.1
67.00	468.8	-335.5	85.2	1.177	-9.357	1.387	30.00	121.1	121.1
67.50	469.4	-340.1	85.9	1.064	-9.370	1.387	30.00	121.1	121.1
68.00	469.9	-344.8	86.6	0.951	-9.382	1.387	30.00	121.1	121.1
68.50	470.4	-349.5	87.3	0.837	-9.393	1.388	30.00	121.1	121.1
69.00	470.7	-354.2	88.0	0.723	-9.402	1.388	30.00	121.1	121.1
69.50	471.1	-358.9	88.7	0.609	-9.411	1.388	30.00	121.1	121.1
70.00	471.4	-363.6	89.4	0.495	-9.417	1.389	30.00	121.1	121.1
70.50	471.6	-368.3	90.1	0.381	-9.423	1.389	30.00	121.1	121.1
71.00	471.7	-373.0	90.8	0.266	-9.426	1.390	30.06	121.1	121.1
71.50	471.8	-377.8	91.5	0.153	-9.428	1.392	30.22	121.1	121.1
72.00	471.9	-382.5	92.2	0.039	-9.429	1.396	30.49	121.1	121.1
72.50	471.9	-387.2	92.9	-0.074	-9.427	1.403	30.84	121.1	121.1
73.00	471.8	-391.9	93.6	-0.186	-9.422	1.412	31.29	121.1	121.1
73.50	471.7	-396.6	94.3	-0.297	-9.416	1.423	31.80	121.1	121.1
74.00	471.5	-401.3	95.0	-0.409	-9.407	1.437	32.41	121.1	121.1
74.50	471.3	-406.0	95.7	-0.518	-9.394	1.459	33.70	121.1	121.1
75.00	471.0	-410.7	96.5	-0.625	-9.377	1.486	34.67	121.1	121.1
75.50	470.7	-415.4	97.2	-0.736	-9.358	1.507	34.98	121.1	121.1
76.00	470.3	-420.1	98.0	-0.849	-9.337	1.522	35.08	121.1	121.1
76.50	469.8	-424.7	98.7	-0.963	-9.316	1.534	35.16	121.1	121.1
77.00	469.3	-429.4	99.5	-1.079	-9.293	1.543	35.25	121.1	121.1
77.50	468.7	-434.0	100.3	-1.196	-9.269	1.552	35.32	121.1	121.1
78.00	468.1	-438.7	101.1	-1.313	-9.244	1.559	35.39	121.1	121.1
78.50	467.4	-443.3	101.8	-1.431	-9.218	1.565	35.45	121.1	121.1
79.00	466.7	-447.9	102.6	-1.548	-9.190	1.570	35.49	121.1	121.1
79.50	465.9	-452.5	103.4	-1.667	-9.161	1.575	35.52	121.1	121.1
80.00	465.0	-457.0	104.2	-1.785	-9.130	1.579	35.54	121.1	121.1

80.50	464.1	-461.6	105.0	-1.904	-9.099	1.584	35.55	121.1	121.1
81.00	463.1	-466.1	105.8	-2.024	-9.066	1.587	35.55	121.1	121.1
81.50	462.1	-470.7	106.6	-2.144	-9.031	1.590	35.53	121.1	121.1
82.00	461.0	-475.2	107.4	-2.264	-8.995	1.592	35.50	121.1	121.1
82.50	459.8	-479.7	108.2	-2.385	-8.958	1.594	35.46	121.1	121.1
83.00	458.6	-484.1	109.0	-2.507	-8.920	1.594	35.40	121.1	121.1
83.50	457.3	-488.6	109.8	-2.630	-8.880	1.593	35.25	121.1	121.1
84.00	455.9	-493.0	110.6	-2.753	-8.839	1.589	34.94	121.1	121.1
84.50	454.5	-497.4	111.3	-2.878	-8.797	1.581	34.43	121.1	121.1
85.00	453.1	-501.8	112.1	-3.005	-8.755	1.567	33.65	121.1	121.1
85.50	451.5	-506.2	112.9	-3.134	-8.713	1.546	32.56	121.1	121.1
86.00	449.9	-510.5	113.7	-3.266	-8.671	1.516	31.15	121.1	121.1
86.50	448.3	-514.8	114.4	-3.399	-8.629	1.480	29.62	121.1	121.1
87.00	446.5	-519.1	115.2	-3.533	-8.588	1.438	28.09	121.1	121.1
87.50	444.7	-523.4	115.9	-3.667	-8.548	1.393	26.55	121.1	121.1
88.00	442.9	-527.7	116.6	-3.800	-8.508	1.345	25.02	121.1	121.1
88.50	440.9	-531.9	117.2	-3.932	-8.470	1.295	23.49	121.1	121.1
89.00	438.9	-536.2	117.8	-4.063	-8.432	1.243	21.95	121.1	121.1
89.50	436.9	-540.4	118.5	-4.191	-8.394	1.189	20.42	121.1	121.1
90.00	434.7	-544.6	119.0	-4.319	-8.357	1.133	18.89	121.1	121.1
90.50	432.6	-548.7	119.6	-4.444	-8.321	1.075	17.36	121.1	121.1
91.00	430.3	-552.9	120.1	-4.567	-8.286	1.016	15.82	121.1	121.1
91.50	428.0	-557.0	120.6	-4.687	-8.251	0.955	14.29	121.1	121.1
92.00	425.6	-561.1	121.1	-4.805	-8.216	0.891	12.76	121.1	121.1
92.50	423.2	-565.2	121.5	-4.920	-8.183	0.825	11.23	121.1	121.1
93.00	420.7	-569.3	121.9	-5.032	-8.151	0.757	9.69	121.1	121.1
93.50	418.2	-573.4	122.3	-5.140	-8.119	0.686	8.16	121.1	121.1
94.00	415.6	-577.4	122.6	-5.244	-8.089	0.612	6.63	121.1	121.1
94.50	412.9	-581.5	122.9	-5.343	-8.060	0.535	5.09	121.1	121.1
95.00	410.2	-585.5	123.1	-5.438	-8.034	0.456	3.56	121.1	121.1
95.50	407.5	-589.5	123.3	-5.526	-8.009	0.375	2.03	121.1	121.1

96.00	404.7	-593.5	123.5	-5.609	-7.987	0.291	0.50	121.1	121.1
96.50	401.9	-597.5	123.6	-5.685	-7.967	0.205	-1.04	121.1	121.1
97.00	399.0	-601.5	123.7	-5.754	-7.951	0.117	-2.57	121.1	121.1
97.50	396.1	-605.4	123.7	-5.816	-7.937	0.028	-4.10	121.1	121.1
98.00	393.2	-609.4	123.7	-5.871	-7.928	-0.063	-5.63	121.1	121.1
98.50	390.2	-613.4	123.7	-5.916	-7.922	-0.154	-7.17	121.1	121.1
99.00	387.3	-617.3	123.6	-5.953	-7.920	-0.244	-8.70	121.1	121.1
99.50	384.3	-621.3	123.4	-5.981	-7.922	-0.333	-10.18	121.1	121.1
100.00	381.3	-625.2	123.2	-5.999	-7.930	-0.409	-10.61	121.1	121.1
100.50	378.3	-629.2	123.0	-6.002	-7.947	-0.459	-9.79	121.1	121.1
101.00	375.3	-633.2	122.8	-5.995	-7.973	-0.482	-8.58	121.1	121.1
101.50	372.3	-637.2	122.5	-5.978	-8.004	-0.489	-7.40	121.1	121.1
102.00	369.3	-641.2	122.3	-5.957	-8.039	-0.485	-6.34	121.1	121.1
102.50	366.3	-645.2	122.0	-5.930	-8.076	-0.474	-5.38	121.1	121.1
103.00	363.4	-649.3	121.8	-5.901	-8.114	-0.458	-4.50	121.1	121.1
103.50	360.4	-653.3	121.6	-5.869	-8.153	-0.438	-3.69	121.1	121.1
104.00	357.5	-657.4	121.4	-5.834	-8.192	-0.415	-2.94	121.1	121.1
104.50	354.6	-661.5	121.2	-5.797	-8.231	-0.391	-2.27	121.1	121.1
105.00	351.7	-665.7	121.0	-5.758	-8.271	-0.365	-1.65	121.1	121.1
105.50	348.8	-669.8	120.8	-5.717	-8.310	-0.339	-1.09	121.1	121.1
106.00	346.0	-674.0	120.6	-5.676	-8.348	-0.312	-0.59	121.1	121.1
106.50	343.2	-678.1	120.5	-5.633	-8.387	-0.284	-0.14	121.1	121.1
107.00	340.4	-682.4	120.4	-5.590	-8.424	-0.257	0.24	121.1	121.1
107.50	337.6	-686.6	120.2	-5.547	-8.461	-0.229	0.57	121.1	121.1
108.00	334.8	-690.8	120.1	-5.505	-8.496	-0.201	0.84	121.1	121.1
108.50	332.1	-695.1	120.0	-5.463	-8.531	-0.173	1.05	121.1	121.1
109.00	329.3	-699.3	120.0	-5.422	-8.564	-0.146	1.21	121.1	121.1
109.50	326.6	-703.6	119.9	-5.384	-8.595	-0.120	1.32	121.1	121.1
110.00	324.0	-707.9	119.8	-5.347	-8.625	-0.097	1.39	121.1	121.1
110.50	321.3	-712.3	119.8	-5.313	-8.653	-0.075	1.42	121.1	121.1
111.00	318.7	-716.6	119.8	-5.281	-8.680	-0.056	1.42	121.1	121.1

111.50	316.0	-720.9	119.7	-5.251	-8.704	-0.039	1.40	121.1	121.1
112.00	313.4	-725.3	119.7	-5.224	-8.727	-0.025	1.36	121.1	121.1
112.50	310.8	-729.7	119.7	-5.199	-8.748	-0.014	1.31	121.1	121.1
113.00	308.2	-734.0	119.7	-5.177	-8.768	-0.006	1.26	121.1	121.1
113.50	305.6	-738.4	119.7	-5.156	-8.787	-0.001	1.22	121.1	121.1
114.00	303.0	-742.8	119.7	-5.137	-8.804	0.003	1.18	121.1	121.1
114.50	300.5	-747.2	119.7	-5.119	-8.820	0.005	1.15	121.1	121.1
115.00	297.9	-751.7	119.7	-5.102	-8.835	0.006	1.12	121.1	121.1
115.50	295.4	-756.1	119.7	-5.086	-8.850	0.006	1.11	121.1	121.1
116.00	292.8	-760.5	119.7	-5.070	-8.864	0.006	1.09	121.1	121.1
116.50	290.3	-764.9	119.7	-5.055	-8.878	0.007	1.08	121.1	121.1
117.00	287.8	-769.4	119.7	-5.040	-8.891	0.008	1.06	121.1	121.1
117.50	285.3	-773.8	119.7	-5.026	-8.903	0.011	1.03	121.1	121.1
118.00	282.8	-778.3	119.7	-5.013	-8.915	0.014	1.00	121.1	121.1
118.50	280.3	-782.7	119.7	-5.000	-8.927	0.019	0.95	121.1	121.1
119.00	277.8	-787.2	119.8	-4.988	-8.937	0.025	0.88	121.1	121.1
119.50	275.3	-791.7	119.8	-4.978	-8.947	0.032	0.79	121.1	121.1
120.00	272.8	-796.2	119.8	-4.969	-8.956	0.039	0.68	121.1	121.1
120.50	270.3	-800.6	119.8	-4.961	-8.964	0.046	0.56	121.1	121.1
121.00	267.8	-805.1	119.8	-4.956	-8.970	0.051	0.42	121.1	121.1
121.50	265.3	-809.6	119.9	-4.953	-8.975	0.056	0.28	121.1	121.1
122.00	262.9	-814.1	119.9	-4.951	-8.979	0.059	0.14	121.1	121.1
122.50	260.4	-818.6	119.9	-4.952	-8.981	0.060	-0.00	121.1	121.1
123.00	257.9	-823.1	119.9	-4.954	-8.982	0.060	-0.14	121.1	121.1
123.50	255.4	-827.6	120.0	-4.958	-8.983	0.059	-0.26	121.1	121.1
124.00	253.0	-832.1	120.0	-4.963	-8.982	0.055	-0.37	121.1	121.1
124.50	250.5	-836.5	120.0	-4.970	-8.980	0.050	-0.46	121.1	121.1
125.00	248.0	-841.0	120.1	-4.977	-8.978	0.044	-0.53	121.1	121.1
125.50	245.5	-845.5	120.1	-4.985	-8.975	0.037	-0.57	121.1	121.1
126.00	243.0	-850.0	120.1	-4.994	-8.972	0.029	-0.60	121.1	121.1
126.50	240.5	-854.5	120.1	-5.003	-8.969	0.020	-0.60	121.1	121.1

127.00	238.0	-859.0	120.1	-5.011	-8.965	0.012	-0.59	121.1	121.1
127.50	235.5	-863.5	120.1	-5.019	-8.962	0.004	-0.56	121.1	121.1
128.00	233.0	-867.9	120.1	-5.027	-8.959	-0.003	-0.51	121.1	121.1
128.50	230.5	-872.4	120.1	-5.035	-8.956	-0.009	-0.46	121.1	121.1
129.00	227.9	-876.9	120.1	-5.041	-8.954	-0.013	-0.40	121.1	121.1
129.50	225.4	-881.4	120.1	-5.047	-8.952	-0.017	-0.34	121.1	121.1
130.00	222.9	-885.9	120.1	-5.053	-8.950	-0.019	-0.28	121.1	121.1
130.50	220.4	-890.3	120.1	-5.057	-8.949	-0.019	-0.23	121.1	121.1
131.00	217.8	-894.8	120.1	-5.062	-8.948	-0.018	-0.19	121.1	121.1
131.50	215.3	-899.3	120.1	-5.066	-8.947	-0.017	-0.15	121.1	121.1
132.00	212.8	-903.7	120.1	-5.070	-8.946	-0.014	-0.13	121.1	121.1
132.50	210.2	-908.2	120.1	-5.073	-8.945	-0.011	-0.12	121.1	121.1
133.00	207.7	-912.7	120.0	-5.077	-8.943	-0.008	-0.12	121.1	121.1
133.50	205.2	-917.2	120.0	-5.081	-8.942	-0.004	-0.13	121.1	121.1
134.00	202.6	-921.6	120.0	-5.085	-8.940	-0.001	-0.14	121.1	121.1
134.50	200.1	-926.1	120.0	-5.090	-8.939	0.002	-0.16	121.1	121.1
135.00	197.5	-930.6	120.0	-5.095	-8.937	0.004	-0.18	121.1	121.1
135.50	195.0	-935.0	120.0	-5.100	-8.934	0.005	-0.20	121.1	121.1
136.00	192.4	-939.5	120.0	-5.106	-8.932	0.005	-0.22	121.1	121.1
136.50	189.9	-944.0	120.1	-5.111	-8.929	0.005	-0.24	121.1	121.1
137.00	187.3	-948.4	120.1	-5.117	-8.926	0.004	-0.24	121.1	121.1
137.50	184.8	-952.9	120.1	-5.123	-8.924	0.002	-0.24	121.1	121.1
138.00	182.2	-957.4	120.1	-5.129	-8.921	-0.000	-0.24	121.1	121.1
138.50	179.6	-961.8	120.1	-5.134	-8.918	-0.003	-0.22	121.1	121.1
139.00	177.1	-966.3	120.1	-5.139	-8.916	-0.005	-0.20	121.1	121.1
139.50	174.5	-970.7	120.0	-5.144	-8.914	-0.008	-0.17	121.1	121.1
140.00	171.9	-975.2	120.0	-5.148	-8.912	-0.010	-0.14	121.1	121.1
140.50	169.3	-979.6	120.0	-5.152	-8.910	-0.012	-0.10	121.1	121.1
141.00	166.8	-984.1	120.0	-5.155	-8.909	-0.013	-0.07	121.1	121.1
141.50	164.2	-988.6	120.0	-5.157	-8.908	-0.014	-0.03	121.1	121.1
142.00	161.6	-993.0	120.0	-5.159	-8.907	-0.014	0.00	121.1	121.1

142.50	159.0	-997.5	120.0	-5.161	-8.907	-0.013	0.03	121.1	121.1
143.00	156.5	-1001.9	120.0	-5.162	-8.906	-0.012	0.05	121.1	121.1
143.50	153.9	-1006.4	120.0	-5.163	-8.906	-0.010	0.07	121.1	121.1
144.00	151.3	-1010.8	120.0	-5.163	-8.906	-0.008	0.08	121.1	121.1
144.50	148.7	-1015.3	120.0	-5.164	-8.907	-0.006	0.08	121.1	121.1
145.00	146.1	-1019.7	120.0	-5.164	-8.907	-0.003	0.07	121.1	121.1
145.50	143.5	-1024.2	120.0	-5.164	-8.907	-0.001	0.06	121.1	121.1
146.00	141.0	-1028.6	120.0	-5.165	-8.907	0.001	0.05	121.1	121.1
146.50	138.4	-1033.1	120.0	-5.165	-8.907	0.003	0.03	121.1	121.1
147.00	135.8	-1037.5	120.0	-5.166	-8.907	0.004	0.01	121.1	121.1
147.50	133.2	-1042.0	120.0	-5.166	-8.907	0.005	-0.00	121.1	121.1
148.00	130.6	-1046.5	120.0	-5.167	-8.906	0.006	-0.02	121.1	121.1
148.50	128.0	-1050.9	120.0	-5.168	-8.906	0.006	-0.04	121.1	121.1
149.00	125.5	-1055.4	120.0	-5.168	-8.906	0.005	-0.05	121.1	121.1
149.50	122.9	-1059.8	120.0	-5.169	-8.906	0.004	-0.05	121.1	121.1
150.00	120.3	-1064.3	120.0	-5.170	-8.905	0.003	-0.06	121.1	121.1
150.50	117.7	-1068.7	120.0	-5.171	-8.905	0.002	-0.06	121.1	121.1
151.00	115.1	-1073.2	120.0	-5.171	-8.905	0.000	-0.05	121.1	121.1
151.50	112.5	-1077.6	120.0	-5.172	-8.905	-0.001	-0.04	121.1	121.1
152.00	110.0	-1082.1	120.0	-5.172	-8.905	-0.002	-0.03	121.1	121.1
152.50	107.4	-1086.5	120.0	-5.172	-8.905	-0.003	-0.02	121.1	121.1
153.00	104.8	-1091.0	120.0	-5.171	-8.905	-0.004	-0.00	121.1	121.1
153.50	102.2	-1095.4	120.0	-5.171	-8.906	-0.005	0.01	121.1	121.1
154.00	99.6	-1099.9	120.0	-5.170	-8.907	-0.005	0.02	121.1	121.1
154.50	97.0	-1104.3	120.0	-5.169	-8.907	-0.005	0.03	121.1	121.1
155.00	94.4	-1108.8	120.0	-5.168	-8.908	-0.004	0.04	121.1	121.1
155.50	91.9	-1113.2	120.0	-5.167	-8.909	-0.004	0.05	121.1	121.1
156.00	89.3	-1117.7	120.0	-5.165	-8.910	-0.003	0.05	121.1	121.1
156.50	86.7	-1122.2	120.0	-5.164	-8.910	-0.002	0.05	121.1	121.1
157.00	84.1	-1126.6	120.0	-5.163	-8.911	-0.001	0.05	121.1	121.1
157.50	81.5	-1131.1	120.0	-5.162	-8.912	0.000	0.04	121.1	121.1

158.00	78.9	-1135.5	120.0	-5.161	-8.913	0.001	0.03	121.1	121.1
158.50	76.4	-1140.0	120.0	-5.160	-8.913	0.002	0.03	121.1	121.1
159.00	73.8	-1144.4	120.0	-5.159	-8.914	0.003	0.02	121.1	121.1
159.50	71.2	-1148.9	120.0	-5.158	-8.914	0.003	0.01	121.1	121.1
160.00	68.6	-1153.3	120.0	-5.157	-8.915	0.003	-0.00	121.1	121.1
160.50	66.1	-1157.8	120.0	-5.157	-8.915	0.003	-0.01	121.1	121.1
161.00	63.5	-1162.3	120.0	-5.156	-8.915	0.003	-0.01	121.1	121.1
161.50	60.9	-1166.7	120.0	-5.156	-8.916	0.002	-0.02	121.1	121.1
162.00	58.3	-1171.2	120.0	-5.156	-8.916	0.002	-0.02	121.1	121.1
162.50	55.7	-1175.6	120.0	-5.155	-8.916	0.001	-0.02	121.1	121.1
163.00	53.2	-1180.1	120.0	-5.155	-8.916	0.000	-0.02	121.1	121.1
163.50	50.6	-1184.6	120.0	-5.155	-8.917	-0.000	-0.01	121.1	121.1
164.00	48.0	-1189.0	120.0	-5.154	-8.917	-0.001	-0.01	121.1	121.1
164.50	45.4	-1193.5	120.0	-5.154	-8.917	-0.001	-0.00	121.1	121.1
165.00	42.9	-1197.9	120.0	-5.153	-8.918	-0.002	0.01	121.1	121.1
165.50	40.3	-1202.4	120.0	-5.153	-8.918	-0.002	0.01	121.1	121.1
166.00	37.7	-1206.8	120.0	-5.152	-8.918	-0.002	0.02	121.1	121.1
166.50	35.1	-1211.3	120.0	-5.151	-8.919	-0.002	0.02	121.1	121.1
167.00	32.5	-1215.8	120.0	-5.151	-8.919	-0.002	0.03	121.1	121.1
167.50	30.0	-1220.2	120.0	-5.150	-8.920	-0.002	0.03	121.1	121.1
168.00	27.4	-1224.7	120.0	-5.149	-8.920	-0.001	0.03	121.1	121.1
168.50	24.8	-1229.1	120.0	-5.149	-8.920	-0.001	0.03	121.1	121.1
169.00	22.2	-1233.6	120.0	-5.148	-8.921	-0.000	0.03	121.1	121.1
169.50	19.7	-1238.1	120.0	-5.148	-8.921	0.000	0.02	121.1	121.1
170.00	17.1	-1242.5	120.0	-5.147	-8.921	0.001	0.02	121.1	121.1
170.50	14.5	-1247.0	120.0	-5.147	-8.922	0.001	0.02	121.1	121.1
171.00	12.0	-1251.4	120.0	-5.147	-8.922	0.002	0.01	121.1	121.1
171.50	9.4	-1255.9	120.0	-5.146	-8.922	0.002	0.01	121.1	121.1

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This report describes the application HalManeuver for predicting maneuvering of the Canadian Navy's HALIFAX class. HalManeuver was developed using ShipMo3D, an object-oriented library for predicting ship motions in calm water and in waves. Predicted maneuvering motions are determined by evaluating forces acting on the hull, rudder, propeller, and other appendages. Input parameters to HalManeuver include increments to hull maneuvering force coefficients, which can be adjusted to optimize agreement between observed and predicted maneuvering properties. HalManeuver demonstrates the development of an application using the ShipMo3D library. Other applications for ship maneuvering in both calm water and in waves will be developed as requirements arise.

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