# Analysis of Hydrodynamic Interaction Between HMCS FREDERICTON and USNS KANAWHA

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**Defence R&D Canada – Atlantic**

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# Abstract

HMCS FREDERICTON collided with USNS KANAWHA on 18 November 2010 while FREDERICTON was approaching KANAWHA for replenishment at sea. The ships were in calm water of depth greater than 600 m. VENTURE Naval Officers Training Centre (NOTC) requested that DRDC Atlantic investigate whether hydrodynamic interactions between the two ships contributed to the occurrence of the collision. It is unlikely that hydrodynamic interaction effects were a factor in causing a collision between FREDERICTON and KANAWHA. In the present report, the non-dimensional lateral separation is defined as the lateral separation distance divided by the beam of the larger ship. FREDERICTON and KANAWHA had a non-dimensional lateral separation of 3.0 when FREDERICTON commenced unexpected motion behaviour. Available data suggest that hydrodynamic interaction forces at the onset of unexpected motion behaviour were likely less than 10 percent of hydrodynamic interaction forces that would have been experienced when closer to the alongside refuelling position. During replenishment operations, ships typically have forward speed Froude numbers less than 0.2. Under such conditions, wave-making effects will be small, simplifying analysis of flow conditions.

# Résumé

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# Executive summary

## Analysis of Hydrodynamic Interaction Between HMCS FREDERICTON and USNS KANAWHA

Kevin McTaggart; DRDC Atlantic TM 2012-122; Defence R&D Canada – Atlantic; September 2012.

**Introduction:** On 18 November 2010, HMCS FREDERICTON collided with USNS KANAWHA while FREDERICTON was approaching KANAWHA for replenishment at sea. The ships were in calm water of depth greater than 600 m. VENTURE Naval Officers Training Centre requested that DRDC Atlantic investigate whether hydrodynamic interactions between the two ships contributed to the occurrence of the collision.

**Principal Results:** It is unlikely that hydrodynamic interaction effects were a factor in causing a collision between FREDERICTON and KANAWHA. In the present report, the non-dimensional lateral separation is defined as the lateral separation distance divided by the beam of the larger ship. FREDERICTON and KANAWHA had a non-dimensional lateral separation of 3.0 when FREDERICTON commenced unexpected motion behaviour. Available data suggest that hydrodynamic interaction forces at the onset of unexpected motion behaviour were likely less than 10 percent of hydrodynamic interaction forces that would have been experienced when closer to the alongside refuelling position. During replenishment operations, ships typically have forward speed Froude numbers less than 0.2. Under such conditions, wave-making effects will be small, simplifying analysis of flow conditions.

**Significance of Results:** When considering factors influencing the collision between FREDERICTON and KANAWHA, hydrodynamic interaction effects can likely be excluded. If future investigations of replenishment at sea are to be considered, then three-dimensional potential flow modelling can be used to investigate hydrodynamic interaction forces robustly and efficiently.

**Future Plans:** Computation of steady hydrodynamic interaction forces between vessels in close proximity will be implemented into DRDC Atlantic's ShipMo3D ship motion library and virtual ship simulation software.

# Sommaire

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# 1 Introduction

While approaching for replenishment on 18 November 2010, HMCS FREDERICTON (FRE) collided with USNS KANAWHA (KAN). The ships were in calm water of depth greater than 600 m. VENTURE Naval Officers Training Centre (NOTC) requested that DRDC Atlantic investigate whether hydrodynamic interactions between the two ships contributed to the occurrence of the collision.

Section 2 describes the scenario including the positions of the ships leading up to the collision. Section 3 gives a review of literature relevant to analysis of the hydrodynamic interactions. Section 4 gives an evaluation of the hydrodynamic interaction effects in the context of the collision, and is followed by conclusions in Section 5.

# 2 Scenario for Interaction Between HMCS FREDERICTON and USNS KANAWHA

Table 1 gives dimensions for FREDERICTON at the time of the incident, and for KANAWHA assuming fully loaded. KANAWHA was travelling at 13 knots at a course of 030 in preparation for replenishment of FREDERICTON. Table 2 gives FREDERICTON motion data that were obtained from a video prepared by VENTURE NOTC of the FREDERICTON bridge console. The course and speed columns of Table 2 give course made good and speed made good respectively.

***Table 1:*** *Ship Dimensions for HMCS FREDERICTON and USNS KANAWHA*

| | HMCS FREDERICTON (during incident) | USNS KANAWHA (assuming fully loaded) |
|---|---|---|
| Displacement, $\triangle$ | 4,770 tonnes | 41,000 tonnes |
| Length overall, $L$ | 134 m | 200 m |
| Beam, $B$ | 16.4 m | 27 m |
| Draft, $T$ | 5 m | 11 m |

FREDERICTON experienced unexpected motion behaviour commencing approximately at time 233715. At that time, the video indicated that FREDERICTON's bow was just ahead of KANAWHA's stern and the lateral separation (beam to beam) between the two ships was 90 yards. For the present analysis, this position of KANAWHA was used to estimate KANAWHA's position at other times assuming a course of 030 and speed of 13 knots. Figure 1 shows time series of motions for

FREDERICTON, with the $x$-axis in the direction of course 030 and the $y$-axis in the port direction relative to course 030. Figure 2 shows the trajectories of the two ships and Figure 3 shows the trajectory of FREDERICTON relative to KANAWHA.

*Table 2:* *FREDERICTON Motion Data from Video*

| Time (Zulu) | Heading (deg) | Course (deg) | Speed (knots) | Latitude (N) | Longitude (W) | Comment |
|---|---|---|---|---|---|---|
| 233400 | 29.1 | 30.1 | 13.3 | 28° 2.877′ | 79° 18.436′ | |
| 233410 | 28.3 | 28.0 | 13.1 | 28° 2.909′ | 79° 18.416′ | |
| 233420 | 28.1 | 27.5 | 13.1 | 28° 2.941′ | 79° 18.397′ | |
| 233430 | 28.0 | 28.2 | 13.0 | 28° 2.973′ | 79° 18.377′ | |
| 233440 | 28.7 | 27.3 | 13.4 | 28° 3.006′ | 79° 18.358′ | |
| 233450 | 29.3 | 28.3 | 14.3 | 28° 3.040′ | 79° 18.338′ | |
| 233500 | 30.0 | 29.0 | 16.1 | 28° 3.078′ | 79° 18.315′ | |
| 233510 | 30.2 | 29.7 | 17.0 | 28° 3.118′ | 79° 18.289′ | |
| 233520 | 30.1 | 29.3 | 17.9 | 28° 3.158′ | 79° 18.263′ | |
| 233530 | 30.1 | 29.3 | 18.6 | 28° 3.205′ | 79° 18.234′ | |
| 233540 | 29.8 | 27.8 | 19.1 | 28° 3.256′ | 79° 18.202′ | |
| 233550 | 29.5 | 29.2 | 19.6 | 28° 3.298′ | 79° 18.175′ | FRE 400 yards astern, 100 yards lateral sep |
| 233600 | 29.2 | 28.9 | 19.9 | 28° 3.347′ | 79° 18.145′ | |
| 233610 | 28.5 | 28.1 | 19.8 | 28° 3.396′ | 79° 18.115′ | |
| 233620 | 29.1 | 27.9 | 20.1 | 28° 3.440′ | 79° 18.088′ | |
| 233630 | 29.4 | 29.0 | 20.0 | 28° 3.493′ | 79° 18.056′ | |
| 233640 | 28.7 | 28.6 | 20.0 | 28° 3.547′ | 79° 18.022′ | |
| 233650 | 28.4 | 27.7 | 20.1 | 28° 3.591′ | 79° 17.995′ | |
| 233700 | 28.4 | 27.6 | 19.8 | 28° 3.641′ | 79° 17.966′ | |
| 233710 | 27.9 | 26.8 | 19.3 | 28° 3.689′ | 79° 17.936′ | |
| 233715 | 26.4 | 26.7 | 18.2 | 28° 3.712′ | 79° 17.923′ | FRE bow just ahead of KAN stern, 90 yards lateral sep |
| 233720 | 24.9 | 25.7 | 17.4 | 28° 3.734′ | 79° 17.910′ | |
| 233725 | 21.1 | 21.9 | 16.4 | 28° 3.758′ | 79° 17.896′ | OOW orders steer 028 |
| 233730 | 16.8 | 18.1 | 16.0 | 28° 3.775′ | 79° 17.888′ | |
| 233735 | 12.6 | 14.8 | 15.2 | 28° 3.799′ | 79° 17.877′ | |
| 233740 | 9.4 | 10.3 | 15.1 | 28° 3.816′ | 79° 17.872′ | |
| 233745 | 8.7 | 9.7 | 14.8 | 28° 3.837′ | 79° 17.869′ | |
| 233750 | 9.6 | 8.6 | 14.0 | 28° 3.856′ | 79° 17.865′ | Full speed astern ordered |
| 233755 | 12.8 | 13.6 | 12.9 | 28° 3.878′ | 79° 17.861′ | FRE bow aligned with KAN bridge |
| 233800 | 16.6 | 12.9 | 11.7 | 28° 3.891′ | 79° 17.860′ | |
| 233805 | 21.2 | 15.8 | 10.4 | 28° 3.903′ | 79° 17.858′ | |
| 233808 | 23.1 | 32.8 | 10.2 | 28° 3.911′ | 79° 17.854′ | FRE bow hits KAN at 7 degree angle |
| 233810 | 26.0 | 26.9 | 8.4 | 28° 3.917′ | 79° 17.852′ | |

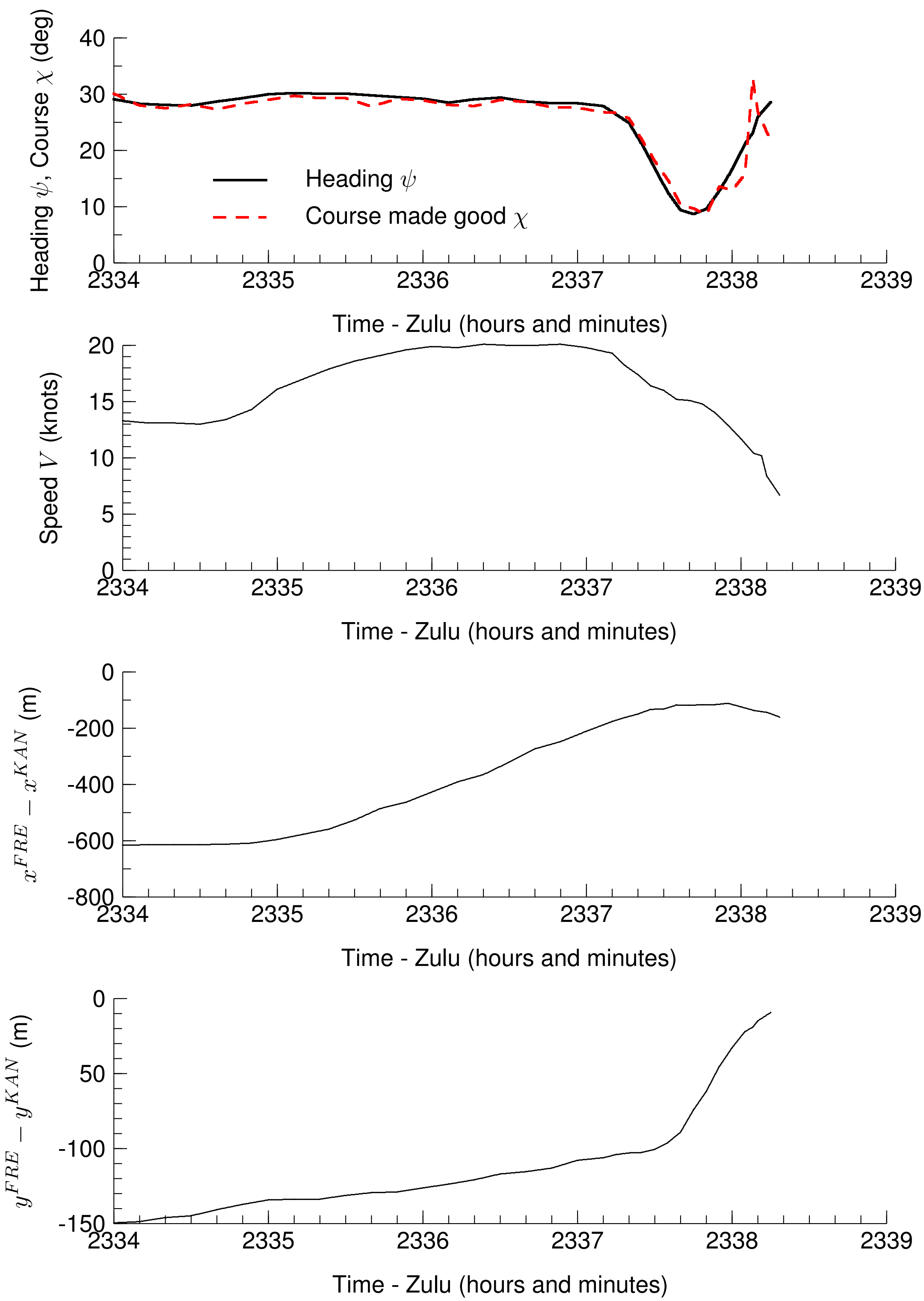


***Figure 1:*** *Time Series of FREDERICTON Heading, Speed, Relative Longitudinal Position, and Relative Lateral Position*

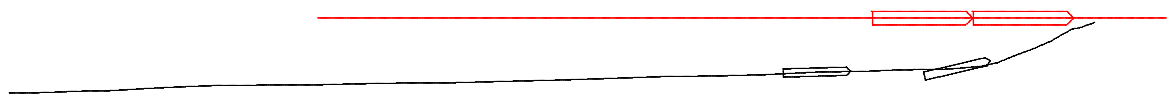

***Figure 2:*** *Trajectories of FREDERICTON and KANAWHA, Ships Shown at Times 233700 and 233730*

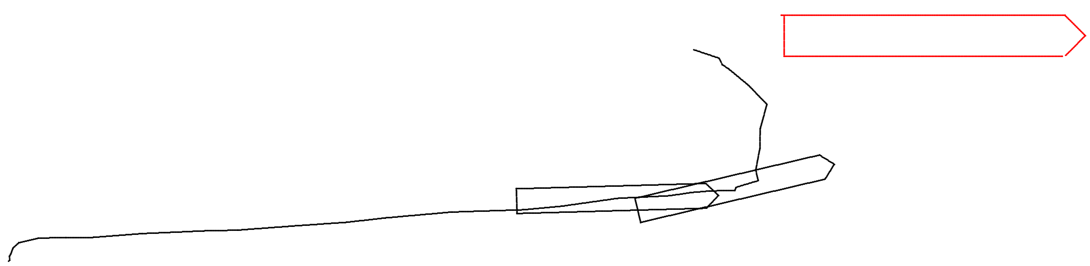

***Figure 3:*** *Trajectory of FREDERICTON Relative to KANAWHA, Ships Shown at Times 233700 and 233730*

# 3 Literature Review

Hydrodynamic interactions during replenishment at sea have been examined in many studies. Several studies have examined hydrodynamic interactions in waves [2, 3, 4, 5]. The present literature review considers interaction effects in calm water, which are relevant to the present scenario.

Among the relevant literature, a model test study by Layne [1] is most useful for providing an appreciation of hydrodynamic interactions relevant to FREDERICTON and KANAWHA. Layne's study considers an aircraft carrier (CVF) and fast attack support ship (AOE). The relative sizes of the two ships in Layne's study are similar to FREDERICTON and KANAWHA. Layne gives sway and yaw interaction forces acting on the smaller ship for comprehensive ranges of relative lateral and longitudinal positions. At this point it is useful to introduce the forward speed Froude number, $Fn$, which is given by:

$$Fn = \frac{U}{\sqrt{g\ L}} \tag{1}$$

where $U$ is forward ship speed, $g$ is gravitational acceleration, and $L$ is ship length. Froude numbers for model tests by Layne are applicable to the collision between FREDERICTON and KANAWHA.

Dove [6, 7] performed model tests to examine hydrodynamic interaction forces of a LEANDER class frigate near an Australian support ship. The results are of limited relevance to the present study because the model tests were conducted for a lateral ship separation of 18 m, compared to a lateral separation of approximately 80 m when unexpected motion behaviour began with FREDERICTON.

Skejic et al. [8] recently published a paper on simulation of replenishment maneuvering. They model hydrodynamic interaction forces using the slender body theory of Tuck and Newman [9]. Skejic et al. indicate that wave making effects will be small for ships travelling at Froude numbers of approximately 0.2 and lower, which is applicable to FREDERICTON and KANAHWA. Tuck and Newman show good agreement of their force prediction method with experimental data. It should be noted that Tuck and Newman's work was performed in the 1970's; thus, slender body theory was attractive because of it's minimal computational requirements. Using a relatively modest present-day computer, more accurate three-dimensional potential flow computations of hydrodynamic interactions could likely be performed within seconds. Xiang and Faltinsen [10] have implemented this approach and demonstrate improved accuracy over slender body theory. The three-dimensional approach for computing steady hydrodynamic interaction forces will be introduced into DRDC Atlantic's ShipMo3D ship motion library [11] during the next year.

Dimmick et al. [12] developed a simulation of ship steering control during underway replenishment. They evaluated hydrodynamic interaction forces using model test data from Colvano [13].

# 4 Evaluation of Hydrodynamic Interactions for FREDERICTON in the Vicinity of KANAWHA

Possible hydrodynamic interactions that influenced the motions of FREDERICTON have been examined using two different methods. In the first method, the flow velocity in the vicinity of a hemisphere has been considered. This method provides an appreciation of the influence of proximity to a body on local flow conditions. In the second method, available experimental force data for two ships have been examined. This method provides an appreciation of whether interaction forces would have significantly affected the motions of FREDERICTON.

## 4.1 Conditions of Interest for Examining Hydrodynamic Interactions

When examining hydrodynamic interactions between FREDERICTON and KANAWHA, it is important to consider which conditions of are of interest. During fuel replenishment, ships will typically have a lateral separation (beam to beam) of 30 m to 42 m. For the incident under consideration, FREDERICTON commenced unexpected behaviour when the lateral separation was 82 m (90 yards). The non-dimensional lateral separation can be evaluated by:

$$s' = \frac{\Delta y - B^{KAN}/2 - B^{FRE}/2}{B^{KAN}} \tag{2}$$

where $\Delta y$ is the lateral distance (centreline to centreline) ship positions. The non-dimensional separation distance $s'$ had a value of 3.0 when unexpected motion behaviour commenced. During refueling, ships have non-dimensional separations between 1.1 and 1.6.

The relative longitudinal position of the smaller ship is also of interest. The non-dimensional relative longitudinal position of FREDERICTON (midships to midships) can be determined by:

$$\Delta x' = \frac{x^{FRE} - x^{KAN}}{L^{KAN}} \tag{3}$$

The relative longitudinal position of FREDERICTON was $-162$ m when unexpected behaviour occurred, corresponding to a relative longitudinal position $\Delta x'$ value of $-0.81$. Note that both $s'$ and $\Delta x'$ are non-dimensionalized based on dimensions of the larger ship.

In the present analysis, hydrodynamic interaction effects are at non-dimensional separations corresponding to the beginning of unexpected behaviour for FREDERICTON ($s' = 3.0$) and for representative separation distances during refuelling ($s' = 1.1$ and $1.6$). This approach permits comparison of hydrodynamic effects on FREDERICTON with those that would have been experienced during a normal refuelling operation.

## 4.2 Assumptions of Potential Flow and No Surface Waves

The analysis of hydrodynamic interaction effects can be simplified if potential flow can be assumed (i.e. water viscosity is zero) and if surface waves generated by the ships can be assumed to be negligible. The assumption of zero viscosity is commonly used in analysis of ship hydrodynamics, permitting application of potential flow methods (see Newman [14]). The assumption of potential flow is typically valid if the following conditions are simultaneously applicable:

- the influence of the flow boundary layer is small,
- the hull is relatively slender,
- the incident flow angle of attack is small.

The above conditions apply to the present scenario.

The influence of surface waves generated by the forward speed of the vessels can be assumed to be negligible when the ships are travelling with forward speed Froude numbers of less than 0.2 [8, 10]. When travelling at 13 knots, FREDERICTON has a Froude number of 0.18 and KANAWHA has a Froude number of 0.15; thus, the assumption of ship generated waves being negligible is reasonable.

Two previous studies support the application of potential flow with no wave generation for predicting ship interaction forces at moderate Froude numbers. Tuck and Newman [9] use slender body theory (a further simplification to potential flow theory) and show good agreement between prediction and experimental interaction forces. Xiang and Faltinsen [10] show three-dimensional predictions that give excellent agreement with experimental data.

## 4.3 Flow in the Vicinity of a Hemisphere

An appreciation of the influence of a body on surrounding flow can be gained by examining flow velocities in the vicinity of a hemisphere, as shown in Figure 4. The solution of the potential flow field is given by Newman [14]. Figures 5 and 6 give flow velocities at locations representative of the near side of a smaller ship in the vicinity of a larger ship. For both longitudinal and lateral flow velocity components, modification of the flow at the largest separation distance $s' = 3.0$ is less than 10 percent of the modification of the flow at the smallest separation distance $s' = 1.1$. This analysis suggests that the unexpected motion behaviour of FREDERICTON commencing at $s' = 3.0$ was likely not caused by hydrodynamic interaction with KANAWHA.

## 4.4 Hydrodynamic Interaction Forces from Experimental Data

There are several reports that have experimental data for hydrodynamic interactions acting on a smaller ship in the vicinity of a larger ship. When considering the applicability of experimental data, it should be noted that FREDERICTON had a non-dimensional lateral separation $s'$ of 3.0 and a non-dimensional relative longitudinal position $\Delta x'$ of $-0.81$.

Layne [1] gives results from a comprehensive series of model tests for a fast attack support ship in the vicinity of an aircraft carrier. Table 3 gives particulars of the two ships tested. Using appropriate scaling between the model tests and the interaction between FREDERICTON and KANAWHA being considered in this report, the results reported by Layne for a ship of 15 knots and 20 knots are of greatest interest (the ship speed of 13 knots for KANAWHA has the same Froude number as the CVA travelling at 16 knots). The largest lateral separation for the model tests had a non-dimensional value $s'$ of 1.93, which is significantly less than the value of 3.0 for FREDERICTON when unexpected motion behaviour commenced.

Figures 7 and 8 show interaction sway forces and yaw moments acting on the AOE from Layne. The sway forces and yaw moments are non-dimensionalized as follows:

$$Y' = \frac{Y}{1/2\,\rho\,V^2\,L^2} \tag{4}$$

$$N' = \frac{N}{1/2\,\rho\,V^2\,L^3} \tag{5}$$

where $Y$ is sway force, $V$ is ship horizontal plane velocity, and $N$ is yaw moment. Froude numbers for model tests by Layne are applicable to the collision between

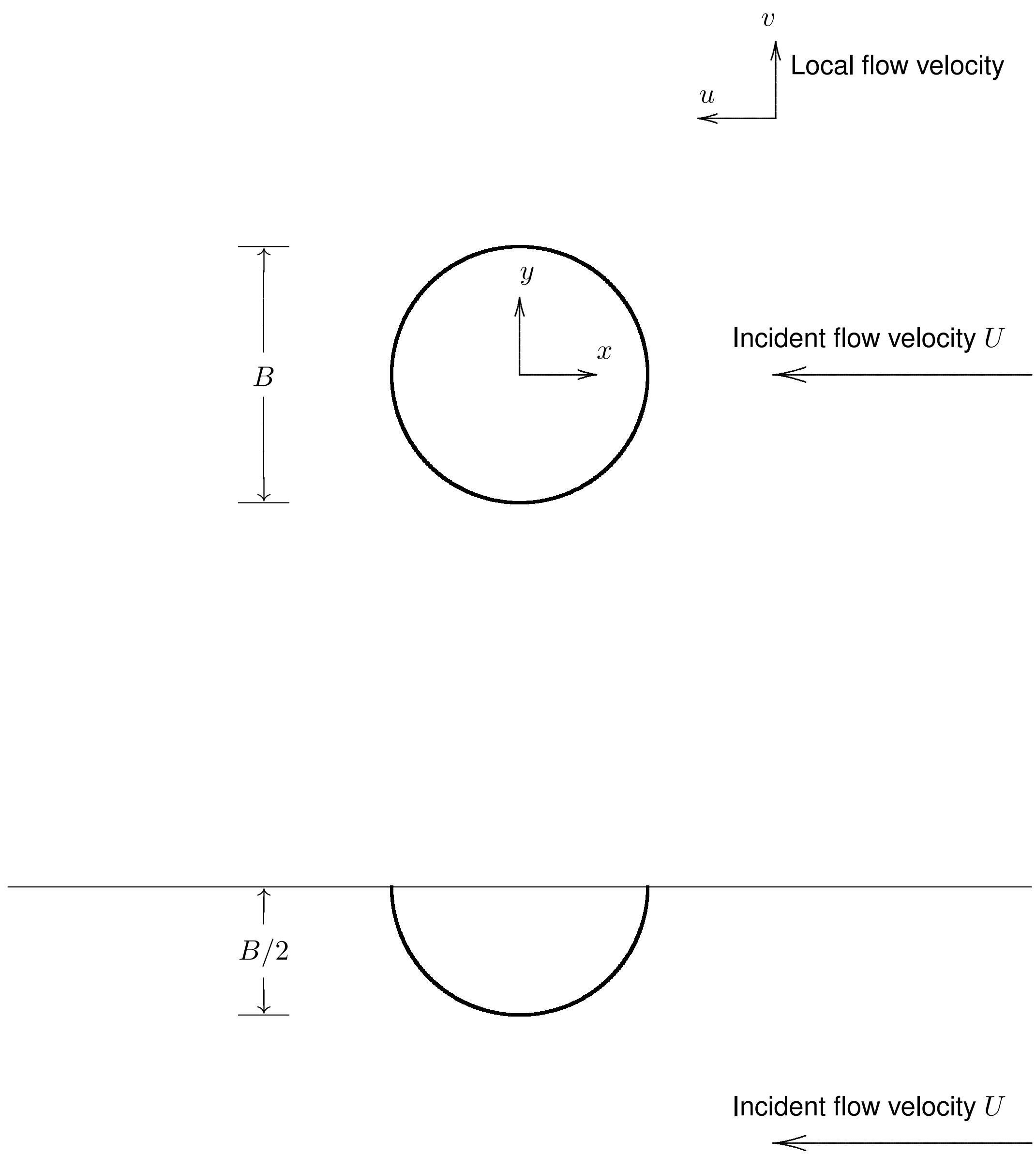


***Figure 4:*** *Plan and Elevation Views of Flow Near a Hemisphere*

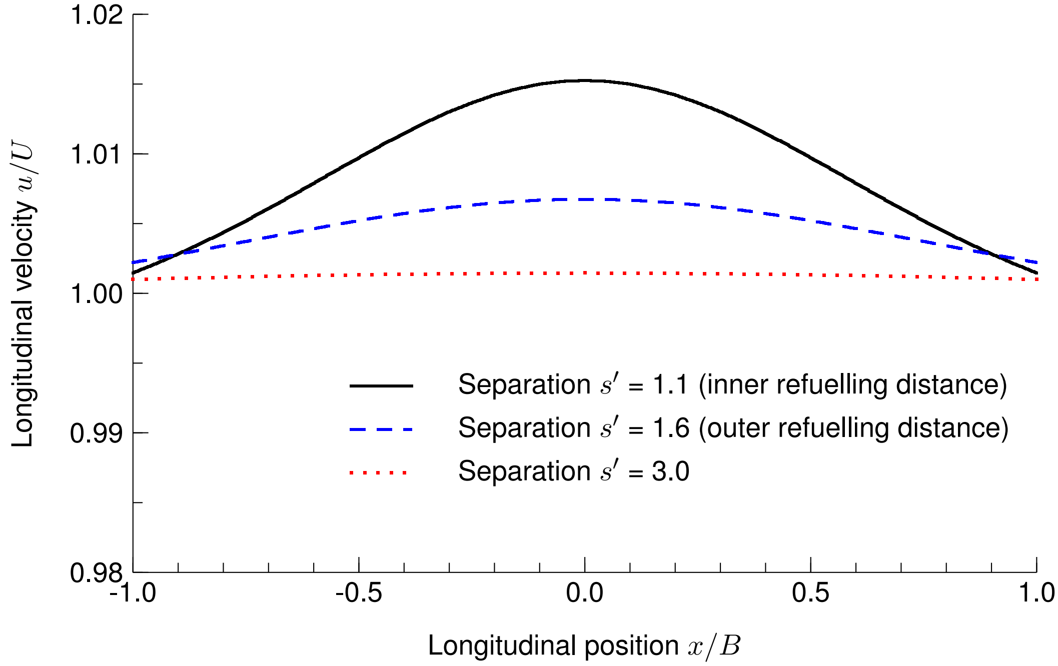


***Figure 5:*** *Longitudinal Flow Velocity $u/U$ Near a Hemisphere*

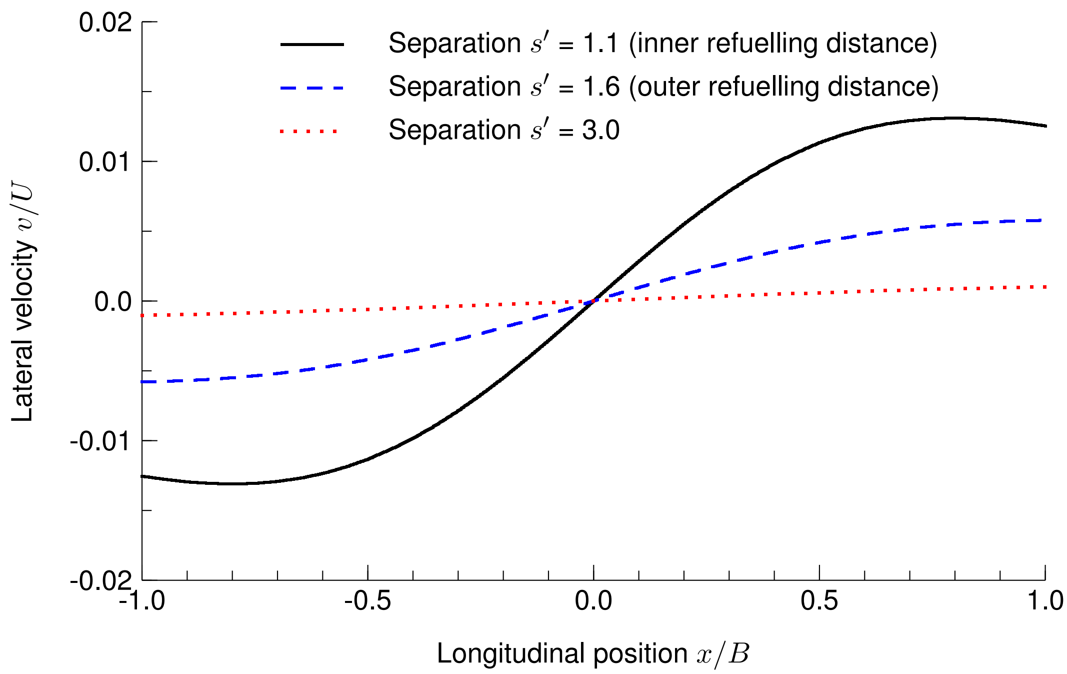


***Figure 6:*** *Lateral Flow Velocity $v/U$ Near a Hemisphere*

***Table 3:*** *Main Particulars for Aircraft Carrier CVA-59 and Fast Attack Support Ship AEO-1 for Ship Interaction Model Experiments*

| | Aircraft carrier CVA-59 | Support ship AOE-1 |
|---|---|---|
| Length, $L$ | 301.8 m | 234.7 m |
| Beam, $B$ | 39.4 m | 32.6 m |
| Draft $T$ | 10.3 m | 11.6 m |

FREDERICTON and KANAWHA. Experimental data are shown for a full-scale speed of 20 knots because the Froude number is representative of conditions for FREDERICTON and because comprehensive experimental data were given for this model test condition. Note that the non-dimensional separation distances of 1.16, 1.55 and 1.93 are the three largest separation distances for the experiments, and are significantly smaller than the value of 3.0 for for FREDERICTON when unexpected motion behaviour commenced. Nevertheless, the experimental data demonstrate the decay in magnitude of interaction forces as separation distance between ships increases. The experimental data suggest that the sway and yaw interaction forces when FREDERICTON commenced unexpected motions were likely less than 10 percent of the interaction forces that FREDERICTON would have experienced when nearer the alongside replenishment position.

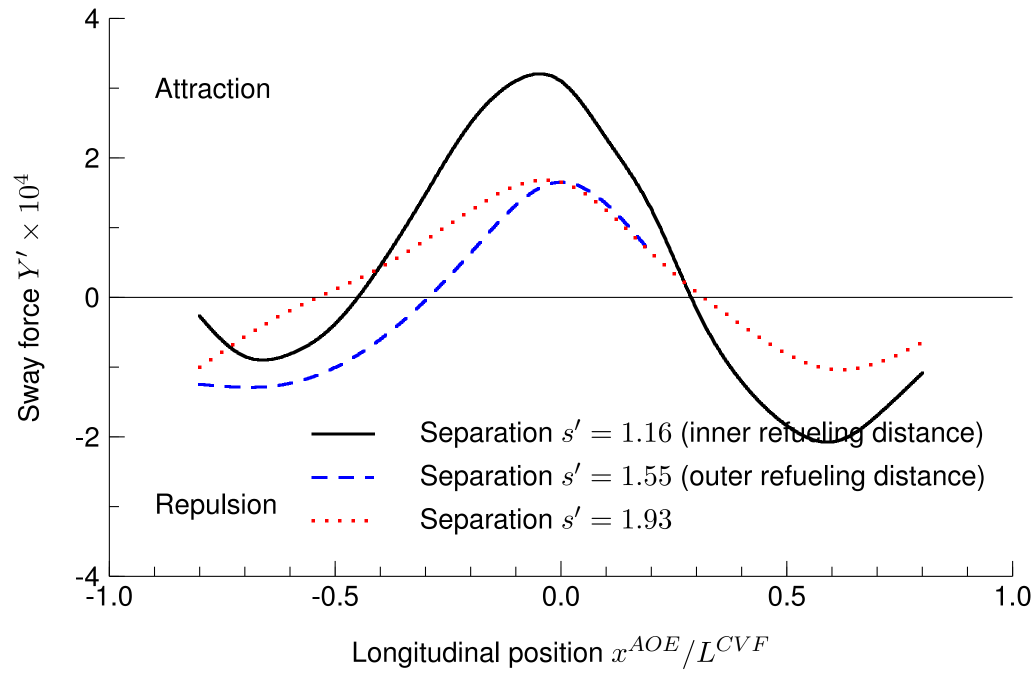


***Figure 7:*** *Support Ship AOE Sway Interaction Force at 20 knots from Layne [1]*

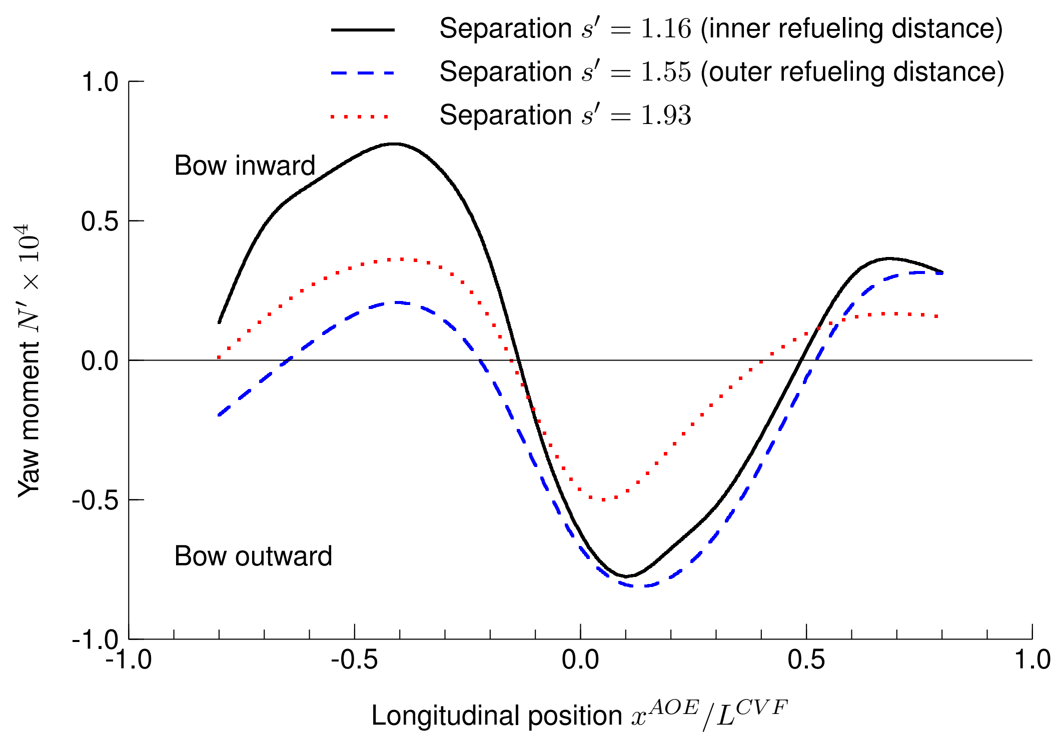


***Figure 8:*** *Support Ship AOE Yaw Interaction Moment at 20 knots from Layne [1]*

# 5 Conclusions

It is unlikely that hydrodynamic interaction effects were a factor in causing a collision between FREDERICTON and KANAWHA. The ships had a non-dimensional lateral separation of 3.0 when FREDERICTON commenced unexpected motion behaviour. Available data suggest that hydrodynamic interaction forces at the onset of unexpected motion behaviour were likely less than 10 percent of hydrodynamic interaction forces that would have been experienced when closer to the alongside refuelling position. During replenishment operations, ships typically have forward speed Froude numbers less than 0.2. Under such conditions, wave-making effects will be small, simplifying analysis of flow conditions.

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# Symbols and Abbreviations

| | |
|---|---|
| $B$ | ship beam |
| FRE | HMCS FREDERICTON |
| $g$ | gravitational acceleration |
| KAN | USNS KANAWHA |
| $L$ | ship length |
| $N$ | interaction yaw moment |
| $N'$ | nondimensional interaction yaw moment |
| NOTC | Naval Officers Training Centre |
| $s'$ | non-dimensional lateral separation (beam to beam) between ships |
| $T$ | ship draft |
| $U$ | ship forward speed |
| $u$ | longitudinal velocity of flow near hemisphere |
| $V$ | ship total velocity in horizontal plane |
| $v$ | lateral velocity of flow near hemisphere |
| $x$ | longitudinal position along course of USNS KANAWHA |
| $Y$ | interaction sway moment |
| $Y'$ | nondimensional interaction sway moment |
| $y$ | lateral position relative to course of USNS KANAWHA |
| $\Delta x'$ | non-dimensional relative longitudinal distance between ship positions |
| $\Delta y$ | lateral distance between ship positions |
| $\chi$ | ship course made good |
| $\psi$ | ship heading |

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HMCS FREDERICTON collided with USNS KANAWHA on 18 November 2010 while FREDERICTON was approaching KANAWHA for replenishment at sea. The ships were in calm water of depth greater than 600 m. VENTURE Naval Officers Training Centre (NOTC) requested that DRDC Atlantic investigate whether hydrodynamic interactions between the two ships contributed to the occurrence of the collision. It is unlikely that hydrodynamic interaction effects were a factor in causing a collision between FREDERICTON and KANAWHA. In the present report, the non-dimensional lateral separation is defined as the lateral separation distance divided by the beam of the larger ship. FREDERICTON and KANAWHA had a non-dimensional lateral separation of 3.0 when FREDERICTON commenced unexpected motion behaviour. Available data suggest that hydrodynamic interaction forces at the onset of unexpected motion behaviour were likely less than 10 percent of hydrodynamic interaction forces that would have been experienced when closer to the alongside refuelling position. During replenishment operations, ships typically have forward speed Froude numbers less than 0.2. Under such conditions, wave-making effects will be small, simplifying analysis of flow conditions.

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hydrodynamic interaction
maneuvering
replenishment at sea
ship motions