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Near-Surface Pilot Experiments with the Albert Model of the VCS

M. Mackay

Defence R&D Canada – Atlantic

Technical Memorandum
DRDC Atlantic TM 2008-187
October 2008

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Abstract

Early in 2008, a series of pilot near-surface experiments was done with the Albert model of the Victoria class submarine in the NRC Institute for Ocean Technology towing tank. These and other pilot tests were done to aid in planning a more extensive test program later in the year, the overall objective being to gather data on littoral manoeuverability. The near-surface results provide a look at the hydrodynamic loads imposed on the submarine operating between deep water and periscope depth in calm water. They are reviewed here in sanitized form.

Résumé

Au début de 2008, une série d'expériences pilotes près de la surface a été réalisée avec le modèle Albert du sous-marin de la classe Victoria dans le bassin d'essais des carènes de l'Institut des technologies océaniques du CNRC. Ces expériences et d'autres essais pilotes ont été réalisés pour aider à planifier un programme d'essais plus exhaustif plus tard au cours de l'année, l'objectif global étant de recueillir des données concernant la manœuvrabilité près du rivage. Les résultats près de la surface donnent un aperçu des charges hydrodynamiques qui s'exercent sur le sous-marin qui circule entre les grandes profondeurs et la profondeur périscopique en eaux calmes. Ces résultats sont ici passés en revue sous forme épurée.

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Executive Summary

Near-Surface Pilot Experiments with the Albert Model of the VCS

M. Mackay, DRDC Atlantic TM 2008–187, Defence R&D Canada – Atlantic, October 2008.

Introduction

Submarine operation in the littoral involves manoeuvering near the bottom, near the surface, or both. An extensive model test program has been proposed to investigate Victoria class submarine (VCS) littoral manoeuverability. In order to provide experience and guidance for planning this program, a number of pilot near-surface tests were done early in 2008; this memorandum reviews the results of those tests in sanitized form.

Results

The pilot experiments involved the 1/15 scale Albert model of the VCS between deep submergence and periscope depth in calm water in the NRC Institute for Ocean Technology towing tank. In ahead flight, the incremental normal force due to surface proximity was small and the corresponding pitching moment was negligible. Similar results were found with the model at an angle of drift, while the incremental sideforce, rolling moment, and yawing moment exhibited modest increases at shallow depth. Froude number (i.e., speed) was not a significant parameter in any of the experiments.

Significance

The influence of the surface appears unlikely to affect controllability below periscope depth. However, this will have to be corroborated by numerical studies.

Future Developments

Calm water near-surface effects will be included in numerical simulations to evaluate the influence of the incremental loads that are generated. Of likely greater significance are the forces induced by surface waves, and these will be a topic for future work.

Sommaire

Near-Surface Pilot Experiments with the Albert Model of the VCS

M. Mackay, DRDC Atlantic TM 2008–187, R&D pour la défence Canada – Atlantique, octobre 2008.

Introduction

L'utilisation d'un sous-marin près du rivage fait appel à des manœuvres près du fond, près de la surface ou les deux. Un programme d'essais de modèles exhaustif a été proposé dans le but d'étudier la manœuvrabilité des sous-marins de la classe Victoria près du rivage. Afin d'acquérir de l'expérience et de guider la planification de ce programme, un certain nombre d'essais pilotes près de la surface a été réalisé début 2008; le présent document passe en revue les résultats de ces essais sous forme épurée.

Résultats

Les expériences pilotes ont été effectuées avec le modèle Albert à échelle 1/15 du sous-marin de classe Victoria entre les grandes profondeurs et la profondeur périscopique en eaux calmes dans le bassin d'essais des carènes de l'Institut des technologies océaniques du CNRC. En marche avant, la force normale incrémentielle causée par la proximité de la surface était faible et le moment de tangage correspondant était négligeable. Des résultats semblables ont été obtenus avec le modèle à un angle de dérive, alors que la force latérale incrémentielle, le moment de roulis et le moment de lacet augmentaient légèrement en eau peu profonde. Le nombre de Froude (c.-à-d. la vitesse) n'était pas un paramètre significatif dans aucune des expériences.

Portée

Il est peu probable que la surface ait une incidence sur le contrôle sous la profondeur périscopique. Cependant, cela devra être corroboré par les études numériques.

Recherches futures

Les effets près de la surface de l'eau calme seront inclus dans simulations numériques afin d'évaluer l'incidence des charges incrémentielles qui sont produites. Les forces produites par les vagues de surface sont probablement d'une plus grande importance; elles feront l'objet de recherches futures.

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Acknowledgments

We gratefully acknowledge the contributions of IOT for their collaboration in these experiments and for support to the MDTF and Albert model. The IOT project manager for the February/March 2008 test program was Ahmed Derradji-Aouat. We thank all the IOT staff — too numerous to mention individually — involved in the preparation and conduct of the tests.

1 Introduction

DRDC and the NRC Institute for Ocean technology (IOT) have been collaborating on a series of experimental programs with the Albert model (IOT model 590) of the Victoria class submarine (VCS). For DRDC, the initial objective was to create an experimental database for the VCS with which to validate and improve numerical simulations of manoeuvering and emergency recovery. A static test program was done in 2004, and an incomplete series of dynamic tests in 2006 [1,2]. More recently a full set of dynamic and additional static tests were done in February/March 2008, completing the basic experimental database for the submarines.

Further tests are required to address specific areas of the hydrodynamic models in more detail, and also to account for expanded requirements for the VCS such as littoral operation. Anticipating that littoral operation would be the focus of the next major test program, a limited number of pilot, or exploratory, littoral experiments were added to the recent program. These experiments comprised about sixty tests with the model running close to the bottom, and a similar number with the model running close to the surface. They were devised to provide experience and guidance in planning the more comprehensive test program. Nevertheless, within limitations described here, the results are applicable to modeling littoral manoeuverability. The near-bottom results are documented in reference [3]. This report presents results obtained from the near-surface test series.

Although the near-surface experiments are applicable to the littoral in that a submarine may by necessity operate near the surface in shallow water, they are more correctly deep-water near-surface tests since the tank bottom and side clearances were what are normally required for deep water testing. The water was undisturbed before the passage of the model, so that the measured loads are steady and due to the proximity of the boundary and to wavemaking. Near-surface operation in a seaway excites additional steady and unsteady loads [4]; they may be measured in future experiments.

Submarine hydrodynamic data are generally scarce in the open literature, notably so for littoral operations, and there are few other data for comparison. In the early 1990s, several series of experiments were done to generate systematic deep-water near-surface data for a model of the Canada-Netherlands Standard Submarine. This has a generic hullform [5] that is similar in proportions to that of the VCS. Trends in the present results appear to be consistent with those observed for the fully-appended Standard Submarine.

This report does not include comparison with numerical predictions. Calculating the near-surface loads in calm water is complicated by the need to realistically model the surface itself. At low Froude numbers the surface can be approximated by a rigid boundary, analogous to near-bottom flight [3]. Otherwise, either the boundary must be relaxed to the surface produced by wave-making or the boundary condition must be modified to an equivalent normal component of flow. These procedures exceed the scope of the present effort, and we shall make near-surface numerical modeling a separate task.

To permit the widest distribution of this report, the data presented herein are sanitized by omitting vertical scales from the graphs.

2 Model Experiments

Albert is a model of the VCS at approximately 1/15 scale, figure 1. For these tests it was in the fully appended configuration, including extended bowplanes and the foredeck sonar fairing. Because the model is attached to a sting in the tail, it has no propeller. The sting mounting is provided by the Marine Dynamic Test Facility (MDTF), figure 2, which, in use, is installed in the test frame of the Clearwater Towing Tank carriage at IOT in St. John's, NL. Figure 3 shows CAD sketches of the test arrangement. The towing tank is 200 m long, 12 m wide, and 7 m deep, giving a typical run of about 30 seconds at a carriage speed of 4 m/s (a typical value for submarine testing with the MDTF — the maximum is 10 m/s).

The MDTF can manoeuver the captive model in any simultaneous combination of heave, pitch, sway, and yaw motions. Loads on the model are measured by an internal six-component balance. Model motions and attitudes are measured by an on-board PHINS inertial system (`www.ixsea.com`), supplemented by a MotionPak inertial system (`www.systron.com`), inclinometers for pitch and roll, and fore and aft triplets of accelerometers. All the data channels are sampled at a rate of 50 s^{-1}. Reference 2 contains more details on submarine model testing with the MDTF.

Parameters for each test run are listed in annex A. Model attitudes, loads, etc., were measured in body-fixed coordinates with the origin O on the pressure hull axis at the LCB. However, following standard submarine practice, the depth of the model was measured from the keel, 304 mm below O at model scale. Thus, the depth parameter d is depth of the keel at the LCB, figure 4. The smallest value, $d = 1204$ mm, corresponds roughly to periscope depth at full scale; the greatest, $d = 2304$ mm, is about 4.5 hull diameters, where we normally assume the effect of the free surface to be negligible in model experiments.

Test carriage speeds U_c were 0.5, 1.0, 1.5, and 2.0 m/s. They correspond to Froude numbers ($F_r = U_c/\sqrt{g\ell}$, where g is gravity and ℓ is hull length) equal to 0.0737, 0.147, 0.221, and 0.295 respectively. In the discussions below these values are rounded to nominal Froude numbers: 0.075, 0.15, 0.225, and 0.3. Half the tests were done with a nominal — zero speed — drift angle of 5 degrees.

3 Data Reduction

Structural compliance of the MDTF/balance/model system gives rise not only to deflections under load, noted in annex A, but to vibrations. Balance vibration is illustrated in annex I of reference 1. In analyzing the near-bottom littoral experiments, short time histories under nominally steady conditions required smoothing of the data as described in reference [3]. However, data smoothing was not required for the present study, in which near-surface time histories were 30 seconds long, figure 5, so load estimates were obtained by averaging the raw data directly. In a few cases where data smoothing was tried as a quality check, the difference between the means of the raw and smoothed data was negligible. Data averaging was done with `Origin` 7.5 software (`www.originlab.com`).

4 Results

The loads on the model are presented, in each case, as a set of curves, one for each Froude number, plotted against depth d, and also as a set of curves, one for each depth, plotted against Froude number. Although numerical values are not given, the loads are nondimensionalized in the usual manner [1] to eliminate carriage speed as a direct parameter. For example, the nondimensionalized normal force and pitching moment are:

$$Z' = \frac{Z}{\frac{1}{2}\rho\ell^2 U_c^2} \; , \quad M' = \frac{M}{\frac{1}{2}\rho\ell^3 U_c^2} \tag{1}$$

Since a sting support compromises accurate measurement of longitudinal force, the axial force X' is not discussed this report.

The averaging algorithm in `Origin` provides an estimate of standard error of the mean (SEM) of the data. Error bars corresponding to ± 2 SEM are appended to each data point. As the averaging was done here on raw, not smoothed, data, the error bars are typically larger, and perhaps better representative of uncertainty, than those found in the near-bottom test report [3].

4.1 Ahead Runs

The loads of interest in ahead runs are the normal force Z' (directed downwards, see Nomenclature), figure 6, and pitching moment M', figure 7. Both decrease as depth is reduced, resulting in an upward force and bow down pitching moment with respect to deep submergence. Since over the range of depth in these experiments they are of the same order as the deep submergence loads (nondimensionally Z'_* and M'_*, see reference [1]), the incremental loads are quite small and would require only minor deflections of the control planes to compensate for.

While there may be some systematic variation of the loads with Froude number, it is very small — almost within experimental uncertainty for Z', and clearly within it for M'. This is consistent with the Standard Model results, in which $F_r = 0.3$ was considered to be the limit of low speed near-surface operation.

4.2 At 5 Degrees Drift

At an angle of drift, Z' and M' are increased significantly from their ahead values by the out-of-plane force and moment [6]. The out-of-plane force was reduced to about half at the shallowest depth tested, figure 8, while the moment was, apart from some irregularity at $F_r = 0.15$, unaffected by depth, figure 9. Since the out-of-plane loads themselves do not normally constitute a problem for control, the reduction in the force at shallow depth is unlikely to do so.

The effect of Froude number is irregular and again fairly small, although the largest apparent variation, for $d = 2304$ mm in figure 8(b), occurs (for reasons unknown) at deep submergence rather than near-surface. Froude number variation of both force and moment is essentially within experimental uncertainty at the other depths tested.

At an angle of drift there are in-plane loads present that are significantly larger: side-force Y', rolling moment K', and yawing moment N', the results for which are plotted in figures 10 to 12. All three show a relatively small increase as depth decreases. This agrees with the trend for in-plane coefficients observed with the Standard Model. The principal mechanism involved is modification of circulation about the sail in the proximity of the surface.

There is little in figures 10 to 12 to suggest that Froude number is a significant parameter other than, perhaps marginally, at the shallowest depths tested.

5 Concluding Remarks

This memorandum records a pilot study of near-surface effects using captive model experiments with the Albert model of the VCS. The test conditions comprised variations of depth and model speed with the model in ahead flight and at a 5 degree angle of drift in calm water.

Between approximately periscope depth and deep submergence, the incremental normal force due to depth was quite small, and the pitching moment virtually negligible, in all the experiments. Changes in the in-plane loads at an angle of drift were similarly small. Nevertheless, to corroborate whether the calm water incremental loads constitute a control problem, we will have to include them in numerical simulations to see their effect on specific manoeuvers. Variation in Froude number between 0.1 and 0.3 introduced small irregular perturbations in the incremental loads, but it was, for practical purposes, a negligible parameter at the depths tested.

The model was not propelled in these experiments. Since a propulsor can modify flow over the afterbody of the submarine, further study is needed to establish the significance of propulsion on the near-surface loads. Future investigations will also examine the influence of surface waves on the submerged submarine.

References

References denoted Limited Distribution are not, for proprietary and other reasons, available for public release.

1. Mackay, M. (2007). Hydrodynamic Coefficients for the fully-Appended Albert Model: 2004 and 2006 Test Programs. DRDC Atlantic TM 2007–178. Defence R&D Canada. Limited Distribution.

2. Mackay, M., Williams, C.D., and Derradji-Aouat, A. (2007). Recent Model Submarine Experiments with the MDTF. 8th Canadian Marine Hydromechanics and Structures Conference. St. John's, NL.

3. Mackay, M. (2008). Near-Bottom Pilot Experiments with the Albert Model of the VCS. DRDC Atlantic TM 2008–172. Defence R&D Canada.

4. Field, A. (2000). SubMo3: a Frequency Domain Simulation Tool for Submarine Motion in Waves, and its use with Maneuvering Models. DREA CR 2000–049. Defence Research Establishment Atlantic.

5. Mackay, M. (2003). The Standard Submarine Model: a survey of Static Hydrodynamic Experiments and Semiempirical Predictions. DRDC Atlantic TR 2003–079. Defence R&D Canada.

6. Mackay, M. (2004). A Review of Submarine Out-of-Plane Normal Force and Pitching Moment. DRDC Atlantic TM 2004–135. Defence R&D Canada.

Figure 1. Albert model in the preparation area, before mounting on the MDTF.

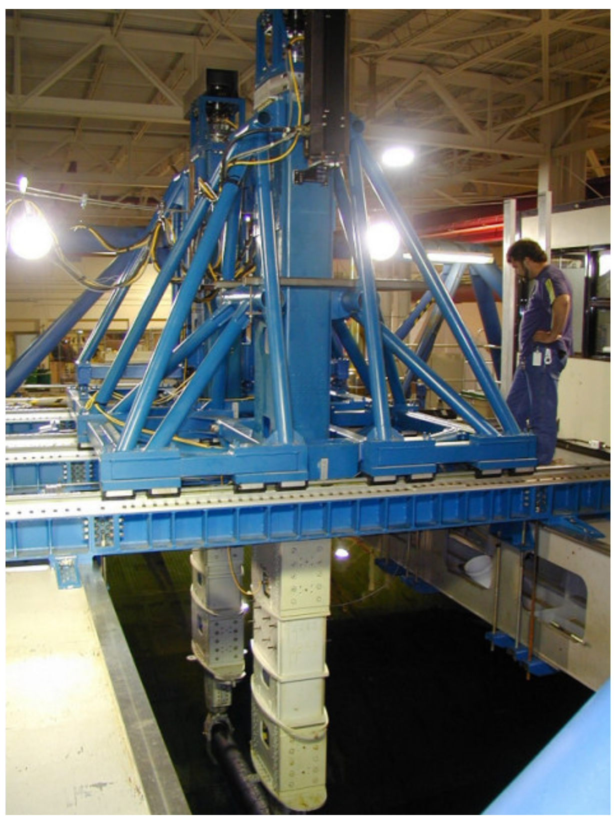
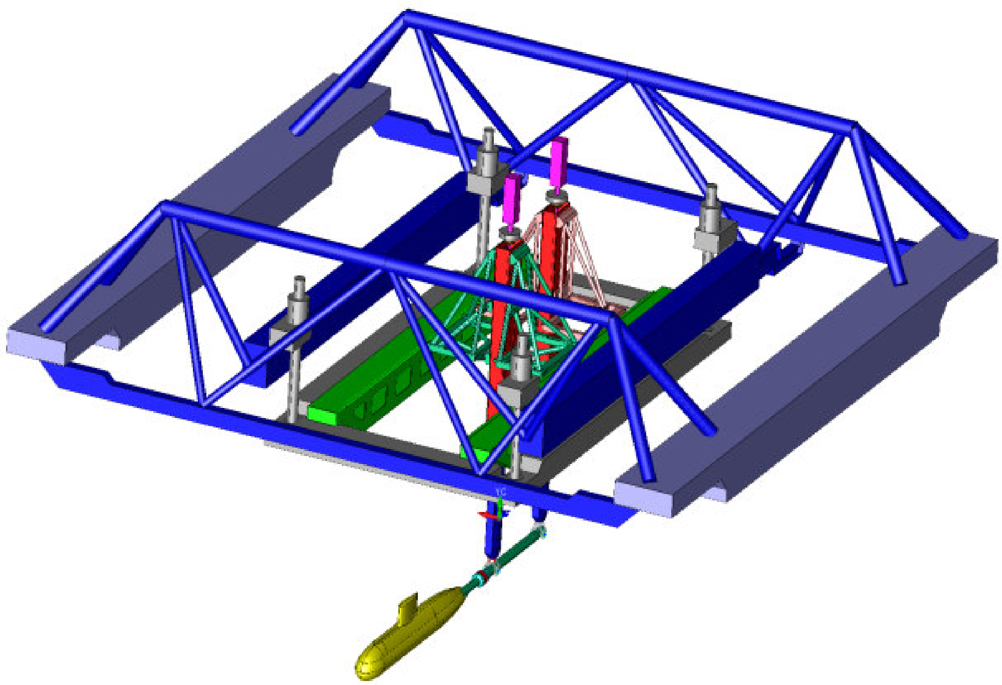
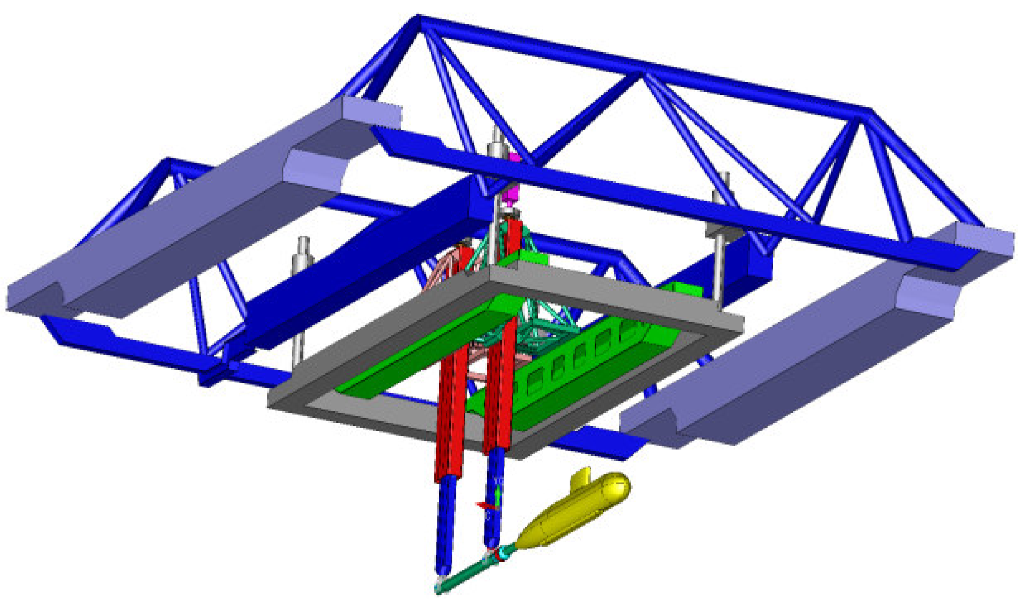


Figure 2. MDTF, viewed from the deck of the towing tank carriage.



(a)



(b)

Figure 3. CAD sketches of the test arrangement, (a) from above and (b) from below. The towing carriage structure is rendered in blue, and the adjustable test frame, which is part of the carriage, in grey and green.

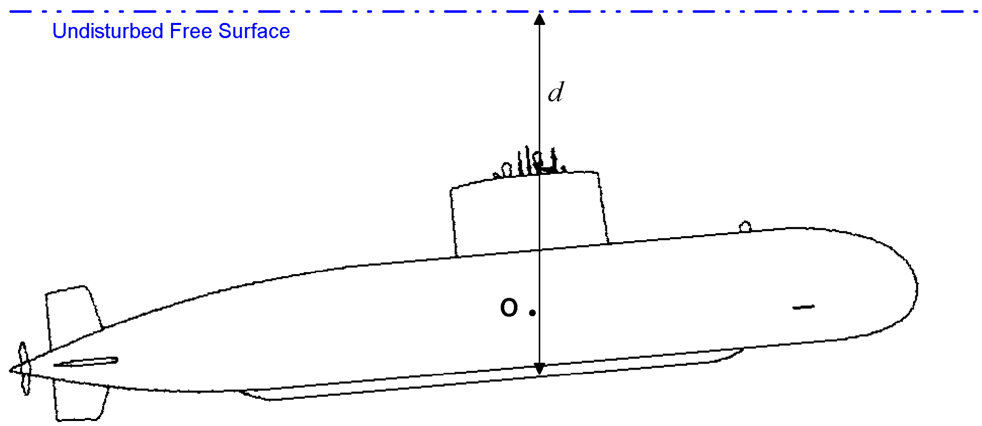


Figure 4. Depth parameter d. (The submarine is shown at 5 degrees pitch.)

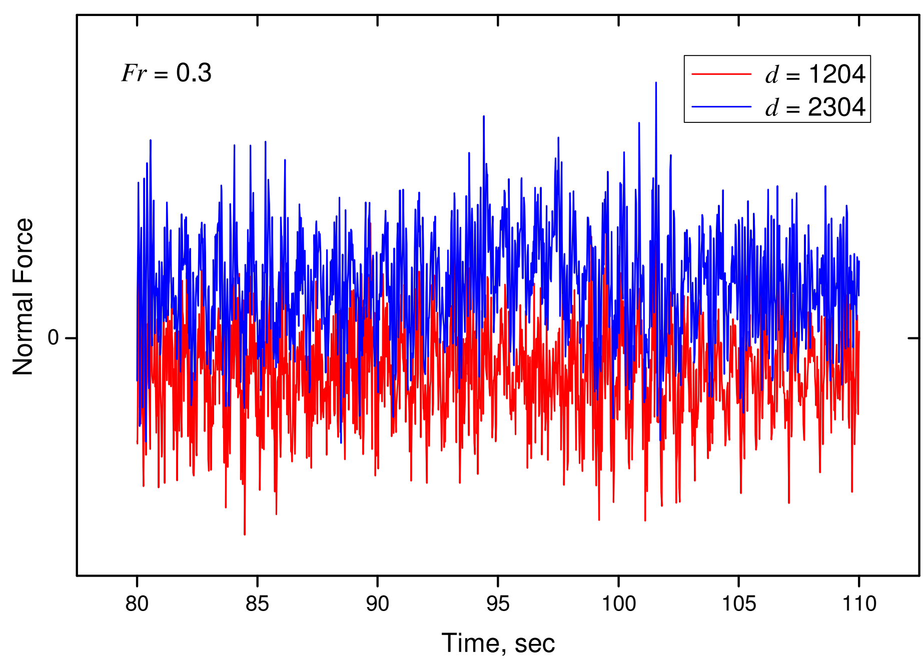
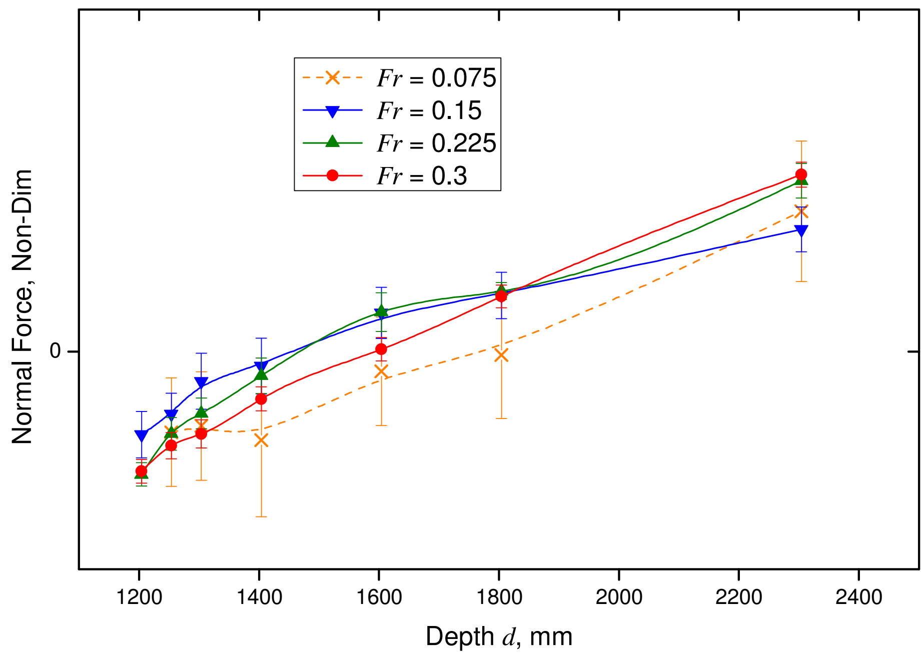
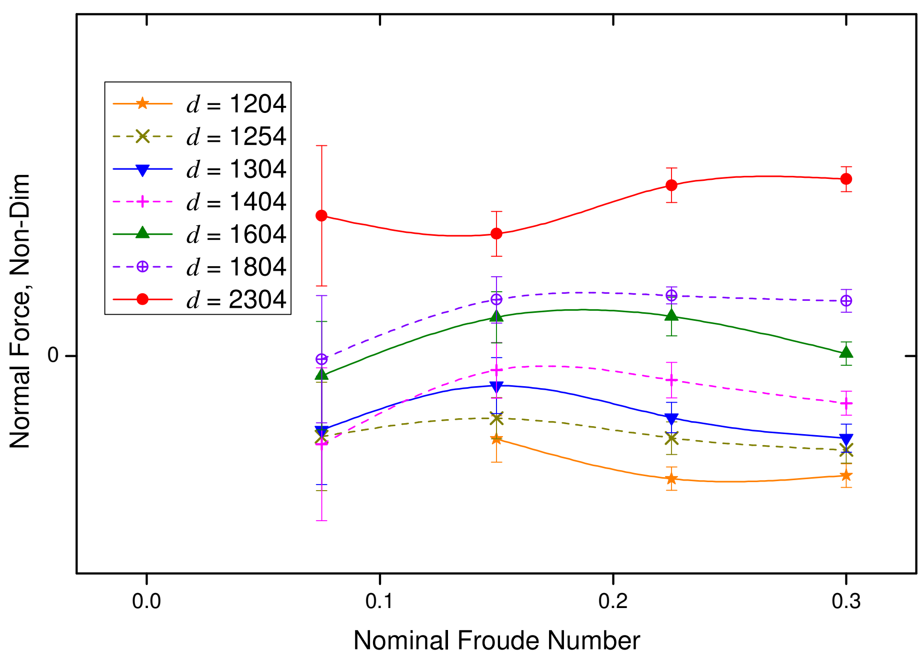


Figure 5. Raw data time histories of normal force at minimum and maximum depth, $F_r = 0.3$; d is in mm.

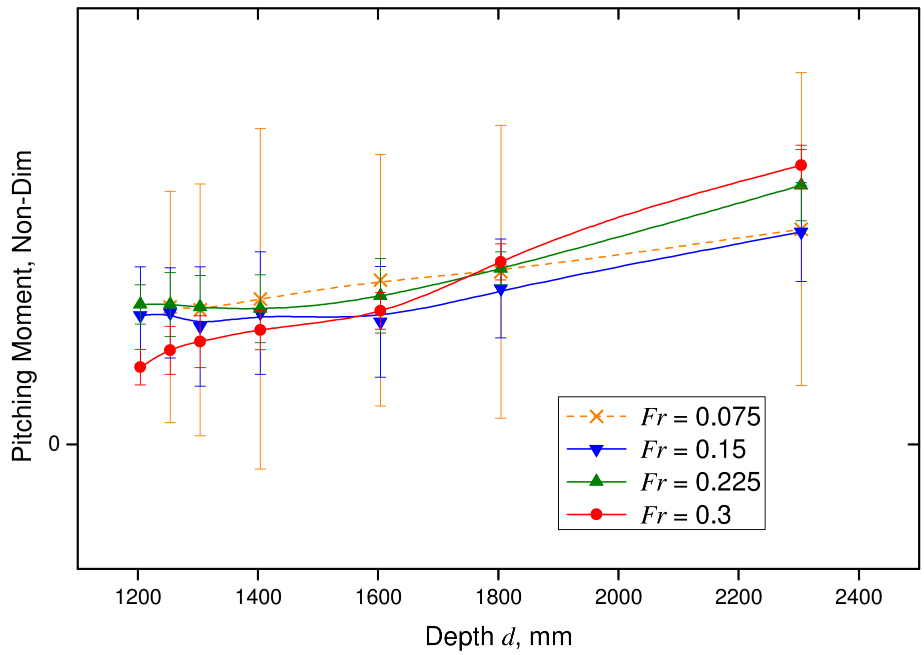


(a) *vs* depth.

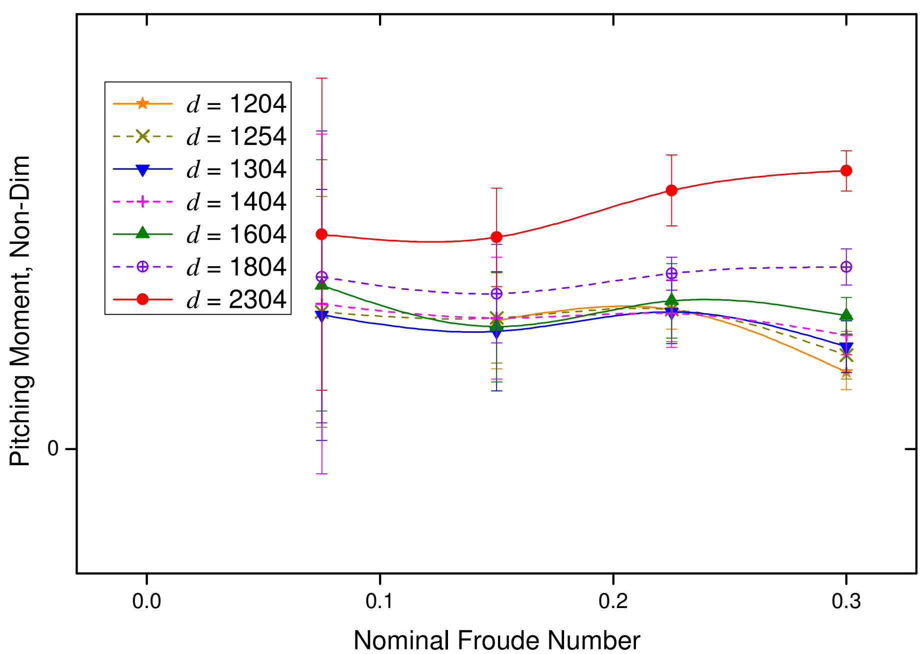


(b) *vs* Froude number; d in mm.

Figure 6. Normal force going ahead.

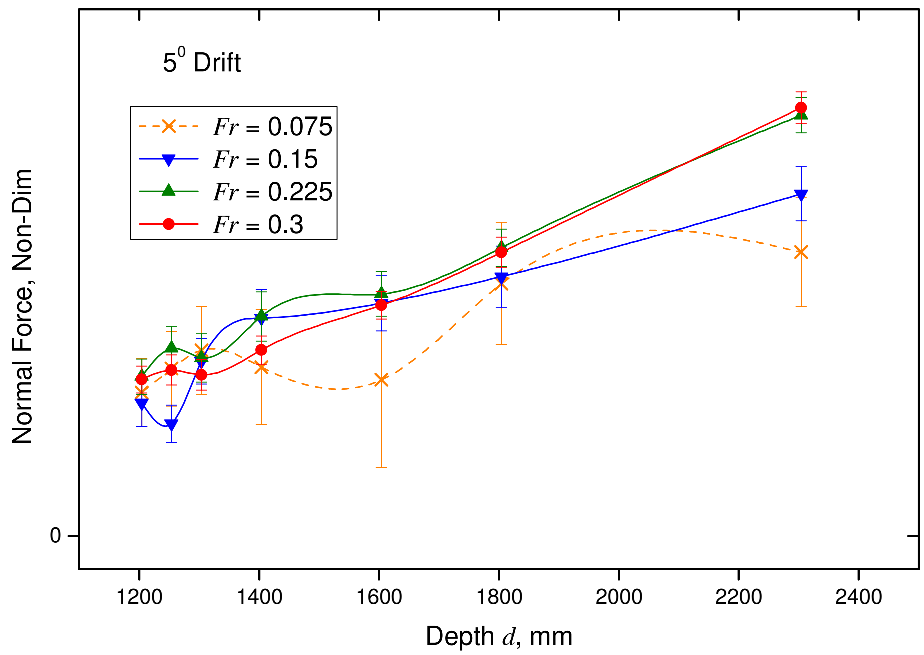


(a) *vs* depth.

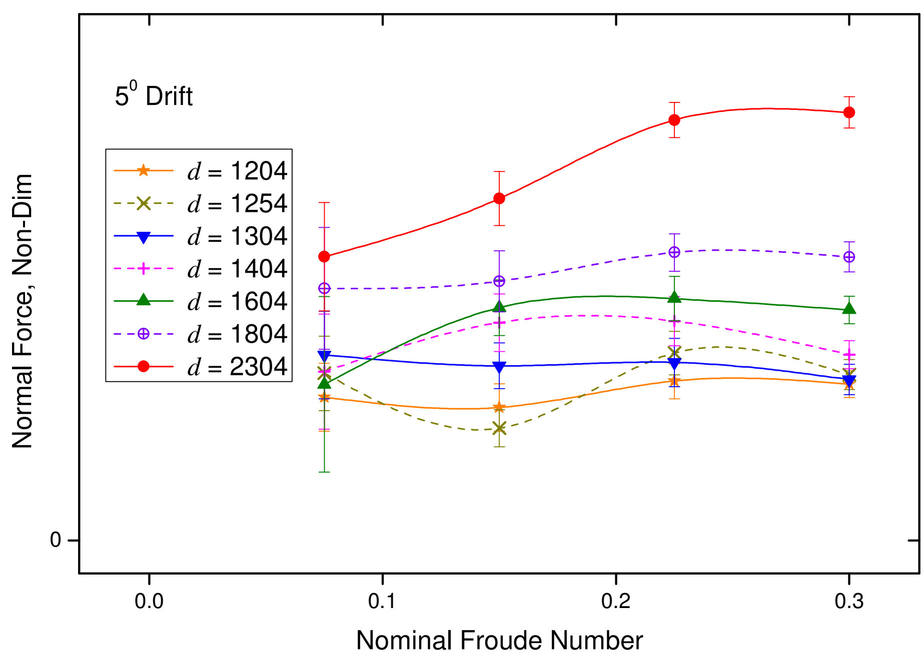


(b) *vs* Froude number; d in mm.

Figure 7. Pitching moment going ahead.

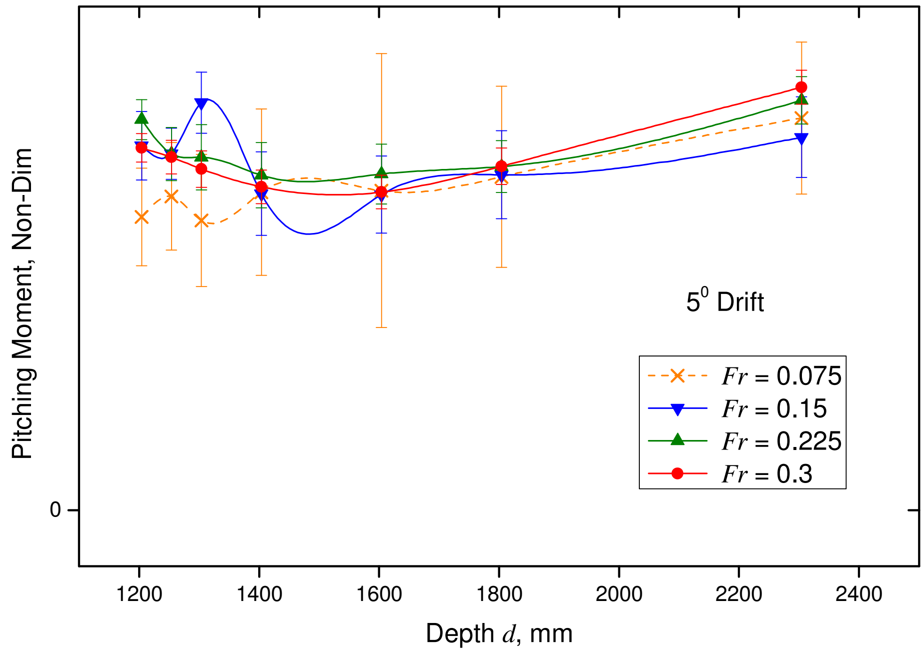


(a) *vs* depth.

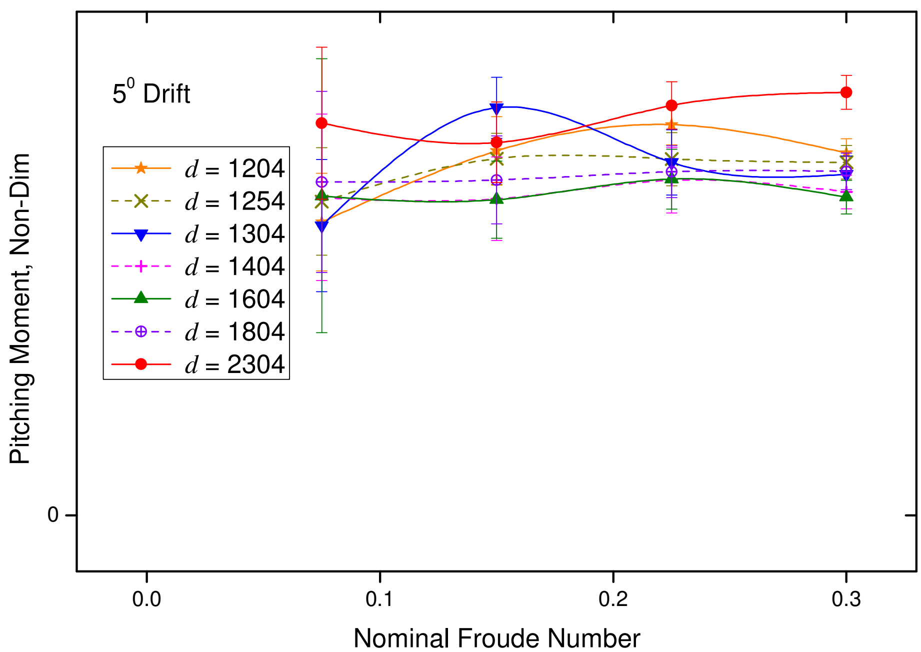


(b) *vs* Froude number; d in mm.

Figure 8. Normal force at 5 degrees drift.

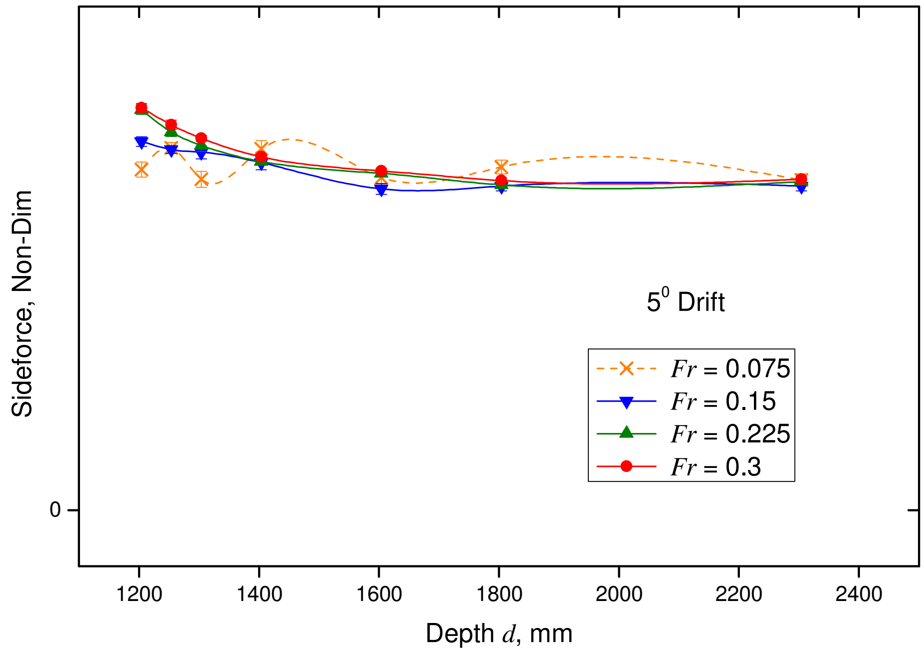


(a) *vs* depth.

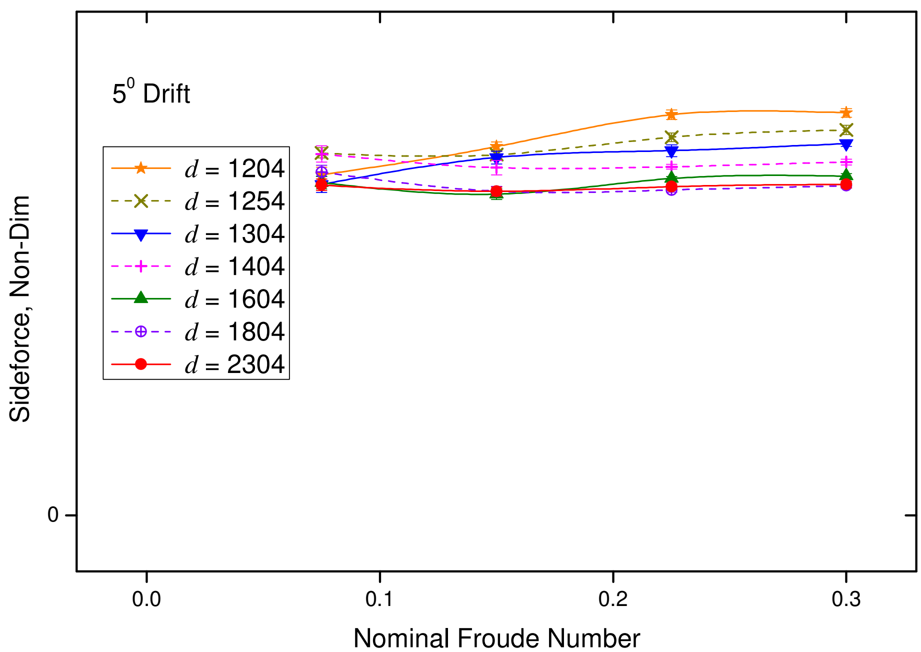


(b) *vs* Froude number; d in mm.

Figure 9. Pitching moment at 5 degrees drift.

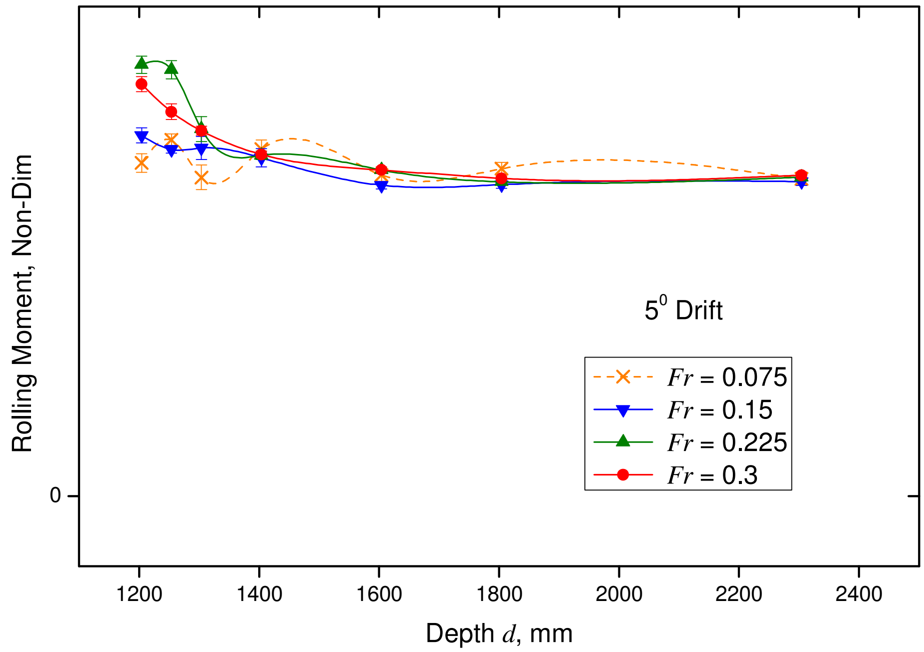


(a) *vs* depth.

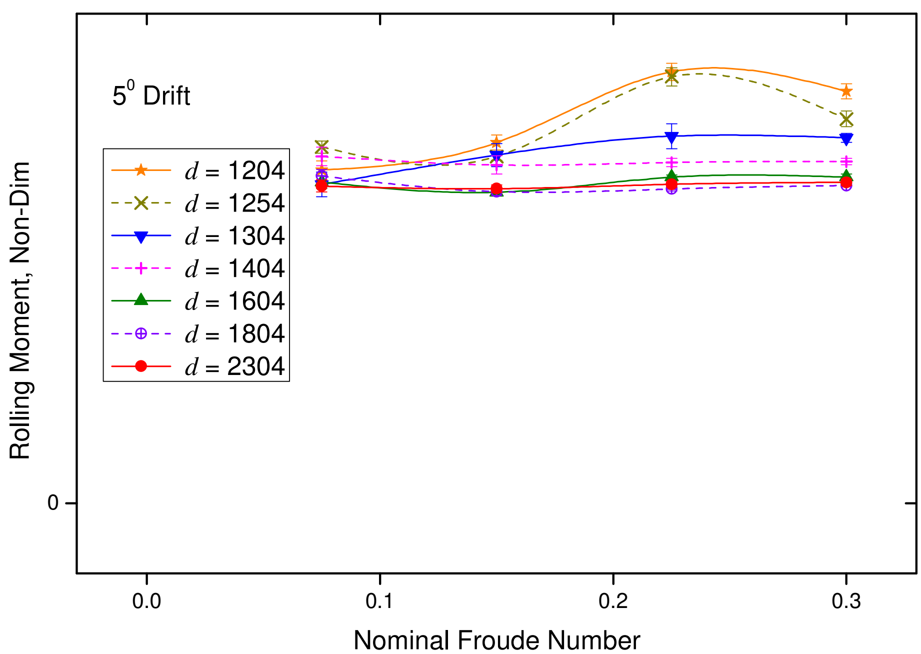


(b) *vs* Froude number; d in mm.

Figure 10. Sideforce at 5 degrees drift.

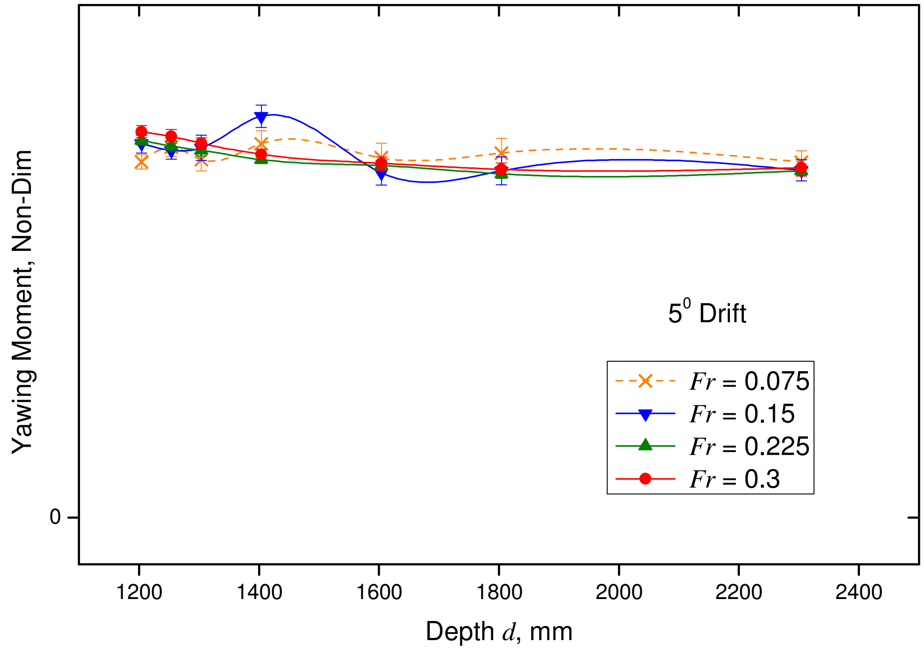


(a) *vs* depth.

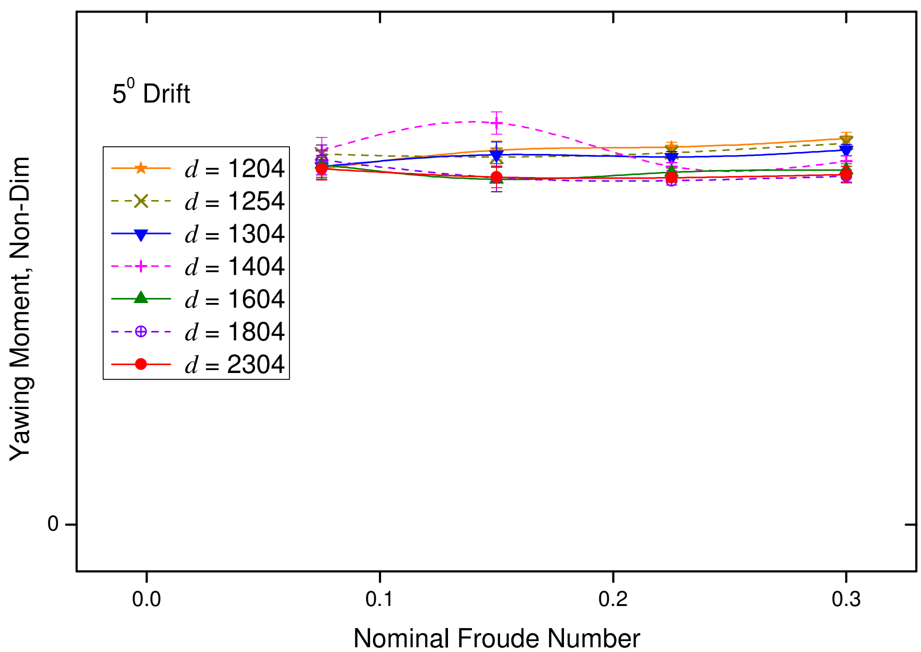


(b) *vs* Froude number; d in mm.

Figure 11. Rolling moment at 5 degrees drift.



(a) *vs* depth.



(b) *vs* Froude number; d in mm.

Figure 12. Yawing moment at 5 degrees drift.

Annex A. 2008 Pilot Near-Surface Test Runs

In the following table U_c is the speed of the towing carriage. Depth and the angle of drift are the nominal values at zero speed. Both are likely to be different under load because of structural compliance of the MDTF (and to a much lesser extent, of the balance and model). Correction for this is the subject of an ongoing study.

Table A.1. Pilot Near-Surface Run Parameters.

Run	d mm	U_c m/s	Drift, deg
1	2304	0.5	0
2	2304	1.0	0
3	2304	1.5	0
4	2304	2.0	0
5	2304	0.5	5
6	2304	1.0	5
7	2304	1.5	5
8	2304	2.0	5
9	1804	0.5	0
10	1804	1.0	0
11	1804	1.5	0
12	1804	2.0	0
13	1804	0.5	5
14	1804	1.0	5
15	1804	1.5	5
16	1804	2.0	5
17	1604	0.5	0
18	1604	1.0	0
19	1604	1.5	0
20	1604	2.0	0
21	1604	0.5	5
22	1604	1.0	5
23	1604	1.5	5
24	1604	2.0	5
25	1404	0.5	0
26	1404	1.0	0
27	1404	1.5	0
28	1404	2.0	0
29	1404	0.5	5
30	1404	1.0	5
31	1404	1.5	5
32	1404	2.0	5

Run	d mm	U_c m/s	Drift, deg
33	1304	0.5	0
34	1304	1.0	0
35	1304	1.5	0
36	1304	2.0	0
37	1304	0.5	5
38	1304	1.0	5
39	1304	1.5	5
40	1304	2.0	5
41	1254	0.5	0
42	1254	1.0	0
43	1254	1.5	0
44	1254	2.0	0
45	1254	0.5	5
46	1254	1.0	5
47	1254	1.5	5
48	1254	2.0	5
49	1204	0.5	0
50	1204	1.0	0
51	1204	1.5	0
52	1204	2.0	0
53	1204	0.5	5
54	1204	1.0	5
55	1204	1.5	5
56	1204	2.0	5

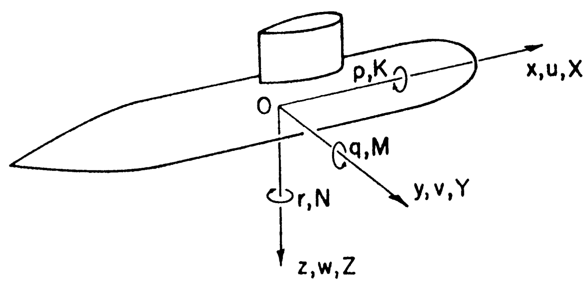
Nomenclature

Primed quantities are nondimensionalized as in equation (1).

Symbols

d	depth of the keel at LCB
K, M, N	roll, pitch, and yaw moment
ℓ	reference length for nondimensionalizing, typically LBP
p, q, r	roll, pitch, and yaw rate; also see r below
r	axisymmetric hull radius
u, v, w	axial, lateral, and normal velocity
U_c	carriage speed
x, y, z	body-fixed axes, see sketch below
X, Y, Z	axial, lateral, and normal forces
ρ	density of water

Coordinate System



Acronyms

CAD	Computer Aided Design
IOT	Institute of Ocean Technology
LCB	Longitudinal Center of Buoyancy
MDTF	Marine Dynamic Test Facility
MARIN	Maritime Research Institute Netherlands
NRC	National Research Council Canada
SEM	Standard Error of the Mean
VCS	Victoria Class Submarine

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13. ABSTRACT

Early in 2008, a series of pilot near-surface experiments was done with the Albert model of the Victoria class submarine in the NRC Institute for Ocean Technology towing tank. These and other pilot tests were done to aid in planning a more extensive test program later in the year, the overall objective being to gather data on littoral manoeuverability. The near-surface results provide a look at the hydrodynamic loads imposed on the submarine operating between deep water and periscope depth in calm water. They are reviewed here in sanitized form.

14. KEYWORDS
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