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Duisburg Test Case Containership Squat Prediction using ShallowFlow Software

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"If ignorance is bliss, then knock the smile off my face"
- Rage Against the Machine

Abstract

The 2013 Duisburg ship squat benchmarking workshop involves an (almost) blind validation of ship squat prediction methods against model test experiments for a Duisburg Test Case (DTC) containership. The benchmarking hull is described in El Moctar et al. (2012), and an IGES file was supplied for this hull.

One set of benchmarking tests was done for a towed model in a rectangular canal. Another set of benchmarking tests was done for a self-propelled model in an asymmetric canal. This report describes ShallowFlow squat predictions for both sets of benchmarking tests.

1. ShallowFlow software

ShallowFlow is a code for predicting ship squat, developed at the Centre for Marine Science and Technology (CMST) at Curtin University. It is based on slender-body shallow-water theory, originally developed by Tuck (1966,1967). For longitudinally-constant water depth, as in this benchmarking test case, the shallow-water equations are solved by Fourier transform in the longitudinal direction, which allows a wide range of transverse bathymetry profiles to be modelled. The method is described in detail in Gourlay (2008).

2. Towed model in rectangular canal

We shall first consider the case of a towed DTC containership model in a rectangular canal. These tests were primarily for resistance prediction, but sinkage and trim were also measured. The ship and canal configuration is shown in Figure 1, for the DTC containership at full scale. Model tests were performed at 1:40 scale.

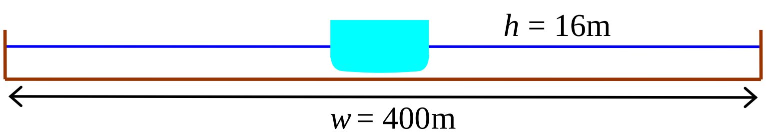

Figure 1: Modelled ship and canal configuration (approximately to scale) for towed model in rectangular canal

For the rectangular canal, raw ShallowFlow calculations used the method described in §3 of Gourlay (2008), which contains only slight modifications to the original theory of Tuck (1967).

2.1 Empirical corrections for towed model

Tuck's method is known to under-predict the LCF sinkage of towed cargo ship models by around 20-25% (see e.g. Gourlay 2006). Tuck's method uses both a linearized hull-boundary condition, and a linearized free-surface boundary condition. In order to check the relative importance of each assumption, the sinkage force on the equivalent double-body was calculated using CMST's HullWave software, which uses a fully-nonlinear hull boundary condition, through the panel method of Hess and Smith (1964). The double-body flow approximates to the free-surface flow in the limit of small depth Froude number, when the free surface becomes effectively rigid. These comparisons showed that methods using the linear or nonlinear hull-boundary condition gave almost identical results for cargo ships.

Therefore we conclude that the under-prediction of LCF sinkage for a towed model is not due to linearization of the hull-boundary condition, except as coupled to the free-surface boundary condition. ShallowFlow calculations for the DTC containership suggest that rearward flow velocities for the DTC containership are up to 24% of the ship speed for the towed model test case. The linearized free-surface boundary condition neglects terms proportional to the square of this ratio, which are not negligible. Furthermore, the sign of these neglected terms results in an under-prediction of the sinkage.

In ShallowFlow, we account for errors due to free-surface nonlinearities by applying a multiplicative empirical correction to the LCF sinkage. This correction has been found to be approximately constant across the speed range for bulk carriers. Unfortunately, no other towed model containership squat measurements could be found to compare this empirical correction factor with.

Initial calculations for the supplied test case data point showed that for the DTC containership the experimental LCF sinkage was 23% larger than the raw ShallowFlow predictions. This is a similar correction to what is applied for bulk carriers, as described above. This empirical correction has been applied as a multiplicative correction to all the towed model results.

In calculating dynamic trim, Tuck's method is known to predict a more bow-down (or less stern-down) trim than is measured in towed model tests. This is primarily due to viscous energy dissipation in the boundary layer of a towed model, which decreases the stern pressure as compared to inviscid predictions. In the comparisons given in Gourlay (2006), it was found that the measured trim was approximately 0.0005 radians less bow-down than predicted, for Froude depth numbers of 0.3 to 0.5.

Dynamic trim calculations for the supplied DTC towed model data point showed a calculated dynamic trim of 0.00040 radians bow-down, as opposed to a measured result of 0.000003 radians stern-down, at a model speed of 0.791m/s. Therefore we have added an empirical dynamic trim correction of 0.00040 radians stern-down at this speed. To make the dynamic trim correction physically consistent, we shall scale it according to the Froude depth number squared at other speeds.

2.2 Final results for towed model in rectangular canal

Final results from ShallowFlow software with empirical corrections are shown in Table 1. These will be compared with measured results following their publication at the 2013 Duisburg ship squat workshop.

Towing speed (m/s)	Froude number F_n	Trim (minutes of degree, +ve stern-down)	Midship sinkage (mm)
0.475	0.051	0.0	3.9
0.632	0.067	0.0	7.2
0.791	0.084	0.0	11.8
0.949	0.101	-0.1	18.1
1.027	0.109	-0.2	22.0

Table 1: Calculated sinkage and trim (at model scale) for towed model in rectangular canal

3. Self-propelled model in asymmetric canal

ShallowFlow assumes non-lifting flow, which is only strictly valid for canal configurations that are symmetric about the ship centreline. The canal configuration tested here is not strongly asymmetric, so a non-lifting approach is reasonable. According to slender-body shallow-water theory, the most important canal parameters regarding squat are the canal's cross-sectional area, depth in the vicinity of the ship, and waterline width (Gourlay 2008). Therefore, the test case has been modelled with the ship travelling along the centreline of a symmetric canal. This canal has the same waterline width, cross-sectional area and depth at the ship, as the test case. The modelled ship and canal configuration is shown in Figure 2.

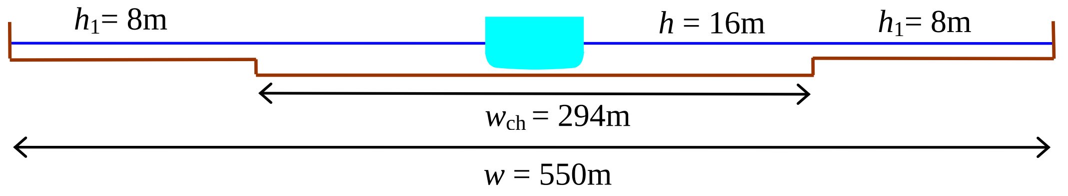

Figure 2: Modelled ship and canal configuration (approximately to scale) to represent self-propelled model in asymmetric canal

With this canal configuration, the squat is calculated as described in §5 of Gourlay (2008) for a stepped canal. Compared to the 16m depth open-water situation at the same speed, it is predicted that the LCF sinkage in the canal is 30% larger at 6 knots and 49% larger at 14 knots.

3.1 Effect of self-propulsion

Compared to a towed model, a self-propelled model tends to have much lower pressure just ahead of the propeller (Tahara et al. 2006, Fig. 24). This results in a greater LCF sinkage and more stern-down (or less bow-down) dynamic trim. Model test comparisons between towed and self-propelled cases include:

1. Duffy (2008, Figs. 3.22-3.25) found that for a MarAd bulk carrier, self-propulsion increases the sinkage force by 18-34% across the speed and depth range tested. Self-propulsion decreases the bow-down trim moment at (depth/draft)=1.2 by an almost

constant value, corresponding hydrostatically to 0.0010 radians of trim. However at (depth/draft)=1.1 the corresponding trim change varied from 0.0011 radians at Froude depth number 0.33, up to 0.0016 radians at Froude depth number 0.50.

2. Blaauw and van der Knaap (1983, §3.3.4) found that for a tanker, bow sinkage remains approximately the same, while midship sinkage increases by 5-10%.
3. Lataire et al. (2012, Figs. 16,17) found that for a VLCC, bow sinkage remains approximately the same, while stern sinkage was around 16% larger on average for the self-propelled model.
4. Delefortrie et al. (2010, Figs. 12,15) found that for a containership operating within the sediment layer, LCF sinkage was increased by 45% and stern-down trim increased by 0.0001 radians for the self-propelled model.

Note that the greater effect of self-propulsion in experiments (1) than experiments (2,3) for high-block-coefficient hulls may be partly due to the smaller Reynolds numbers of experiments (1).

3.2 Other comparisons of ShallowFlow with self-propelled experiments

Gourlay (2008a) shows measured sinkage and trim on full-scale containerships up to 352m length overall entering and leaving Hong Kong harbour, as compared with theoretical predictions from Tuck's method. Tuck's method was seen to generally under-predict the LCF sinkage for these containerships at full scale, although exact comparisons were not possible due to the complex bathymetry. Dynamic trim is quite sensitive to hull shape, so was difficult to calculate theoretically without the ships' full lines plans. Of the 20 full-scale containership transits analyzed, around half had a dynamic trim by the stern, and half by the bow (Gourlay & Klaka 2007).

Eloot et al. (2006, Fig. 2) describe self-propelled model test results for a 352m length overall, 42.8m beam, 14.5m draft containership in open water at 10% static UKC. These results correspond to an open-water LCF sinkage coefficient (Gourlay 2008) of 2.1, which is 50% larger than the raw ShallowFlow result of 1.4 for a similar hull. Based on the DTC towed model test case comparison described in §2, it is likely that around half this difference is due to errors in the bare hull flow, with a similar error due to the effect of self-propulsion.

3.3 Empirical corrections for self-propelled model

ShallowFlow does not model the effect of self-propulsion. Therefore, empirical corrections need to be made for the increase in LCF sinkage and stern-down trim due to self-propulsion.

Initial calculations for the supplied data point for the DTC hull showed that measured LCF sinkage was 44% larger than the raw ShallowFlow calculations. Using the results of §3, this suggests an increase of around 23% due to free surface nonlinearity, and 21% due to self-propulsion. Both of these corrections are thought to be multiplicative, so a multiplicative factor of 1.44 has been applied to all ShallowFlow LCF sinkage results as an empirical correction.

Initial calculations for the supplied data point for the DTC hull showed a calculated dynamic trim of 0.000425 radians bow-down, as opposed to a measured result of 0.000433 radians stern-down. Using the results of §2 (at approximately the same Froude depth number), this suggests a stern-down trim change of around 0.00040 radians due to viscous effects on stern pressure, and around 0.00046 radians due to self-propulsion.

We shall use this difference of 0.00086 radians stern-down as an empirical trim correction for all ship drafts, which is to be scaled according to Froude depth number squared. This empirical trim correction is to take account of viscous and self-propulsion effects on trim, which are not modelled in ShallowFlow software.

3.4 Final results for self-propelled model in asymmetric canal

Final results of the ShallowFlow software with empirical corrections, for the supplied test matrix, are shown in Table 2 and Table 3. These will be compared with measured results following their publication at the 2013 Duisburg ship squat workshop.

Draft (m) / Speed (knots)	14.5	14.0	13.0
6	0.21	0.22	0.22
8	0.40	0.40	0.41
10	0.65	0.66	0.68
12	1.01	1.02	1.04
14	1.53	1.54	1.57

Table 2: Calculated sinkage (metres) at 16.4m from transom, for self-propelled model in asymmetric canal. Values given at full scale.

Draft (m) / Speed (knots)	14.5	14.0	13.0
6	0.17	0.16	0.13
8	0.33	0.30	0.25
10	0.55	0.51	0.43
12	0.88	0.82	0.69
14	1.39	1.29	1.10

Table 3: Calculated sinkage (metres) at 363.2m from transom, for self-propelled model in asymmetric canal. Values given at full scale.

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