Ocean Engineering 126 (2016) 203–216

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

Practical estimation of sinkage and trim for common generic monohull ships

Chao Ma, Chenliang Zhang, Xi Chen, Yin Jiang, Francis Noblesse*

State Key Laboratory of Ocean Engineering, School of Naval Architecture, Ocean & Civil Engineering, Collaborative Innovation Center for Advanced Ship and Deep-Sea Exploration, Shanghai Jiao Tong University, Shanghai, China

ARTICLE INFO

Keywords:
Sinkage
Trim
Monohull ships
Practical approximations
Neumann-Michell theory

ABSTRACT

Two practical approaches for estimating the sinkage and the trim experienced by a freely floating ship that advances at a constant speed in calm water are considered for common monohull ships at moderate Froude numbers $F \le 0.45$: an experimental approach based on experimental data, given in the literature, for 22 ship models; and a numerical approach based on a practical linear potential-flow theory, the Neumann-Michell theory, that only requires simple flow computations. The experimental approach yields particularly simple analytical relations for the sinkage and the trim, and thus requires no flow computations. The numerical approach only involves flow computations for the ship hull in equilibrium position at rest; i.e., sinkage and trim effects on the position of the ship hull are ignored in these flow computations. Both approaches are found to yield reasonable predictions of sinkage and trim for a wide range of monohull ships at Froude numbers $F \le 0.45$.

1. Introduction

The pressure distribution around a ship hull surface Σ^H that advances at a constant speed V in calm water evidently differs from the hydrostatic pressure distribution around the wetted hull surface Σ_0^H of the ship at rest, i.e. at zero speed V=0. As a result, the ship experiences a hydrodynamic lift and pitch moment, and a related vertical displacement and rotation of Σ_0^H that are commonly called sinkage and trim, as well known and widely considered; e.g. Subramani et al. (2000), Yang et al. (2000, 2007), Yang and Löhner (2002), Ni et al. (2011), Yao and Dong (2012), He et al. (2015), Doctors (2015) and Chen et al. (2016). Fig. 1 illustrates the differences between the hull surface Σ_0^H of a ship at rest and the corresponding actual mean wetted ship hull surface Σ^H for three ship models at a Froude number $F = 0.4$.

The drag of the actual ship hull surface Σ^H can be significantly larger than the drag of the hull surface Σ_0^H, as well documented in the literature, e.g. Subramani et al. (2000), Yang et al. (2000), Ni et al. (2011), and Ma et al. (2016). For instance, Ma et al. (2016) shows that, at a Froude number $F = 0.45$, the Wigley hull and the S60 model experience an increase in total drag of about 15%, while the total drag of the DTMB5415 model is about 7% higher, due to sinkage and trim effects. These examples show that sinkage and trim effects on the drag of a ship can be significant and cannot be ignored, and moreover depend on the hull form. Thus, sinkage and trim effects on the drag need to be considered within the design process, even at early design stages and for hull form optimization.

As already noted, alternative methods for evaluating the sinkage and the trim experienced by a ship have been considered in the literature. In particular, the approach considered in Subramani et al. (2000), Yang et al. (2000), Yang and Löhner (2002), Ni et al. (2011), Yao and Dong (2012), He et al. (2015) and Chen et al. (2016) involve iterative flow computations for a sequence of hull positions. Such iterative flow computations are ill suited for routine practical applications to early ship design and hull form optimization. Indeed, practical methods for estimating the sinkage and the trim of a ship, notably methods that do not require iterative flow computations for several hull positions, are necessary to account for sinkage and trim effects on the drag at early design stages and for hull form optimization.

Two simple approaches — an 'experimental approach' and a 'numerical approach' — that do not require iterative flow computations for several hull positions, are considered here for typical freely floating (free to sink and trim) monohull ships that advance in deep water at moderate Froude numbers

$$F \equiv V/\sqrt{gL} \le 0.45$$

where V and L denote the speed and the length of the ship, and g is the acceleration of gravity. Both the simple numerical approach and the even simpler experimental approach considered here are found to yield realistic overall predictions of sinkage and trim for a wide range of

---

* Corresponding author.
E-mail address: noblfranc@gmail.com (F. Noblesse).

http://dx.doi.org/10.1016/j.oceaneng.2016.09.011
Received 20 April 2016; Received in revised form 22 July 2016; Accepted 7 September 2016

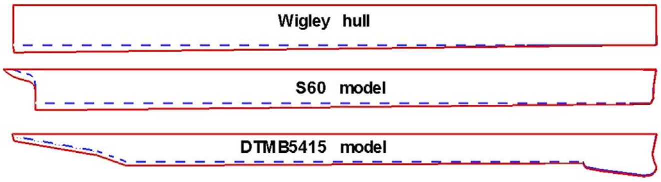

Fig. 1. Profiles of the wetted hull surfaces of the Wigley hull, the S60 model and the DTMB5415 model at rest (blue dashed lines) and in freely floating positions at Froude numbers F=0.4 (red solid lines). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

monohull ships at Froude numbers $F \leq 0.45$.

The experimental approach is based on an analysis of experimental measurements reported in the literature for 22 models of monohull ships. This analysis of experimental data yields particularly simple approximate analytical relations that explicitly predict the sinkage and the trim experienced by a monohull ship — without flow computation — in terms of the Froude number F and three main hull-shape parameters: the beam B, the draft D, and the block coefficient C_b.

The numerical approach involves flow computations based on a linear potential flow method (specifically the Neumann-Michell theory) for the ship at rest, i.e. for the wetted hull surface Σ_0^H, rather than for the mean wetted hull surface Σ^H of the ship at its actual position. Indeed, a main conclusion of the present study is that, for common monohull ships at moderate Froude numbers, the sinkage and the trim can be realistically predicted via computations for the 'static' hull surface Σ_0^H of the ship at rest. This result stems from the fact that the sinkage and the trim are mostly determined by the pressure distribution over the lower part of the ship hull surface, and consequently are not highly sensitive to the precise position of the ship.

However, the drag is more sensitive to the hull position than the sinkage and the trim. As a result, the drag should be computed for a 'dynamic' ship hull surface $\sum_{st}^H$ that accounts for sinkage and trim effects, at least approximately. In fact, Ma et al. (2016) shows that the hull surface $\sum_{st}^H$ does not need to be accurate. Specifically, Ma et al. (2016) shows that the total drag computed for a hull surface Σ_{st}^H chosen as the hull surface $\sum_1^H$ predicted by the numerical approach, i.e. potential flow about the hull surface $\sum_0^H$ of the ship at rest, or as the hull surface $\sum_a^H$ predicted by the even simpler experimental approach, are nearly identical. However, the drag of the hull surface $\sum_1^H$ and the (nearly identical) drag of the hull surface $\sum_a^H$ are found in Ma et al. (2016) to be significantly higher, and in much better agreement with experimental measurements for freely-floating ships, than the drag of the hull surface $\sum_0^H$ of the ship at rest for high Froude numbers.

2. Basic relations for sinkage and trim

The vertical displacement of a ship hull surface Σ^H from its position $\sum_0^H$ at rest, at midship, is called 'midship sinkage' and denoted as H^m. Similarly, the vertical displacement of Σ^H at the ship bow and stern are denoted as H^b and H^s, and called 'bow sinkage' and 'stern sinkage'. Positive values of H^m, H^b or H^s correspond to downward vertical displacements of Σ^H at midship, at a ship bow or at a ship stern, respectively. The rotation of Σ^H from $\sum_0^H$ is defined by the trim angle $\tau^\circ \equiv \tau^{rad}180/\pi$ where the angles τ° and τ^{rad} are measured in degrees or in radians, or by the equivalent 'trim sinkage' H^τ defined as

$$2H^\tau \equiv L\tan(\tau^{rad}) \approx L\tau^{rad} \equiv L\tau^\circ\pi/180 \tag{1}$$

Positive values of τ°, τ^{rad}, H^τ correspond to a bow-up rotation.

The relations $H^s = H^m + H^\tau$ and $H^b = H^m - H^\tau$ hold. These geometrical identities readily yield

$$H^b = 2H^m - H^s \quad \text{and} \quad H^\tau = H^s - H^m \tag{2}$$

The geometrical relations (2) are used in the experimental approach to determine the bow sinkage H^b and the trim sinkage H^τ from an

Table 1
Beam/length ratio B/L, draft/length ratio D/L, draft/beam ratio D/B and block coefficient C_b of the 22 ship models considered here. The table also defines the identification symbols used in Figs. 3–12 for the 22 ship models.

Ship model	B/L	D/L	D/B	C_b	Symbol
USH-3b	0.144	0.071	0.500	0.397	+
USH-4a	0.096	0.064	0.667	0.397	⊡
USH-4b	0.111	0.056	0.500	0.397	+
USH-4c	0.125	0.050	0.400	0.397	⊡
USH-5a	0.078	0.052	0.667	0.397	✱
USH-5b	0.091	0.045	0.500	0.397	⊙
USH-5c	0.101	0.040	0.400	0.397	▼
USH-5d	0.091	0.045	0.500	0.396	◆
USH-5e	0.091	0.045	0.500	0.398	△
USH-6a	0.066	0.044	0.667	0.397	△
USH-6b	0.076	0.038	0.500	0.397	✱
USH-6c	0.085	0.034	0.400	0.397	✱
Wigley	0.100	0.063	0.625	0.445	+
S60	0.130	0.052	0.400	0.600	×
DTMB5415	0.134	0.043	0.323	0.510	✱
Delft372	0.080	0.050	0.625	0.403	⊙
ONRT	0.122	0.036	0.292	0.539	⊡
JHSS-BB	0.111	0.031	0.276	0.437	▼
JHSS-EB	0.111	0.031	0.276	0.437	◆
JHSS-GB	0.108	0.030	0.276	0.432	△
JHSS-ST	0.111	0.031	0.276	0.437	△
Model5365	0.148	0.033	0.226	0.438	✚