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# Practical evaluation of sinkage and trim effects on the drag of a common generic freely floating monohull ship

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ABSTRACT

A practical method to account for the influence of sinkage and trim on the drag of a freely floating (free to sink and trim) common monohull ship at a Froude number $F \leq 0.45$ is considered. The sinkage and the trim are estimated via two alternative simple methods, considered previously. The drag is also estimated in a simple way, based on the classical Froude decomposition into viscous and wave components. Specifically, well-known semiempirical expressions for the friction drag, the viscous pressure drag and the drag due to hull roughness are used, and the wave drag is evaluated via a practical linear potential flow method. This simple approach can be used for ship models as well as full-scale ships with smooth or rough hull surfaces, and is well suited for early ship design and optimization. The method considered here to determine the sinkage and the trim, and their influence on the drag, yields theoretical predictions of the drag of the Wigley, S60 and DTMB5415 hulls that are much closer to experimental measurements than the corresponding predictions for the hull surfaces of the ships in equilibrium position at rest. These numerical results suggest that sinkage and trim effects, significant at Froude numbers $0.25 < F$, on the drag of a typical freely floating monohull ship can be realistically accounted for in a practical manner that only requires simple potential flow computations without iterative computations for a sequence of hull positions.



## 1. Introduction

The drag is a critical element of ship design. Accordingly, the prediction of the flow around a ship hull that advances at a constant speed along a straight path, in calm water of large depth and lateral extent, is a classical basic ship hydrodynamics problem that has been widely considered in a huge body of literature. Indeed, a number of alternative methods – including viscous flow computational methods, nonlinear or linear potential flow methods, and semianalytical methods – have been developed to compute the flow around a ship hull. A brief review of these alternative methods can be found in e.g. [1].

The drag of a ship is influenced by several complicated flow features, including flow separation at a ship stern, notably a transom stern, wavebreaking at a ship bow, hull roughness for full-scale ships, and sinkage and trim for freely floating ships (free to sink and trim).

The influence of sinkage and trim on the drag is analyzed here for typical generic freely floating ships at Froude numbers

$$F \equiv \frac{V}{\sqrt{gL}} \leq 0.45 \tag{1}$$

where $V$ and $L$ denote the speed and the length of the ship, and $g$ is the acceleration of gravity.

### 1.1. Influence of sinkage and trim on the drag

The pressure distribution around a ship hull surface $\Sigma^H$ that advances at a constant speed $V$ in calm water evidently differs from the hydrostatic pressure distribution around the wetted hull surface $\Sigma_0^H$ of the ship at rest, i.e. at zero speed $V=0$. Consequently, the ship experiences a hydrodynamic lift and pitch moment, and a related vertical displacement and rotation of $\Sigma_0^H$ that are commonly

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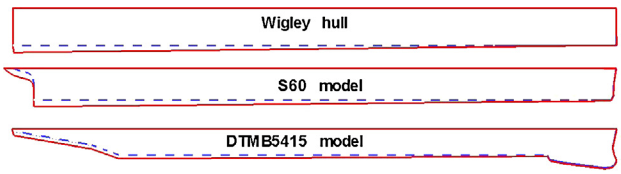


**Fig. 1.** Profiles of the wetted hull surfaces of the Wigley hull, the S60 model and the DTMB5415 model at rest (blue dashed lines) and in freely floating positions at Froude numbers $F = 0.4$ (red solid lines). (For interpretation of the references to color in this figure legend, the reader is referred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

called sinkage and trim. The sinkage and the trim of a freely floating ship have been widely considered in the literature; e.g. [2–12].

The differences between the wetted hull surface $\Sigma_0^H$ of a ship at rest and the corresponding actual mean wetted ship hull surface $\Sigma^H$ are illustrated in Fig. 1 for three freely floating ship models, specifically the Wigley, S60 and DTMB5415 hulls, at a Froude number $F = 0.4$. The wetted hull surfaces $\Sigma_0^H$ of these three models, considered hereafter for purposes of illustration and validation, are depicted in Fig. 2.

The 'dynamic' hull surface $\Sigma^H$ does not differ very much from the 'static' hull surface $\Sigma_0^H$ in Fig. 1. Indeed, [12] shows that the sinkage and the trim can be realistically determined from flow computations for the static hull surface $\Sigma_0^H$ for Froude numbers $F \leq 0.45$.

However, the drag of the dynamic hull surface $\Sigma^H$ can be significantly larger than the drag of the static hull surface $\Sigma_0^H$ at Froude numbers $0.25 < F$, as is well documented in the literature; e.g. [2–4,7]. For instance, the theoretical predictions reported further on show that at a Froude number $F = 0.45$, the Wigley and S60 models experience an increase in (total) drag of about 15%, while the drag of the DTMB5415 model is about 7% higher, due to sinkage and trim effects.

A large part of the increase in the drag stems from the wave drag component, predicted further on to increase by about 20% or 16% for the Wigley or S60 models at $F = 0.45$. These theoretical predictions are consistent with experimental measurements of the residuary drags of the Wigley and S60 models, which increase significantly for $0.25 < F$. These examples show that sinkage and trim effects on the drag, notably the wave drag, of a ship can be significant.

Moreover, sinkage and trim effects on the drag depend on the hull form. E.g., at $F = 0.45$, the wave drag and the viscous drag components are found further on to increase by about 20% and 7% for the Wigley model, by about 16% and 11% for the S60 model, and by 5% and 7% for the DTMB5415 model.

The influence of sinkage and trim must then be taken into account to realistically determine the drag of a freely floating ship at $0.25 \leq F$, and indeed needs to be considered within the design process, arguably even at early design stages and for hull form optimization. The analysis of sinkage and trim effects on the drag involves two obvious basic tasks: the determination of sinkage and trim, considered in [12], and the determination of the drag, examined here.

### 1.2. Practical determination of sinkage and trim

As was already noted, alternative methods for evaluating the sinkage and the trim, as well as the drag, experienced by a freely floating ship have been considered in the literature. In particular, the approach considered in [3,4,6–9,11] involves iterative flow computations for a sequence of hull positions. Such iterative flow computations are shown in [12] to be unnecessary for typical monohull ships at Froude numbers $F \leq 0.45$, and are not well suited for routine practical applications to early ship design and hull form optimization. In fact, practical methods to determine the sinkage, the trim and the drag of a ship, notably methods that do not require iterative flow computations for a sequence of hull positions, are useful if not necessary at early design stages and for optimization.

Ma et al. [12] consider two simple methods, an experimental method and a numerical method, to determine the sinkage and the trim of a typical freely floating monohull ship that advances in deep water at a Froude number $F \leq 0.45$.

The numerical method only involves linear potential flow computations for the ship at rest, i.e. for the hull surface $\Sigma_0^H$, rather than for the hull surface $\Sigma^H$ of the ship at its actual position. Indeed, a main conclusion of [12] is that, for common monohull ships at Froude numbers $F \leq 0.45$, the sinkage and the trim can be realistically predicted via computations for the static hull surface $\Sigma_0^H$, i.e. without iterative flow computations for several hull positions. This practical simplification stems from the fact that the sinkage and the trim are largely determined by the pressure at the bottom of the ship hull (as is shown further on), and consequently are not very sensitive to the precise position of the ship.

The experimental method, based on an analysis of experimental measurements reported in the literature for 22 models of monohull ships, requires no flow computations and is then simpler still than the numerical method. Indeed, the analysis of experimental data considered in [12] yields simple analytical relations that explicitly predict the sinkage and the trim experienced by a monohull ship in terms of the ship speed $V$ and four basic parameters related to the hull geometry: the length $L$, the beam $B$, the draft $D$, and the block coefficient $C_b$.

Both the simple numerical approach and the even simpler experimental approach are found in [12] to yield realistic predictions of sinkage and trim for a wide range of monohull ships at Froude numbers $F \leq 0.45$.

### 1.3. Practical determination of the drag

As is required for routine applications to early ship design, and in accordance with the simple methods considered in [12] to determine the sinkage and the trim, a practical method is used here to predict the drag. Specifically, classical semiempirical relations for the friction drag, the viscous pressure drag and the hull-roughness drag are used, and the wave drag is evaluated via a practical linear potential flow method.

The wave drag (a major component of the total drag at high Froude numbers) is more sensitive to the hull position than the sinkage and the trim (as is explained further on). Accordingly, the

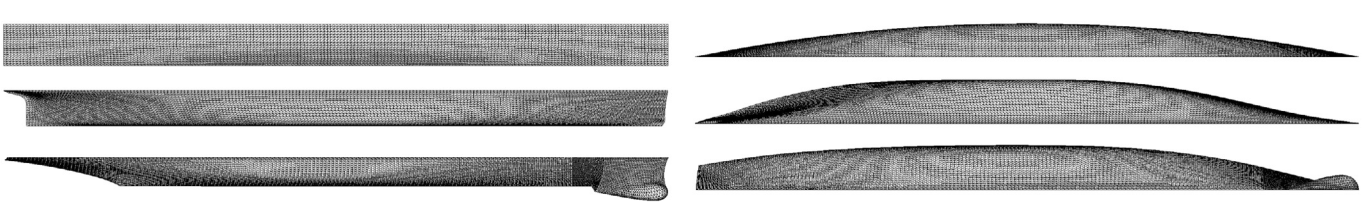

**Fig. 2.** Side views (left) and bottom views (right) of the wetted hull surfaces $\Sigma_0^H$ of the Wigley hull (top), the S60 model (middle) and the DTMB5415 model (bottom) approximated via 7562 (Wigley), 11,542 (S60) and 12,586 (DTMB5415) flat triangular panels, as for the flow computations reported in the study.