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Call for Papers for next COMPIT
Computational Methods for Seakeeping and Added Resistance in Waves

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Abstract

This paper gives an overview of computational seakeeping methods with special focus on the calculation of added resistance in waves. The survey describes the most common approaches, their scope of application and their short-comings. While heave and pitch for conventional ships are predicted well by virtually all approaches, motions in oblique waves and second-order forces such as added resistance are much more difficult to predict. For short waves, all approaches fail to predict added resistance properly. Recent findings put into question the validity of the principle of superposition when applied to the calculation of added resistance.

1. Introduction

Seakeeping considers the response of ships and offshore structures in waves. It is of fundamental importance for the operation of ships and also during the design of many ship types. Tools to predict seakeeping are, Bertram (2012):

- Model tests (time consuming and expensive; rarely performed for commercial ship projects)
- Full-scale measurements on-board ship whilst at sea (problematic due to external “noise” in the measurement, but increasingly performed – adding engineering intelligence in the form of theoretical seakeeping models can improve the accuracy of these experiments.)
- Computations in the frequency domain: determination of ship response to harmonic waves of different wave lengths and wave directions (most popular approach; efficient in computation, but limited accuracy as nonlinear physics must be approximated by linear computational models).
- Computations in the time domain, i.e. simulation in time (increasingly used, but computationally expensive; only short simulations of the order of several seconds to minutes are currently achievable in a reasonable time frame).
- Statistical long-term assessment based on linear frequency-domain computations (for given seaway or given ocean region, based on probability of occurrence of seaways – wave atlas).

This paper surveys various computational seakeeping methods and associated software tools with the purpose of giving a roadmap for non-experts. Particular focus is given to added resistance, as this plays a pivotal role in hull performance management, route optimization and other fuel efficiency applications.

2. Overview of computational seakeeping methods

2.1. Introduction

Many seakeeping investigations comprise the following steps:

- Representation of the irregular, natural seaway as a superposition of a large number of regular (harmonic) waves,
- Computation of the ship response of interest in these harmonic waves, and
- Summation of the responses to the harmonic waves to obtain the total ship response.

This procedure relies on application of the principle of superposition and linearity of the responses; i.e. the response of the ship to one wave is not changed by the simultaneous occurrence of another wave; this assumption is generally valid for small wave heights.
2.2. Prediction of ship motions in waves

Since the 1950s, a range of seakeeping methods has evolved. Beck and Reed (2001) and Bertram (2012) are recommended for structured overviews. The most important approaches can be classified as follows, Bertram (2012):

- Simple design estimates
  Jensen et al. (2003) present a semi-analytical method to predict ship motions for monohull ships. The results are given as closed-form expressions and the required parameters are restricted to the principal dimensions: length, breadth, draught, block coefficient and waterplane area together with speed and heading. Although intended for early design estimates, the approach has been used for other purposes.

- (Linear) Strip method
  Strip methods are still the most popular approach for seakeeping analyses. The essence of strip theory is to reduce the 3D hydrodynamic problem to a series of 2D problems that are easier to solve. The underwater part of the ship is divided into a number of strips, typically 20-40. Fig. 1. Although the underlying physical models are crude, strip methods are able to calculate heave and pitch motions and several other properties of practical relevance accurately enough for displacement monohulls. Strip methods are generally applicable up to Froude numbers of 0.4, thus for almost all types of large, low- to moderate-speed, displacement ships. A multitude of software codes based on the strip method approach has been developed over the decades, but mostly in academia and many codes are now obsolete, undocumented and not portable. Some commercial strip methods exist, e.g. Motions, MOSES (Bentley Systems), OCTOPUS (Amarcon), VERES (Marintek), and VisualISMP (Proteus Engineering). An open-source strip method called PDSTRIP, Bertram et al. (2006), can be downloaded from the internet. However, as no user support is available, PDSTRIP is rarely used in practice.

- High-speed strip method (HSST)
  For displacement hulls at Froude numbers above 0.4, high-speed strip methods (aka 2D+1 methods) are fast and yield good results. Several HSST methods have been coded in academia, but no commercial software is known to the authors.

- Multihull strip method
  Special strip methods have been developed for catamarans, taking into account the interaction of radiated and diffracted waves between the two hulls at forward speed. However, these methods remain inaccessible with neither code nor theory readily available to the public. Therefore industry has generally chosen to apply 3D methods for these types of vessels.

- Nonlinear strip method
  For extreme motions (particularly for roll motions up to capsizing), nonlinear strip methods have been developed. The approach captures geometric nonlinearities of the ship through time-stepping and consideration of instantaneous wetted cross section and viscous effects through semi-empirical corrections. Again, these codes generally come from research projects with very small user groups. Computational times can be considerable, ranging up to several hours, while linear strip methods give results within minutes.
• 3D Green Function Method (GFM) and Rankine Singularity Method (RSM)
For offshore applications, first-order forces and motions are calculated reliably and accurately by 3D GFM, Fig.2. There are a number of commercial codes with relatively large user groups, including Motions, MOSES (Bentley Systems), WAMIT (WAMIT Inc.), AQWA (ANSYS) or Diodore (Principia). GFM are less suitable at non-zero speed, but still widely applied. All GFMs are fundamentally restricted to simplifications in the treatment of the steady flow. Usually the disturbance of the steady flow is completely omitted which introduces large errors in local pressures, especially in the bow region. Both methods can give satisfactory results but they share inherent difficulties representing flows around immersed transom sterns. 3D RSM have been developed as in-house codes, Bertram and Yasukawa (1996); while there are many commercial 3D RSM for the steady wave resistance problem, we are not aware of any commercially available RSM software for seakeeping.

• RANSE solver
State-of-the-art CFD (Computational Fluid Dynamics) codes solve the Reynolds-Averaged Navier-Stokes Equations (RANSE), modeling turbulent fluctuations by semi-empirical turbulence models, Fig.3. As turbulence does not play a significant role in seakeeping, RANSE solvers directly capture all relevant physics. RANSE simulations can be applied to arbitrary geometries, including planing hulls, catamarans, and blunt offshore structures. Most RANSE codes employed for seakeeping analyses are general-purpose codes. RANSE solvers are computationally expensive and require parallel computer hardware for acceptable analysis times; they are prohibitively expensive for long-term simulations. RANSE seakeeping simulations have drifted into practical industry application over the last decade and are now widely used. There are several commercial solvers with sizable user groups in the marine sector: CCM+ and its predecessor Comet (cd-adapco), FINEMarine (Numeca) and Fluent (ANSYS). In addition, the open-source software package OpenFOAM (OpenFOAM Foundation) is particularly popular in academia. OpenCFD (ESI Group) gives commercial user support and provides consulting services based on the OpenFOAM software.

2.2. Don’t believe the hype!

With appropriately chosen problems (i.e. ones that match the limitations of a given computational method), all methods work well. It is for this reason that we always see good agreement with experiments or other computational methods in “sales” publications!

Most publications show results for heave and pitch motions, for several reasons:

• Heave and pitch motions are relatively well predicted by inviscid theoretical models. This is because damping is primarily due to radiated waves and not viscous flow over the hull. These responses are also essentially linear in waves of up to moderate amplitude.
• Heave and pitch motions have significant effect on added resistance, structural loads (slamming) and the safety and comfort of crew and passengers.