Added resistance in waves, computational techniques and impacts on fuel consumption

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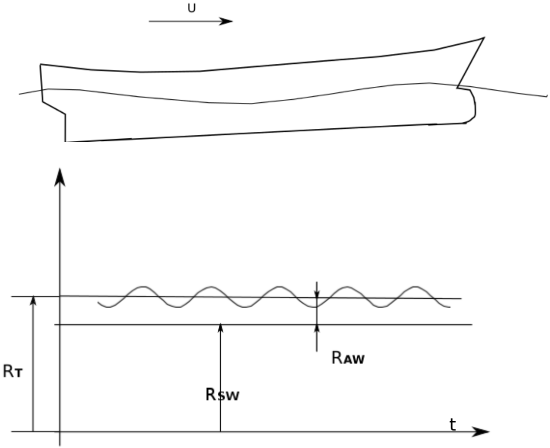
Outline

What is added resistance in waves?

Added Resistance is defined as the mean value by which the calm water resistance is increased when a ship is sailing in waves



Importance of an adequate prediction of the added resistance

R_{aw} may be an important issue in ship design. Its prediction is important in various respects:

to predict the involuntary speed reduction in a seaway.

In alternative its evaluation is necessary to predict the amount of added power required to maintain the speed in moderate seaways.

Importance of an adequate prediction of the added resistance

In fact the total resistance is necessary to determine the thrust and delivered power to the propulsion unit, the shaft r.p.m. and finally the engine power.

So it is also linked to the prediction of the increase in fuel consumption

Recently also its impact on environment has been recognized or is under discussion (EEDI - Energy Efficiency Design Index)

Finally, added resistance is an important element for weather routing

Methods for evaluating added resistance

Added resistance may be evaluated by:

Experiments

- in regular waves
- in irregular waves

Numerical Methods

relationship of added resistance with wave height

Experiments and analytical considerations pointed out that added resistance in waves can be considered proportional to wave height squared.

added resistance in regular and irregular waves

Experiments and computations can be carried out:

- in regular waves at a given encounter frequency ω_e. $\sigma_{AW}(\omega_e) = R_{AW}(\omega_e)/a^2$ may be measured or computed
- in irregular waves in given sea spectrum $S(\omega_e)$. $\overline{R_{AW}}$ may be measured
- In an irregular seaway $\overline{R_{AW}}$ may be also evaluated as:

$$\overline{R_{AW}} = 2\int_0^{\infty} S(\omega_e)\sigma_{AW}(\omega_e)d\omega_e$$

in a sort of linear superposition.

Importance of an adequate prediction of ship motions

Since added resistance depends on wave amplitude squared and on the cross product of ship motions a good evaluation of motions is necessary even light inaccuracies on predicted motions involve significant errors in predicted added resistance.

Ship motions nowadays may be evaluated through:

- strip theories
- 3D methods (pot.)

$$\begin{cases} \text{Rankine sources} & \text{Freq. or time domain} \\ \text{Green functions} & \text{Freq. or time domain.} \end{cases}$$

- unsteady RANS equations

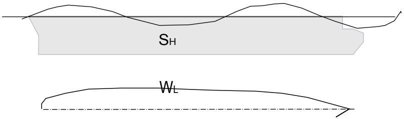
Classification of numerical methodologies

The methodologies for computing added resistance may be broadly classified as:

- Near field methods based on 2^{nd} order mean pressure integration;
- Far field methods $\begin{cases} \text{momentum conservation} \\ \text{radiated energy} \end{cases}$

Near field methods

Near Field methods are based on the integration of the second order mean term of pressure forces on the mean hull surface and on a surface the waterline. These terms can be derived applying a perturbation theory and may be determined from the solution of the first order (linear) motions.



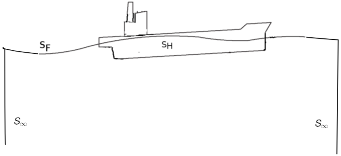
$$R_{AW} = \overline{\int_{S_H} p n_x dS} + \overline{\int_{WL} \int_0^{\zeta} p n_x dz ds}$$

Near field methods in literature

• Faltinsen et al.(1980)	strip theory
• Bertram(1998)	3D Rankine Sources (freq. domain)
• Kim et al. (2007)	3D Rankine Sources (time domain)
• Jonquez et al.(2012)	3D Rankine Sources (time domain)
• Bruzzone & Gualeni (2004)	3D Rankine Sources (freq. domain)
• Ye et al. (2012)	RANS
• Lin et al. (2012)	RANS

far field methods

They are based on the balance of momentum or energy on a control volume.



It was proposed at first by Maruo (1957,1960)
Then several authors based their methods on this principle:
Ohkusu (1984), Naito(1992), Liu et al (2011),
Jonquez et al. (2012) used both pressure integration and momentum approach using Rankine sources.

energy radiated approach

Gerritsma and Beukelman (1972) proposed a method based on energy radiated approach in which the work of the added resistance is related to the energy radiated by the damping forces.
They used a strip theory.
The added resistance takes this simple expression:

$$R_{AW} = \frac{\pi}{\lambda \omega_e} \int_L b_{33} V_z^2 dx$$

in which b_{33} is the sectional damping coefficient and V_Z is the vertical velocity relative to waves.

Some results at University of Genoa

A methodology to evaluate added resistance has been developed adding it to the framemework of a 3D Rankine source methodology for predicting ship motions in the frequency domain

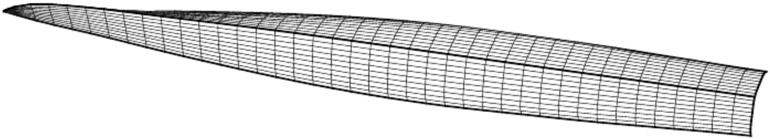
It has been applied to ships and to high speed vessels having mono and multi-hulls such as catamarans and trimarans.

It is based on the solution of the eight relevant boundary value problems for diffraction (wave reflection) and radiation (ship motions).

Once the motions have been computed added resistance is evaluated using a pressure integration methodology.

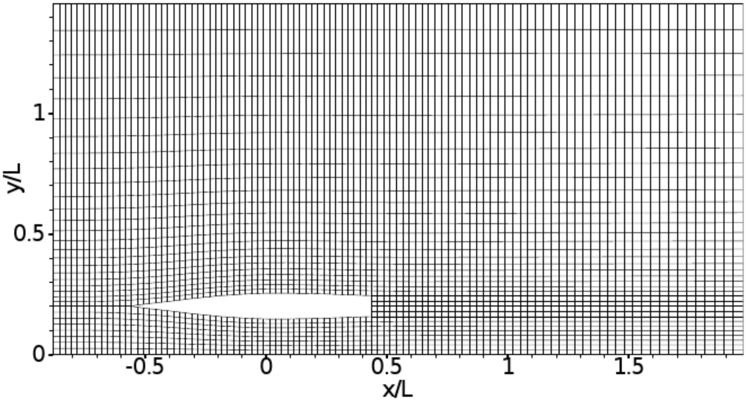
An example of application to a catamaran

As an example an application is presented here for a catamaran hull derived from the NPL series (from Bruzzone & Gualeni 2004). Experiments come from Molland et. al (2000):



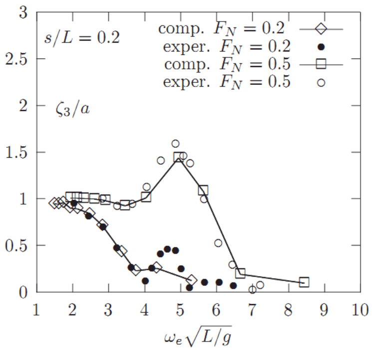
Representation by panels of the hulls surface.

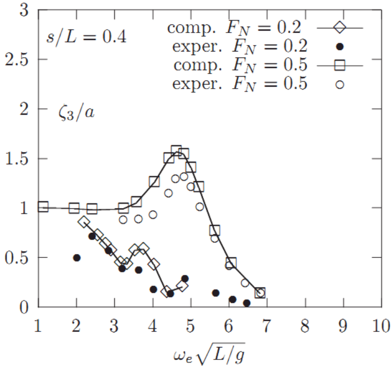
An example of application to a catamaran



Representation by panels of the free surface for a separation between the hulls of $0.4L$.

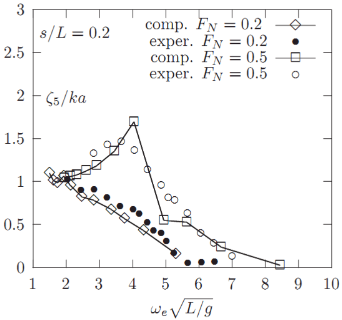
An example of application to a catamaran: heave motion

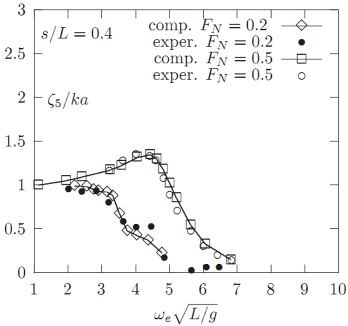




Results for vertical motions plotted against experiments for separations 0.2L and 0.4L

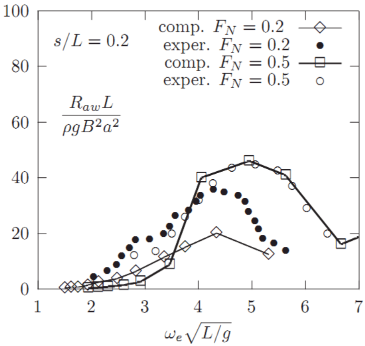
An example of application to a catamaran: pitch motion

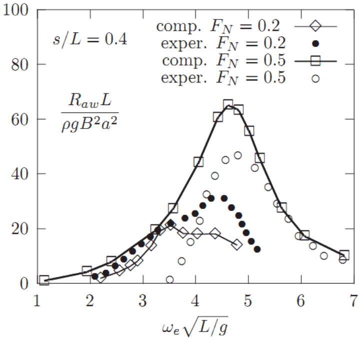




Results for pitch angle plotted against experiments for separations 0.2L and 0.4L

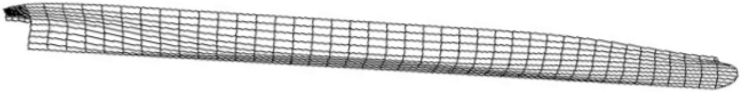
An example of application to a catamaran: added resistance

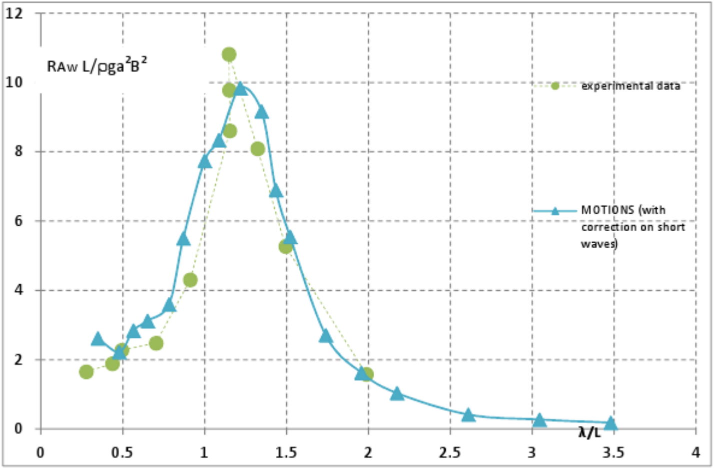




Results for pitch angle plotted against experiments for separations 0.2L and 0.4L

Recently some improvements have been carried out.
In addition, since it is difficult for potential methods to adequately model added resistance for short wavelengths, an empirical method (Kuroda et al 2008) has been added.
An example for the KCS hull (a container ship by Kriso which data have been distributed for CFD validation) is here shown (Ageno 2012, MS Thesis)




RAw L/ρga²B²
12
10
8
6
4
2
0
0
0.5
1
1.5
2
2.5
3
3.5
4
λ/L
experimental data
MOTIONS (with correction on short waves)

The previous evaluations were carried out in the frequency domain.

ongoing work

We are now developing a method for computing motions and added resistance in the time domain.

We plan to compare results from our Rankine source methods with computations with a RANS solver.

Thank you for your attention