Added Resistance of Surface Effect Ships

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1 Introduction

This abstract presents some results from a PhD research project on seakeeping of Surface Effect Ships (SESs). The project is jointly sponsored by MARIN and the Royal Netherlands Navy.

A Surface Effect Ship is a hybridization of a catamaran and a hovercraft. An air cushion is enclosed by the side hulls, the deck, the water surface and flexible seals at the bow and stern (Figure 1). The bow seal is usually of the *finger*-type; a row of vertical loops of flexible material which are open to the cushion. The stern seal is usually of the *bag*-type; a horizontal loop of flexible material which is open to the sides, where the bag is closed by the side-hulls. Internal webs restrain the aft-side of the bag, and divide the bag into several (usually two or three) lobes. The bag is pressurized at a slightly higher pressure than the air cushion. Most of the vessel's weight is carried by the air cushion. The remainder is carried by the buoyancy of the hulls. The air cushion is pressurized by a system of fans. Air leaks under the seals from the cushion.

Up to now Surface Effect Ships were mainly operating in sheltered waters. In these days however there is an increasing interest in large SESs sailing in open seas. The design of these large vessels requires an accurate prediction method for motions and added resistance. The development and validation of such a method is the goal of this research project.

This abstract will focus on the topic of added resistance (i.e. the extra resistance of the vessel due to the ambient waves). SESs are found to have a large speed loss when sailing in waves, although Ehrenberg[1] states that an SES has much less speed loss than a catamaran. At MARIN an added resistance about as large as the calm water resistance was measured. For normal ships added resistance appears to be equal to the wave height squared. Kapsenberg[2] showed that this relation does *not* hold for SESs.

The aim of this extended abstract is to verify the following hypothesis:

The origin of the large added resistance in waves of Surface Effect Ships can be attributed to the air cushion.

The next section presents an argumentation for this hypotheses. It also presents a simple expression for the added resistance of the air cushion. Section 3 presents a brief description of a computational method for motions and added resistance due to the air cushion. Section 4 presents computational and experimental results. Finally a conclusion concerning the hypothesis is drawn.

2 Added resistance components

Several components contributing to the added resistance in waves of a SES are distinguished:

- the "normal" added resistance of the hulls
- the extra resistance due to sinkage
- the extra resistance of the air cushion

The "normal" added resistance of the hulls should be small because only a minor part of the vessel's weight is carried by the buoyancy of the hulls and because the hulls are very slender.

When an SES is sailing in a seaway, the amount of air leakage from the cushion increases as the ambient cause large air gaps under the seals. This causes a decrease of the excess pressure in the air cushion, so a larger part of the vessel's weight has to be carried by the buoyancy of the hulls. Therefore the vessel will sink into the water, and the resistance of the hulls will increase. Kapsenberg[2] showed that the extra resistance due to this sinkage is relatively small.

As the first two components are small, the major part of the large added resistance of SESs must be caused by the air cushion. The (normal) resistance of the air cushion follows from:

$$R_{ac} = p_c \cdot (\zeta_b - \zeta_s) \cdot B_c \tag{1}$$

where p_c is the excess pressure in the air cushion, ζ_b and ζ_s are the mean wave height at the bow and stern seal respectively, and B_c is the width of the cushion. The increase of the mean value of R_{ac} is the added resistance of the air cushion. The resistance due to the momentum of the air flows into and out of the cushion is neglected. This momentum drag is only small because of the low density of air.

As the added resistance of the air cushion is supposed to give the largest contribution to the total added resistance of SESs, it was decided to focus on this component first. It can be calculated easily using equation (1).

3 Computational method

In this section the computational method for motions and air cushion resistance is briefly described. A more complete description can be found in reference [3].

First some basic assumption of the method are presented. The excess pressures in the cushion and stern seal plena are constant in space. This implies that acoustic phenomena of the air in the cushion cannot be resolved (i.e. the cobblestone effect is neglected). Further, the motions of the vessel are assumed to be small. This implies that linear equations of motion and linear hydrodynamics can be used. The dynamics of the air cushion are highly non-linear. Therefore the motions and excess pressures have to be solved in a time simulation procedure. Up to now only heave and pitch displacement are considered.

Next to the unknown heave and pitch displacement two additional unknowns occur: the excess pressure in the cushion plenum p_c, and the excess pressure in the stern seal plenum p_s. Therefore two additional equations are needed. These equations follow from the combination of the equation of continuity for a plenum with the equation of state for the air in that plenum, which is taken to be the isentropic gas law. They represent the dynamical behavior of the air in the cushion and seal plena. Especially the terms representing the leakage of air from the cushion are highly non-linear. When the relative wave height at the seals is large, no air leakage will occur. When this relative wave height becomes smaller the seals may leave a gap. The air leakage flow is proportional to the area of this gap. The sudden opening of a leakage gap cannot be linearized.

The hydromechanical problem is solved using a 3-dimensional Rankine panel method. The boundary value problem was linearized around the undisturbed flow (i.e. Neumann-Kelvin linearization). The interaction of the air cushion with the wave surface is taken into account. Attention has been payed to the flow around the transom sterns. The problem is solved in the frequency domain. The frequency domain results of the panel method are transformed to the time domain using the theory of Cummins[4] and Ogilvie[5].

The stern seal geometry and force are computed using a two-dimensional model (longitudinal plane). The curvature of the wave surface is neglected, which is reasonable for not too short waves. Gravitational and inertial forces acting on the seal canvas are also neglected. The canvas is assumed to have no bending stiffness. The dynamic pressure distribution which occurs under the seal due to air leakage is taken into account. The seal may either touch the water surface or leave a leakage gap.

4 Results

This section presents results for the HYDROSES target vessel; a large SES (cushion length is about 145m) which sails at a speed of 45 Kn. The computational results will be compared with experimental results of MARIN.

Figure 2 and Figure 3 present the RAOs for heave motions and cushion excess pressure. Results for several levels of wave steepness are shown. The agreement is good. The non-linear cushion dynamics appear to have only a small effect on the heave and pressure amplitude. The non-linear cushion dynamics manifest themselves most prominently as sinkage and drop of the mean cushion pressure.

Figure 4 presents the mean resistance of the air cushion in regular waves. Again results for several levels of wave steepness are shown. Contrary to expectations the resistance decreases in waves. This is caused by a drop of the mean cushion pressure. The smaller excess pressure in the air cushion causes a smaller (steady) wave resistance of the air cushion. This decrease of the air cushion resistance is counteracted by an increasing resistance of the hulls due to sinkage, which has not been computed.

Figure 5 presents the added resistance divided by the wave height squared. The computational data only include the added resistance of the air cushion, while the MARIN data include all added resistance components. There seems to be no correlation between the computational and experimental results at all. The experimental data show that the added resistance is not proportional to the wave height squared. Sometimes the measured added resistance is even negative. The hypothesis that the origin of the large added resistance in waves of SESs can be attributed to the air cushion cannot be confirmed.

5 conclusion

The origin of the large added resistance of Surface Effect Ships is not clear yet. According to the calculations the air cushion does not give a large contribution to added resistance. The other components are not likely to be large either. Therefore new model experiments will be carried out. These experiments will be focused on the origin and magnitude of added resistance of Surface Effect Ships.

References

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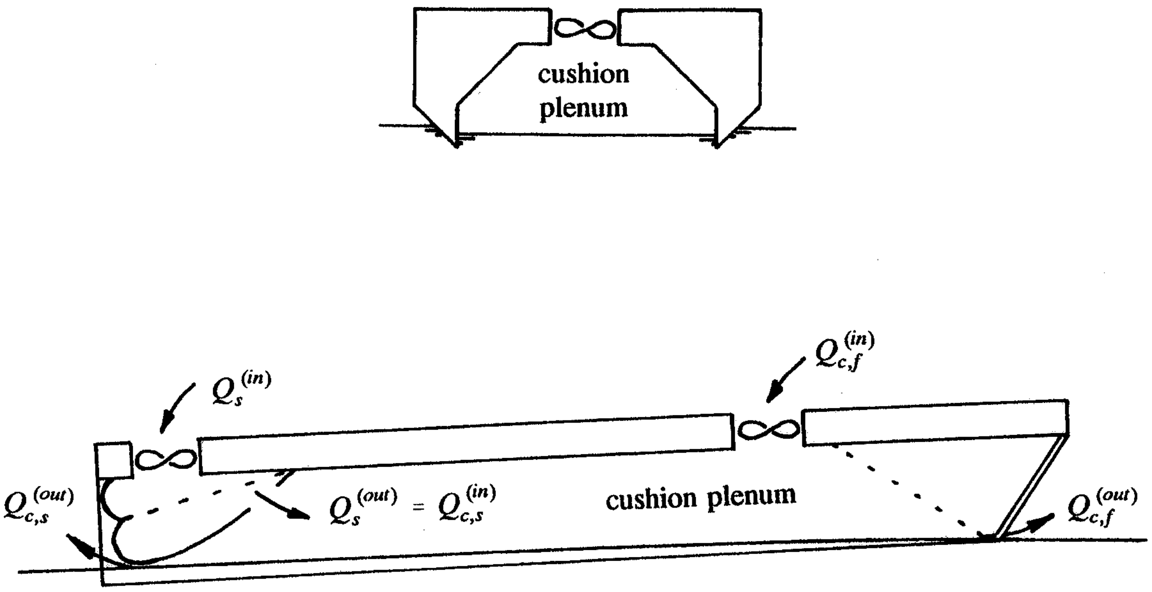

Figure 1: Longitudinal and transverse cut of a Surface Effect Ship

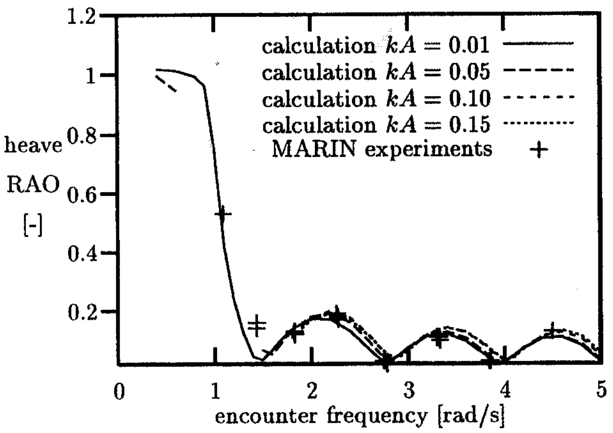

Figure 2: Heave motions of the HYDROSES target vessel

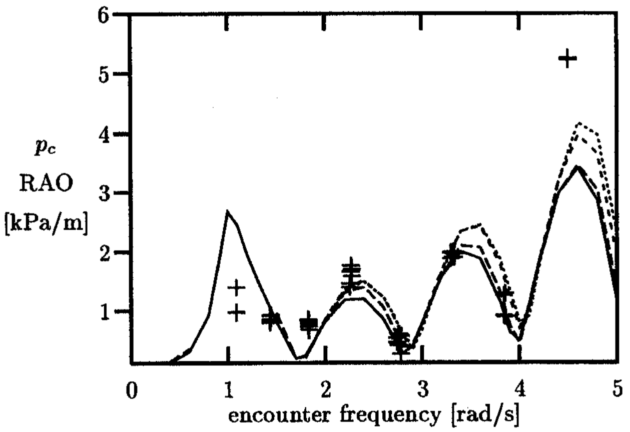

Figure 3: Cushion pressure response of the HYDROSES target vessel

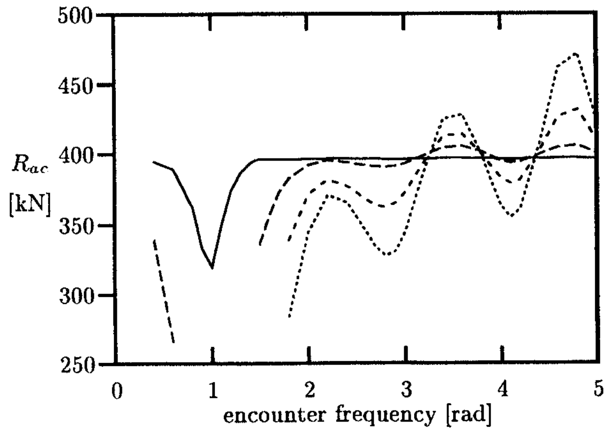

Figure 4: Resistance of the air cushion of the HYDROSES target vessel

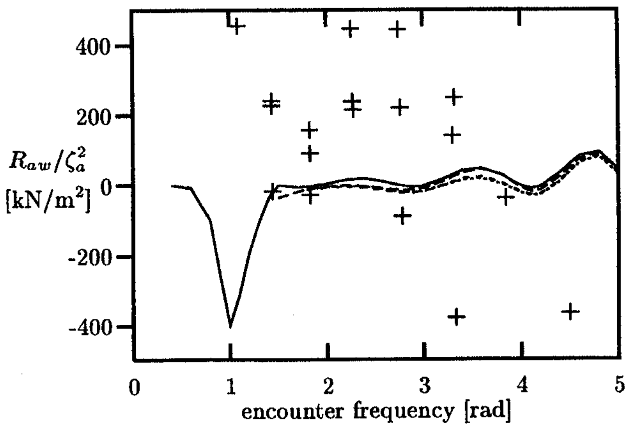

Figure 5: Added resistance operator of the HYDROSES target vessel