INFLUENCE OF DEADRISE ANGLE ON ROLLING DYNAMIC

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SUMMARY

This paper is intended to study mainly the dependence of the deadrise angle on roll behaviour of V-shaped hull in planing and semiplaning range. Of course the roll motion depends on many different parameters, such as displacement, mass distribution, speed, and amplitude and frequency of the exciting force.

Really few researchers have studied the influence of these parameters on rolling behaviour and only some of them were interested in high Froude numbers.

The study of the roll motion is achieved by the identification of the coefficients of a second order roll motion equation.

The comparison among the results of the two models is executed either on the roll amplitude and phase either on the values of the coefficients of the roll motion equation.

1. INTRODUCTION

This work presents the most recent results of an experimental research intended to evaluate the influence of different parameters on the roll behaviour of high-speed V-shaped hull. At FAST 2001 conference it was already described the methodology specifically conceived for the experimental tests [1] and were presented the first results with the model C9707 (deadrise angle β=10°). This paper will present the roll excited behaviour of a prismatic model with β=30° and will compare the results with the previous ones. The models have similar mass distribution and displacement and were excited at different frequencies and model speed. Given the non-linearity of the phenomena the dependencies of the inertial and damping terms on frequency were identified.

2. THE PHYSICAL MODEL

A considerable growth of the physical model complexity is due to the speed of the ship

In this work we will consider the roll motion uncoupled from the other, so the roll equation becomes:

$$\mathrm{a}\ddot{\varphi} + \mathrm{b}\dot{\varphi} + \mathrm{c}\varphi = \mathrm{M_w} \qquad (1)$$

The left side of the equation presents in the order the inertial term, the damping term and the restoring term. On the right side appears the external heeling moment; usually due to wave action M_w.

Our intent, from an experimental point of view, is the assessment of the amplitude and phase shift and of the coefficients a, b and c through measurements of the roll angle in towing tank tests [1]. In this framework the wave moments M_w are zero and their action is replaced by a sinusoidal exciting moment, whose realisation is described in details in [1]. The estimate of the coefficients a, b, c is achieved through the evaluation of the frequency response of the rolling behaviour of the ship. In other words the model is excited by moments of constant amplitude M_f at various frequencies. At each frequency steady-state heeling behaviour is recorded.

As done in Rif [1] the authors identified the dependency of roll equation coefficients on the motion frequency, by adopting a least square fitting of the measured data in narrow frequency windows.

3. EXPERIMENTAL METHODOLOGY

A dedicated procedure was conceived and applied to study the influence of different parameters on the transversal stability behaviour.
The roll excitation was obtained by a particular mechanism with contra-rotating masses (Fig. 1).

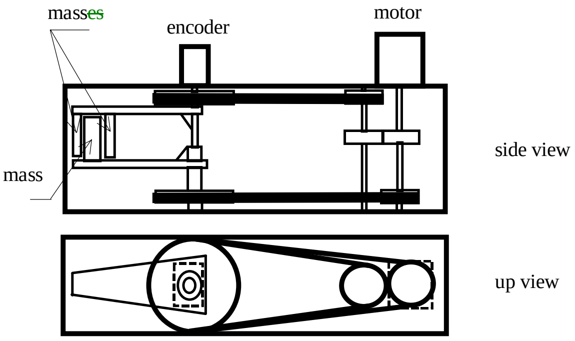


Figure 1 - Roll Exciting Device

This device was preferred to gyroscopes or sliding masses used by other researchers because it had no longitudinal moment to be balanced or effect on the running trim. More details about the exciting device can be found in [1].
Obviously, to obtain the needed route stability, the test devices constrained the model to the towing carriage, so the roll axis was imposed. It was parallel to the model keel line and placed between the centre of buoyancy and the centre of gravity. Due to such fitting, the sway and yaw were locked, while all the other motions were permitted.

4. MODELS TESTED

The research is based on tests of prismatic series of models with constant beam and length. Due to the towing tank facilities the main dimensions of models were chosen as follow:

- Loa = 2.500 m
- Boa = 0.600 m

The models tested till now were:
Hull n. C9707

- β = 10 deg

Hull n. C0201

- β = 30 deg

The prismatic hull form was preferred for different reasons:

- it is a typical generalisation of hull form of this kind of ships;
- it is suitable for possible mathematical representations;
- it was used by many other authors in the past (Fridsma, Savitsky, etc);
- its construction is relatively simple.

5. RESULTS

So far, the experimental tests were conducted with the following parameters:

Hull n. C9707 $-\beta =$ 10 deg model;

- Δ = 657 N
- VCB = 0.051 m
- VCG = 0.240 m
- T = 0.081 m
- $Fn_\nabla = 0 \div 3$ (0 ÷ 6m/s)
- Rolling frequency $\omega(B/2g)^{0.5} = 0 \div 1.55$
- Roll axis at 0.140 m above keel line.

Hull n. C0201 $-\beta =$ 30 deg model;

- Δ = 665 N
- VCB = 0.09 m
- VCG = 0.268 m
- T = 0.1331 m
- $Fn_\nabla = 0 \div 3$ (0 ÷ 6m/s)
- Rolling frequency $\omega(B/2g)^{0.5} = 0 \div 0.9$
- Roll axis at 0.178 m above keel line.

Due to the geometric characteristics and to the restraints in mass distribution, the righting arms of the two hulls were necessarily different.

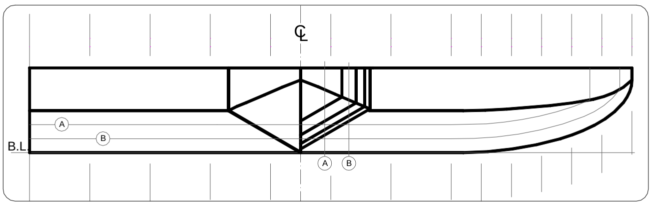


Figure 2 - Hull lines of the model 30 deg deadrise

Figure 3 - A high Fn test in towing tank

After exciting the model with an harmonic roll moment $M_f = M \sin\omega t$ at various frequencies, the amplitude and the phase shift of the first harmonic of the periodical roll motion were determined.

The experimental results are presented in Figures 4 and 5 in terms of influence of model speed and exciting frequency on roll motion amplitude and phase shift.

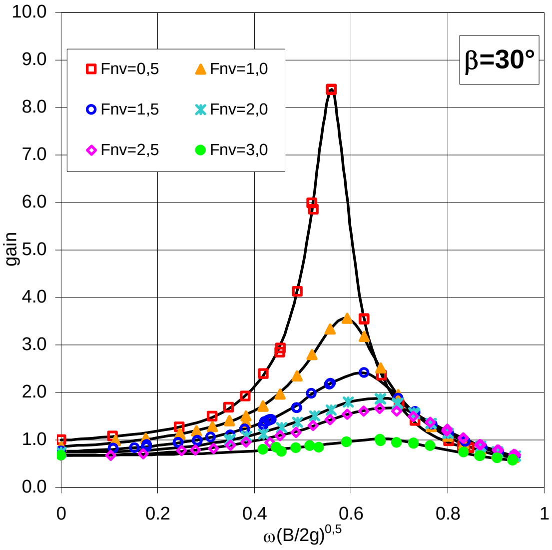


Figure 4

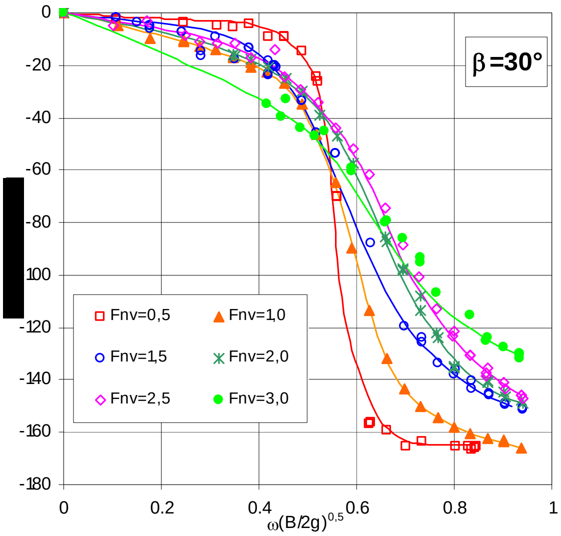


Figure 5

The roll peak amplitude is reported in dimensionless form respect to the heeling angle measured at zero speed and masses on one side.

It is important to notice that:

- the roll amplitude decreases significantly with speed;
- the natural frequency slightly increases with speed and it varies in the range 0,56÷ 0,7 (0,58÷0,73 Hz);
- examining the so called static gain, *i.e.*. the amplification factor at zero exciting frequency, it is quite clear the increase of the stability of the hull with increasing speed.

The last consideration is highlighted by Fig.6, where are reported the heel angles obtained with different feeling moment at various speeds. A different tendency is only showed at the highest speed (Fn_{∇}=3.0) and for high heeling moment.

It should be noted that, due to the towing tank limitations it was not possible to carry out tests at high speed and low frequency. So the curve at Fn_{∇}=3.0 is poor of experimental data.

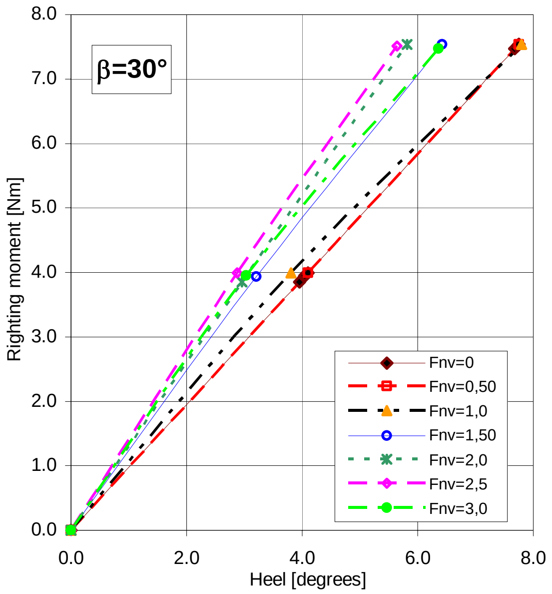


Figure 6

6. MODEL IDENTIFICATION

The roll motion model adopted is described by the following equation:

$$a(\omega)\ddot{\varphi} + b(\omega)\dot{\varphi} + c\,\varphi = M_f \sin\omega t \qquad (2)$$

where the inertial and damping terms a and b are supposed dependent on frequency.

The restoring term c, which varies with the heel angle, was considered as a constant value for each speed. Fig. 6 shows a linear behaviour, particularly at low speed until about 8 deg. At speed higher than Fn_∇=1.0 the obtained heel angle were always lower than 3.5 deg. The values adopted for the restoring term are shown in Table1.

V [m/s]	Fn_∇	c [Nm/rad]
1	0.5	56.4
2	1.0	60.7
3	1.5	72.1
4	2.0	78.3
5	2.5	80.4
6	3.0	76.3

Table 1

To determine the values of the inertial and damping terms it was executed a least square identification considering a limited numbers of amplitude and phase shift values around the each frequency.

The dependency of the coefficients a and b on frequency is exposed in Figures 7 and 8.

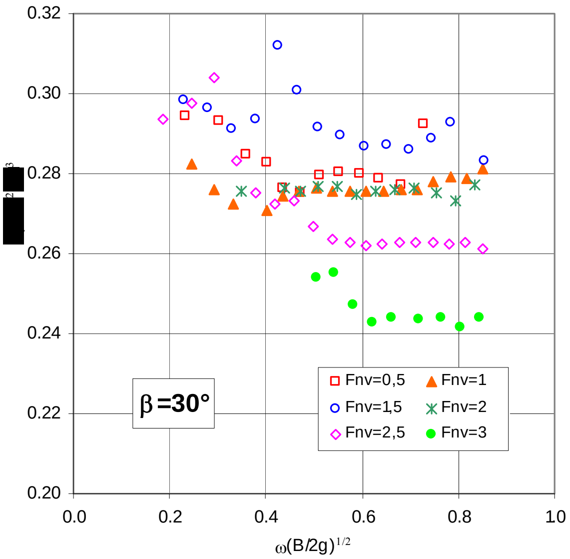


Figure 7

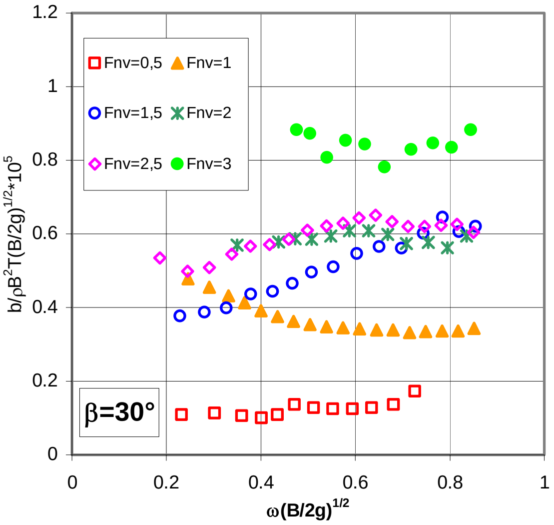


Figure 8

Regarding the coefficient a it can be noticed that the dependency on speed is well clear at non-dimensional frequency higher than 0,45. In this frequency range the inertial coefficient grows at low speed and decrease at higher ones. Its maximum value was obtained at Fn_∇=1.5. The dependency on frequency in this range is rather weak. At non-dimensional frequency lower than 0,45 the dependency on frequency and on speed is less clear.

The damping term grows with speed at lower and higher values while in the intermediate range the dependency is less clear. The variation of the damping coefficient with frequency is less strong.

7. CONSIDERATIONS AND COMPARISONS

For reader’s convenience Figures 9 and 10 report the curves of amplitude and phase of roll motion already published in [1] completed with the curves that approximate the points.

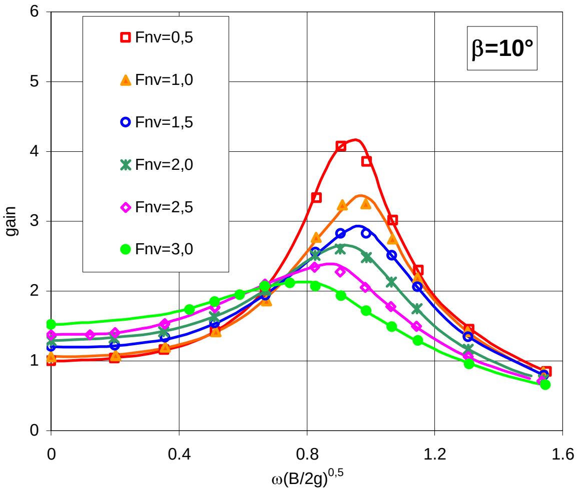
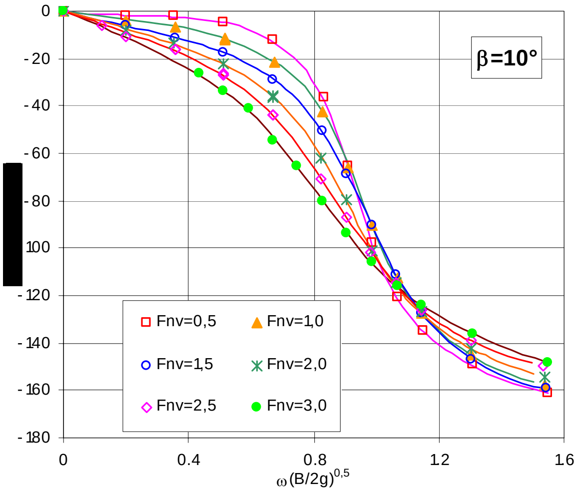


Figure 9



[redacted]

Figure 10

To correctly comprehend the plots it is important to remember that the amplitude values shown in Figures 4 and 9 were adimensionalised respect to the static heeling at zero speed.

To allow a comparison among the results of the two models also the coefficients a and b of the model β=10° were obtained, differently from the results presented in [1], imposing constant values for c at each speed according to eq. (2).

Table 2 reports the values adopted for coefficient c. Figures 14 and 15 illustrate the values obtained for the coefficients a and b.

V [m/s]	Fn_∇	c [Nm/rad]
1	0.5	216,4
2	1.0	203,2
3	1.5	179,4
4	2.0	167,9
5	2.5	157,3
6	3.0	142,7

Table 2

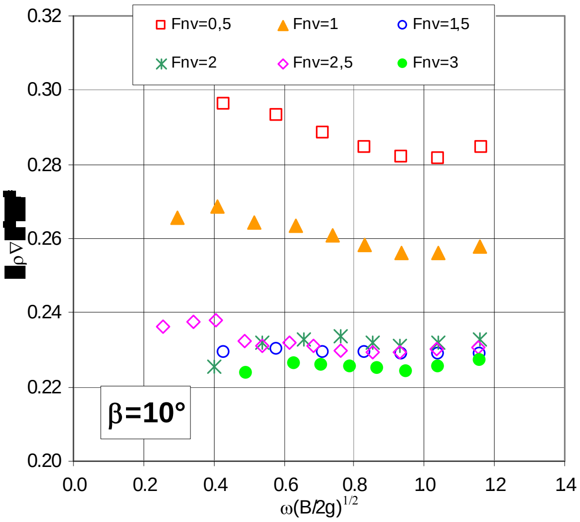


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Figure 14

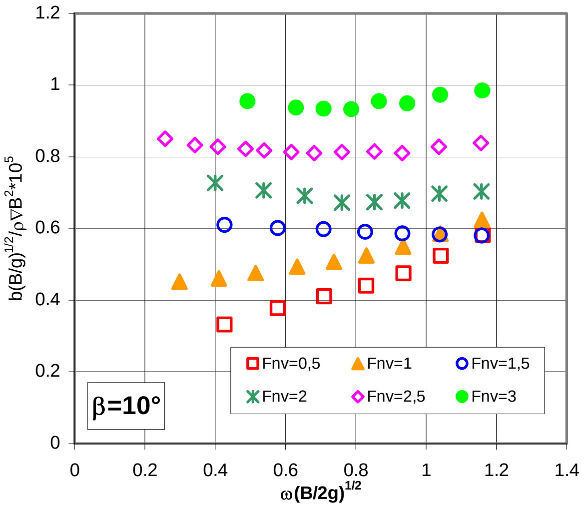

Figure 15

Observing Figures 4 and 9 it is possible to notice that :

- at low frequency the two models present a different behaviour: model β=10° reveals a reduction of stability with speed, while model β=30° shows an opposite behaviour. This could be linked to the different dependency of the coefficient c with speed (see Tables 1 e 2). This difference disappear at frequencies nearer to the natural value where the influence of damping, that grows with speed in both cases, prevails.
- the variation with speed of the natural frequency is quite regular for model β=10°, while it is more sudden for model β=30°; these observation are coherent with the plots of the coefficient b in Figures 8 e 15 in which it is clear the higher concentration of the values of b at intermediate values of Fn. From the comparison among Figures 8 e 15 it can be noticed that model β=10° presents higher damping values.
- the variation of the natural frequency with speed is opposite for the two models; model β=30° infact presents a growth of the natural frequency with speed. This is related with the combined effect of the increase of c and the reduction of a.

Comparing the graphs of the coefficient b among the two models it can be noted a less clear dependency on speed for the model β=30°. This trend could be due to the larger presence of non linear phenomena.

In agreement with the behaviour at low frequency it can be observed in the following Figures 16a and 16b the trend of heel angle with speed.

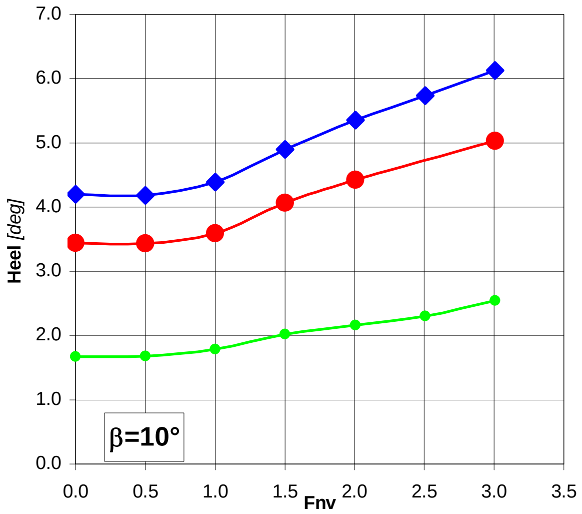

Figure 16a - Influence of speed on static heel

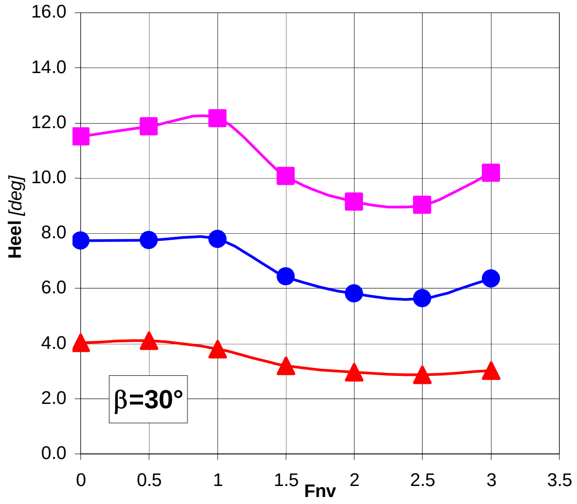

Figure 16b - Influence of speed on static heel

8. CONCLUSIONS

The experimental methodology adopted confirms the strong dependency of roll behaviour on deadrise angle.

In the range of frequency closer to the natural value the higher values measured for the heeling angle make more confident the data acquisition. Of course also the identification of the roll motion coefficients is more accurate in this range of frequency.

The research will be carried on deepening and bettering the measurement technique particularly at the values of frequency more distant from the natural.

In next future test with models $\beta=5°$ and $\beta=20°$ will be carried on.

9. NOMENCLATURE

φ	Heel angle
M_w	Wave induced heeling moment
Δ	Displacement
I	Moment of inertia of the ship
Loa	Length o.a.
Boa	Beam o.a.
B	Waterline Beam
T	Draft
β	Deadrise angle
GH	Metacentric height
a	Virtual mass term
b	Damping term
c	Restoring term
ω	Frequency

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