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Wave and Forces about a Turning Flat Plate

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INTRODUCTION

The analysis of maneuverability performance is becoming a basic step in the preliminary design of a ship. An efficient and reliable numerical prediction of the above performances is expected to accelerate this trend, allowing an easier approach than experimental simulation. In this respect, the main difficulty is the description of the flow field about a maneuvering ship. Once this point has been assessed, the forces acting on the hull are readily available and the simulation of a full maneuver may be attempted.

As far as the main forces acting on a maneuvering hull are due to the fluid inertia and to the presence of concentrated vortices, an accurate description of the rotational effects should allow, in principle, a reliable prediction of the ship motions. Actually, due to high Reynolds number, the convection is predominant in the flow while viscosity essentially fixes the separation regions at the hull surface. On this ground, the basic aspects of the flow-hull interaction are well described in terms of inviscid, rotational fluid-mechanics. In particular, for some simple ideal hull forms, the shape of the body allows to guess in advance the configuration of the separation lines. In the present case the flow about a flat plate in a steady turning maneuver is considered and the separation region is assumed to coincide with the keel and the stern lines, while the free surface displacements are considered in a linearized fashion.

For small drift angles or sufficiently high aspect ratios, the wake geometry may be linearized [1], neglecting the tip separation. Actually, typical hull draught to lenght ratios require a nonlinear wake modeling, developed in [2] without considering free–surface effects. In the current approach, the wave effects are recovered and their role on hydrodynamic loads are exploited.

In view of the large computation involved, an efficient as well as robust numerical scheme is required; here a standard Panel Method on the free surface is coupled with a Vortex Lattice procedure on the body and wake surfaces.

FLOW MODELLING

In the following a flat plate steadily rotating about a vertical axis is considered; as far as the yaw rate $\vec{\Omega}$ is small enough to allow the decaying of the disturbances generated during the previous revolutions, the problem may be assumed to be stationary in a rotating frame of reference fixed with respect to the body (see fig. 1). In this case, the total fluid velocity is decomposed in the form $\vec{U} = \vec{u} - \Omega \times \vec{OQ}$. Outside the wake surfaces $\mathcal{W}$, the perturbation velocity field $\vec{u}(\vec{Q})$ is always irrotational and may be cast in the integral form (see [3])

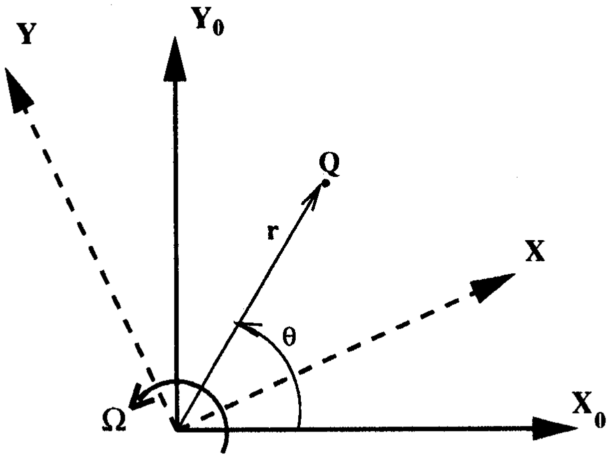

Figure 1:

$$\vec{u}(\vec{Q}) = \nabla_Q \int_{\mathcal{F}} \sigma G(\vec{P},\vec{Q}) dS_P - \nabla_Q \times \int_{\partial\mathcal{B}} \vec{\gamma} G(\vec{P},\vec{Q}) dS_P - \nabla_Q \times \int_{\mathcal{W}} \vec{\gamma}_W G(\vec{P},\vec{Q}) dS_P \ . \qquad (1)$$

Once the wake contribution is known, a boundary integral equation for the body vorticity $\vec{\gamma}$ and the source distribution σ may be obtained by imposing the impermeability constraint

$$\vec{n} \cdot \vec{u} = \vec{n} \cdot \vec{\Omega} \times \vec{OQ} \qquad \forall \vec{Q} \in \partial\mathcal{B} \qquad (2)$$

on the hull surface $\partial\mathcal{B}$ and the Kelvin condition

$$r\frac{\partial U_\theta}{\partial \theta} + \frac{g}{\Omega} U_z = 0 \qquad \forall \vec{Q} \in \mathcal{F} \qquad (3)$$

on the free surface $\mathcal{F}$. The above equation is expressed in cylindrical coordinates r, θ, z and U_z, U_θ stand for the physical velocity components along the z and θ coordinate lines. As concerning the wake integral in (1), the vorticity flux along the prescribed separation lines allows to evaluate the wake strenght $\vec{\gamma}_W$ (Kutta condition). Actually, the wake configuration $\mathcal{W}$ is still unknown and must be determined by an iterative procedure employing the material character of the wake.

NUMERICAL RESULTS

Two sample numerical results are shown; the figure 2 refers to the case of a steady turning flat plate (draught/lenght: 0.09, turning radius/lenght: 2); in particular the normal force and moment coefficients numerically evaluated for the Fr→ 0 case are compared to the ones measured by Inoue [4] during a rotating arm tests. For sufficient high drift angles, the wave effects become important, at least for the yaw moment, and require to account for the free surface. The simpler problem of a submerged doublet steadily rotating (see fig. 3) is preliminarily solved in order to verify the absence of unphysical behaviour due to the special choice of the frame of reference (i.e. the above assumption about the decaying of wave disturbances).

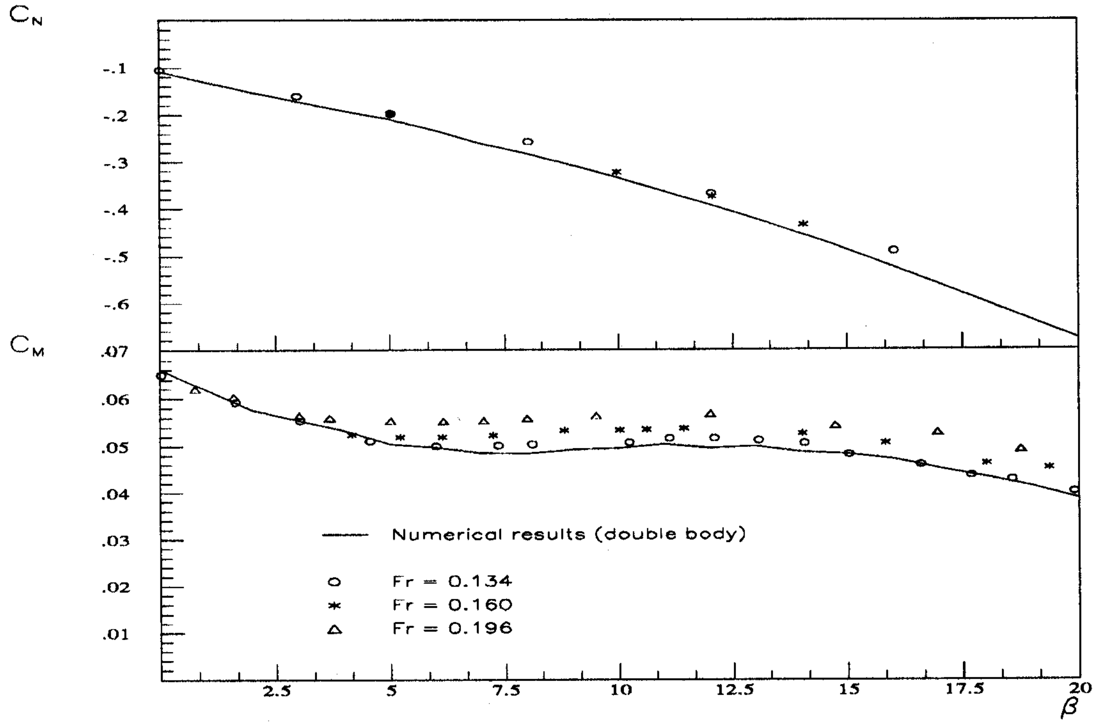

Figure 2: Hydrodynamic coefficients for a flat plate obtained by means of the rotating-arm test at several drift angles. Numerical (double-body) results are compared to experimental measurements at three different Froude numbers.

Extensive numerical results will be shown during the workshop.

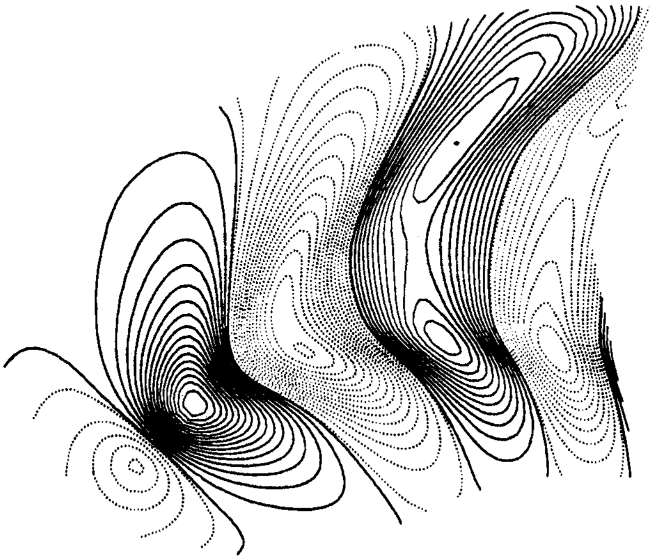

Figure 3: Steady wave pattern due to a rotating submerged doublet (depth: 1., turning radius: 10., yaw rate: .15 rad/sec.)

REFERENCES

[1] H. Maniar, J.N. Newman, H. Xu, *Free Surface Effects on a Yawed Surface-Piercing Plate*. Proc. 18^{th} Symp. on Naval Hydrodynamics. Ann Arbor Michigan, 1990.
[2] M. Landrini, C.M. Casciola, C. Coppola. *A Nonlinear Hydrodynamic Model for Ship Manoeuvrability*. In Proceedings of International Conference on Marine Simulation and Ship Manoeuvrability (MARSIM "93), St. John's (Newfoundland-Canada), 1993.
[3] R. Brard. *Vortex Theory For Bodies Moving in Water*, Proc. 9^{th} Symp. on Naval Hydrodynamics, pp. 1187-1284. 1972.
[4] S. Inoue, *On the turning of ships* Memoirs of the Faculty of Engineering Kyushu University, Vol. XVI, No 2.)

DISCUSSION

Zou, Z. J.: 1) How do you satisfy the radiation condition?

2) How did you discretise the free surface? How are the free-surface panels and grid size and shape chosen for different yaw rates?

Landrini, M. & Çampana, E.: 1) The radiation condition is simply enforced by the upstream shift of the collocation points on the free surface elements.

2) The longitudinal discretisation of the free surface is based on the 2D linear wavelength value, by simply imposing the number of panels per wavelength. The total number of panels used in the computations represent the minimum number required to capture the wave pattern, based on sensitivity studies carried out at the initial stage of this work. A typical arrangement for the steady turning case requires 400 panels on the flat plate and 3500 panels on the free surface.