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COMPUTATIONAL FLUID DYNAMICS WITH STAR-CD TO PREDICT THE MANOEUVRING CHARACTERISTICS OF SUBMARINES

Christophe A. Caux
Manoeuvring division
Bassin d'Essais des Carènes
Paris
France

Bernard L. Cardot
Numerical hydrodynamic division
Bassin d'Essais des Carènes
Paris
France

ABSTRACT

The development of software dedicated to hydrodynamic flow simulation and the always increasing computer capacity allow new attempts in the ship maoeuvrability study. That's why Bassin d'Essais des Carènes decided to evaluate a code named STAR-CD from the manoeuvring point of view. A small model of SSBN was tested in the towing tank with different pitch and drift angles . Experimental and numerical results for loft and moments are compared.

MANOEUVRABILITY OF SUBMARINES

The prediction of manoeuvring performance of a submarine is an important problem for naval architects. Indeed, the knowledge of the mathematical model of the ship in the classical equations of motion is the basis of numerous computer simulations (describing gyrations, crash dives...). The design of a powerful autopilot also requires these datas.

The complete manoeuvrability of a submarine is described by a mathematical model having more than fifty coefficients which can only be identified by tests with a free running model. A simplified model obtained by model tests in towing and turning tanks, gives however a good idea of the main manoeuvring characteristics (course stability, immersion stability gyration radius...). But even if this type of test is less expensive than those with a free running model, the cost remains significant. That is why Bassin d'Essais des Carènes decided to study the possibility of evaluation of hydrodynamic coefficients by Computational Fluid Dynamic codes.

The purpose of this paper is to compare the results of such calculations and tests performed in the towing tank.

EXPERIMENTAL STUDY

Two types of hull have been tested; they are based on the hull-form of the new nuclear submarine "Le Triomphant", but due to the difficulties of mesh design on complicated forms, the appendages were removed. One model is the generic axisymetric hull of the SSBN, the other one also has the bridge and the conning tower. The global lateral and vertical hydrodynamic forces and torques on the hull were measured at different speeds with different pitch and drift angles. The length of the models is about 2.2m and the diameter about 0.2m. These models were towed with a monopode carrier (see figure 1). Some tests were also performed in the gyration tank at different gyration radii. This tests were used to come up with a simplified mathematical model of ship manoeuvrability.

NUMERICAL MODELLING

STAR-CD Software

STAR-CD is a computational fluid dynamics code developed by Computational Dynamics (United Kingdom) and ADAPCO (U.S.A). It is desinged for compressible and incompressible , laminar or turbulent flows.

STAR-CD uses an original formulation with finite volumes allowing unstructured mesh like finite elements methods.The unknowns are localized at the center of each cell of the mesh. Four spatial discretisations are available within the code . For the manoeuvering calculations a first order scheme (Upwind Differencing) is used. The methods for solving the finite volume equations resulting from the discretisation step are of implicit type. STAR-CD incorporates these different algorithms (SIMPLE, PISO and SIMPISO). For the calculations we used SIMPLE, as especially adapted for the unstructured mesh formulation and other STAR-CD requirements.

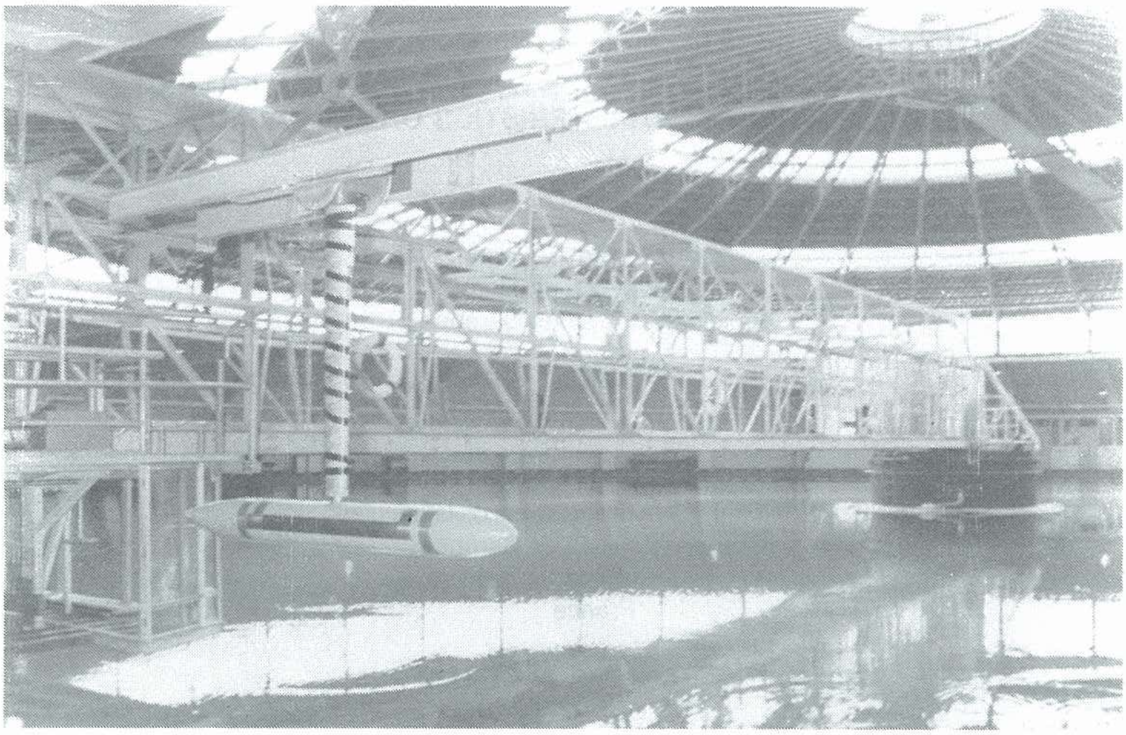


Fig n°1: Axisymetric hull before the tests

Mesh

The mesh is a finite element type with 227,000 nodes and 219,000 cells (parallelepipeds, tetrahedrons and prisms), using a block generation method and a vertex projection on the CAD surface. An idea of the mesh is given by the figure 2 where the projection of the cells on the hull is displayed.

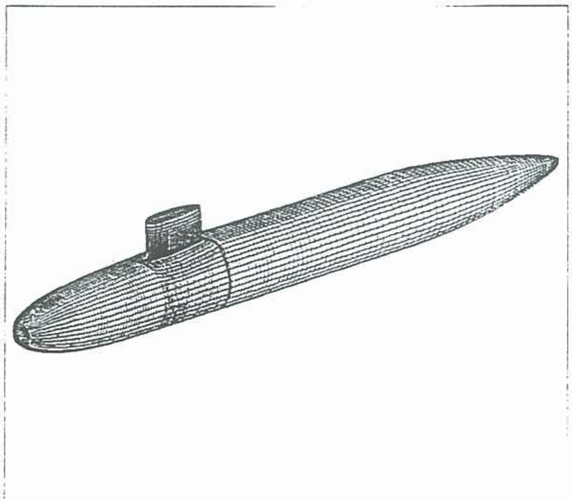


Fig n°2: Projected mesh on the hull

Computational parameters

The computations were realized using the SIMPLE solver. The influence of turbulent structure is simulated using the k-ε RNG two equations model.

The k-ε logarithmic wall laws are used on the surface of the submarine and Neumann conditions are prescribed at the outflow. The inlet values of u, v, w, k, ε, are set according to the experimental values.

The calculations are performed on a HP 900/735 working station and the CPU time is about 8 hours for one case 250 iterations are needed for obtaining all the magnitude with a normal residual rate of 10^{-3}.

COMPARISONS BETWEEN MEASUREMENTS AND CALCULATIONS

Global lift on the axisymetric hull

The graph displayed in figure 3 describes the global lateral force on the axisymetric hull (in kg). The tests and calculations were performed with a drift angle between -60° and +60°.

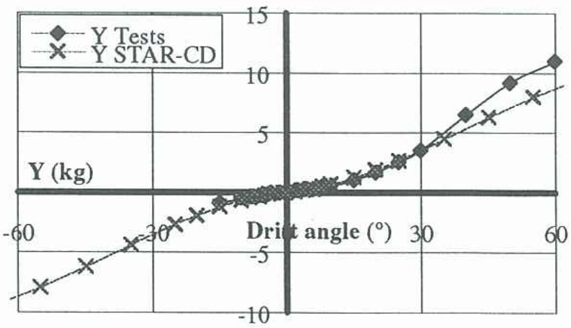


Fig N°3: Y: for the (-60°,+60°) drift domain *(axisymetric hull)*

The results clearly show a good adequation between measurements and calculations for small drift angles. STAR-CD results underestimate the lift at large drift angles.

Figure n°4 shows more precisely the little difference between tests and CFD, with low drift angles (-15°,+15°).

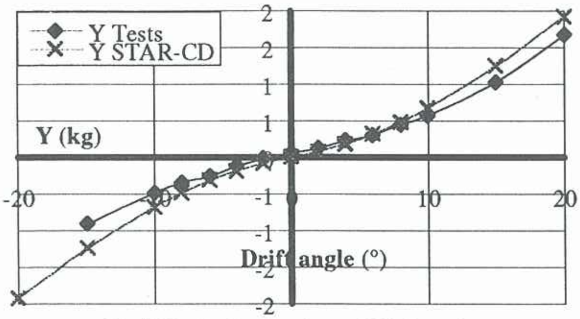


Fig N°4: Y: for a reduce drift domain
(axisymetric hull)

This allows a good comparison of the linear hydrodynamic coefficient obtained by the estimation of the gradient at a drift angle.

Global torque on the axisymetric hull

Figure n°5 shows the same phenomenon for the torque N around the center of buoyancy of the hull.

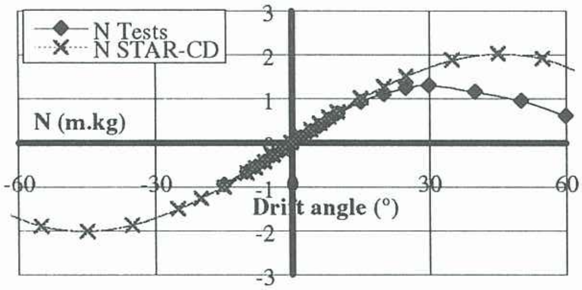


Fig N°5: N: for the (-60°,+60°) drift domain
(axisymetric hull)

The gradient in experimental and numerical between -15° and +15° (see figure 6) is almost identical.

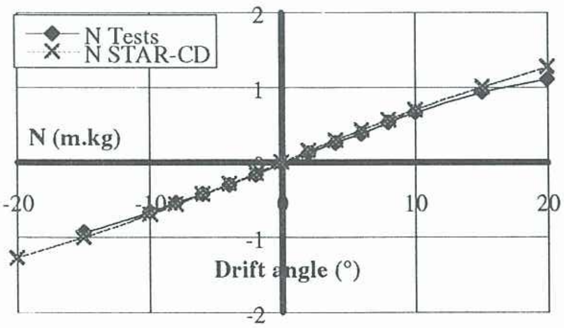


Fig N°6: N: for a reduce drift domain
(axisymetric hull)

The linear mathematical model of maoeuverability of the hull can then be obtained by STAR-CD.

Global vertical forces on the hull with bridge and conning tower

The results displayed figure 7 (for the lift) and 8 (for the torque) when the submarine has a pitch angle also show a quite good adequation.

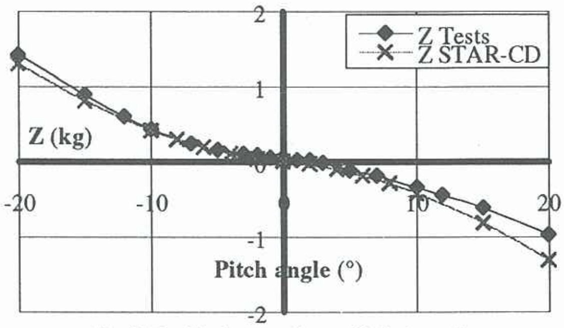


Fig N°7: Z: for a reduce pitch domain
(hull with bridge anfd conning tower)

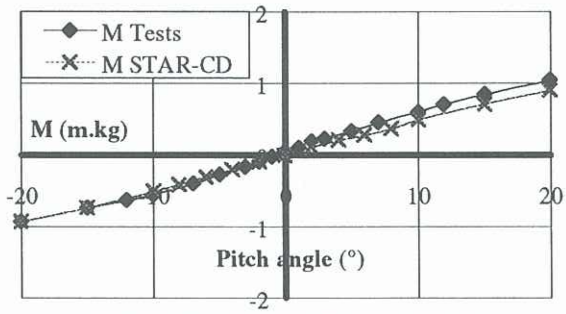


Fig N°8: M: for a reduce pitch domain
(hull with bridge and conning tower)

But the pitch angle range tested was reduced because of technical limitation. Therefore, it is not possible to perform a straight comparison at high pitch angle, but the linear hydrodynamic coefficients obtained experimentally and numerically are quite similar.

Global lateral forces on the hull with bridge and conning tower

With this hull configuration, STAR-CD could perform calculations, without convergence problems, only in a restricted drift angle range (from -8° to +8°). So even if the results displayed figure 9 (for the force) and 10 (for the torque) are satisfying, we cannot extend the domain for higher drift angle.

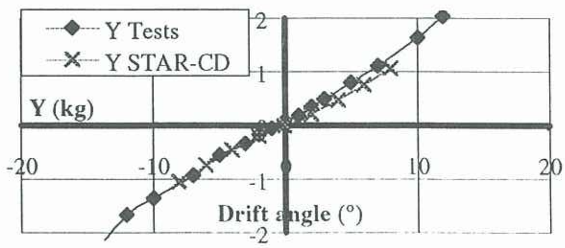


Fig N°9: Y: for a reduce drift domain
(hull with bridge and conning tower)

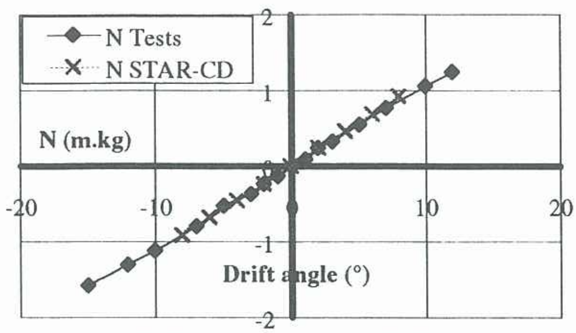


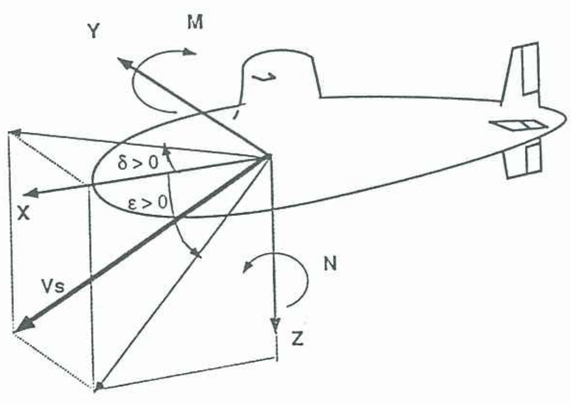
Fig N°10: N: for a reduce drift domain
(hull with bridge and conning tower)

CONCLUSIONS

The good agreement obtained when comparing experimental and numerical results permits us to formulate a linear mathematical model. This type of work will soon be repeated with more complex hull forms, submarine with all the classical appendages, expecting that similarly good results could also be obtained. If so, then STAR-CD could be used to obtain the linear coefficients, and in that case, the procedure of meshing has to be improved: it has to be simplified and accelerated, and we hope it is only a matter of time. Unfortunately, the non-linear coefficients (necessary for a correct modelization of gyration manoeuvres) cannot be obtained with STAR-CD. The developement of other approach of the problem is required.

Nevertheless, such a work coul lead us to a better comprehension of the forces induced by the flow on the hull with drift angle.

NOTATIONS AND SIGNS CONVENTIONS



δ: Drift angle
ε: Pitch angle
Y: Lateral force
Z: Vertical force
M: Pitch moment
N Yawing moment
Vs: Speed of the ship

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