Operator Guidance for French Mine Hunters

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ABSTRACT

STEREDENN is a monitoring system dedicated to stability installed on a French navy mines hunter. It includes several functionalities as hydrostatic calculation and sea states estimator. For the evaluation of capsizes risk, numerical calculations (with FREDYN from CRNAV), model experiments and sea trials were performed by DGA hydrodynamics

KEYWORDS

MONITORING ; OPERATIONAL LIMITS ; OCEAN BASSIN ; SEA STATES ESTIMATOR

INTRODUCTION

The French navy ship CMT class (see Fig1) is mine hunters built in cooperation between Belgium, Netherlands and France. Those ships and their conceptions are quite old now. Naval stability standards and their use have also changed and been reinforced. Therefore modifications for the improvement of the stability (mainly after damage) of those mines hunters could be considered in the near future. Modifications have been or will be carried out independently in each country.

SSF is the part of the French ministry of defence which is in charge of the maintenance of the fleet. Preliminary to the planned modifications and in order to characterise more precisely the current ships, SSF asks DGA Hydrodynamics to assess the dynamics stability of CMT.

Following this study SSF and ALFAN (Navy headquarters) decided to reinforce operational limits for CMT before modifications. In order to help the crew to follow those operational limits instrumentation and screenplay were installed on board in the wheelhouse. This prototype system named STEREDENN is described in this paper. First feed back are encouraging in the use of this prototype. Are such operation systems useful for security improvement?

Fig. 1: CMT "Croix du sud" (French navy).

STEREDEEN: GENERAL ARRANGEMENT

STEREDENN is linked to one motions sensor (speed and 6 degrees of freedom) and includes four functionalities. The first one is a numerical tool (FASTABI). Using the mass distribution given by the crew it computes the hydrostatics characteristics of the ship. The second one is a sea states estimator (SSE) based on a comparison of motion measurements to numerical calculations. By using real time measurement of the roll period, STEREDENN is able to estimate the vertical position of the centre of gravity. These parameters which are those mainly necessary to asses the risk of capsizing by numerical calculations are used to choose the corresponding polar plot which is indicated to the crew (Fig2). This information can help them to select a safer route (speed and relative heading).

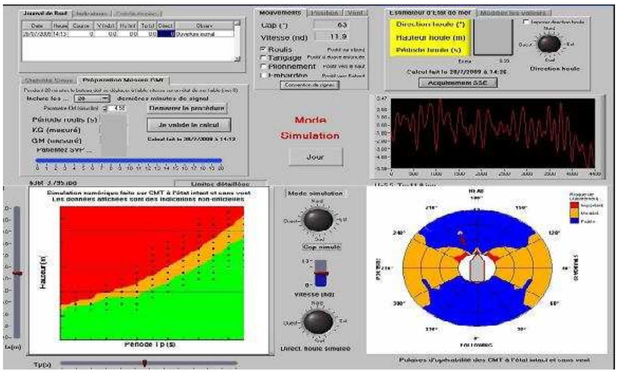

Fig. 2: Screen on the wheel-house

The four functionalities are described bellow.

FIRST: FASTABI

FASTABI is a numerical code that has been internally developed by DGA Hydrodynamics. The programming language is VB8 (Microsoft Visual Basic 2005) which makes maintenance easy and ensures a long lifetime. The code is run through DOS interface, using a mesh defining the hull forms and a series of input files made of various command lines. This type of input data has been adopted to facilitate the learning of the software and its integration in a numerical process of optimisation which necessitates to put a great number of computations in parallel, or in a system such as STEREDENN.

The software presently contains the following modules:

- A loading case being given, searching for the static equilibrium of the ship in draught, heeling and trim for various static wave configurations,
- Starting from the values read on the draught scales, searching for the corresponding load case (displaced volume), which is numerically equivalent to a stability experiment,
- Computation of the internal efforts supported by the hull girder (shearing forces and bending moment),
- Intact stability analysis using the naval ships regulation issued by Bureau Veritas (BV Naval Rules),
- Intact and damage stability analysis using the civil regulations issued by International Maritime Organisation (IMO)
- Computation of tank tables to be used by the hydrodynamic code called FREDYN, that deals with dynamic stability on waves,
- Computation of the various hydrostatic data for the studied hull.

If needed, the free surface effects can be taken into account.

FASTABI processing

To evaluate the stability of a given ship, the displaced volume, the location of the centre of buoyancy, the location of the centre of floatation and the associated inertias of the floatation surface are needed. To get some of these values, volume integrals are to be derived, which can bring some difficulties. To avoid this problem, the hull is modelled using a surface mesh made of a multiple polyhedrons, which allows the volume integrals to be transformed in surface integrals, using the divergence theorem. Going further, the surface integrals are themselves reduced to line integrals applied to the contours of the polyhedrons, using the Green’s theorem. The mathematical problem is then quite simple, consisting in multiplications and additions. To be able to enforce this method, it is nevertheless necessary to have a totally closed mesh, that is without any free edge and the elementary faces of the mesh have to be oriented in the same way. Hence, for

FASTABI, each normal of the mesh points outwards.

FASTABI then automatically computes the displaced volume that balances the weight of the ship (defined by the mass and the location of the centre of gravity) using a converging method by limiting the global mesh to the floatation surface, the latter representing still water or waved surface.

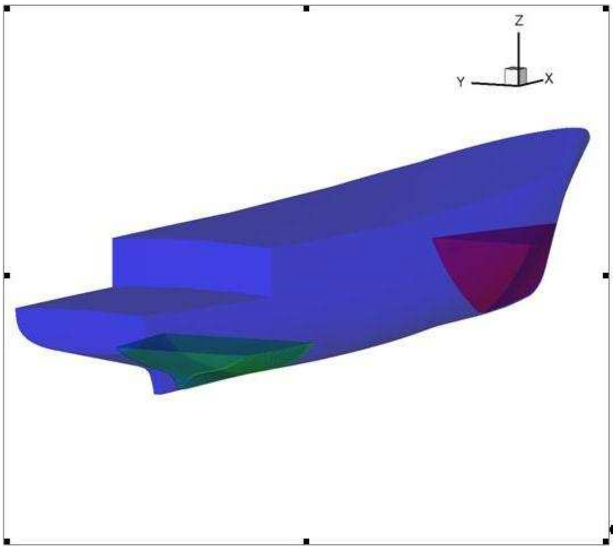

Fig. 3: CMT mesh used by FASTABI

The free surface effect resulting from liquid taking place in tanks is taken into account by meshing the latter and filling them up to the actual level. Each type of tank of the ship can also be automatically meshed by FASTABI, assuming that the walls located in the hull are planar surfaces.

Hence for a pure parallelepiped, 6 planes are used to define the tank, while for which some walls are common with the hull, such as the green and purple ones on Fig. 3, the closed contour is obtained by intersecting limiting planes with the global mesh of the hull. More complicated tanks are obtained by successive removals of smaller tanks from primary one.

As soon as the closed contour is obtained, FASTABI automatically meshes the outer surfaces using the so-called “ear cutting” algorithm, which is a triangle based method.

This meshing technique developed in FASTABI allows to quickly modell each tank with a degree of precision at least equal to that of the mesh of the hull and avoids the use of heavy codes dedicated to meshing operations.

The free surface effect is then automatically computed and taken into account at each step of the converging method when determining the global equilibrium of the ship. Hence, results are greatly improved when comparing with methods that traditionally represent the free surface effect through simple formulations.

Damage stability

A given damage in the hull is considered in FASTABI as the loss of buoyancy volume. The damage is modelled exactly in the same way as the tanks are, and then removed from the global mesh of the ship, providing a new hull with which any computation can be performed. Tanks that are located in the damaged area can be removed or taken into account, being empty or loaded by their filling liquid. In the latter case, the buoyancy of the tank is included in the calculations.

The damaged analysis is carried out on intact situations that satisfy the stability criteria. The computations are made exactly in the same manner as in the intact situation, except that the criteria to be observed are modified.

It can be noted that concerning STEREDENN presently installed on board CMT “Aigle”, the possibility to perform damaged stability analysis is not used.

SECOND: GM ESTIMATOR

The Sea State Estimator (SSE) module used in STEREDENN has already been briefly described in previous papers (Leguen 2007). It is based on a mathematical model of the ship (Transfer functions) that gives the ship's motions on any sea state. The SSE varies the significant height, the period and the heading of the swell till it fits the measured motion of the ship. The ship is modelled through her transfer function and the SSE searches the sea state that minimises the error between the theoretical response and the measured one. The sea state is modelled through a Bretschneider spectrum whose parameters are:

- Significant wave height (H_s in m)
- wave period (peak period T_p or zero up-crossing period T_z in s)
- wave heading (in deg).

Transfer function of the ship are computed thank to the software PRECAL (seakeeping code developed by the CRS, Cooperative Research Ships). What we are interested in are the significant height and the peak period correlation coefficients of the 6 degrees of freedom. Computations are made for each wave period (from 5 to 8s each 1s), each heading (from 0 to 180deg each 15deg) and for several speeds (from 0 to 12knt each 2knt). All the results are gathered in a database stored on-board by STEREDENN. To achieve the estimate, the characteristic values of the measurements (H_s, T_p and correlation coefficients) are compared to the values of the database. For each period and heading, the difference between theoretical and measured value of H_s, T_p and the correlation coefficients are computed. The estimated sea state is the one with the smallest total error.

The motions used to estimate the sea state have an impact on the accuracy of the results. Building from its own experience, for this study DGA Hydrodynamics made the choice to use heave, pitch and sway motions. Heave and pitch are used for comparison of H_s and T_p because these motions are quite linear. The Pitch/Heave correlation is used to differentiate in an efficient way head seas and following seas. The sway/Heave correlation is used to identify if the swell comes from starboard or from port side. Those choices have been validated thank to seas trial aboard a CMT.

THIRD: GM ESTIMATOR

A functionality of the system was developed in order to help the crew to validate the input data of the risk analysis. One of those input data is the vertical position of the centre of gravity. One way to estimate the *GM* value is to measure the roll period (for example Cotta 1985). If the displacement, the position of centre of buoyancy, the mass inertia in roll and the added inertia in roll are known then it is possible to estimate the GM value using (1).

$$T_\phi = 2\pi\sqrt{\frac{I_{xx} + I_{xx}^a}{GM.\Delta.g}} \tag{1}$$

The difficulty is to know the inertia and the added inertia. To obtain those values, the best way seems to be to use measurements made during a stability experiments require by rules for *GM* evaluation. If during one of those experiments the roll period is measured, than it is possible to have the inertia on that day. Then as displacement, inertia can be deduced from this day to another day using mandatory stability package.

Formula (1) is often compressed in formula (2), and called Doyère formula.

$$T_\phi = k\sqrt{\frac{B^2 + 4KG^2}{GM}} \tag{2}$$

Inertia is included in the determination of the value of parameter *k*.

By inversion of (2) the position of centre of gravity is obtain with (3) from roll period measurement.

$$KG = \frac{-T_\phi^2 + \sqrt{T_\phi^4 - 16.k^2\left(B^2k^2 - KM.T_\phi^2\right)}}{8k^2} \tag{3}$$

This methodology does not give measurement with so good accuracy than the usual way, but can be useful for the crew to check their estimation of *KG*.

FOUR: RISK ESTIMATOR

Seakeeping calculations

Seakeeping calculations (including occurrence of capsizing in severe seas) are performed with FREDYN version 9.9 (developed by CRNAV). Only cases without damage were performed (including limited cases with wind). In total 228288 (33x76x7x13) run of 1 to 8 hours (depending of the occurrence of capsize).

- 33 different displacements
- 76 sea states Tp from 5 and 17s and Hs from 2.5 to 17m
- 7 speeds
- 13 wave heading

Two months of calculation on a PC cluster were needed.

Operability polar plot

Results were presented as one polar plot for each sea states displacement and wind conditions (see Fig3).

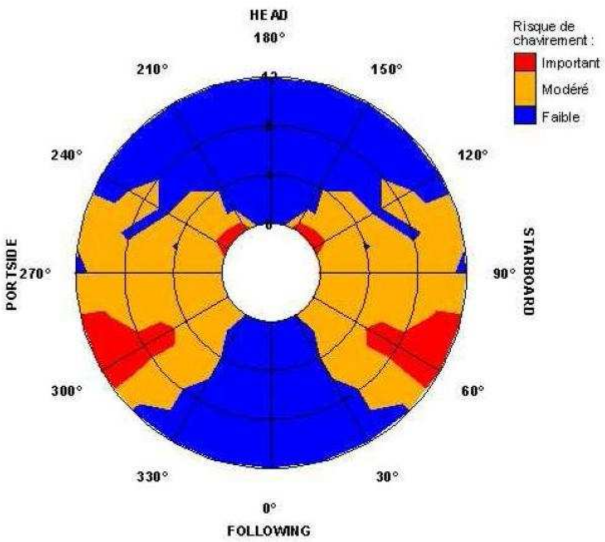

Fig. 3: Operability polar plot

Risk is assessed as the probability of capsizing in the following hour (with same condition). Risk is divided into three levels:

- Blue : low risk
- Orange : moderate risk
- Red : High risk

Experimental validations

Because FREDYN is more dedicated to frigates hull forms, validation was needed for smaller ships as the mine hunters.

Beforehand roll damping was determined in order to include it directly in the code rather than use empirical estimations included in FREDYN. The estimation was determined during sea trials with extinction tests.

Two campaign were performed on two model sizes (1/12 and 1/36 scale). The first was used to validate moderate motions without speed while the small model was used with forward speed. In order to validate the occurrence of capsize it was mandatory to find at least on for the model. Those capsizes occurred on severe seas with low forward speeds and following seas.

CONCLUSIONS

The system STEREDENN was tested at sea for a year. First feed-backs and validations of the SSE are confident. It seems that the information given to the crew is useful for them, even if they have always to make the final decision to evaluate the situation and the risk.

ACKNOWLEDMENTS

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