Numerical prediction of non-cavitation noise from marine propeller

F. Chevalier[1] (frederique.chevalier@navalgroup.com), L. Bordier[2], C. Leblond[3], F. Sainclair[2], J.-M. Sanchez[1], G. Serre[4]

[1] Warship Performance Department, Naval Group, France
[2] Naval Platform Modelling Department, SIREHNA, France
[3]CESMAN, Naval Group, France
[4]CEMIS, Naval Group, France

1 Context & objectives

Assessment and improvement of the radiated acoustic footprint within the design stage of ships has always been crucial to Naval Group, especially at high speed where main noise sources are hydrodynamic flow and propeller.

To evaluate and optimize the propeller radiated noise, Naval Group relies mainly on high level propeller experiments in the Large Hydrodynamic Tunnel (GTH), a very specific facility of DGA Hydrodynamics.

But with shorter delays required for shipbuilding, it is also necessary to invest in numerical approaches to estimate the propeller main contributions to noise and to reduce the number of model tests, which remains a technical challenge in this domain.

These numerical approaches are also complementary to model tests in their capability to provide additional information like the seabed effect or the propeller radiated noise directivity, which are not available in the tunnel experiments.

Each developed numerical approach must be evaluated by comparisons to experimental data or through numerical benchmarks. One of the biggest difficulties in the application of these approaches is the adaptation of models widely used and validated for aeronautical applications but not necessarily in sea conditions.

The challenge is then to develop and adapt models for marine applications where predominant contributions may be different because of a much lower Mach number and a strong coupling between a heavy fluid and the structure.

2 Non-cavitation noise from marine propeller

At Naval Group, propellers are designed in order to push away far enough cavitation inception and to reduce noise contribution without cavitation.

Regarding the propeller acoustic performance without cavitation, several contributions must be modelled as illustrated in figure 1.

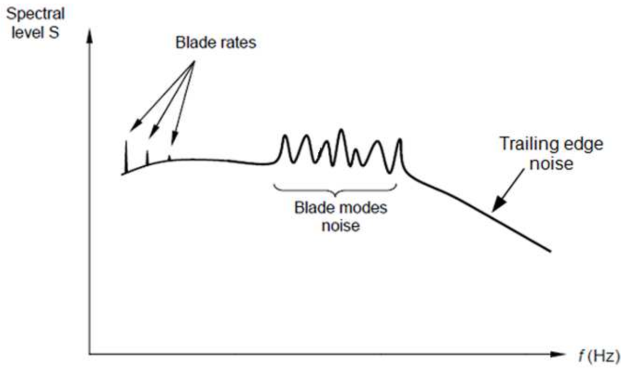

Fig. 1. Non-cavitation direct noise spectrum from marine propeller

For non-cavitating propellers, the main direct noise contributions are:

- The blade rates (BR) noise generated by supposedly rigid blade passage into the mean disturbed inflow,
- The blade modes noise associated to the blade vibro-acoustic response under hydrodynamic turbulent boundary layer excitation,
- The trailing edge noise associated to turbulence diffraction at the blade trailing edge.

Each of these contributions requires specific modelling approaches. Hereafter, the blade modes noise approach is first described because it is the most important propeller noise contribution and the more complex to model. Then, BR noise and trailing edge noise approaches are introduced.

3 Numerical approaches and results

3.1 Blade modes noise prediction

3.1.1 Approach description

To predict the blade modes noise, it is necessary to calculate the vibro-acoustic response of the blade excited by the turbulent boundary layer (TBL).

The main difficulty here is to estimate the parietal pressure fluctuation created by the TBL on each blade of the rotating propeller. Usually, DNS (Direct Numerical

Simulation) or LES (Large Eddy Simulation) CFD (Computational Fluid Dynamics) calculations are necessary to well describe the turbulent structures appearing in the boundary layer but these methods are very time consuming because of the required accuracy of spatial and temporal discretisations.

That is why a specific calculation methodology is developed (as described in figure 2) to get this pressure excitation with less computation time.

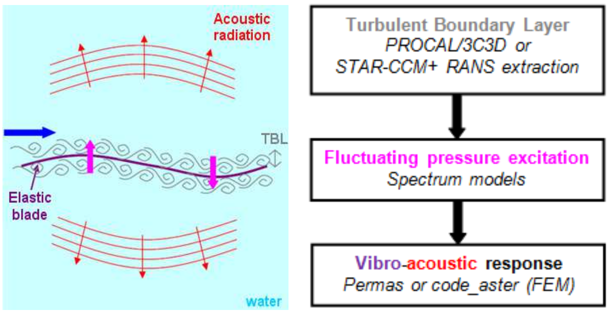

Fig. 2. Blade modes noise calculation methodology

First, to calculate TBL parameters (exterior TBL velocity, TBL thickness, friction coefficient, etc.), two approaches can be used:

- A coupling can be done between the potential flow code PROCAL, developed by the CRS (Cooperative Research Ships) and the boundary layer code 3C3D (ONERA software); or
- Naval Group specific developments enable to extract directly TBL parameters from RANS (Reynolds Averaged Navier-Stokes) STAR-CCM+ (SIEMENS) calculations.

Then, the TBL parameters are used as an input to Naval Group specific developments to calculate the parietal pressure spectrum with models like Chase [1] or Rozenberg [2] and to provide the pressure excitation on the blade within vibro-acoustic models [3].

Finally, two different FEM (Finite Element Method) codes can be used to calculate the vibro-acoustic response: PERMAS (INTES) and code_aster (EDF).

This methodology is an improvement of the previous approach described in [4], especially:

- Several pressure spectrum models are available;
- Fluctuating pressure excitation takes into account spatial evolution of the turbulent boundary layer parameters [3]; and
- Vibro-acoustic response of the blade into the water is directly calculated with the FEM software, contrary to BEM (Boundary Element Method) software like Virtual.Lab Acoustics which needs *in vaccum* blade modes as an input.

3.1.2 Approach evaluation

To evaluate the blade modes noise approach, a specific test case is considered: two projects of propeller with a close structural behaviour generate a very different blade modes noise level measured at model scale.

First, TBL parameters calculation is evaluated by comparison between STAR-CCM+ developments and 3C3D results. Indeed, no measurement of these TBL parameters on a rotating blade is available. Results illustrated on figure 3 show that the two methods are in good agreement.

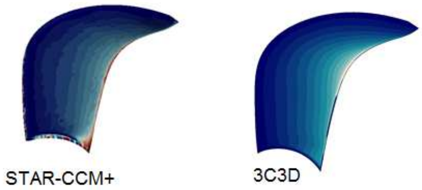

Fig. 3. TBL thickness calculation for propeller N°1

Then, blade wetted modes calculation is evaluated by comparison between code_aster, PERMAS and measurements. Results illustrated on figure 4 show that both calculations are in good agreement with measurements available on propeller N°2. To simplify calculations with code_aster method, only one blade is modelled, that is why there are slight differences with PERMAS for which the whole propeller is modelled.

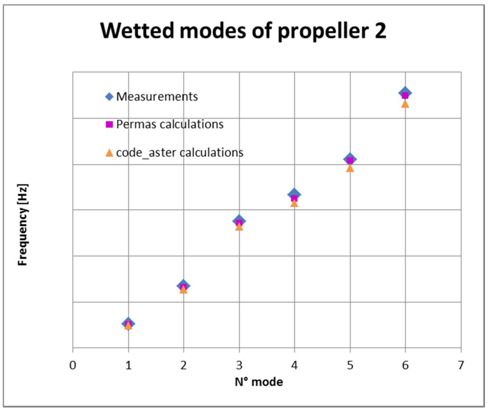

Fig. 4. Wetted modes of propeller N°2

On figure 5, examples of wetted blade deformation calculation are introduced. According to calculations, the two propellers get close structural behaviour.

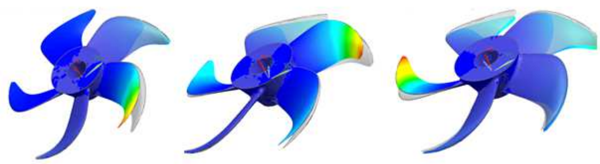

Fig. 5. Examples of wetted blade deformation calculation

Finally, the blade modes noise is calculated on the two propellers and results illustrated in figure 6 show that the numerical approach (based on PERMAS) enables to well reproduce the vibro-acoustic phenomenon. Indeed, the noise gap measured between the two propellers is well predicted.

code_aster calculations are not introduced here but predicted noise levels are close to PERMAS ones.

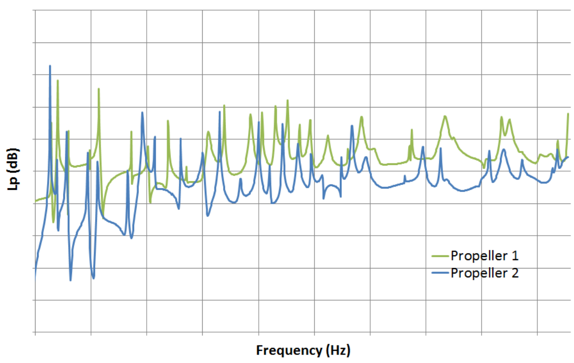

Fig. 6. Radiated noise results with Permas approach

3.1.3 Approach improvements

To get more accurate prediction, some ways remain to improve the blade modes noise approaches. Especially, other models like Slama [5] can be tested to calculate TBL excitation directly from RANS calculations which should enable to take rigorously into account the curvatures and the mean pressure gradient effects. Improvements can be also obtained with the excitation implementation in the vibro-acoustic response to get faster calculations.

3.2 Blade rates noise prediction

To predict the BR noise, acoustic analogies [6] are used to propagate pressure fluctuations from the blade surface with a BEM approach to take into account for free surface and installation effects. The previous numerical approach [7] was improved as illustrated on figure 7.

First, the propeller inflow and the pressure field on blades are obtained through CFD computations with STAR-CCM+. Then, the hydro-acoustic response is calculated with Virtual.Lab Acoustics (SIEMENS).

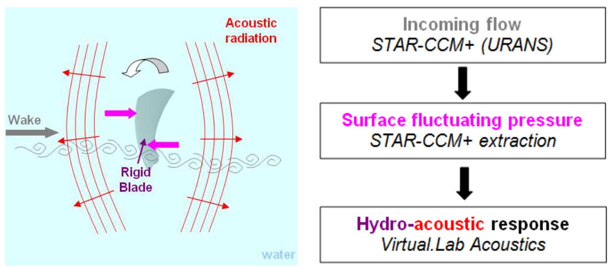

Fig. 7. Blade modes noise calculation approach

To evaluate the numerical results, model test measurements are used to get only the propeller noise (without hull/propeller contribution). The noise level prediction for the first BR frequency is generally close to the model measurements. However, the noise level seems to be underestimated for the other BR frequencies.

Benchmark with other commercial software is in process to keep improving predictions.

3.3 Trailing edge noise prediction

To predict trailing edge noise, a numerical approach is developed. To calculate the parietal pressure spectrum, models like TNO Blake [8] or “Scaling law” [9] are implemented in the approach. Then, to calculate the far field radiated noise, low Mach number models like Howe [10] and Amiet [11] are used.

First, a validation is done on a NACA0012 into the air [12]. Results illustrated in figure 8 are in good agreement with measurements.

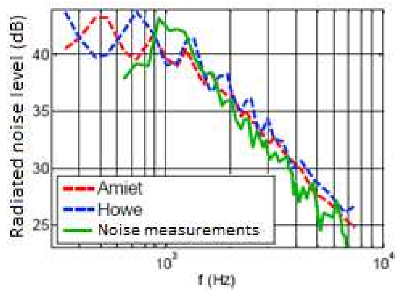

Fig. 8. Radiated noise results for NACA0012 into the air

Then, the numerical approach is used to evaluate blade trailing edge noise into the water: experimental noise slope is well predicted. Results show that the main noise contribution is associated to the blade tip one.

Improvements are possible on this approach. For example, parietal pressure excitation extracted directly from CFD calculations can be used. Other models can be developed to take trailing edge vibration into account and to predict tip vortex noise.

4 Conclusions

Finally, the developed numerical approaches for each propeller noise contribution give valuable results for the propeller design process.

Some improvements remain to be included to get a more accurate noise prediction. Moreover, ongoing validation tests will bring useful data to refine these approaches.

The implementation of these numerical approaches will enable to predict the radiated noise from marine propellers before model tests. Moreover, these numerical studies will also accelerate the design process of silent propellers within a numerical optimisation loop.

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Author/Speaker Biographies

Frédérique Chevalier, hydro acoustics specialist at Naval Group for 8 years. **Luc Bordier**, hydrodynamics research engineer at Naval Group SIREHNA for 10 years. **Cédric Leblond**, vibro-acoustics specialist at Naval Group Research for 6 years. **Florent Sainclair**, hydrodynamics research engineer at Naval Group SIREHNA for 6 years. **Jean-Max Sanchez**, vibro-acoustics expert at Naval Group for 14 years. **Gilles Serre**, aero acoustics specialist at Naval Group Research for 3 years.