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Original Paper

Development of ship noise analysis program based on the combination of simplified Janssen method and SEA method

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Abstract: The comprehensive CAE software development company TechnoStar (hereinafter, TS) has developed the Ship Noise Analysis Program (hereinafter, SNA Program), under the instruction of Dr. H. Shuri, Professor at Tokai University, who has been leading the joint research and development with ClassNK and ten shipbuilding companies in Japan, under the scheme of "ClassNK joint R&D for the maritime industry." The SNA program with its outstanding capabilities such as (1) easy and quick creation of analysis model, (2) closer link with acoustic data base, (3) precise simulation based on the SEA algorithm, and (4) excellent operability by means of versatile GUI, has been making a significant contribution to accomplishing the joint development of a Ship Noise Prediction System which will provide an effective and strong design tool for customers to comply with the noise level code of the International Maritime Organization (IMO).

Keywords: Ship noise, Janssen method, SEA method, Structure-borne and air-borne noise

1. Introduction

To conform to the IMO code for ship noise levels of the concerned ships, the most important functions required in a ship noise prediction system are: (1) a more precise estimation function by the best use of past available data in the early design stage, (2) an appropriate adjusting function to measure data through the rational tuning procedures in the verification stage of the ship production phase, and (3) the most effective and optimum countermeasures, if any, to maintain noise levels as required by the IMO code **[4]** in the final stage of ship delivery.

The SNA Program has been developed to enable the above functions to be performed easily, quickly, and precisely.

Table 1: New Noise levels (dB(A)) Codes for Accommodation spaces **[4]**

Designation of rooms and spaces	Old Code (Non-compulsory)	New Code (compulsory)	
		1,600~10,000 GT	≥10,000 GT
Accommodation spaces			
Cabin and hospitals	60	60	55
Mess rooms	65	65	60
Open recreation areas (external recreation areas)	75	75	
Offices	65	65	60

2. Computational Algorithm of Ship Noise

The computational algorithm of the SNA Program is based on the most practical method specialized for the ship noise prediction that combines the simplified Janssen method and the simplified SEA method, as proposed by Professor Shuri in the NK Joint Research **[1]**.

In this algorithm, the following five types of the sound sources are taken into account for the prediction of cabin noise in question: structure-borne sound L_{pS}, air-borne sound L_{pA}, air conditioner and ventilator noise L_{AC}, exterior fan noise L_{FN}, and funnel exhaust noise L_{EX}.

The resultant sound pressure level L_p in the concerned cabin is evaluated by the following logarithmic summation of the noises caused by each sound source.

$$L_p = 10\,log\left(10^{\frac{L_{pS}}{10}} + 10^{\frac{L_{pA}}{10}} + 10^{\frac{L_{AC}}{10}} + 10^{\frac{L_{FN}}{10}} + 10^{\frac{L_{EX}}{10}}\right) \quad (1)$$

2.1 Structure-Borne Sound

As structure-borne sound is the most significant factor for ship noise prediction, it is necessary to apply an analytical method in order to numerically evaluate the sound energy transmission mechanism considering the various complex

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structures (material, shape, and size) and transmission factors of the sound power incident, reflection, absorption, radiation through transmitting route from the sound sources to cabins, instead of an empirical method such as the Janssen method.

Therefore, the SEA method is selected to be applied in this study, by simplifying the sound power transmission mechanism and the analysis structure model, as practically as possible.

By applying the statistical averaging procedure in specifying the frequency range, the transmitted power flow between adjacent elements is shown in **Figure 1** and calculated by the fundamental power balance equation as shown in **Equation (2)**. The transmitted power P_{ij}(=-P_{ij}) depends on the difference of vibration energy levels of elements E_i , E_j and the internal power loss in element P_i^d.

$$P_i^{in} \quad = P_i^d + P_{ij} = \omega\eta_i E_i + \omega N_i \eta_{ij}\left(\frac{E_i}{N_i} - \frac{E_j}{N_j}\right) \qquad (2)$$

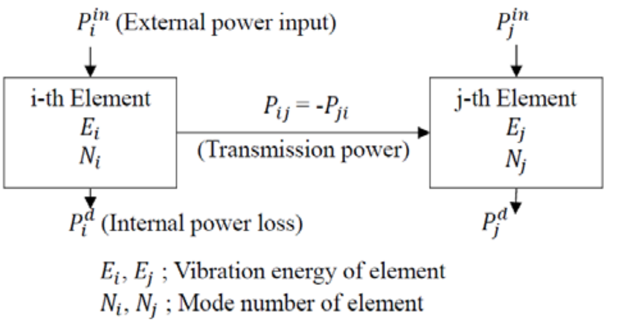


Figure 1: Transmission of vibration energy between elements

where, *ω* is the center angular frequency in 1/3 or 1/1 octave band and η_i *(ω)* is the internal loss factor of the specific material of panel element on the frequency basis, which is experimentally verified and specified in the vibration transmission database.

The coupling loss factor η_{ij} *(ω)* is calculated by the group velocity of the flexural wave on flat panel element c_{gi} and the connected joint condition c_τ as per **Equation (3)** and **Equation (4)**.

$$\eta_{ij}(\omega) = (c_{gi}c_\tau)/\omega\pi \qquad (3)$$

$$c_\tau \quad = \tau_{ij}(L_{cij}/\ S_i) \qquad (4)$$

where, L_{cij} is the joint length between element *i* and *j*, and S_i is the area of element *i*. In addition, τ_{ij} is the vibration energy transmission efficiency at the joint which is computed by the fundamental formula of L. Cremer and M. Heckl **[2]** for each flat plate connection form as shown in **Figure 2**.

Here, the vibration energy transmission is estimated by considering only the flexural vibration mode on the flat panel element as simplified.

Furthermore, the mode number N_i existing in the range of band width *Δω* at the center frequency *ω* is given as **Equation (5)**.

$$N_i(\omega) = S_i/4\pi \cdot \sqrt{M_i/B_i} \cdot \Delta\omega \qquad (5)$$

where, S_i, M_i, and $B_i$are the area, surface density, and bending stiffness of the flat panel element, respectively.

Moreover, the radiation loss factor η_i^r , the boundary loss factor η_i^b, and the damping loss factor η_i^d are introduced into the power balance equation, so that the influences of power losses on sea water under the ship draft, other structures out of the analysis modeling range, and the application of special damping construction are considered.

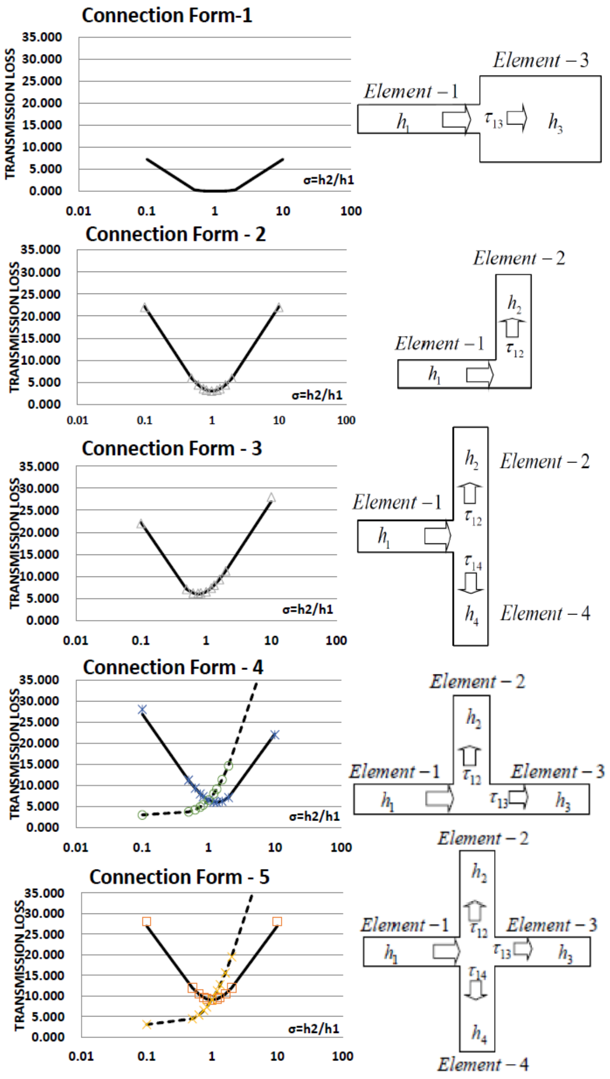


Figure 2: Transmission of vibration energy between elements

The resultant sound power transmission is calculated by solving the simultaneous equations for all the elements in the concerned model.

Figure 3 shows the analysis process for cabin noise due to structure-borne sound.

As we can estimate the vibration velocity level L_v on the deck structure under the concerned cabin, by the solution of the power balance equations, the cabin sound pressure level L_{ps} is predicted as the summation of the sound pressure level L_{psf} radiated by the floor vibration and sound pressure levels L_{psi} radiated by the surrounding walls and ceiling as per the following **Equation (6) ~ (8)**, taking into consideration the floor insertion loss IL_n by special application such as the floating floor, the transmission loss ΔL_{vwi} from deck to wall, and the average acoustic radiation efficiency of members of the sound receiving room $\bar{\sigma}$, which are experimentally verified and specified in the sound receiving room database, including the data of area of floor S_f and each walls S_i and the sound absorption area of the sound receiving room A_E.

$$L_{psf} = L_v - IL_n + 10log\left(4S_f/A_E\right) + 10log\,\bar{\sigma} \tag{6}$$

$$L_{psi} = L_v - \Delta L_{vwi} + 10log(4S_i/A_E) + 10log\,\bar{\sigma} \tag{7}$$

$$L_{ps} = 10log\left(10^{\frac{L_{psf}}{10}} + \sum_{i=1}^{5} 10^{\frac{L_{psi}}{10}}\right) \tag{8}$$

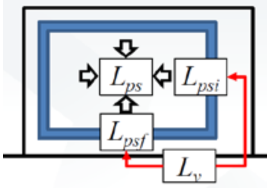


Figure 3: Analysis model for structure-borne sound prediction

2.2 Air-Borne Sound

The air- borne sound level L_{pA} in the sound receiving room is predicted by the sound pressure level L_{p0} in the adjacent sound source room or by the sound power level L_w of the sound source device as shown in **Figure 4** and as per **Equation (9)** and **Equation (10)**. In addition, the calculation of the air- borne sound level L_{pA} requires the data of the sound absorption area in the sound source room A_S and the sound receiving room A_E, the sound transmission loss TL, and the area S of the partition wall/deck plate. The verified data measured at the shop test or sea trial are specified in the database.

$$L_{p0} = L_w + 10log(4/A_S) \tag{9}$$

$$L_{pA} = L_{p0} - TL + 10log(S/A_E) \tag{10}$$

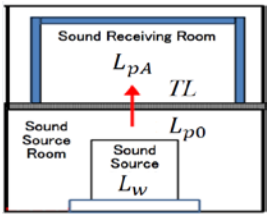


Figure 4: Analysis model for air-borne sound prediction

2.3 Air Conditioner and Ventilator Noise

As shown in **Equation (11)** and **Equation (12)**, the sound pressure level L_{AC} in the cabin is given by the measured data or predicted by the power level of sound source L_{ACw} in front of the air outlet of the air conditioner or ventilator. Here, the directivity factor Q, the distance r from the point of the sound source, the room constant of sound receiving room R, the mean sound absorption coefficient $\bar{\alpha}$, and the total surface area S of the cabin are taken into account.

$$L_{AC} = L_{ACw} + 10log(Q/4\pi r^2 + 4/R) \tag{11}$$

$$Where,\ R = \bar{\alpha}S/(1-\bar{\alpha}) \tag{12}$$

2.4 Exterior Fan Noise

As shown in **Equation (13)** ~ **Equation (15)**, the sound pressure L_{FN} in the cabin caused by the exterior fan noise is predicted by the measured sound pressure level L_{FNp} or sound power level L_{FNw} at a distance of 1 m from the exterior fan, and the attenuation of the distance r from the fan to the sound receiving room. In addition, the sound transmission loss TL of the walls and roof, and the directivity factor Q are taken into account. Here, the effect of sound diffraction is not considered.

$$L_{FN} = L_{FNpin} - TL + 10log(S/A_E) \tag{13}$$

$$L_{FNpin} = L_{FNw} + 10log(Q/4\pi r^2) \tag{14}$$

$$L_{FNw} = L_{FNp} + 10log(4\pi) \tag{15}$$

2.5 Funnel Exhaust Noise

Similarly to the exterior fan noise, the sound pressure L_{EX} in the cabin caused by the funnel exhaust noise is predicted by the measured sound pressure level L_{EXp} or sound power level L_{EXw} at a distance of 1 m apart from the funnel top, as per **Equation (16)** ~ **Equation (18)**.

$$L_{EX} = L_{EXpin} - TL + 10log(S/A_E) \tag{16}$$

$$L_{EXpin} = L_{EXw} + 10log(Q/4\pi r^2) \tag{17}$$

$$L_{EXw} = L_{EXp} + 10log\,(4\pi) \tag{18}$$

3. System Design of SNA Program

The dedicated SNA Program based on the algorithm described in the previous section is composed from three sub programs as shown in **Figure 5**, which are developed on the platform of TS multi-purpose CAE software “TSV-Pre” (hereinafter, TSV).

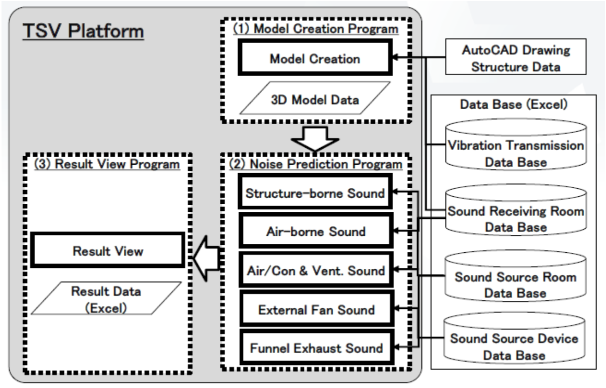


Figure 5: Overall configuration of SNA Program

3.1 Supporting Database System

All necessary data for the model creation and noise prediction analysis are defined in the supporting database system (hereinafter, DB) as per the formulated MS Excel format as shown in **Table 2**, which are specified and updated on the basis of the data verified by shop tests, measurements at sea trial, and so on, by each user.

The entire DB can be automatically controlled by the DB control function in the DB system which enables the following functions:

① Selecting and importing necessary data files from the DB

② Data format conversion to TSV

③ Data check, error detection, and notification

Table 2: Contents of database (DB) definition

Data Base	Data Contents
[A] Sound Receiving Room DB	[A-1] Definition of Sound Receiving Room
	[A-2] Characteristics of Vibration and Sound
[B] Sound Source DB	[B-1] Definition of Sound Source (Structure-bone)
	[B-2] Definition of Sound Source (Air-borne)
	[B-3] Definition of Sound Source (Air-con. & Ventilator)
	[B-4] Definition of Sound Source (Exterior Fun)
	[B-5] Definition of Sound Source (Funnel Exhaust)
[C] Sound Source Room DB	[C-1] Sound Source Room Data
[D] Vibration Transmission DB	[D-1] Ship Structural Data
	[D-2] Material Property Data

3.2 Model Creation Program

The 2D forms of the relevant frame sections of the hull structure are defined by using the point, line, and surface layer data that are extracted from AutoCAD data (dxf format) by the layer control method. Then, the 3D analytical model can be automatically created on the platform of TSV by placing the 2D forms in the order of the identified frame number and connecting the adjacent points, lines and surfaces as per the following steps as shown in **Figure 6** and **Figure 7**.

Step-1: Import the 2D cross-sectional data from AutoCAD data and identify their frame position data.

Step-2: Project the cross-sectional lines onto the cross-section plane.

Step-3: Connect the adjacent frames’ data and create surfaces.

Step-4: Edit (cut, add or delete) surfaces, as needed.

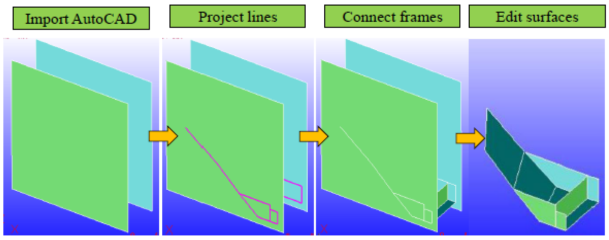


Figure 6: Model creation procedure

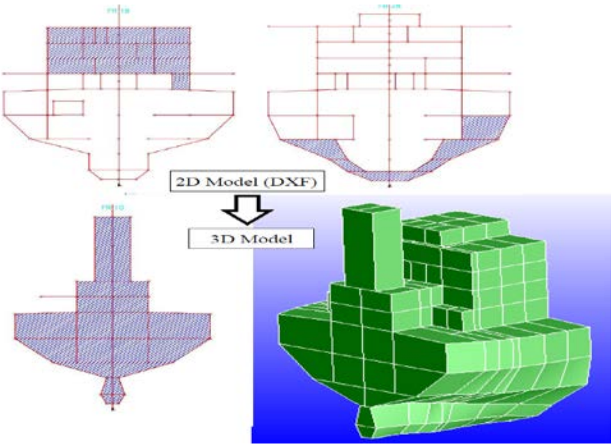


Figure 7: 3D model assembly

As shown in **Figure 8**, the simplified model is composed from flat panels of the significant structures for energy transmission elements, such as shell, deck, and wall, excluding stiffeners.

The effectiveness and accuracy of the prediction using these simplified models has been validated by comparison of the measured results in actual ships and the predicted results.

Thus, it is confirmed that the easy and quick creation of analysis models has a significant impact on saving the time and effort required for ship noise analysis thereby providing a high potential tool for the optimum design of ship noise control.

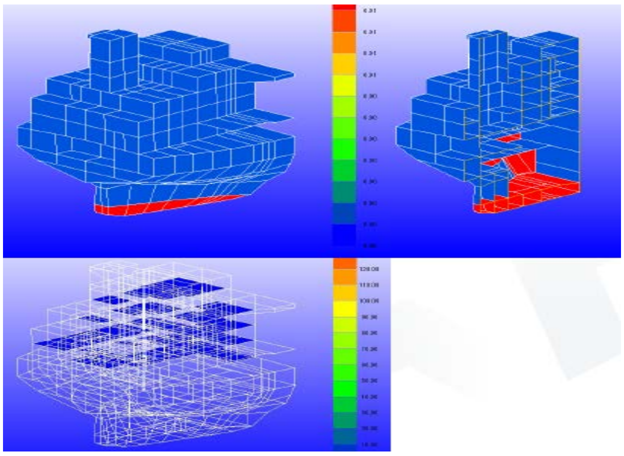


Figure 8: Structural modeling for analysis

3.3 Noise Prediction Program

Here, the simplified SEA method is applied, where only the sound energy transmission due to the flexural vibration modes of an element is taken into account.

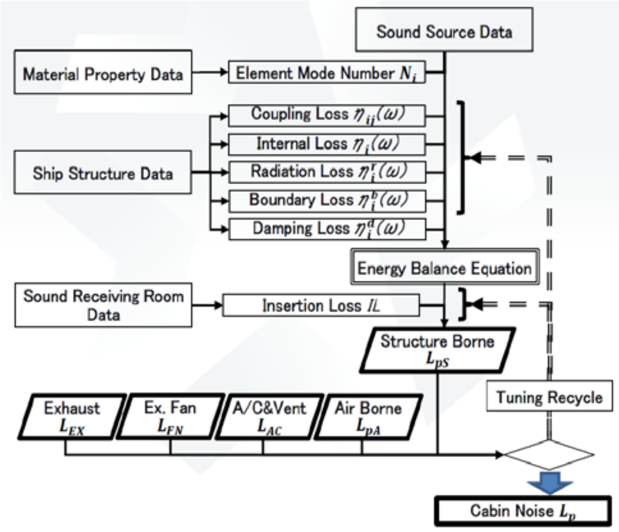


Figure 9: Program flow of noise prediction function

The effects caused by the simplified analysis can be adjusted by introducing a tuning process for the loss factors such as the internal loss factor η_i and the coupling loss factor η_i as shown in **Figure 9**. The effectiveness of this procedure has been experimentally validated **[3]**.

Moreover, the operation of the noise prediction is easily executed by one-push, using the simplified model and the formulated DB system, according to the following six functional steps by the work bench as shown in **Figure 10**.

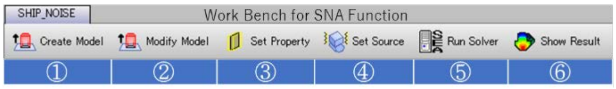


Figure 10: Work Bench for SNA function

① Create model function (Model read on to TSV)

② Modify model function (Model merge, add parts, and delete)

③ Set property function (Read DB, and define calculation condition, material and thickness, damping material, pillar, draft, tank and boundary condition)

④ Set source function (Define sound source of Structure-borne, Air-borne, AC &Vent, Ex. Fan and Exhaust sound)

⑤ Run solver (Perform analysis as per the program flow shown in **Figure 9**, by 1/1 or 1/3 Octave band basis, and re-calculate due to the modification of the model and DB for tuning operation.

⑥ Show result function (Display of analysis results for confirmation, by overall value, octave band curve, and contour figure (vibration velocity/acceleration/energy, sound pressure, element thickness, mode number, and loss factors)

3.4 Result View Program

To verify the analysis results in comparison with the measured data, the following two functional steps are performed after step ⑥ in the previous subsection.

⑦ Plot function (Output of calculation result for verification study by plotting the response of elements, frequency and cabin on the basis of frequency or element)

⑧ Tuning function (MS Excel file output of factors for tuning)

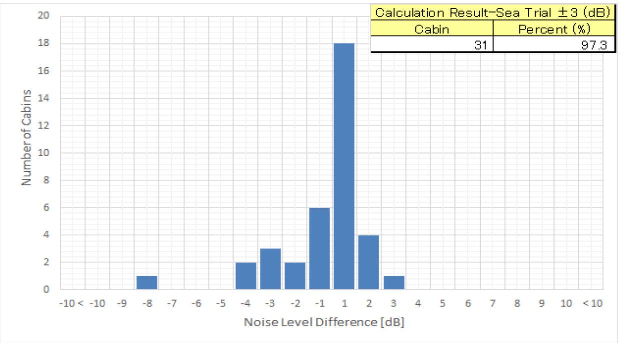
The cycle of steps from ⑧ back to ⑤is repeated for the tuning operation as shown in **Figure 9**, which is the most important and invaluable function for practical ship noise control procedures with reference to the measured data.

4. Conclusion

The SNA Program was developed in accordance with the computational algorithm based on the combination of the simplified Janssen method and simplified SEA method under the instruction of Professor H.Shuri.

This program has outstanding capabilities in ship noise prediction: easy and quick model creation, close link to the formulated DB, precise simulation of the phenomenon of vibration transmission, and excellent operability.

The analysis accuracy for noise prediction must depend heavily on the accuracy of the sound energy loss factors, and it has been confirmed that this method can provide the correct prediction by using the verified factors as shown in **Figure 11**.



Calculation Result−Sea Trial ±3 (dB)	
Cabin	Percent (%)
31	97.3

Figure 11: Histogram of Calculation Result - Measured value

Meanwhile, the tuning function of this program is invaluable to define the most suitable factors to adjust to the verified value, and will be expanded to the automatic optimum tuning by using sensitivity analysis and the curve fit method.

Acknowledgements

The SNA Program was developed under the instruction of Professor H.Shuri leading the Joint Research & development with ClassNK and 10 Shipbuilding Companies in Japan.

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[4] IMO/MSC 91/22/Add.1 Annex 1, Resolution MSC.337(91).