プロペラ及び主機の波浪中負荷変動が燃料消費量に与える影響の考察

株式会社MTI / 日本海事協会　Badalotti Timoteo
株式会社MTI　◎小知井 秀馬
日本海事協会　宋 玉中　髙木 道雄　見良津 黎　若生 拓也

1. Introduction

The International Maritime Organization has set a challenging timeline to achieve net zero greenhouse gas (GHG) emissions by around 2050. Increasing propulsive efficiency is a crucial enabler for green shipping in that it reduces the fuel amount and related GHG emissions for traditional fuels and it mitigates the need for large storage space for green fuels with low energy density. While efficiency in steady conditions and calm water has been thoroughly studied, propulsive efficiency in heavy seas has been the subject of limited research[1)-3)]. In the present investigation, the impact of a fluctuating propeller load due to heavy seas on the main engine, which is a topic still lacking thorough analysis, was examined.

2. Fluid-Dynamic Analysis and Propeller Torque Assessment

The target ship is JBC (Japan Bulk Carrier), whose hull shape, resistance, and performance data were published by NMRI[4)], together with studies detailing related CFD methods[5)-6)]. CFD was set up on a ship scale of 1:40 to validate the model against the towing-tank tests. The fluid domain was set with suitable boundary conditions, see Fig. 1. A ship speed of 14.5 kn and full conditions were adopted. The Unsteady Reynolds Averaged Navier Stokes set of equations was solved in STAR-CCM+. Excellent agreement was observed between CFD results and tests in calm water, see Tab. 1, thus confirming the accuracy of the present CFD method. Then, simulation in waves, Fig. 2, allowed to compute the wake amplitude, Fig. 3. The reduction in flow speed on the propeller with respect to the ship speed is exactly in phase with the wave amplitude as measured at a location along the propeller disk not disturbed by the ship, showing that the wake fraction is determined mainly by the incident wave and not by the waves radiated by the ship oscillations. That is, for large ships, the ship oscillations are so small that the propeller does not perceive them.

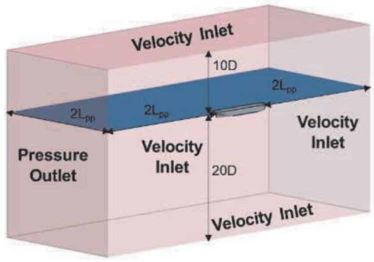

Fig. 1　Fluid Domain and Boundary Conditions

	Test	CFD
Resistance [N]	36.36	36.22
Sinkage [mm]	-6.02	-6.02
Trim [deg]	-0.103	-0.108

Tab. 1　CFD Accuracy

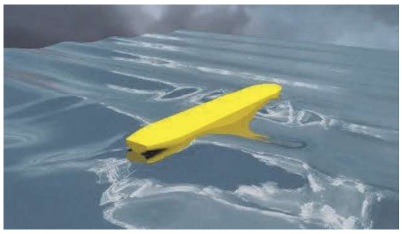

Fig. 2　JBC in Heavy Seas

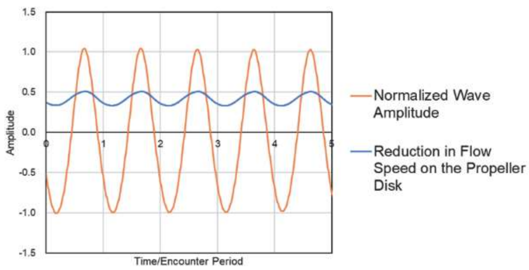

Fig. 3　Wave and Wake

The propeller rotational speed at full scale such that the thrust generated by the propeller equates resistance was found through the propeller curves for calm water resistance, average resistance in waves, and fluctuating resistance in waves, where the flow speed on the propeller disk was evaluated through CFD. Once the rotational speed is known, the propeller torque can be assessed, see Fig. 4.

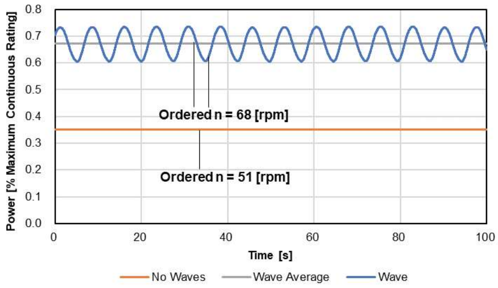

Fig. 4 Propeller Power in Different Conditions for a Severe Realistic Sea State

3. Engine Fuel-Consumption Analysis

The engine torque was plugged into a GT-Suite engine model which accounts for the full unsteady behavior of all engine components, where combustion is solved along each cylinder. The details of the engine governor and injection controller reflect realistic algorithms adopted for a bulk carrier of a similar size as JBC. Fig. 5 shows that the effects of fluctuating torque are negligible. The key reason for this behavior is that, for large marine engines, the fuel oil consumption (FOC) obtained from steady simulations is roughly a linear function of the torque, as shown in Fig. 6, where unsteady deviations in engine speed are minimal for a fast modern engine controller, and unbalances to the left and right of the average torque occurring due to scavenging and other delays are also minimal. Therefore, the fuel consumption obtained for an average steady torque and ordered engine speed is close to the average value obtained in fluctuating conditions, as long as propeller emergence does not occur and the power is below its maximum value for a given engine speed.

4. Conclusions

The effect of wave-generated ship motion on the wake can be generally discarded, and only the wave-generated fluctuations on the propeller wake can be considered.

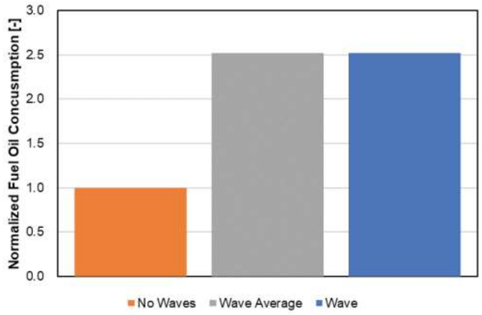

Fig. 5 Normalized Fuel Oil Consumption

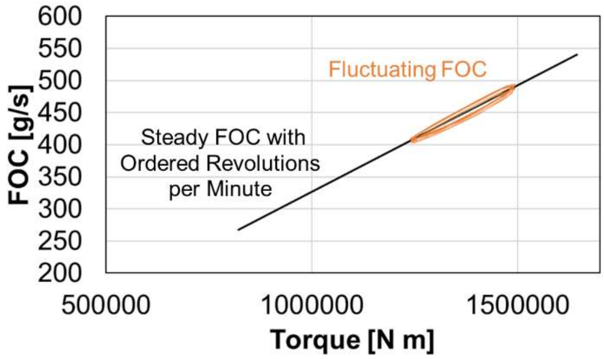

Fig. 6 Unsteady Load Schematic

Additionally, for a large marine engine in heavy seas, the average propeller torque can be adopted to satisfactorily predict the fuel consumption, and fast dynamics can be discarded. Therefore, as a general guideline, formula-based wave-generated resistance can be plugged into a propeller model and a Mean Value Engine Model to predict real-time with a reasonable computational cost fuel consumption for ocean-going vessels.

References

1) O. Bondanrenko et al., Dynamic Behavior of Ship Propulsion Plant in Actual Seas, 2010
2) K. Yum et al., Simulation of a two-stroke diesel engine for propulsion in waves, 2017
3) H. Mikkelsen, Numerical Study of Ship Performance in Calm Water and in Waves, 2021
4) https://www.t2015.nmri.go.jp/jbc.html
5) K. B. Korkmaz, CFD Predictions of Resistance and Propulsion for the JAPAN Bulk Carrier (JBC) with and without an Energy Saving Device, 2015
6) Z. Liu, Resistance and wake distortion optimization of JBC considering ship-propeller interaction, 2021