Deep Neural Network (DNN) Assisted Parametric Optimisation of Stern Flap for a High Speed Displacement Ship

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ABSTRACT

A stern flap is an energy-saving device installed at the aft section of a ship. These flaps are considered one of the best design solutions for reducing the drag of old and newly constructed high-speed ships and crafts. Traditionally, the design and optimisation of the stern flap are undertaken using towing tank model tests and CFD numerical simulations. Stern flap parameters are predicted by trial and error or from the inputs of previous successful installations. Since the traditional approach is time-consuming and costly, only a few design configurations can be evaluated. The best design is chosen based on these few simulations/test, which does not guarantee an optimised design. Surrogate Based Optimisation (SBO) is a powerful and cost-effective tool that can be used in addition to the traditional methods to arrive at the optimised design combination. The best-predicted design combination can then be assessed using traditional techniques to validate the prediction. In this paper, Deep Neural Network (DNN) has been used to construct a surrogate mathematical model (meta-model) to predict the optimum parameters of the stern flap for reducing the total resistance, $R_T$, of a high-speed displacement ship. Ship speed, flap angle, flap chord length, and flap span are provided as inputs to the DNN model, which predicts the resistance of the stern flap appended hull form. DNN is trained using the resistance values, which have been calculated using model tests and CFD simulations for a limited number of combinations. One hundred fifty-six experimental data points have been used to analyze a large number of combinations of stern flap features to arrive at the optimised stern flap. The study presented in this paper illustrates that DNN can be used to construct a surrogate function and evaluate large design spaces without actually conducting the physical tests/simulations of those combinations to arrive at optimised design parameters.

KEY WORDS: Stern Flap; Energy Saving Devices; Surrogate Based Optimisation (SBO); Deep Neural Network (DNN); Towing Tank Model Test; CFD Numerical Simulation; Artificial Intelligence (AI)

INTRODUCTION

Flow at the aft section of the ship influences the drag of the ship. Various energy-saving devices have been experimented with, developed, and installed to reduce the drag force experienced by the ship. The stern flap is one such device installed onboard surface combatants for over three decades, Cusanelli (2002). A stern flap akin to a bilge keel is an extension of the ship’s hull at the aft which modifies the ship’s aft flow, decreases the flow velocity resulting in pressure recovery at the aft, and increases the transom exit velocity. The aft wave system gets modified, which causes a reduction in the transom wave height and far-field wave energy. Due to the stern flap, the ship’s hydrodynamic length increases. Additionally, the ship aft trim and sinkage reduce, and lift and drag forces are developed on the flap.

Gabor Karafiath (1999) has discussed the U.S. Navy’s experience using appendages such as stern wedges, stern flaps, and integrated wedge and flap. These appendages have been retrofitted or installed successfully on approximately 170 U.S. Navy and Coast Guard Ships (Cusanelli & Karafiath, 2012) across 13 classes, among which stern flaps have shown the best results. Japanese Maritime Self-Defense Force has also installed stern flaps on D155 class destroyers Maki et al. (2016). It has been found that the stern flaps are effective for Froude Number, $F_n$ greater than 0.2 Gabor Karafiath (1999), which coincides with the operational speed regimes of surface combatants and high-speed displacement ships. An increase in ship speed and a reduction in effective power have been observed in sea trials of the ships, which were retrofitted with stern flaps, Cusanelli (2002). Stern flaps have also shown beneficial results in planing hull vessels. Stern flaps, due to their success, have been retrofitted/installed in a variety of naval platforms by the U.S. Navy, such as LPDs, LSDs, Patrol Boats, Frigates, and Destroyers. Stern flap’s technology can be utilized on commercial vessels also Cusanelli (2003); however, there is no reported study for commercial vessels. Traditionally, model tests and CFD simulations are used to design the stern flaps; however, getting an optimised configuration over various speed regimes is a challenge. Surrogate-based optimization using DNN as a surrogate model is being explored in this study to overcome this problem.