Fuel saving effectiveness of a ship’s stern-addeded device

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Abstract：

一、After taking office, President Ma Ying-jeou set an “energy saving and carbon reduction” policy into motion. In response to this policy, the Ministry of National Defense (MND) established an executive team to take practical steps for compliance.

二、If the annual fuel consumption remains the same, fuel expenses will gradually increase year by year, succumbing to soaring oil prices. To avoid a reduction in training contents, some aggressive approaches to fuel savings should be developed and implemented immediately.

三、Over the past few decades, the training program of swimmers has primarily focused on increasing their propulsive force. However, it reached a bottleneck preventing further improvement; therefore, drag reduction has now become the goal to achieve.

四、Since a ship’s hull design is based on mission requirements from the outset, its fuel consumption generally depends on the maintenance and characteristics of its propulsion system.

Introduction

In response to the trend in environmental protection followed by the international community, on the 2008 National Day, President Ma Ying-jeou declared that the government would take the lead in this movement by promoting an “energy saving and carbon reduction” policy. The Ministry of National Defense (MND) established an executive team in line with the government’s policy with the goal of achieving fuel savings of up to 7% by 2015. To achieve this goal, the use of airplanes, ships, and military vehicles will be rigidly evaluated under the prerequisites of maintaining combat readiness and not disrupting training. Therefore, military exercises and training were correspondingly reduced the following year to cope with this dilemma. For example, an annual live-fire military exercise where Kidd-class destroyers take the place of Sovremenny-class destroyers and act as a hostile force was cancelled because of insufficient fuel[1]. Such consequences show that this policy actually has negative effects, as revealed in the quality and quantity of armed forces training.

In the 2008 Beijing Olympics, the “Exocet,” Michael Phelps garnered 8 gold medals and broke several world records. Over the past few decades, the training program of swimmers has primarily focused on increasing their propulsive force. However, at present, a bottleneck has been reached in relation to propulsive methods, and drag reduction has taken over as the common goal, as seen in the shark-mimetic swimsuits that are now available. With its large volume and complex weaponry, a modern warship focuses mainly on maneuverability, efficiency, and speed, rather than fuel savings, in order to ensure combat readiness. Under these prerequisites, drag reduction techniques should be investigated to prolong sailing distances or training periods with fixed fuel spending.

Ship’ s drag reduction

As a ship moves through the sea, frictional resistance is generated due to the motion of the hull through a viscous fluid. The interaction between the seawater and the ship causes a shear force that resists the ship’ s advance,known as drag. There have three effective ways to attain drag reduction;they are the microbubble techniques, the polymer techniques and adding a device on the transom

1.Microbubble drag reduction

Experimental results have shown that the effectiveness of the microbubble technique depends on various parameters and that it is possible to reduce the hull resistance by approximately 10％ to 18％[2].In other words, the optimum drag reduction effect can be achieved within specified parameter ranges[3].Even though the microbubble technique has an added advantage of lessening the noise, the design and fabrication of a bubble generation system is very complicated and expensive.

A similar technique called micro-blowing reduces skin friction. Several experimental results have shown the effectiveness of this technique for a high-speed ship and estimate the drag reduction to be about 25～35％[4].In future, this technique will be applied to large, high-speed ships.

2.Drag reduction coating

The objective of a drag reduction coating is to alter the surface roughness of a fluid-solid interface by adding a coating material to the surface of an object to reduce the friction resistance. However, the coating will gradually wear away over time, which is a technical problem that must be solved.

The advantages of the polymer coatings are the ease with which they can be used. However, they only have significant effectiveness below certain speeds, as demonstrated from the experimental results in the published literatures[5].The use of a fish-mimicking mucin mixture has shown a drag reduction efficiency as high as 16％[6]. Recently, the Office of Naval Research (ONR) developed a type of high-speed craft, or ” X-craft,” and intends to use polyethylene oxide ejected from the lifting body to mimic the drag reducing effect of mucin. Experiments have shown that this compound can reduce the drag on a vessel by as much as 80％[7].Some experimental results about the nano-coating have shown that a ship traveling at moderate speed would experience an average resistance reduction of 11～14%[8].

3.Stern-added devices

Trim mechanisms such as a stern wedge, stern flap, and interceptor (shown in Fig.1) are commonly used to gain lift at the stern. The advantages of the stern-added devices are their simple shapes, ease of fitting, and extensive installation in the U.S. Navy and Coast Guard, where their effectiveness has been publicly proven, making them a smart fuel saving choice for the ROC. Navy.

Evaluating the drag reduction of a stern-added device

These stern-added devices cause a decrease in flow at the bottom of a hull at a location extending from the aftmost portion of a ship to a point generally forward of the propellers. During the early 1980s, the U.S. Navy used an Arleigh Burke class (DDG 51) AEGIS guided missile destroyer in a series of experiments with several wedge geometries to test their drag reduction efficiencies; however, the results were not as good as expected in moderate speed ranges. To further compare the working mechanism, a combined wedge-flap device was proposed (shown in Fig.2(a)). Experimental results indicated that a stern wedge and stern flap both act on the same fluid, and hence, their combination would provide no more benefit than either acting alone, or may even be counterproductive. To thoroughly assess the efficacy of an individual or combined device, a ship model test was performed, the results of which are shown in Fig.3[9]. It shows that the speed had to be higher than 18 knots to save power using the wedge alone but only higher than 14 knots for the flap alone. The main advantage of the combined wedge-flap is that it affords a greater reduction in delivered power than does either the wedge acting alone or the flap acting alone. Conclusively, a reduction in the output power depends not only on the ship speed but also on the geometry and location of the device, irrespective of whether an individual or a combined device is used. In model testing, it was discovered that a stern flap was more effective than a stern wedge. In fact, for any geometry, installation, or powering performance, a flap device was found to fit the mission requirements of the U.S. Navy better than a wedge, and was subsequently applied to the FFG-7 frigate class for further assessment[10].

The present paper primarily discusses a stern flap. Not only has this device shown its benefit at moderate speeds but it has also been in service for more than a decade on a variety of U.S. Navy and Coast Guard classes. A stern flap has been used to provide a better balance between a ship' s power requirements and engine operating capability, increase the interval between engine overhauls, and extend the service life of the propulsion machinery. A flap can also reduce propeller loading, cavitation, vibration, and noise. As a way to decrease the outlay for national defense, it may be only a timely rainfall rather than a downpour, but it is still worth the investment.

Stern flaps have been applied to a wide variety of ships, with systematic investigation using a diverse array of geometry variations and locations.

Fig.4 shows six kinds of flaps developed by the U.S. Navy[11] and Fig. 5 shows the performance of a full-scale ship with different flaps corresponding to several speeds in which the value below 1.0 indicates a power reduction due to the flap.

Ships equipped with a stern flap range from the first frigate class Copeland of U.S. Navy in 1989 to a Coast Guard cutter in 2002. Table 1 shows their remarkable performances during sea-trial tests. Conclusively, the power was reduced by up to 15%, the fuel savings by as much as 10%, and the speeds were increased by nearly 1 knot on combatants and almost 2 knots on patrol boats. Therefore, when using either high speeds for combat drills or moderate speeds for a regular cruise, a minimum fuel savings of nearly 5% could be attained in sea trials. Moreover, stern flaps are constructed with simple techniques and are generally installed when ships enter dry-dock as part of the regular overhaul cycle or using a cofferdam while still in service (shown in Fig. 6). It is also relatively inexpensive to back-fit for any kind of ship, and no negative impacts on ship service have thus far been reported. With the exception of some combatant ships, the U.S. Navy has installed this stern-added device on Whidbey Island dock landing ships (LSD 41) since April 2009[12].

Recently, due to an increase in the demand for high-speed and high-efficacy ships in the military field, a trim mechanism called an interceptor was developed. Experimental results show that a well-designed interceptor can effectively reduce the running trim and the resistance of a high-speed double-hull craft[12].

For a large combatant ship, experiments were performed using a frigate model equipped with the combined interceptor-flap device (shown in Fig. 3(b)). As shown in Fig.7, the resistance varied with speed under the given data for the interceptor protruding length and flap angle. The three solid lines represent the measured values under the conditions of a bare hull, the interceptor alone, and the interceptor-flap. The results show that the resistance decreases by approximately 10% with the interceptor alone and by 12% with the combined interceptor-flap device near the design speed. However, there is a fuel penalty near moderate speeds of approximately 10 ~18 knots[13].

## Concluding Remarks

The objective of the present study was to determine a method to attain maximum fuel saving effectiveness under the current limitations. Some modern drag reduction techniques were discussed in the present paper, along with their advantages, applicability, and cost. Because the U.S. Navy has persistently installed stern-added devices on their in-service ships, these devices have been proven to be a premium option under the present situation. To develop an effective measure under the fuel savings policy, the present study proposes the U.S. Navy’s example or a domestically developed device for ready-made reference. To reap fuel savings in the long run, the present mechanisms can be a useful tool.

註釋：

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