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Stern flaps: A cost-effective technological option for the Indian shipping industry

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ABSTRACT

Surface Combatants are highly dependent on fossil fuels for their propulsion. During the course of its voyage, these vessels experience considerable amounts of drag or resistance based on the operational environment and their hull form. Reduction of this drag would result in a corresponding reduction in fuel costs, exhaust emissions, and an increase in the vessel's speed and range. The operational flexibility of the vessel is enhanced by an increase in the time between successive refuellings, as well as the distance over which the vessel can operate without the need for replenishment. Of the many energy saving devices, fitment of a stern flap on Surface combatants is a very popular cost-effective means for drag reduction. The U.S Navy has extensively installed stern flaps on their combatants and, through this experience, found that suitably designed stern flaps had reduced the power requirement of the vessel they were fitted on by about 4–19%, an amount that translates to significant fuel savings and reduction in emissions. This paper will discuss the concept of stern flaps, examine the benefits offered by this technology on U.S Naval platforms, and will present the scope of leveraging this technology in Indian Defence Shipbuilding and Ship repair which could lead to significant reductions in power and emissions without compromising the platform's performance.

KEYWORDS

Stern flap; energy saving device; cost effective technology; surface combatant

Introduction

Ocean-going surface combatants are heavily dependent on fossil-fuels for their operation. Reducing energy usage onboard has significant benefits by way of reduction in fuel costs incurred, increase in the range of a vessel and reduction in fuel emissions. An increase in the range can substantially reduce the operational turnaround time for a vessel. This could result in a reduction of the amount of strategic reserves that have to be maintained, thereby providing more flexibility in operational costs. If energy saving methods are used on a significant number of surface combatants, an increase in range might permit a reduction in reliance on fuel-related force structures (oil tankers) and infrastructure (storage facilities). Further, due to surge in crude oil prices and a great demand for carbon dioxide reduction owing to environmental issues, it is prudent to reduce fuel-oil consumption on ships. As a result, more and more ships around the world are exploring the utilisation of energy

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efficient devices to improve their fuel efficiency. A Stern Flap is one of many such energy saving devices which can be fitted at a low-cost during refits or even at the new-build stage of a vessel. A stern flap is an extension of the hull bottom surface which extends the rear-most part of the vessel. It is a relatively small appendage, built of plate steel and welded to the transom.

Many solutions exist to allow vessels to save fuel or increase speed, but most of these tend to be costly or complicated to implement. On the other hand, a stern flap is a relatively small, simple, and unobstructive device which alters the flow around the hull to produce performance benefits. It is easy to install, inexpensive and can be retrofitted on an already constructed vessel or fitted on a new construction vessel (Figure 1).

Evolution of the stern flap

The flow around an ocean-going surface combatant and the design of hull form greatly influence the drag encountered by the vessel. Drag reduction mechanisms such as stern flaps have witnessed profound changes over the years. The evolution of the stern flap technology on surface combatants over the last 30 years will now be discussed. The idea of a stern flap first originated from the experience gained by using a device called a "stern wedge". As per the published literature available in the open domain,[1] the first reported usage of stern wedges on surface combatants dates back to their fitment on German Type 34 destroyers which were built before World War II, and later in the 1980's, on the Italian Maestrale class frigates. Thereafter, extensive research was conducted on the usage of stern wedges on U.S naval vessels, primarily on FFG 7 Class frigates and DDG 51 Class Destroyers. While the stern wedge exhibited improvement in the powering performance of destroyers, it was less than expected for the FFG Class frigates, which prompted the U.S Navy to explore other options such as stern flaps. Fitment of the stern flap on FFG 7 Class frigates improved the powering performance of the vessel by about 8.4%. Thus the FFG 7 frigates became the first class of U.S naval surface combatants to be fitted with a stern flap.

Frigates: Subsequent to the success achieved on FFG 7 class frigates, stern flaps were retrofit on the FFG 25 Class frigate, USS Copeland in 1989, which was the first full-scale prototype stern flap retro fitment. It has been reported that, the fitment of this stern flap reduced the annual delivered power by about 8% with annual fuel savings of

Figure 1. Stern flaps present in US Naval vessels. Source: Cusanelli DS. Stern Flaps – A Chronicle of Success at Sea (1989–2002). *SNAME Innov Mar Transp*. 2002 (M): 1–16.

1,050 barrels amounting to about $39,000 annually per ship. With the success of stern flap fitment on FFG 25 class frigates, U.S Navy then embarked on a study to retrofit stern flaps on their USS *Oliver Hazard Perry* class of frigates. On completion of this study in 1993, it was estimated[2] that the maximum power required to propel the vessel would reduce by about 8% at its cruising speed, with an annual fuel consumption saving of over $50,000 per ship, resulting in a total annual savings of about $2.5 million. It was also observed that within a timeframe of about 10 months, the cost incurred in research, manufacturing, and retrofitting of stern flaps could be fully recovered. Later, a stern flap with FFG-25 design was also fitted on the FFG-61 Class frigate, USS *Ingrahm*, and on Australian Adelaide Frigates. Based on the US Navy's success with stern flaps, the Royal Canadian Navy instituted a study to retrofit their Halifax Class frigates[3] with stern flaps during their life extension refit, with an aim to reduce the escalating cost of fuel consumption to operate these vessels. On conclusion of the study in 2007 it was estimated that an annual fuel consumption of about 2.33% could be achieved.

Destroyers: In 1996, the stern flap design programme was initiated by the U.S Navy for DDG 51 Class Destroyers, USS *Arleigh Burke Flight I/II*, which already had a stern wedge installed. On conclusion of the study, it was estimated that the fitment of the stern flap, in addition to the existing wedge (integrated wedge flap design) would reduce the power consumption by about 4.4 % with an annual fuel saving of 2,950 barrels, amounting to $109,000. It was later reported[4] that the U.S Navy had fitted all 28 of its DDG 51 class USS *Arleigh Burke* destroyers with stern flaps. In 1997, after the success of stern flaps on frigates, a stern flap was retrofit on a DD 963 class destroyer, USS *A.W. Radford*. Sea trials indicated a power reduction of approx. 6–14% with an increase of ship speed by about 0.75knots. The annual fuel savings were estimated to be 3,650 barrels, i.e. about $135,000 annually per ship. This was followed by another stern flap installation on DDG 61 class destroyer USS *Ramage* in the year 2000. The stern flap was installed while the vessel was afloat, at the pier-side, using a cofferdam. It was estimated that the annual fuel savings would be about 4700 barrels, with a total savings in fuel cost of $195,000 per ship. In the year 2001, a stern flap was fitted by the U.S Navy on a new construction DDG 79 Destroyer Class vessel, USS *Oscar Austin*. The annual fuel consumption was estimated to be reduced by about 6%, with an associated fuel savings of $155,000 per ship. The stern flap also increased the maximum speed of the vessel by 0.3 knots. The Japanese Maritime Self Defence Force (JMSDF) has also installed stern flaps on JDS Akizuki (DD 115) Class destroyers.

Patrol boats: Several flap installations were undertaken by the U.S Navy on its patrol vessels. Some notable installations include Cyclone Class (PC1) Patrol vessel, as well as the installation of a prototype stern flap on USS *Shamal* in 1995 which exhibited a powering reduction of about 7.7% and an increase the top speed of about 0.9 knots. The U.S Coast Guard also installed the first prototype stern flap on USCG WPB1340 *Jefferson Island* in the year 2000. This was followed by another stern flap installation by the U.S Coast Guard on WPB1345 *Staten Island* in the year 2001, which represented the smallest platform to which the stern flap had been fitted. Another unique feature of this fitment was that the design represented the use of a flap with greatly reduced width. Sea trials indicated a power reduction in the range of 10.9–19% with a 1.9 knot increase in top speed. The associated annual savings in fuel cost was estimated over $50,000. In the year 2001, a stern flap was installed on a HAMILTON CLASS U.S Coast Guard vessel, WHEC722

Morgenthau. The unique feature of this installation was that the flap was manufactured to match the shape of the aft contour of the vessel.

Other classes of vessels: The applicability of stern flap technology for drag reduction on a wide range of vessels is evident from the fact that fitment of stern flaps was undertaken[5] by the U.S Navy on a variety of platforms such as the San Antonio Class (LPD 17) amphibious docks, amphibious assault ships of the Tarawa (LHA 1), Wasp (LHD 1), America (LHA 6), Makin Island (LHD 8) classes, dock landing ships of the Whidbey Island (LSD 41) and Harpers Ferry (LSD 49) classes of vessels. In addition to these, extensive studies have also been undertaken on the application of stern flaps to aircraft carrier hulls.[6]

Table 1 gives an idea of the initial cost incurred in installation/retro-fitment of stern flaps on U.S Naval vessels, the corresponding annual savings achieved, and the period of return on initial investment. The data indicated has been sourced from reported literature. As of 2016, it has been reported that new construction and retro-fit of stern flaps have been undertaken on 170 U.S navy and coast guard vessels. A very limited amount of literature on the fitments of stern flap technology have been published, and many studies of stern flap hydrodynamics on surface combatants and their publications remain *classified* and are not available in open domain.

Basic concept of a stern flap

A stern flap can be defined as a relatively small, hull appendage, fitted on the transom aft bottom portion of a ship, for the purpose of reducing the drag experienced by the ship by modification of flow around the hull. The critical geometrical parameters used to define a stern flap are chord length, span and flap angle. Schematic of the stern flap is illustrated in Figure 2.

Mechanism of drag reduction: A stern flap, like a conventional foil section, produces lift force at the aft of the vessel where it encounters flow. The stern flap, when fitted to the transom of a ship, reduces the velocity of the flow coming to it from the forward portion of the vessel. This reduction in velocity in turn increases the pressure (termed as lift) under the flap. A component of this pressure acts in the direction of the ship's motion, consequently reducing the drag on it. Further, the turbulent flow region in the aft of the vessel caused due to the separation of flow which represents energy lost by the ship is greatly modified by the fitment of the stern flap, which again, in turn decreases the drag on the vessel. The stern flap also decreases wave heights in the aft of the vessel thereby adding to the reduction in drag.[7]

Table 1. Details of initial capital and value on investment achieved by fitment of stern flaps.

Ser.	Year	Vessel/class	Type	Cost of installation ($)	Power reduction (%)	Increase in top speed (knots)	Annual fuel savings ($)	Payback period (years)
(a)	1989	USS *Copeland*	Frigate	60,000	4–11	0.3	62,000	1.0
(b)	1995	USS *Shamal*	Patrol Boat	10,000	5–10	0.9	23,000	0.4
(c)	1997	USS *A.W.Radford*	Destroyer	170,000	6–14	0.75	160,000	1.1
(d)	2000	USS *Ramage*	Destroyer	160,000	5–15	0.9	195,000	0.8
(e)	2001	WPB1345 *Staten Island*	Patrol Boat	14,000	3–19	1.9	50,000	0.3

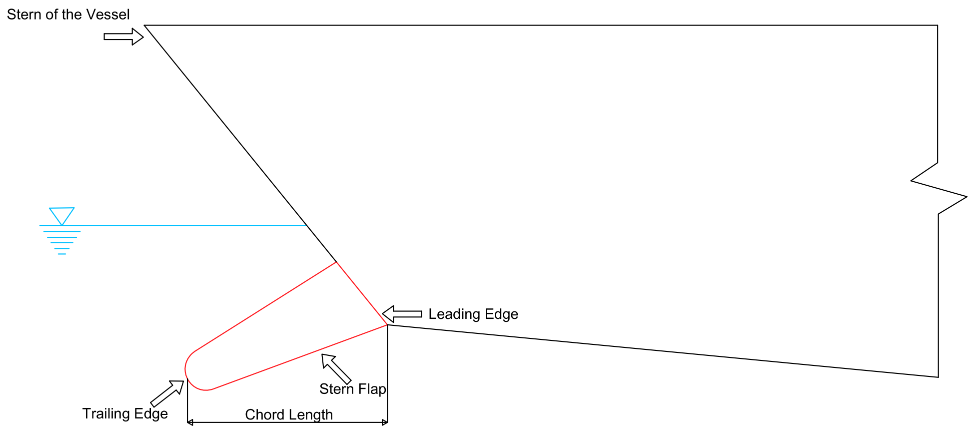

Figure 2. Critical geometrical parameters.

Design methodology

A stern flap is designed or tailor made for a particular ship's hull form, for a specific service speed regime in which the vessel is expected to operate for most of the time. The aim of the designer would be to evolve an optimum stern flap for the vessel, i.e. to find the right combination of the above mentioned critical geometrical parameters so as to result in maximum reduction in resistance and powering requirements, once the flap is fitted on the vessel. As previously discussed, the stern flap could either be retrofit on an already constructed vessel, or could be installed afresh on a vessel under construction. The entire process of optimisation of the stern flap right from its design to its installation can be broadly discretised into five distinct stages.

Hull form modelling and computational fluid dynamics analysis: In the first stage, computer modelling of the hull form for a given vessel is undertaken. This hull form is analysed using simple numerical techniques, such as Computational Fluid Dynamics (CFD), which are widely used in all fields of engineering. The aim of the CFD analysis is to computationally simulate the performance of the vessel in terms of drag reduction with various configurations of the stern flap installed and to narrow down the potential stern flap configurations for subsequent experimental testing. Generally, CFD simulations involve large computational time and need to be preferably undertaken in high speed computational environments. First, the resistance values from CFD simulations of a bare hull model, (hull model without a stern flap), are validated against model test reports of a particular vessel. After ascertaining the accuracy of these results, simulations of the model hull form with various stern flap configurations are undertaken and the resistance values are compared to calculate and achieve drag reduction.

Preparation of model: From the CFD simulations, suitable stern flap configurations are shortlisted which correspond to the maximum projected decrease in drag. These shortlisted stern flaps are then manufactured to a model scale, fitted on to the scaled hull model and analysed by experimental testing in a towing tank. In the second stage, a model of ship is prepared which has been scaled down by a factor. Determination of this scale factor is dependent on various hydrodynamic considerations and experimental test facilities available. The model is generally prepared using conventional model making techniques, with reinforced FRP material. During model making, precision is of utmost importance as any error in the preparation of the scaled model can lead to large errors when the results are scaled up for a full-scale prototype vessel.

Hydrodynamic testing in a towing tank: Towing tanks are large experimental test facilities where the scaled models of ships are towed in a tank to analyse various facets of engineering interest, so that the results obtained can be scaled up and corrected for the actual ship. These model tests are to be conducted in accordance with the procedures promulgated by the widely accepted International Towing Tank Conference (ITTC) recommendations at a Towing Tank facility. The tank dimensions and the maximum towing carriage speed are to be of sufficient capacity to accurately predict the hydrodynamic performance of the vessel. Data is acquired in the towing tank tests using precision instrumentation and recording facilities. The model is towed using a towing carriage for several runs to cover the range of targeted speeds both, in bare hull condition (hull without the stern flap), and when fitted with various stern flap configurations that have been shortlisted during CFD simulations. The resistance or drag values are recorded in each of these conditions and compared with the CFD results for accuracy. The configuration of the stern flap that produced the least resistance or drag is selected as the most optimum stern flap for a given vessel at a particular speed range of interest. Figure 3 illustrates the model testing of a scaled ship model in a towing tank facility.

Manufacture of the full-scale prototype stern flap: Based on the Stern Flap configuration finalised during the CFD analysis and experimental towing tank facility, the full-scale stern flap is manufactured. The stern flap could be either installed on a new construction ship or be retro-fitted on to an already built vessel, in a dry-dock or using a cofferdam. The construction of a stern flap can be considered relatively simple as compared to the other drag reduction mechanisms. The construction of the flap is akin to that of a bilge keel, where in the internal structure consists of simple A-frames while the outer skin is generally fabricated using flat plates. Complexity associated with plate bending and associated welding at the edge of the flap can be avoided by using perimeter piping. Figure 4 illustrates the fabrication of a stern flap for U.S Naval vessel *Whidbey Island* (LSD 41).

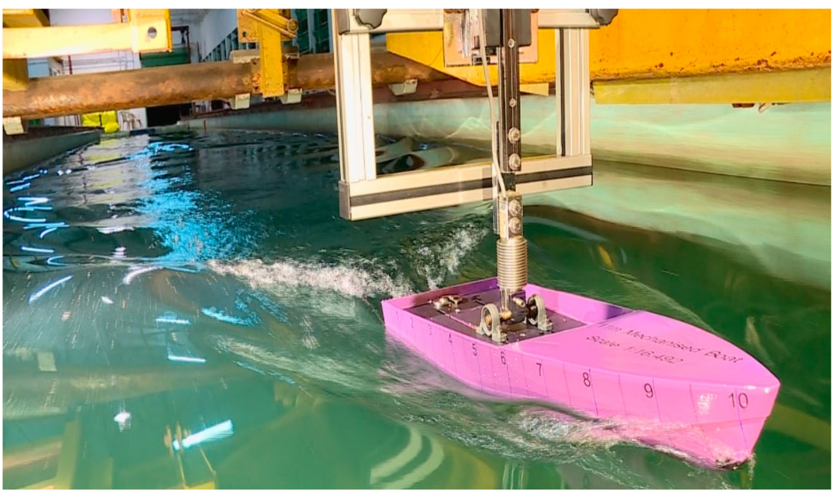

Figure 3. Hydrodynamic testing of a scaled ship model in a towing tank.

Figure 4. Fabrication of Stern Flap for Whidbey Island (LSD 41).

Table 2. Cost incurred for fitment of stern flap on US naval vessels based on the type of installation.

Ser.	Type of installation	Cost incurred per unit ($)
(a)	In dry-dock	100,000
(b)	Using a cofferdam	160,000 for the first vessel and 150,000 for subsequent vessels

Installation and full-scale trials: Once the prototype stern flap is manufactured, it is fitted on to the vessel by one of the methods indicated in Table 2. The table indicates the cost incurred in stern flap installations on U.S naval ships in a dry-dock and using a cofferdam. The U.S Navy destroyer, USS *Ramage* was retrofitted with a stern flap using a cofferdam. Usage of a cofferdam for installation has its advantages in terms of flexibility of undertaking the retro fitment when the vessel is afloat and eliminating any requirement of dry-docking the vessel. However, the cost associated with manufacturing a large cofferdam also needs to be considered. It is opined that dry-docking could be an economical option when stern flap retro fitment is being done for a single vessel, and usage of a cofferdam could prove beneficial if the installations are being done on a large scale for the same type of the vessels. For a retro fit, it would be beneficial if the installation of the stern flap could be dovetailed with the refit of the vessel for optimum utilisation of the dock space. Once the flap is installed, full scale sea trials of the ship fitted with stern flap are conducted and results are obtained for analysing the reduction in drag, reduction in power required at particular speed range, and the increase in the top speed of the vessel, if any. It would be prudent for the time gap between pre and post flap trials to be restricted to a minimum in order to minimise the underwater hull fouling effects. During sea trials, care has to be taken that the displacement of the vessel is same as that during the time of stern flap optimisation. From the experience of U.S Navy, it has been reported[8,9] that the performance of the stern flap in drag reduction and increasing the powering performance far exceeded that of the results obtained during the CFD analysis and towing tank experiments. The flow chart in Figure 5 summarises the process involved in the implementation of stern flap technology (Tables 3 and 4).

Environmental aspects of using stern flap technology

More than 90% of the world's trade by volume is undertaken on the ocean shipping lanes. As a consequence, there is a large dependency of maritime transportation on fossil fuels.

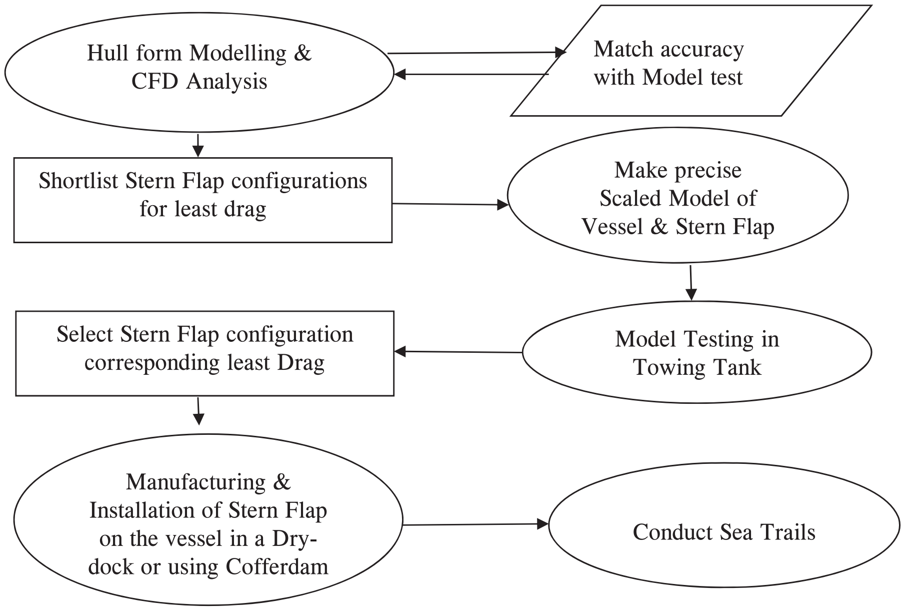

Figure 5. Flow chart of process for implementation of stern flap technology.

Several organisations, such as the IMO, have been at the forefront in formulating benchmark regulations for mitigating the effects on climate change effect due to ships. As per the EXIM Bank of India's report,[10] apart from the IMO, industry experts from OCEANA (an International organisation solely focused on Ocean conservation), suggested various measures for energy conservation on ships. One of the energy saving measures suggested by the experts include the usage of stern flaps on ships. A direct consequence of the reduction in drag and improved powering performance of the vessel due to the fitment of a stern flap is the decrease in fuel consumption and consequent emissions from the vessel. It has been extensively reported[11] that several of the noxious emissions such as NO_x, SO_x, CO_2 and particulate matter have reduced from the vessel due to the fitment of a stern flap. Cusanelli, one of the foremost researchers in developing the stern flap technology, put the environmental impact of stern flaps in perspective. The annual fuel consumption and emissions of the US Navy's DDG 51 Flight I/II Class Destroyer was

Table 3. Summary of analytical, experimental and installation infrastructure required for implementing stern flap technology.

Ser.	Infrastructure/facility	Requirement	Availability
(a)	CFD Modelling Software	Preferably RANS based software in a High-Performance Computing Environment	Academic institutions/R & D Laboratories and Shipyards
(b)	Precision Model making facilities	Conventional model making techniques. Latest technologies such as 3D Printing/Rapid prototyping could also be explored	Academic Institutes, Dockyards/Ship repair yards, R&D Laboratories and Shipyards
(c)	Towing Tank facility	Approved by ITTC. Should be of sufficient capacity	Academic institutions/R&D Laboratories
(d)	Manufacturing Facilities	Quality as per the requirements	Dockyards/Ship repair yards and Shipyards
(e)	Dry Dock/Slipway or Cofferdam	–	Dockyards/Ship repair yards and Shipyards

Table 4. Role of various Stakeholders involved in implementing the technology.

Ser.	Task	Implementing Agency	Role
(a)	Specification of requirement	Owner of the Vessel	Formulation of the requirement and Provision of relevant ship data (drawings, model test reports etc.) to the contractor
(b)	Analytical and experimental testing	Contractor or Sub-contractor in presence of contractor (if facilities have been hired)	Undertake computational analysis, manufacture of model and conduct of tests in towing tank
(c)	Manufacturing prototype stern flap	Contractor (Shipyard/Dockyard)	Manufacturing the prototype stern flap as per quality requirements
(d)	Sea trials	Contractor (Shipyard/Dockyard)	During the sea trials, the contractor would be required to demonstrate improvement in powering performance

compared to that of the national annual fuel consumption and emissions of a typical passenger car. That is to say, the fuel consumption of a few surface combatants, (which individually consume large amounts of fuel), is equivalent to that of millions of cars consuming relatively small amounts of fuel. It emerged that the stern flap of a single destroyer class vessel saved fuel (amounting to 7.5% annually) equivalent to that of approximately 383 (national averaged) mid-sized cars. Similarly, it was also reported that reductions in NO_x (10%) and SO_x (7.5%) emissions was also equivalent to that of hundreds of cars.

Outlook for the indian defence shipbuilding and ship repair industry

The International Maritime Organization (IMO), in 1973 adopted the International Convention for the Prevention of Pollution from Ships. Since then, the IMO, has adopted several resolutions[12] covering all aspects of shipping including energy efficiency for ships. Various resolutions adopted by the IMO emphasise the need for research and development for the improvement of energy efficiency of ships. Recognising the challenge posed by climate change and the need for energy efficient systems, India has adopted a National Action Plan on Climate Change[13] which hinges on the development and use of new technologies for dealing with energy efficiency. On the other front, keeping pace with the growth rate, India's on-going Defence Shipbuilding programme constitutes majority of the ships being constructed indigenously, which for the most par involves conventional mono-hull designs which are optimised for hydrodynamic performance in their design. Given the emerging technology trends in warship building globally, as also India's commitment to battle the challenge of climate change, a natural progression towards the application of cost effective, energy efficient technologies, such as the installation of stern flaps, really is the need of the hour as these could be leveraged by the Indian Shipbuilding industry and implemented on surface combatants for achieving better speeds, less operational turnaround periods with high combat efficiency and low emissions. As discussed, advanced navies have already made rapid strides in implementing stern flap technology towards enhancing their capabilities. India's defence shipbuilding programme can also benefit by adopting such global best practices and early realisation of such capabilities. While it is true that India, compared to other nations, exhibits relatively lower emissions from shipping, it is best to reduce the emissions from ships on a sustainable basis. Stern flap technology, in this context, is a cost effective and sustainable technological option available.

Table 5. Age composition of indian shipping fleet as on 30th December 2016.[a]

Category	0–5 years	6–10 years	11–15 years	16–20 years	above 20 years	Total
Coastal trade	154	158	86	105	392	898
Overseas trade	74	91	43	62	133	403
Total	231	249	129	167	525	1301

[a]*Statistical Year Book India*. 2016.

In addition to the application of stern flap technology on surface combatants discussed so far, there is tremendous scope for Indian shipbuilders to leverage this technology on commercial vessels as well. Cusanelli studies on the applicability of stern flap technology in commercial vessels indicate that mono hull and trimaran large car ferries are potential candidates for application of this technology. A stern flap fitted on a conventional passenger car ferry of about 400ft length at a service speed of 18 knots could reduce the power consumption by as much as 9%, which is quite a substantial reduction keeping in view of the cost sensitivity involved in the commercial shipping industry. Large passenger ferries of 800ft length and 19knots service speed exhibited a 5% powering reduction. In addition to these vessels, it has also been reported[14] that reduction in powering due to the installation of stern flaps was exhibited by 150ft crew boats (8%), monohull wide transom planing hulls such as private yachts, offshore patrol and work boats (10%), and 500ft fast freight container ships (10%).

As far as the ship repair is concerned, there is an enormous scope for retro fitment of stern flaps on already constructed vessels. According to Indian Shipping Statistics-2016,[15] the age composition of the shipping fleet as on 30 December 2016 is indicated in Table 5.

From the data above, it is evident that of the total registered commercial fleet, about 13% of the fleet is aged between 16 and 20 years and about 40% of the fleet is above 20 years; this opens up opportunities for leveraging the benefits of energy efficiency inherent to the adoption of stern flap technology on these aging vessels which could translate to significant savings for all stake holders involved, especially the ship owners while operating these vessels.

Secondary benefits of stern flap technology

With many modern navies having fitted stern flaps on their vessels, certain additional benefits were observed, such as

- Improved propulsive efficiencies
- Reduced propeller loading
- Increase in onset of cavitation inception speed
- Reduced vibration and noise
- Slight increase in the maximum vessel speed

Conclusion

Ab-initio designs of surface combatants have a well optimised hull form, usually optimised at the design stage. Hydrodynamic performance varies significantly with changes in weight and draft. Penalties are paid in terms of increased drag or reduced operational speed.

All the principal twenty-first-century blue water navy surface combatants, carry out numerous sorties all over the world. The usefulness of stern flaps as an energy saving device has already been established; installing this device on the surface combatant class of frontline vessels will reduce the hydrodynamic resistance of the entire class of vessels, consequently saving millions of rupees in fuel cost and reducing the dependence of this class of vessels on oil tankers for frequent refuelling, which translates to greater range with enhanced speed for these vessels.

Indian shipbuilders can foster research in stern flap technology by collaborating with academic and research institutions, where good potential for research and infrastructure exists to incorporate stern flaps at the design stage itself on new generation surface combatants that are under construction.

Provision of an optimised stern flap during regular refits/life extension refits of ageing surface combatants could be explored which could go a long way in minimising the operational costs and exhaust emissions, in a cost-effective manner.

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