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STERN FLAP FOR RESISTANCE REDUCTION OF PLANING HULL CRAFT: A CASE STUDY WITH A FAST CREW BOAT MODEL

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Abstract. The study on various methods of reducing the resistance of patrol craft have been carried out by many researchers. These methods included the application of stern flaps, stern wedges, and microbubble injection. However, due to its simplicity and practicality, stern flap is the most promising and cost effective method. The effect of a stern flap on the resistance performance of the planing hull crew boat is presented. Model tests were conducted to prove the effectiveness of the stern flap on reducing planing hull craft resistance. Five different stern flap designs were tested as part of systematic investigation to determine the optimum geometrical characteristics of the stern flap. Results of model resistance experiments showed that four of the flaps tested showed an increase in resistance while the flap at zero degree angle reduced the total resistance by 7.2 percent at 23 knots, and an average reduction rate of 4.5 percent. At 23 knots, an 8.2 percent reduction in effective power was predicted.

Keywords: Patrol boats design, model testing, fast craft

Abstrak. Kajian terhadap pelbagai cara mengurangkan rintangan bot peronda telah dilakukan oleh ramai penyelidik. Kaedah yang dikaji termasuk penggunaan kepak buritan, baji buritan dan suntikan gelembung mikro. Walau bagaimanapun, disebabkan oleh sifatnya yang mudah dan praktikal, kepak buritan didapati amat berpotensi. Kertas kerja ini membentangkan kajian terhadap kesan kepak buritan terhadap prestasi rintangan bot kelasi berbentuk planing. Ujian model dijalankan bagi membuktikan keberkesanan kepak bagi mengurangkan rintangan. Lima kepak berlainan telah digunakan dalam rangka kajian sistematik bagi menentukan ciri geometrik optimum kepak buritan. Hasil ujian model menunjukkan empat kepak menambah rintangan kapal manakala kepak kelima pada sudut sifar mengurangkan rintangan sehingga 7.2 peratus pada 23 knots dan pengurangan purata sekitar 4.5 peratus. Pada 23 knots, pengurangan 8.2 peratus kuasa berkesan diperolehi.

Kata kunci: Reka bentuk bot peronda, ujian model, pesawat laju

1.0 INTRODUCTION

Ship resistance will not only affect the choice of propulsion machinery but also the attainable speed, and economics of operation of the vessel. If resistance can be reduced, less power will be required to propel the ship at a given speed, or for a given power, the ship can travel faster. Bulbous bow is commonly used to reduce

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resistance of displacement hull vessels like tankers [1,2]. However, planing hulls are different from displacement hull in terms of their shape, range of speed, hydrodynamic characteristics, etc. Thus a different approach is needed in reducing the frictional drag.

There are several methods or devices that are being used or still under experimentation for reducing resistance of planing hulls. Amongst them are the stern flap [3-6], wedges [3,7], microbubble injection [8-10], riblets [11], and boundary layer additives [12]. Most of these methods can be applied to both hull types, but the effectiveness may be different, depending on their respective resistance reduction mechanisms.

A brief comparison was made among the various methods for installation on a planing hull craft. After careful consideration of the merits and demerits of various methods, stern flap was selected. Table 1 summarises the reasons for not selecting other methods.

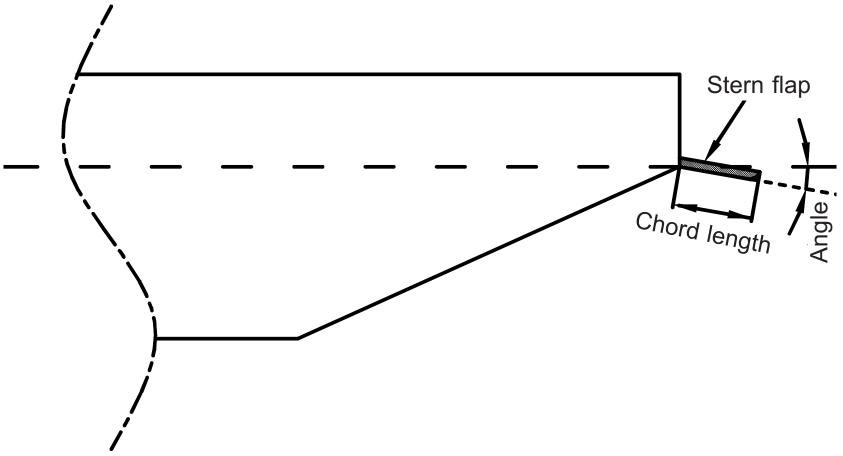
Table 1 Summary of demerits of various methods

Methods	Demerits
Bulbous bow	Not suitable for planing hull
Riblets	Marine growth causes loss in drag reduction performance
Boundary layer additives	Complex additive requirement high cost
Stern wedge	Poorer performance compared with stern flap. Slots weld might be needed
Microbubble injection	Problems of gas flow generation system high cost

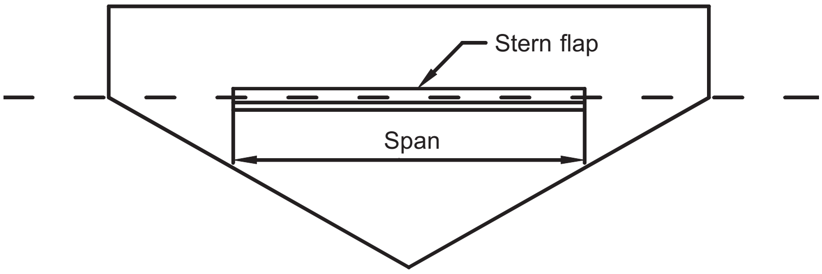
2.0 THE STERN FLAP AS RESISTANCE REDUCTION MECHANISM

Stern flaps have been used on many high-speed small craft, such as workboats, patrol craft, and pleasure craft [3]. A stern flap represents an extension of the hull aft of the transom in the form of a flat plate. The flap is mounted to the transom at an angle relative to the centreline buttock of the ship [4], as in Figure 1.

Previous works [3-6] have shown that a stern flap has a similar effect on ship powering performance as a stern wedge. All stern flaps, independent of what vessels size or type they are used on, create a vertical lift force at the transom, and modify the pressure distribution on the after portion of the hull. The modification of the afterbody flow field causes the principal performance enhancement on a displacement hull. A stern flap causes the flow to slow down under the hull at a location extending



Side view



Stern view

Figure 1 Stern flap location

from its position to a point generally forward of the propellers. This decreased flow velocity will cause an increase in pressure under the hull, which in turn, causes reduced resistance due to the reduced afterbody suction force (reduce form drag).

Wave heights in the near field stern wave system, and far field wave energy, are both reduced by these devices. Localised flow around the transom, which represents lost energy through eddy making, wave breaking, and turbulence, is significantly modified by the stern flap. The flow exit velocity from the trailing edge of the flap is increased in comparison with the baseline transom, leading to a lower speed for clean transom flow separation, and again, reduced resistance [5].

Secondary effects of the stern flap include the lengthening of the hull, improved propeller-hull interactions, and improved propeller performance due to reduced loading, and reduced cavitations tendencies.

3.0 SHIP CHARACTERISTICS

In this study, a stern flap was designed, and tested on a fast crew boat model. The body plan of the fast crew boat is shown in Figure 2, whilst the main particulars are given in Table 2. A scaled model designated MTL 006 was constructed, and tested at the Marine Technology Laboratory, Universiti Teknologi Malaysia. Testing was carried out in the 120 m × 4 m × 2.5 m towing tank, whose towing carriage can reach a maximum speed of 5 m/s.

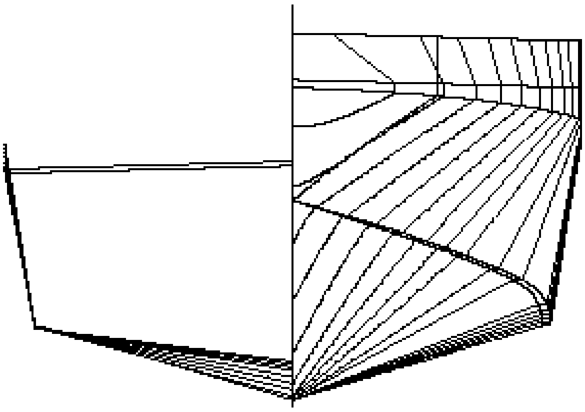


Figure 2 Body plan of the fast crew boat

Table 2 Ship particulars

LOA	34.00 m
LWL	31.80 m
LBP	30.80 m
Breadth moulded	7.60 m
Depth moulded	3.30 m
Volume displacement	126.05 m^3
LCB (aft of amidship)	2.02 m
Block coefficient	0.43
Prismatic coefficient	0.73
LCG (from AP)	14.20 m
KG	2.49 m
Model: Ship scale ratio	1:13.6
Full load draft	1.26 m

4.0 STERN FLAP DESIGN AND SELECTION

The general practice with regard to stern flap design is to conduct model experiments that optimise the selected stern flap geometry with regard to the selected span, chord length, and flap angle. Past experience with model testing stern flaps of various spans has indicated that the maximum span of the flap should be one that avoids the region of turbulent flow, which typically originates from the transom corner [3].

Computational fluid dynamics (CFD) efforts have been invaluable with regard to understanding the hydrodynamic mechanisms responsible for the improved performance with stern flap. However, these calculations are still costly and difficult to perform. The limited level of experience with these calculations precluded their use as the sole design tool without the benefit of model test. Thus, the decision was made to conduct model tests and rely on engineering experience to generate several stern flap designs for testing. Tests were conducted at the full load conditions of 129.2 tonnes, and LCG = 14.2 m from AP.

Five model stern flaps were designed and manufactured. The geometry of these stern flaps are presented in Table 3. These stern flaps were designed as several different series to systematically investigate variations in flap chord length, span, and angle of attack. The first series, comprised of Flaps 1 and 2, were designed to investigate variations in flap chord length, while holding the angle and span constant at 13 degrees, and 250 mm respectively. This span was judged as the maximum reasonable width possible, without impinging on the high-speed wake off the transom corners.

A second series, comprising of Flaps 3 and 4, was designed to investigate variations in span, while having chord length at 35.1 and 46.8 mm. The last flap is the same geometry as Flap 4 but in a different flap angle.

Table 3 Geometry of model-scale stern flaps

Flap	Chord length (mm)	Span (mm)	Angle (°)
1	35.1	250	13
2	46.8	250	13
3	46.8	200	15
4	35.1	200	13
5	35.1	200	0

5.0 RESULTS

Summary of model-scale results for stern flap series are shown in Table 4. The resistance performance for each flap portrayed as a model total resistance versus ship speed are shown in Figure 3.

The performance of Flap 1 shows a reduction on model resistance at the first two speeds tested beyond which resistance is higher than the resistance of the bare hull. Flaps 2 and 3's performance were poorer than Flap 1, although Flap 3 is slightly better than Flap 2. Flap 4's performance showed a slight reduction on resistance for the first two speeds tested. However, similar as the other flaps, the resistance increased from the third speed.

The results from the four tests (Flap 1 to 4) have indicated that, while changing flap geometry does affect the resistance of the boat, the resistance value is still much higher than the bare hull (without flap) resistance, especially at high speeds. Therefore, an attempt has been made to investigate the effect of changing the flap angle of Flap 4 to zero degree. The results obtained from this zero degree angle flap, designated as Flap 5, showed a significant reduction on resistance at all speed tested. The performance shows a large resistance reduction attained at speeds of 23 to 27 knots.

Table 4 Summary of model-scale stern flaps resistance performance

Ship speed (knots)	**Model total resistance (N)**					
	Bare hull	**Flap 1**	**Flap 2**	**Flap 3**	**Flap 4**	**Flap 5**
20	45.5435	44.3679	46.0909	45.8349	44.5364	43.0423
23	54.3901	53.9700	55.8062	56.5000	53.8460	50.3988
27	62.3015	69.2977	81.1866	73.3873	67.1354	58.7020
30	66.9531	84.6019	–	88.4957	77.0137	65.3376
32	70.5636	–	–	–	–	69.3357

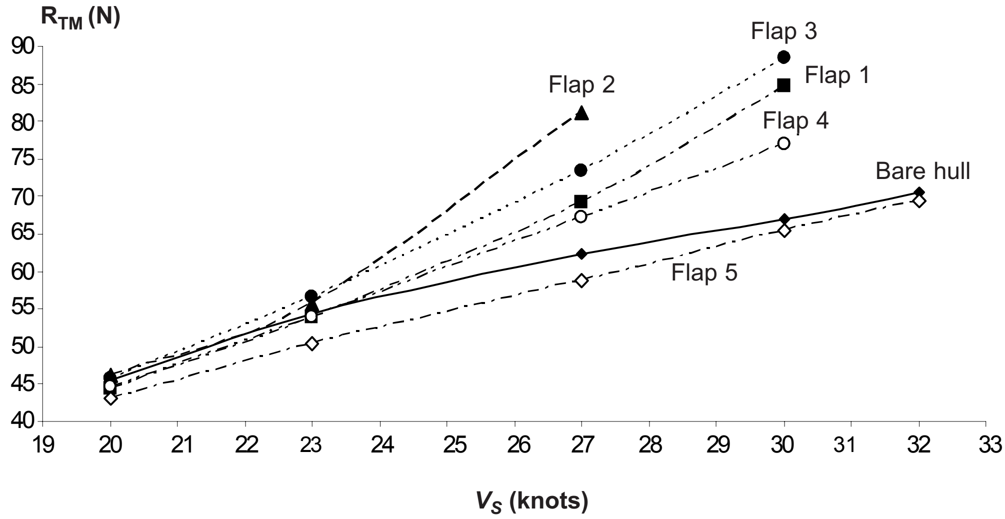


Figure 3 Resistance performances for flap selection

6.0 DISCUSSIONS

6.1 Performance of Flap 5

Flap 5's results, as shown in Figure 3, indicated a decrease in resistance at all speeds tested with the average decrease in resistance of approximately 4.5 percent. The maximum resistance reduction due to Flap 5 was predicted to be 7.2 percent at a speed of 23 knots. In terms of full scale effective power and speed, the flap caused a maximum decrease effective power of 8.2 percent at 23 knots, and increased about 0.88 knots at design speed (30 knots). The full scale effective power performances of the boat are shown in Table 5, and Figure 4. It should be noted here that this result was not the optimum reduction that can be achieved by using stern flap. Further works need to be carried out to investigate effects of variations of flap parameters around Flap 5.

6.2 Stern Flap Scale Effect

While reduction on resistance are indicated by these MTL 006 stern flap experiments, the actual full scale stern flap on the Fast Crew Boat would generally be expected to exceed the performance indicated on the model. Based on past experiences, the actual performances of full-scale prototype stern flaps have been found to exceed that of their model scale predictions [4-6]. It was determined through comparisons of predicted resistance at three different model-scale ratios that stern flap performance did improved as model size was increased [3]. Ship trial indicated that the experimental model tend to generally under-predict the stern flap performance in the range of roughly 2 percent to as much as 12 percent, with the greatest performance discrepancies at the lower end of the speed range [1, 3-6].

6.3 Limitations

It was observed that running trim is very important on evaluating stern flaps effect on planing hull craft. It is desirable to get running trim on the tests. However, it was very disappointing when a technical failure occurred during the tests which were carried on. The data acquisition system on the towing carriage could not read out the running trim of the model. Based on that, this report did not include the effect of the ship's trim on its resistance performance.

Time limitation also means that full calm condition could not be obtained. The speed ranges of these tests are very high that is between three to four meter per second on the towing tank. This range of speeds created big waves on the towing tank, and resulted in a very long time to wait for the water to calm again. That situation may have a small effect on the results attained (added resistance).

Table 5 Full scale effective power performances

V_s (knots)	R_{TS} (kN)		P_E (kW)	
	Bare hull	**Flap 5**	**Bare hull**	**Flap 5**
20	102.01	95.72	1049.50	984.77
23	120.56	110.73	1426.42	1310.08
27	135.43	126.38	1881.00	1755.24
30	142.79	138.72	2203.49	2140.78
32	148.78	145.69	2448.97	2398.13

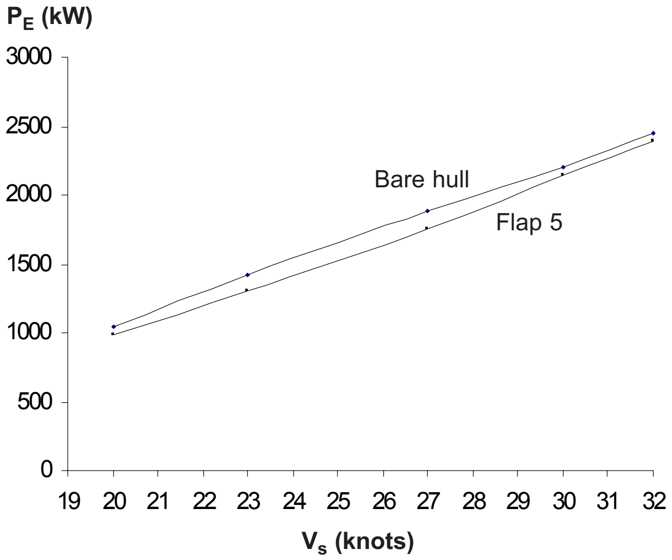


Figure 4 Full scale effective power with and without Flap 5's performance

7.0 TRANSOM FLOW OBSERVATION

Excessive wave height, eddy making, and turbulence, represent lost energy in the local transom flow of a vessel. A great deal of qualitative information can be obtained about the performance of a stern flap by careful observations of its effects on the flow past the transom, and the localised waves generated at the transom. Transom flow can be categorised by three simplified descriptions. At low speeds, the transom and flap are fully wetted, and the flow is said to be "attached". Resistance is increased by the "base drag" of the immersed transom, and significant eddy making. As speed increases, the transom becomes less submerged, and less water tends to flow back over the flap. Over a small speed range, the stern flow becomes "transitional", periodically breaking free of the transom, and flap, then rolls forward to wet them again. At a yet higher speed, the flow detaches cleanly or "breaks-away" from the

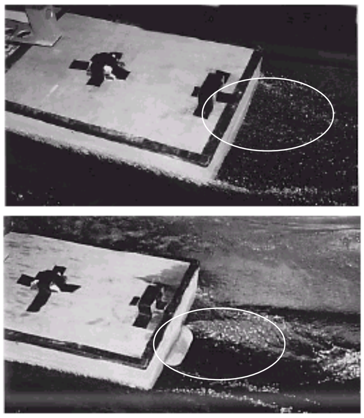


Figure 5 Model-scale transom flow comparison, bare hull (upper) and with stern Flap 5 (lower), full load, 23 knots

bottom edge of the transom or flap. The speed at which this detachment occurs is affected by factors, which include ship displacement, ship trim, transom design and depth of submergence, and the specific design of the transom and the stern flap.

The effect of the stern flap on the localised flow around the transom was observed. Photographs comparing the transom flow, with and without the stern flap installed, taken at full load condition at 23 knots, are shown in Figure 5. Referring to the comparison photographs at 23 knots, the baseline still exhibits attached flow, while the stern Flap 5 exhibits detached flow. This shows that stern Flap 5 caused the transom flow to detach (break-away) early.

8.0 CONCLUDING REMARKS

Model testing results have shown that attachment of the stern flaps modifies hull resistance. In one particular stern flap design, at zero degree angle, substantial reduction in resistance was obtained. The model resistance predictions indicate a decrease in resistance due to stern Flap 5 of an average of 4.5 percent. The maximum stern flap resistance reduction attain is 7.2 percent. The stern flap model-scale parameters to attained those results are; chord length = 35.1 mm, flap angle = 0 degree, and flap span = 200 mm. The summary of these results is shown in Table 6. It should to be kept in mind that the results attained is still not the optimum performance that can be attained by attachment of stern flap to the fast crew boat. Further analysis is still required before an optimum design can be determined.

The performance benefits of decreased resistance or improvements on power requirements can be expressed directly in terms of reduced fuel consumption, and increased speed and range. The capability to maintain ship speed with less delivered power, and lower shaft speed, may also reduce maintenance costs, and extend the service life of the propulsion plant machinery. Beneficial ship characteristics such as

Table 6 Flap 5's performance summaries

Chord length	35.1 mm
Span	200 mm
Flap angle	0°
Average resistance reduction	4.50%
Maximum resistance reduction	7.2% @ 23 knots
Average delivered power reduction	5.40%
Maximum delivered power reduction	8.50%
Increase of speed at Design speed (30 knots)	0.95 knots

reduced propeller loading, cavitation, vibration, or noise tendencies are also achievable, as a result of the decreased power levels.

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REFERENCES

[1] Hoyle, J. W., B. H. Cheng, B. Johnson, and B. Nehrling. 1986. A Bulbous Bow Design Methodology for High-Speed Ships. *SNAME Trans*. 94: 31-56.

[2] Schneekluth, H., and V. Bertram. 1998. *Ship Design for Efficiency and Economy*. Second Edition. Great Britain: Butterworth-Heinemann.

[3] Karafiath, G., D. S. Cusanelli, and C. W. Lin. 1999. Stern Wedges and Stern Flaps for Improved Powering – U.S. Navy Experience. *SNAME Annual Meeting*. Baltimore.

[4] Cave, W. L., and D. S. Cusanelli. 1993. Effect of Stern Flaps on Powering Performance of the FFG-7 Class. *Marine Technology*. 30(1): 39-50.

[5] Cusanelli, D. S., S. D. Jessup, and S. Gowing. 1999. Exploring Hydrodynamic Enhancements to the USS ARLEIGH BURKE (DDG 51). *FAST'99, Fifth International Conference on Fast Sea Transportation, Seattle.*

[6] Karafiath, G., D. S. Cusanelli, S. D. Jessup, and C. D. Barry. 2002. *Hydrodynamic Efficiency Improvements to the USCG 110 Ft. WPB ISLAND Class Patrol Boats*. http://www.sname.org/AM2001/paper10.pdf, 12.50 a.m., 15.06.2002.

[7] Karafiath, G., and S. C. Fisher. 1987. The Effect of Stern Wedges on the Powering Performance. *Naval Engineer Journal*. 99: 27-38.

[8] Lattore, R., A. Miller, and R. Philips. 2002. *Microbubble Resistance Reduction for High-Speed Craft.* http://www.sname.orgAm2002/papers/paper11/pdf, 9.35 p.m., 03.07.2002.

[9] Kato, H. *Skin Friction Reduction by Microbubbles*. http://www.turbulence-control. gr.jp/PDF/symposium/FY1999/Kato.pdf, 3.45 p.m., 17.06.2002.

[10] Sugiyama, K., T. Kawamura, S. Takagi, and Y. Matsumoto. *Numerical Simulations on Drag Reduction Mechanism by Microbubbles.* http://www.turbulence-control. gr.jp/PDF/symposium/FY2001/Sugiyama.pdf. 3.50 p.m. 17.06.2002.

[11] Choi, K. S. 1991. Drag Reduction by Riblets for Marine Applications. *RINA Trans.* 133: 269-282.

[12] Canham, H. J. S., J. P. Catchpole, and R. F. Long. 1971. Boundary Layer Additives to Reduce Ship Resistance. *RINA Trans*. 113: 187-213.