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Hydromechanics Directorate Report

U.S. Coast Guard Island Class 110 WPB: Stern Flap Evaluation and Selection (Model 5526)

By
Dominic S. Cusanelli
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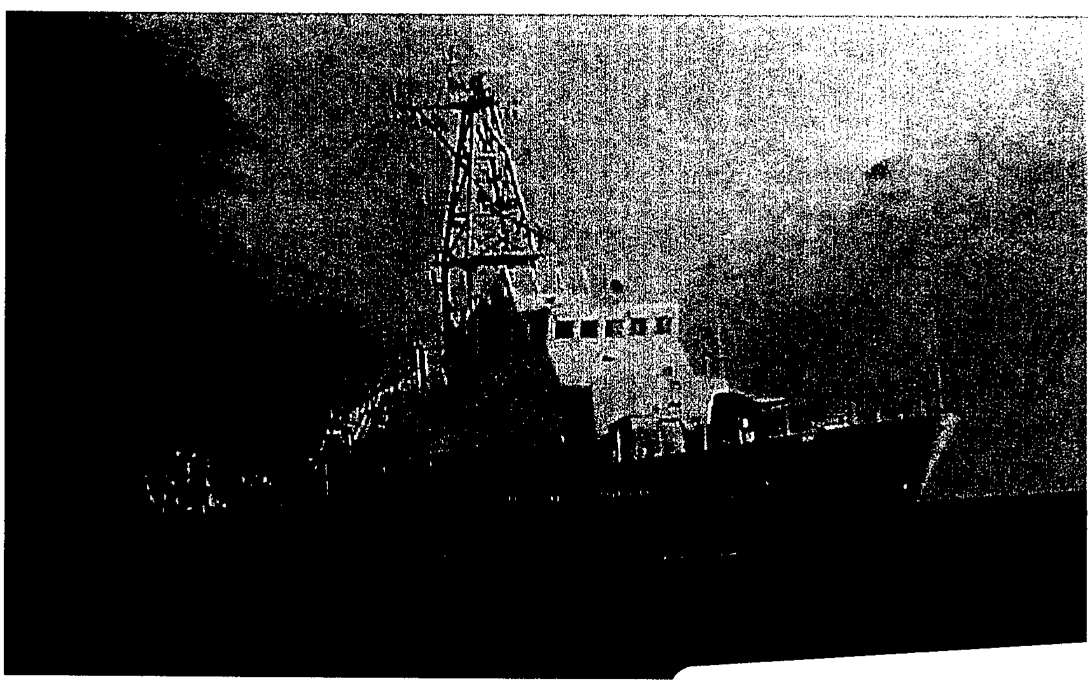

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ABSTRACT

Model experiments were performed to evaluate the performance of a stern flap on a U.S. Coast Guard Island Class 110 WPB patrol boat. Several stern flap designs of various chord lengths, spans, and angles were evaluated. The selected stern flap design was based upon maximizing power reduction at high speed, while satisfying secondary powering criteria prescribed at cruising speed, and limits set on desired running trim angle. A stern flap with chord length 2 ft (0.61 m), span of 8.7 ft (2.7 m), and an angle of 7.5 degrees trailing edge down, is recommended for installation on the Island Class. At full load, with the stern flap installed, the maximum attainable speed will increase by 0.8 knots. . The stern flap maximum power reduction of 5.8 percent was attained at 16 knots. This 5.8% powering reduction includes an empirical 1.5% reduction for stern flap scaling effects as determined from tests on other ship models. Stern flap annual fuel savings for the Island Class is estimated at more than 13,000 gallons/year. The time to recover the estimated cost for stern flap fabrication and installation is less than one year.

It is recommended that bow spray rails also be installed in the Island Class. The bow spray rails effected a significant reduction in the amount of spray and forward deck-wetting generated at the bow. A new DTMB Model 5526 was constructed for this project. A ship/model correlation allowance of $C_A = 0.0003$ was estimated from a powering comparison between BAINBRIDGE ISLAND (WPB 1343) and Model 5526.

ADMINISTRATIVE INFORMATION

The work described in this report was performed at the David Taylor Model Basin, Carderock Division, Naval Surface Warfare Center, herein referred to as DTMB, by the Hydromechanics Directorate, Resistance and Powering Department, Code 5200. The work was sponsored by the US Coast Guard, Boat Engineering Branch (ELC-024), Order No. DTCG40-99-X-60002, Work Unit No. 1-5200-056.

INTRODUCTION

The Island Class 110 WPB patrol boats, with 49 units in active service, represents the largest class of patrol vessels presently in the U.S. Coast Guard (USCG) arsenal. The hull is a modified Vosper-Thornycroft (British) patrol boat design, 110 ft (33.5 m) in overall length, with twin shafts, and 49.6 inch (126 cm) diameter fixed-pitch propellers. The Island Class was acquired for offshore surveillance, law enforcement, and search-and-rescue operations, replacing the older 95 ft (29 m) and 82 ft (25 m) WPBs; Polmar [1]. The USCG has initiated a research and development program with the intention of improving the performance capabilities of the Island Class 110 WPB patrol boats. The preliminary goals of the Coast Guard's R&D program, of which the flap selection is one area of investigation, are to increase the maximum attainable speed at full power, and to reduce the propeller cavitation and cavitation erosion damage tendencies to the propeller's blades. A secondary objective is the improvement of habitability by reducing the propulsion generated onboard radiated noise and vibration levels. In addition, ship trials on the Island Class 110 WPB series C, have indicated that the Caterpillar 3516 main propulsion engines must be operated in exceedance of the specified engine performance curve (brake horsepower vs. engine speed). This has resulted in the inability of this particular engine design, as installed in the WPB 1343, to reach full engine RPM. Therefore, an additional objective of the class performance improvement is to bring into better balance the ship's speed/power characteristics with the engine operating envelope.

As an opening phase of the Island Class 110 WPB improvement initiative, model experiments were performed to evaluate the performance of a stern flap on these patrol boats. A stern flap, which is an appendage fitted to the hull at the transom, reduces the power required to propel the ship through the water. The U.S. Navy has been investigating the potential of stern flaps, as low cost retrofits, on many recent ship designs. Stern flaps represent a viable means of reducing power and increasing top speed for many hullforms, as test programs have shown at both model scale, Cusanelli and Forgach [2], and full scale, Cusanelli [3]. Reductions in propulsion generated vibrations and in signature levels, due to improvements in propeller cavitation characteristics, can also be realized through a stern flap installation.

DTMB Model 5526, representing the Island Class 110 WPB patrol boats, was constructed for this project. Eight stern flaps were manufactured for the present Model 5526 experiments. These stern flaps were designed as a series, to systematically investigate variations in flap dimensions of chord length, span, angle, and planform area distribution. The selection of the best stern flap design for the Island Class was based upon several factors. There was a desire to reduce power at high speed (28 ~ 32 knots), to satisfy secondary powering criteria prescribed at cruising speed (24 knots) and best economic speed (12 knots), and to stay within the trim criteria.

A ship/model correlation allowance was estimated by the comparison of Model 5526 data to the BAINBRIDGE ISLAND (WPB 1343) standardization trials results. A ship/model correlation insures that the most accurate assessment of ship performance will be achieved. Traditional model scale powering experiments, which are necessary for a formal determination of correlation allowance, were not performed on Model 5526. Instead, model resistance predictions were utilized to estimate Island Class powering data for comparison to the standardization trials results.

DESCRIPTION OF MODEL AND EXPERIMENTAL PROCEDURE

A new geosim model, DTMB Model 5526 (linear scale ratio $\lambda = 5.706$), representing the Island Class 110 WPB patrol boats, was constructed for this project, Figure 1. Appendages installed on the model were: twin roll stabilizer fins, twin rudders, and twin shaft and strut propulsion appendages. The model also included a 5° wedge at the transom, inlayed into the hull surface. Experiments were conducted with eight different stern flap designs. Appendix A presents a more complete description of Model 5526.

All data presented in this report are for the full scale Island Class 110 WPB patrol boats operating in smooth, deep salt water with a uniform standard temperature of 59^0 Fahrenheit (15^0 Celsius). Unless explicitely stated otherwise, all full scale data include all relevent corrections, <u>including</u> the correction for the stern flap scale effect, as is described in a later section. All model experiments were conducted on Carriage 1, in the deep water basin of DTMB. Model experiments were conducted in accordance with standard procedures outlined for model experiments at DTMB. A more complete description of the experimental procedure is presented in Appendix B.

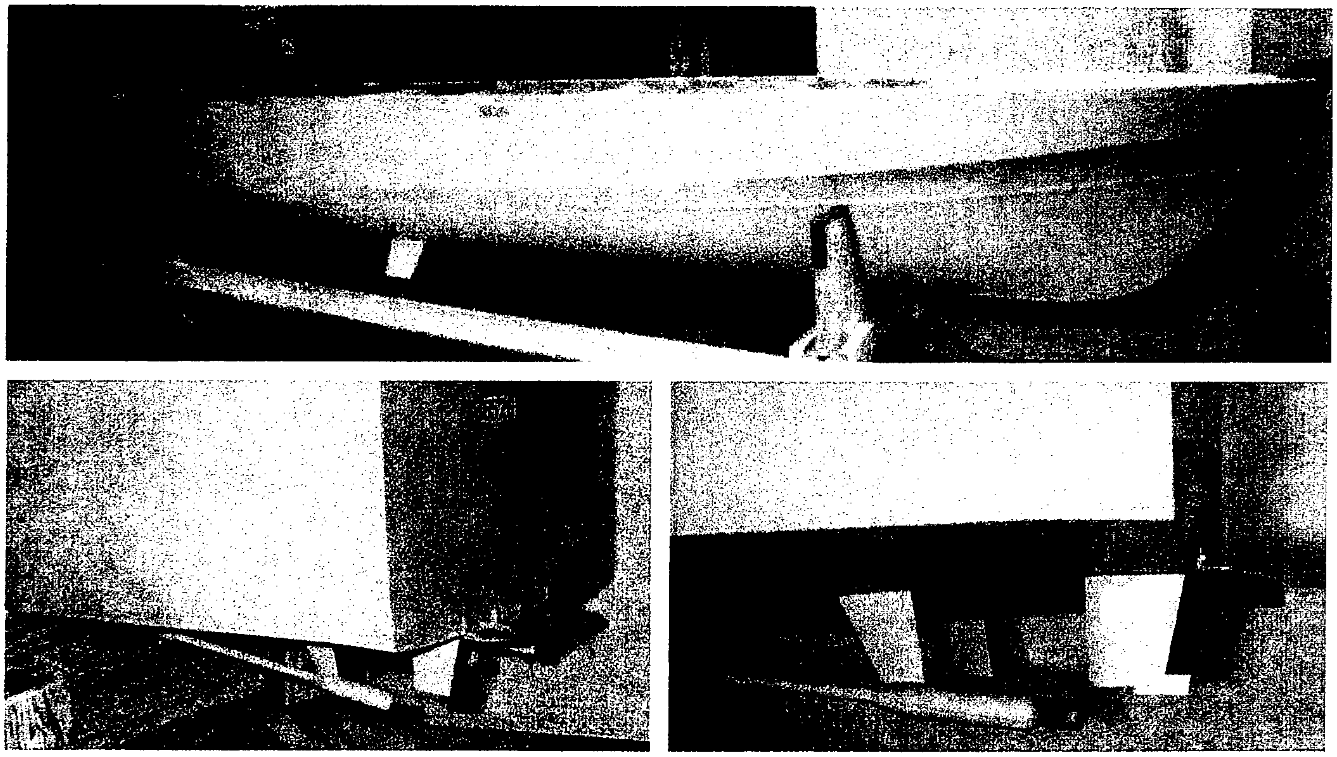


Fig 1. Island Class Model 5526 with stern flap installed

SHIP/MODEL COMPARISON - CORRELATION ALLOWANCE ESTIMATE

A ship/model comparison was performed between the BAINBRIDGE ISLAND (WPB 1343) standardization trials results, Haupt and Puckette [4], and Model 5526 estimated powering data. From this comparison, a ship/model correlation allowance was estimated for the new Model 5526. Model scale powering experiments, which are necessary for a formal determination of correlation allowance, were not performed on Model 5526. Present Model 5526 resistance test data, representative Island Class propeller open water performance data, and estimated propeller-hull interaction coefficients were utilized to estimate Island Class powering data. The estimated model powering data was then used for comparison to the ship trials results, presented in Appendix B.

From the ship/model comparison between BAINBRIDGE ISLAND (WPB 1343) trials results and Model 5526 estimated powering data, it is recommended that the value of C_A = 0.0003 be used as the correlation allowance for the Island Class 110 WPB. The stated Island Class correlation allowance, C_A = 0.0003, should be viewed only as a model testing adjustment factor which brings the present model estimated powering performance (based on resistance tests and propeller open water tests) in line with the measured trials powering data. At this time, any comparison to the US Navy Correlation Data Base [5] should be done with great caution. It is recommended that an effort should be made to determine the Island Class correlation allowance through a traditional model powering test series.

STERN FLAP EVALUATION AND SELECTION

The stern flap selection experiments were conducted at an equivalent Full Load condition of 163.39 long tons, LCG = 4.645ft (1.42m) aft of midships. Eight stern flaps were manufactured for the present Model 5526 experiments, their principal dimensions are presented in Table 1. These stern flaps were designed as a series to systematically investigate variations in flap dimensions of chord length, span, angle, and planform area distribution. The first series, comprised of flaps #1, #2, #3, and #4, was designed to investigate variations in flap chord length, while holding span constant at 16 ft (4.9 m). The second series, comprised of flaps #3, #5, and #6, was designed to investigate variations in span, while holding chord length constant at 2 ft (0.61 m). The third series, comprised of flaps #1, #7, and #8, was also designed to investigate variations in span, while holding chord length constant at only 1 ft (0.3 m). And the fourth series, comprised of flaps #1 versus #6 and #2 versus #5, was designed to investigate variations in planform area distribution, while holding respective total planform area constant. All flaps were evaluated over a range of angles, nominally 0 to 10 degrees, trailing edge down.

Table 1. Principle dimensions of stern flaps tested on Model 5526

	Island Class 110 WPB Stern Flaps			
	Ship Scale Dimensions			
Flap#	Chord Length (ft)	Span (ft)	Planform Area (sq. ft)	Angles Tested (trail edge down)
1	1	16	15.6	0°, 5°, 7.5°, 10°
2	1.5	16	23.0	0°, 5°, 10°
3	2	16	30.3	0°, 5°, 7.5°, 10°
4	2.5	16	37.3	0°, 5°, 10°
5	2	12.4	23.0	0°, 5°, 7.5°, 10°
6	2	8.7	15.6	0°, 5°, 7.5°, 10°
7	1	12.4	11.9	0°, 5°, 7.5°, 10°
8	1	8.7	8.2	7.5°, 10°

The selection criteria for the Island Class 110 WPB stern flap design was prescribed by the USCG Boat Engineering Branch (USCG ELC-024), as follows:.

Selection criteria for the Island Class 110 WPB stern flap design

- Maximize reduction in ship powering over high speed range of 28 to 32 knots.
- Disallow any increase in ship powering at cruising speed, as indicated by performance at 24 knots.
- Limit ship running trim modification (bow down) to 1.0 degrees, at all speeds.

Model resistance experiments were conducted for the stern flap evaluation. Stern flap resistance performance is generally considered to be indicative of powering performance. Therefore, the prescribed powering criteria for the Island Class stern flap design were evaluated through model resistance experiments. The complete Model 5526 data and analysis, pertaining to the stern flaps evaluation, selection, and performance, on the Island Class 110 WPB patrol boats, is contained within Appendix B. A summary of the Island Class model stern flap optimization experiments is presented in Table 2. The data of Table 2 is presented for each stern flap only at the angle where the maximum high speed performance was exhibited, while also satisfying the secondary powering and trim modification criteria.

Table 2. Summary of stern flap optimization experiments

Stern Flap Optimization - Model Scale Resistance Performance

Flap#	Angle TED (degrees)	Economic Speed: 12 knots (PE flap/base)	Cruising Speed: 24 knots (PE flap/base)	High Speed: 30 knots (PE flap/base)	Maximum Trim Modification (Δ degrees)
1	7.5	0.979	0.982	0.999	-0.65
2	5.0	0.976	0.993	1.003	-0.26
3	5.0	0.962	0.992	1.003	-0.32
4	5.0	0.969	0.995	1.009	-0.31
5	7.5	0.969	0.976	1.007	-1.00
6	**7.5**	**0.979**	**0.979**	**0.997**	**-0.63**
7	10.0	0.986	0.974	0.999	-0.96
8	10.0	0.993	0.983	1.002	-0.72

Model stern flap #6, at 7.5 degrees, exhibited the best overall reduction in ship resistance at high speed while still satisfying the secondary powering and trim modification criteria. This design represents a full scale stern flap with chord length 2 ft (0.61 m), span of 8.7 ft (2.7 m), and an angle of 7.5° trailing edge down relative to the local slope (run) at the 4 ft (1.22 m) buttock.

STERN FLAP PERFORMANCE

Resistance

The resistance performance of the selected stern flap, chord length 2 ft (0.61 m), span 8.7 ft (2.7 m), and angle of 7.5° TED, on the Island Class 110 WPB patrol boats, over the entire speed range of 10 through 32 knots, was predicted directly from experimental data on Model 5526. Resistance predictions were made at both the Full Load condition of 163.39 L. tons, LCG = 4.645ft (1.42m) aft of midships, and at the Minimum Operating Load (Min-Ops) condition of 143.61 L. tons, LCG = 5.253ft (1.6m) aft of midships. The following predictions are determined at model scale for the two loading conditions.

Full Load: Model resistance predictions indicate a decrease in ship effective power (P_E) when the stern flap is installed for all speeds tested (10 - 32 knots). The maximum stern flap P_E reduction is predicted to be 3.76 percent at a speed of 16 knots. The average decrease in P_E, over the high speed range (as indicated by 28 through 32 knots), is approximately 0.82 percent.

Min-Ops: A decrease in ship P_E, when the stern flap is installed, is again indicated for all speeds tested. The maximum stern flap P_E reduction is predicted to be 3.74 percent at a speed of 15 knots. The average high speed decrease in P_E is approximately 0.96 percent.

Full Scale Projected Delivered Power

The model resistance predictions were then used to estimate powering with and without the stern flap. Model resistance, representative class propeller open water performance data, and estimated propeller-hull interaction coefficients, were utilized to estimate Island Class powering data. For a complete description of the powering estimation procedures, refer to Appendix B.

While significant powering improvement is indicated from these Model 5526 stern flap experiments, the actual full scale stern flap on the Island Class would generally be expected to exceed the performance improvement shown on the model. Ship trials have indicated that the actual performance improvement of full scale prototype stern flaps generally exceed that of the model predictions, in the range of roughly 2% to as much as 12%, Cusanelli [3]. Within the last year, a beneficial stern flap scale effect has been firmly identified through full scale ship trials, model testing with varying model sizes, and computational fluid dynamics calculations. A simple quantitative empirical "performance projection tool", for estimating the magnitude of the stern flap scale effect, is under development. This performance tool was utilized to calculate new projections of Island Class stern flap performance.

Island Class 110 WPB stern flap performance projections, adjusted for stern flap scaling effects, are presented in Figure 3 and summarized in Table 3. Data in Figure 3 is presented as delivered power and propeller RPM ratios, defined as the value required with the stern flap installed divided by the value required for the baseline (no flap) configuration, as a function of ship speed. A ratio below 1.0 denotes a reduction in power or propeller RPM, due to the installation of the stern flap. The Island Class performance estimations, shown in figure 3 and also in table 3, do not account for propeller cavitation.

The installation of the stern flap on the Island Class 110 WPB results in a delivered power (P_D) reduction for all speeds in the ship operating profile. The incipient speed where the stern flap results in a P_D reduction is estimated to be below the 12 knot ship minimum operating speed at engine idle (best economic speed). The stern flap allows the captain the capability to maintain any ship operating speed with less delivered power, and lower engine (or shaft) speed, thus increasing range. Conversely, any equivalent engine horsepower or engine RPM maintained with the flap installed, would result in an increase in speed over the existing patrol boat.

The selected stern flap caused a power reduction at high speed, satisfied the secondary powering criteria prescribed at cruising speed and best economic speed, and did not exceed the trim criteria.

Table 3. Island Class stern flap: Summary of full scale projected performance

Island Class 110 WPB Stern Flap		Projected Performance	
Item	Design Criteria	Full Load	Min-Ops
Power @ High Speed: 28-32 knots	Maximize Reduction	-0.82%	-0.96%
Projected Maximum Speed		27.85 kts	30.38 kts
Increase in Maximum Speed		+0.80 kts	+0.38 kts
Power @ Cruising Speed: 24 knots	No Increase	-3.7%	-3.3%
Maximum Reduction in Powering		-5.8% @ 16 kts	-5.8% @ 15 kts
Incipient Speed for Effectiveness		< 12 (@ idle)	< 12 (@ idle)
Annual Fuel Consumption		-4.5%	-3.9%
Modification to Trim (Bow Down)	Not to Exceed 1.0°	-0.6°	-0.6°

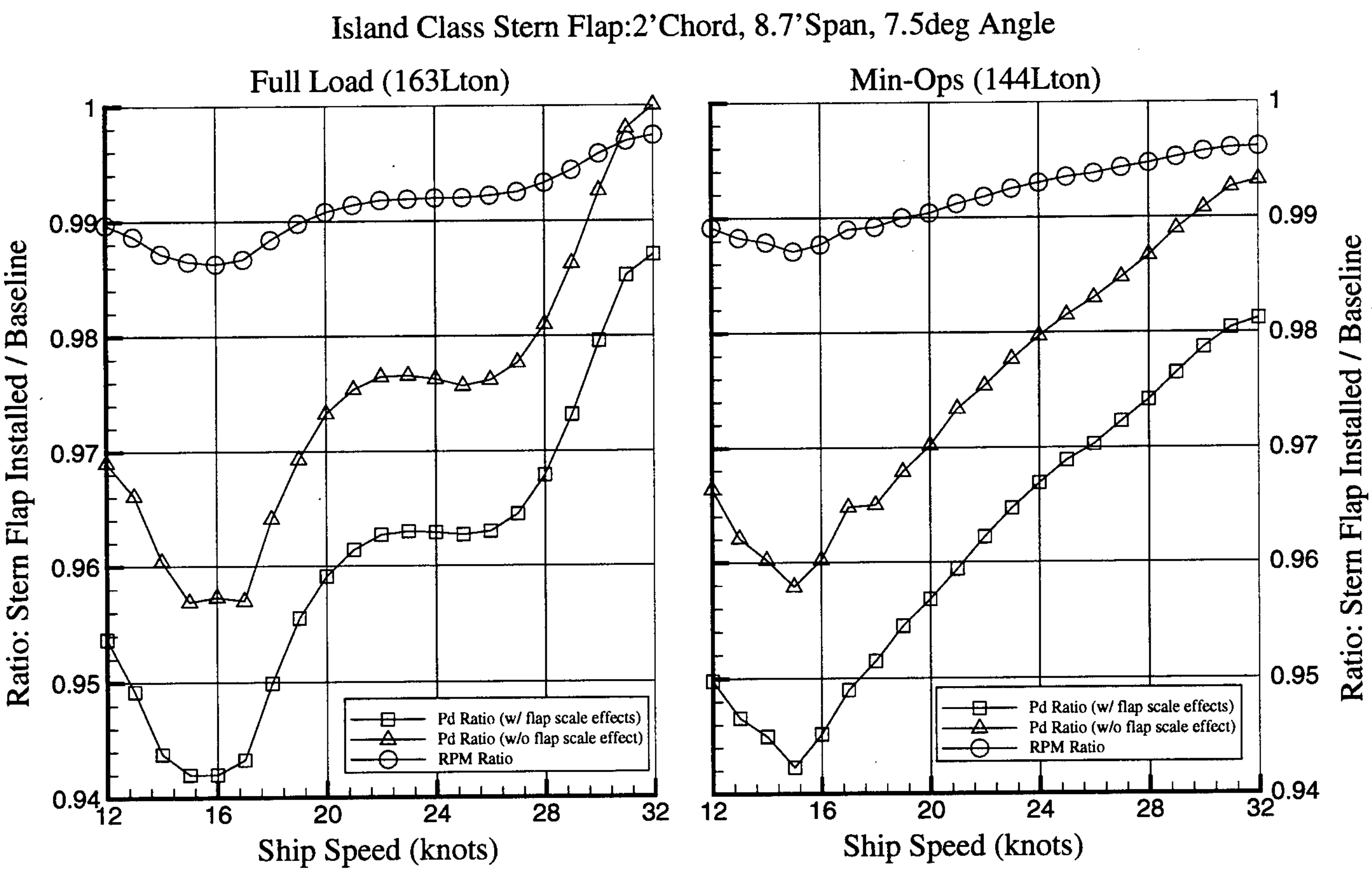


Fig 2. Island Class, full scale projected stern flap performance

The following predictions for both the Full Load condition, and the Min-Ops condition are based on model resistance data, propeller characteristics, and flap scale effect adjustments.

Full Load: The maximum stern flap P_D reduction is projected to be 5.8 percent at a speed of 16 knots. The maximum attainable speed, for the Island Class 110 WPB patrol boats with the stern flap installed, is projected to be 27.85 knots, at a total shaft power of 2583 hP, with a propeller speed of 786.3 RPM (engine speed 1832 RPM). This represents an increase in top speed of 0.80 knots over the existing boats.

Min-Ops: The maximum stern flap P_D reduction is projected to be 5.8 percent at a speed of 15 knots. The maximum attainable speed, with the stern flap installed, is projected to be 30.38 knots, at a total shaft power of 2635 hP, with a propeller speed of 812.9 RPM (engine speed 1894 RPM). This represents an increase in top speed of 0.38 knots.

The projected shaft powering at both the Full load condition and the Min-Ops condition, with/without stern flap installed, were compared to the engine operating envelope of the Island Class 110 WPB C series Caterpillar 3516 main engines. The projected performance at both the Full Load condition (163 L. tons) and at the Min-Ops condition (144 L. tons), indicate delivered power vs. engine speed requirements higher than that of the stated Caterpillar 3516 engine operating envelope (exceeds specified engine performance curve), over most of the speed range. Ship trials on the BAINBRIDGE ISLAND (WPB 1343), at the 151 L. tons displacement, also indicated that the engines were operated in exceedance of the manufacturer's specified engine performance curve. The installation of the stern flap does move the projected powering curve closer to the manufacturer's specified engine performance curve. However, an even greater reduction in the ship's speed vs. power relationship is necessary for the ship performance to remain below the manufactuerer's specified engine performance envelope.

Fuel Savings Potential

The installation of a stern flap on the Island Class 110 WPB results in the capability to maintain ship speed with less delivered power, and lower shaft speed, and therefore, represents a potential for propulsion fuel savings. Fuel consumption rates, measured on the BAINBRIDGE ISLAND (WPB 1343) Caterpillar 3516 main engines, were utilized to estimate fuel consumption at the Full Load and Min-Ops conditions, with and without the flaps. An estimated speed-time profile, shown in table 4, based on 3000 annual operational hours, was supplied by USCG ELC-024 as discussed by Code 5200 personnel and customer representative Debu Ghosh. Assuming equivalent time-at-speed for the class with stern flap installed, the estimated average reduction in annual fuel consumption is 4.5 percent when operating at Full Load, and 3.9 percent for Min-Ops. Fuel savings was then estimated assuming a split of 2/3 time (2000 hr.) at full load, and 1/3 time (1000 hr.) at min-ops.

Table 4. Island Class: Estimated Speed Time Profile

Speed	163Lton Speed-Time Profile (% of time at given speed)	144Lton Speed-Time Profile (% of time at given speed)
12	40	40
15	25	25
18	10	10
21	5	5
23	5	5
25	5	5
27	10	-
30	-	10

The annual fuel savings, resulting from a stern flap installation of the Island Class 110 WPB, would amount to 13,328 gallons, or approximately $13,000 per ship / per year, on average. The indicated cost for fabrication and installation of a stern flap on this class is in the range of $10,000 or less. Therefore, the time to recover the cost of the stern flap installation (pay-back on investment) is less than one year.

Ship Running Trim

Comparisons were made between the ship running trim, for the Island Class with and without the stern flap installed, for both the full load and min-ops conditions, Figure 3. The Island Class ship running trim, at both Full Load and Min-Ops, was affected very similarly by the stern flap. The net change in bow down trim angle, resulting from the stern flap, increased as ship speed increased. The change in trim angle remained within 0.6 degrees over the range of ship operational speeds (12 ~ 30 knots). Therefore, the selected stern flap satisfied the design criteria for ship running trim modification (bow down) not to exceed 1.0 degrees, at any speed.

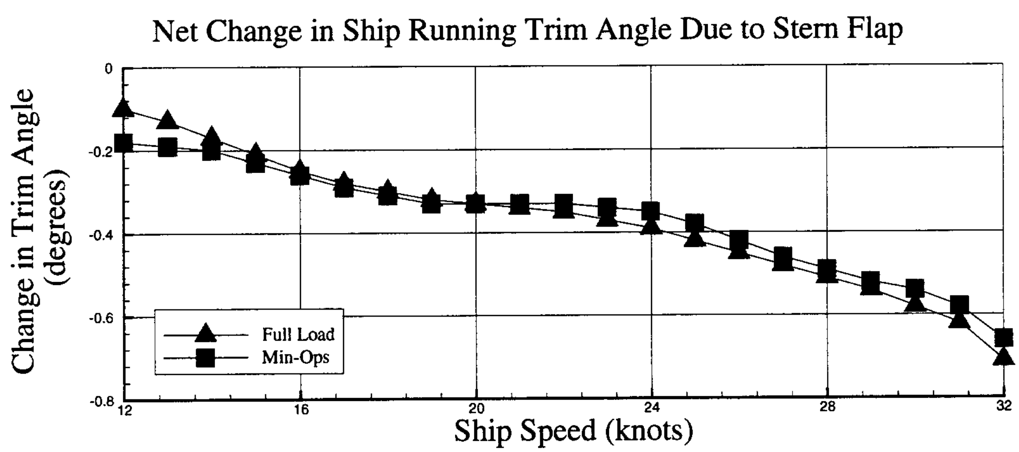


Fig 3. Island Class, stern flap effect on ship running trim

Stern Waves

Visual observations and photographs were taken of the local transom flow generated behind Model 5526, with and without the stern flap installed, at 2 knot increments of ship speed, from 10 to 32 knots. The complete set of photographs is presented in Appendix B. Figure 4 presents the with/without stern flap comparison photographs at a ship speed of 16 knots, at the Full Load condition. The character of the transom flow was considerably altered by the stern flap over the speed range of 12 ~ 20 knots. Within these speeds, the transom flow appears to be decreased in both wave height and overall width by the stern flap. The ship speed at which the transom flow detaches (break-away) was reduced from approximately 17 knots for the baseline hull to 15 knots with the stern flap installed. Referring to Figure 4, the baseline hull at 16 knots still exhibits attached flow, while the stern flap case exhibits fully detached flow. At this speed, the stern flap exhibited the greatest modification to the transom flow. Not coincidentally, the stern flap also exhibited its maximum powering reduction at this 16 knot speed. For speeds in excess of 22 knots, there appears to be little visual difference in the local transom flow generated behind Model 5526 with or without the stern flap installed. However, at these higher speeds, the stern flap does appear to reduce the visual wake deficit behind the rudders, which appears as a trail of "white water" behind each rudder. This change in the rudder wake is a stern flap effect which had not previously been documented.

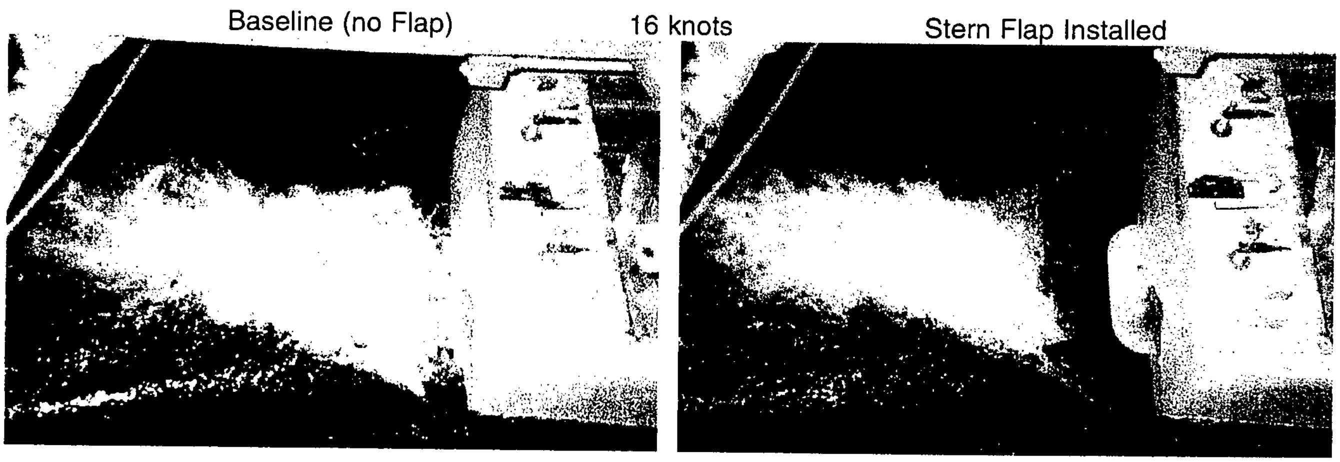


Fig 4. Island Class, model scale transom flow comparison, with/without stern flap installed

A qualitative assessment as to stern flap effects on transom flow can be generalized as follows. The stern flap causes a reduction in the observed slopes of the trailing waves, the overall height and sharpness of the ridges along these waves, the amount of residual "white water" trailing in the wake, the apparent height of the first wave crest (transom convergence wave), and the location of the first wave crest. The amount of wave breaking both directly behind the stern (the rooster tail) and also at the edge of the inner transom wave region is visually reduced with the flap.

Effects on Propeller Cavitation

Cavitation may be induced on a full scale ship propeller over parts of it's operating profile, due to the wide range of demands on speed and power. Propeller cavitation effects are not simulated in traditional tow tank model experiments. The reduced power due to the stern flap, leading to reduced propeller loading, combined with the flap's associated increased pressure and reduced flow velocity under the hull, can serve to suppress propeller cavitation and reduce thrust breakdown losses. Slight improvements in cavitation inception speed can also result from the reduced propeller loading at moderate speeds.

A complete assessment of the possible stern flap effects on propeller cavitation, will be made by NSWCCD Code 5400 during the Island Class 110 WPB propeller design study. This information will be published in a later report.

Measurement Uncertainty

As part of the standard model testing procedure for the David Taylor Model Basin, an estimate of the uncertainty in the model measurements is prepared. The details of the uncertainty analysis, as well as the repeat model test data, are presented in Appendix B, Table B3. The estimated uncertainty in the resistance measurement is 0.49% at 16 knots and 0.96% at 24 knots.

For this hullform, the measured improvement in the model resistance due to the stern flap is 3.8% at 16 knots and 2.2% at 24knots The magnitude of the performance improvement due to the stern flap far exceeds the uncertainty in the measurement.

SPRAY RAIL INSTALLATION

In order to promote a cleaner flow separation along the model lower chine, model scale chine rails were installed along an 87 inch (221 cm) length of the chine. This is a technique used at model scale only, in order to promote flow separation similar to that of the full scale ship, along the existing ship lower chine. This model scale chine rail is not to be interpreted as an additional hull treatment or appendage necessary for flow separation at full scale.

However, during model testing, it was noted that a significant amount of spray was being generated from the bow region, forward of the chine rails, at ship speeds in excess of 24 knots. At higher speeds, this spray resulted in model deck-wetting. Representatives of the USCG ELC-024, present at the model testing, reported that similar spray patterns - leading to forward deck-wetting, have been observed at full scale. The flow streamlines, which appear to generate this spray, originate in the region of the bow between the forwardmost edge of the bow stem and the ship's existing lower chine. Since there is nothing in the hull lines to deflect these flow streamlines (either at ship or model scale), the water tends to cling to the hull and progress upwards. At ship speeds of 24 ~ 30 knots, the flow appears to separate off the upper chine. At higher speeds, the flow progresses all the way to the deck line before separating. Once at the upper chine or deck level, the flow separates in a spray sheet which increases in size as speed increases. It was suggested by the DTMB test engineers to add "bow spray rails" as a continuation of the chine rails, in order to promote better flow separation of the flow streamlines which appeared to generate the bow spray sheet.

In contrast to the chine rails which were installed on the model, the addition of "bow spray rails" extending forward of the existing hull lower chine represents a modification to the existing Island Class hull. The bow spray rails promoted flow separation at the level of the lower chine for all ship speeds, and affected a significant reduction in the amount of spray generated by the bow at higher speeds. Figure 5 shows a comparison of the bow wave and spray with/without bow spray rails installed, for full load at 28 knots. With the bow spray rails installed, there was no forward deck-wetting observed on the model at any speed. Model test data showed that the bow spray rails increase the effective power 0.2 to 1.3% for the 14 ~ 19 knot speed range, but do not affect the predicted power above 19 knots (see table B9a. "Island Class, resistance prediction (no flap), full load 163 L.tons, original model configuration without spray rail extension, Exp. 17" and table B9b. "Island Class, resistance prediction (no flap), full load 163 L.tons, Exp. 18 with "bow spray rails""). See Appendix A, "Model 5526 Description and Inspection", for further details regarding the installation of the chine rail, and bow spray rails on the model.

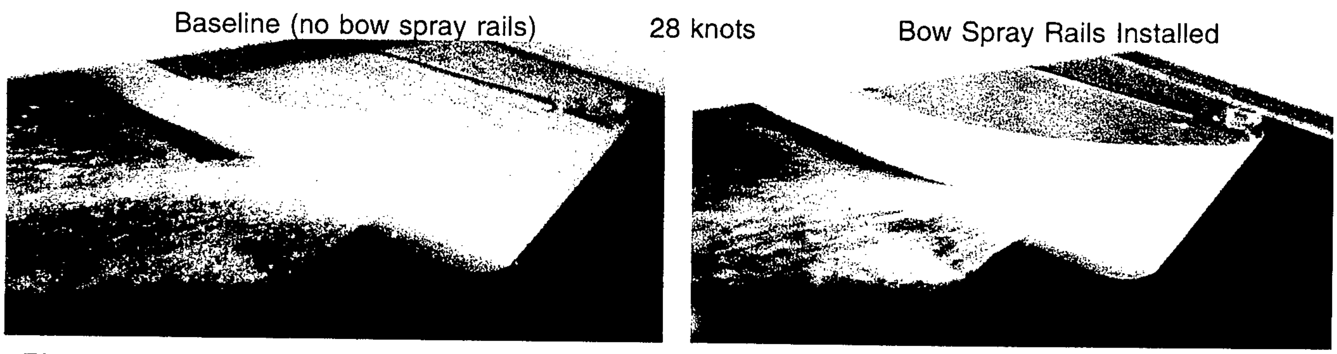


Fig 5. Island Class, model scale bow wave and spray comparison, with/without bow spray rails

It is recommended that bow spray rails be installed in the Island Class. The exact length of the bow spray rails should be determined through observation of the full scale spray pattern on the Island Class Patrol Boat. They should extend aft <u>at least</u> 7.25 ft (2.2 m) from the bow stem, following the contour indicated by the existing lower chine line, and project from the hull (thickness) approximately 1.5 inches (3.8 cm).

CONCLUSIONS

The U.S. Coast Guard initiated a research and development program with the intention of improving the performance capabilities of the Island Class 110 WPB patrol boats. As an opening phase of this program, model experiments were performed to evaluate the performance of a stern flap on this class. Eight stern flaps were designed and tested on Model 5526. These stern flaps were designed as a series, to systematically investigate variations in flap dimensions of chord length, span, angle, and planform area distribution.

The recommended stern flap for the Island Class 110 WPB is: chord length 2 ft (0.61 m), span 8.7 ft (2.7 m), and angle of 7.5° trailing edge down relative to the local slope (run) at the 4 ft (1.22 m) buttock.

<u>The model tests directly show that the Full Load performance on the Island Class 110 WPB, with the stern flap, will have the following characteristics</u>:

- Maximum attainable speed of 27.55 knots, increase of 0.5 knots
- Power reduction of 2.4% at cruise speed of 24 knots (Conversely range increased by 2.4%)
- Annual propulsion fuel savings of approximately $8,500 per ship.

Our experience with stern flaps scale effects (model scale to ship scale performance) indicates that there will be an additional benefit above and beyond the benefit shown by the model tests.

<u>With stern flap scaling taken into account the Full Load Performance on the Island Class 110 WPB, with stern flap, will have the following characteristics:</u>

- Maximum attainable speed of 27.85 knots, increase of 0.8 knots
- Power reduction of 3.7% at cruise speed of 24 knots (Conversely range increased by 3.7%)
- Annual propulsion fuel savings of approximately $13,000 per ship.

It is also recommended that bow spray rails be installed on the Island Class 110 WPB. The bow spray rails promoted flow separation at the level of the lower chine for all ship speeds, and caused a significant reduction in the amount of spray generated by the bow at higher speeds. At ship scale, the bow spray rails should extend at least 7.25 ft (2.2 m) aft from the bow stem, and follow the contour indicated by the existing lower chine line. The bow spray rails should project from the hull (thickness) approximately 1.5 inches (3.8 cm).

In order to insure that an accurate assessment of ship performance was achieved, a ship/model correlation allowance of $C_A = 0.0003$ was estimated, from model resistance experiments, prior to the stern flap testing. It is recommended, however, that an effort should be made to determine the Island Class correlation allowance through a traditional model powering test series.

ACKNOWLEDGMENTS

The authors would like to thank Chris Barry and Debu Ghosh, of the U.S. Coast Guard, Boat Engineering Branch (ELC-024), for their contributions and support towards this project.

REFERENCES

[1] Polmar, N., *Naval Institute Guide to the Ships and Aircraft of the U.S. Fleet*, Sixteenth Edition, Naval Institute Press, Annapolis, Maryland, (1997).

[2] Cusanelli, D.S., and K.M. Forgach, "Stern Flaps for Enhanced Powering Performance", Proceedings of Twenty-Fourth American Towing Tank Conference, College Station, Texas, (Nov. 1995).

[3] Cusanelli, D.S., "Stern Flap Installations on Three U.S. Navy Ships", ASNE 1998 Symposium - 21st Century Combatant Technology, Biloxi, Mississippi, (Jan. 1998).

[4] Haupt, K.D., and L.T. Puckette, "U.S. Coast Guard 110 ft WPB Island Class C Standardization Trials Results USCG BAINBRIDGE ISLAND (WPB-1343)", NSCSES Report No. 60-264, (Oct. 1991).

[5] Karafiath, G., "US Navy Ship-Model Powering Correlation and Propeller RPM Prediction", Proceedings of Propellers/Shafting '97 Symposium, Hampton Roads, VA, (Sept. 1997)

[6] Cusanelli, D.S. and J. Bradel, U.S. Patent Number 5,343,742, "Floating Platform Tow Post", (Sept. 1994).

[7] Grant, J. W., and C. J. Wilson, "Design Practices for Powering Predictions", DTNSRDC/SPD-0693-01, (Oct. 1976)

[8] Hadler, J.B., et al., "Ship Standardization Trial Performance and Correlation with Model Predictions", SNAME Transactions, Vol. 70, (1962)

APPENDIX A

MODEL 5526 DESCRIPTION AND INSPECTION

- APPENDIX A -

A new geosim model, DTMB Model 5526, representing the U.S. Coast Guard Island Class 110 WPB patrol boats, was built for this project. Descriptions of Model 5526 hull, fabrication, and comparisons of the model hull surface to the numerical model, and descriptions of all model appendages included on the model during testing, are contained within this appendix.

MODEL 5526 - HULL

Model 5526, representing the USCG Island Class 110 WPB, is built to a scale ratio λ = 5.706 and is shown in figure A1, and in table A1. The model is constructed of sugar pine and was cut on a 5-axis numerically controlled milling machine based on a non-uniform rational b-spline (NURBS) Fastship file. The file is based on offsets provided by the sponsor in the form of an electronic data file.

An inspection of model 5526 was performed using DTMB's Laser Scanner and the results compared to the original Fastship surface. The results of the comparison are shown in figure A2. The results indicate that the majority of the model is within .03 inches (.076cm) of the Fastship surface and all points on the surface are within .05 inches (.13cm). Anything within a tolerance of .05 inches is considered acceptable.

MODEL 5526 - APPENDAGES

Appendages installed on Model 5526 during all the present experiments were: twin roll stabilizer fins, twin rudders, and open shaft and strut propulsion appendage suite. Experiments were also conducted with six different stern flap designs installed. The model surface also included a small wedge at the transom. All appendages were inspected in accordance with Code 52 ISO 9000 requirements and found to be acceptable.

Chine Rails: In order to promote a cleaner flow separation along this chine, model scale chine rails were installed. The chine rails were installed on both port and starboard sides of the model, extending from 15.25 in (38.7 cm) aft of the bow stem to 8.0 ft (2.43 m) aft of the bow stem on the model. The chine rails were made of plexi-glass 1/4 inch (0.64 cm) thick, and 1/2 inch (1.28 cm) in height. Therefore, the chine rails extended the lower chine 1/4 inch (0.64 cm) beyond the existing hull lines. This is a technique used at model scale only, in order to promote flow separation similar to that of the full scale ship along the existing ship lower chine. Figure A3 depicts the installation of the chine rails.

"Bow Spray Rails": In contrast to the chine rails, additional "bow spray rails" were added to the model which represent an additional hull treatment which will alter the location of flow separation at full scale in addition to model scale. The bow spray rails extend from the bow stem to 15.25in (38.7cm) aft of the bow stem along the line indicated by the existing lower chine. These bow spray rails were added to the model at the suggestion of the DTMB engineers when tests indicated that there was significant bow spray at model scale. Representatives of the USCG ELC-024, present at the model testing, reported that similar spray patterns - leading to forward deck-wetting, have been observed at full scale. Figure A3 depicts the installation of the bow spray rails.

Stern Flaps: Eight stern flaps were designed and manufactured for the Model 5526 experiments. A small-scale sketch depicting the geometry of the model tested stern flaps, and tabulated principal dimensions, are presented in Figure A4. These stern flaps were designed as several different series to systematically investigate variations in flap dimensions of chord length, span, angle, and planform area distribution. The first series, comprised of flaps #1, #2, #3, and #4, was designed to investigate variations in flap chord length, while holding span constant at 16 ft (4.9 m). The span selected was the maximum reasonable width across the transom, without the flap impinging on the wake off the corners of the transom, and without requiring significant curvature of the flap around the tight radius at the turn of the bilge. The second series, comprised of flaps #3, #5, and #6, was designed to investigate variations in span, while holding chord length constant at 2 ft (0.61 m). The third series, comprised of flaps #1, #7, and #8, was also designed to investigate variations in span, while holding chord length constant at only 1 ft (0.3 m). And the fourth series, comprised of flaps #1 versus #6 and #2 versus #5, was designed to investigate variations in planform area distribution, while holding respective total planform area constant. A simple radiused corner treatment (in plan view) equal to the flap chord length, was chosen for all flap designs, to simplify construction and reduce full scale flap manufacturing costs. All flaps were evaluated over a range of angles, nominally in 2.5 degree increments, from 0 to 10 degrees trailing edge down (TED). The coordinate system used for flap angle is defined with zero degrees parallel to the slope of the local buttock angle (run) at the 4 ft (1.22 m) buttock. The gap between the transom and the flap was bridged by a small fairing strip fastened to the model to prevent cross-flow and pressure loss at the intersection between the forward edge of the flap and the transom.

Transom Wedge: A small transom wedge designed to be an integral part of (inlayed into) the ship plating at the transom. The manufacture of Model 5526 included this wedge as part of the model surface, and therefore, as on the ship, it is not a removable appendage. Bollinger Shipyard drawing No. 110WPB 085-003 indicates that the transom wedge has a longitudinal chord length of 2.5 ft (0.76 m) and a wedge angle of 5 degrees specified at the 4 ft (1.22 m) buttock.

Rudders: The rudders were designed and built for Model 5526 to conform with Bollinger Shipyard drawing No. 110BWPB 562-001. The rudders are designed with a root chord length 2.35 ft (0.72 m), a tip chord length 1.68ft (0.52m), and a total rudder height of 2.5ft (0.76m). The total wetted surface for the pair of rudders is 21.1ft^2 (1.96m^2). The rudders were aligned parallel to the ship centerline for all experiments on Model 5526.

Roll Stabilizer Fins: The roll stabilizer fins were designed and built for Model 5526 to conform with Bollinger Shipyard drawing No. 110BWPB 565-001. The roll stabilizer fins are designed with a root chord length 3.75ft (1.14 m), a tip chord length 2.75ft (0.84m), and a total fin height of 3.0ft (0.91m).

The twin roll stabilizer fins total wetted surface is 40.0ft^2 (3.72m^2). The roll stabilizer fins were aligned parallel to the ship centerline for all experiments on Model 5526.

Propulsion Suite: The open shaft and strut propulsion (twin shaftline) appendage suite consists of the shafts, main and intermediate shaft support struts, and main and intermediate strut barrels. The appendage were designed and built for Model 5526 to conform with Bollinger Shipyard drawing No. 110BWPB 161-001. Shaft angle relative to the baseline is 6.9 degrees, parallel to the ship centerline. The scope of the present model tests did not include model self-propulsion (powering) experiments. Therefore, in order to provide a model at a lower cost, the Model 5526 propulsion appendage suite was constructed of renwood in lieu of standard construction materials. This necessitates that standard functioning propulsion appendages must be manufactured for Model 5526 if future model experiments are to include self-propulsion.

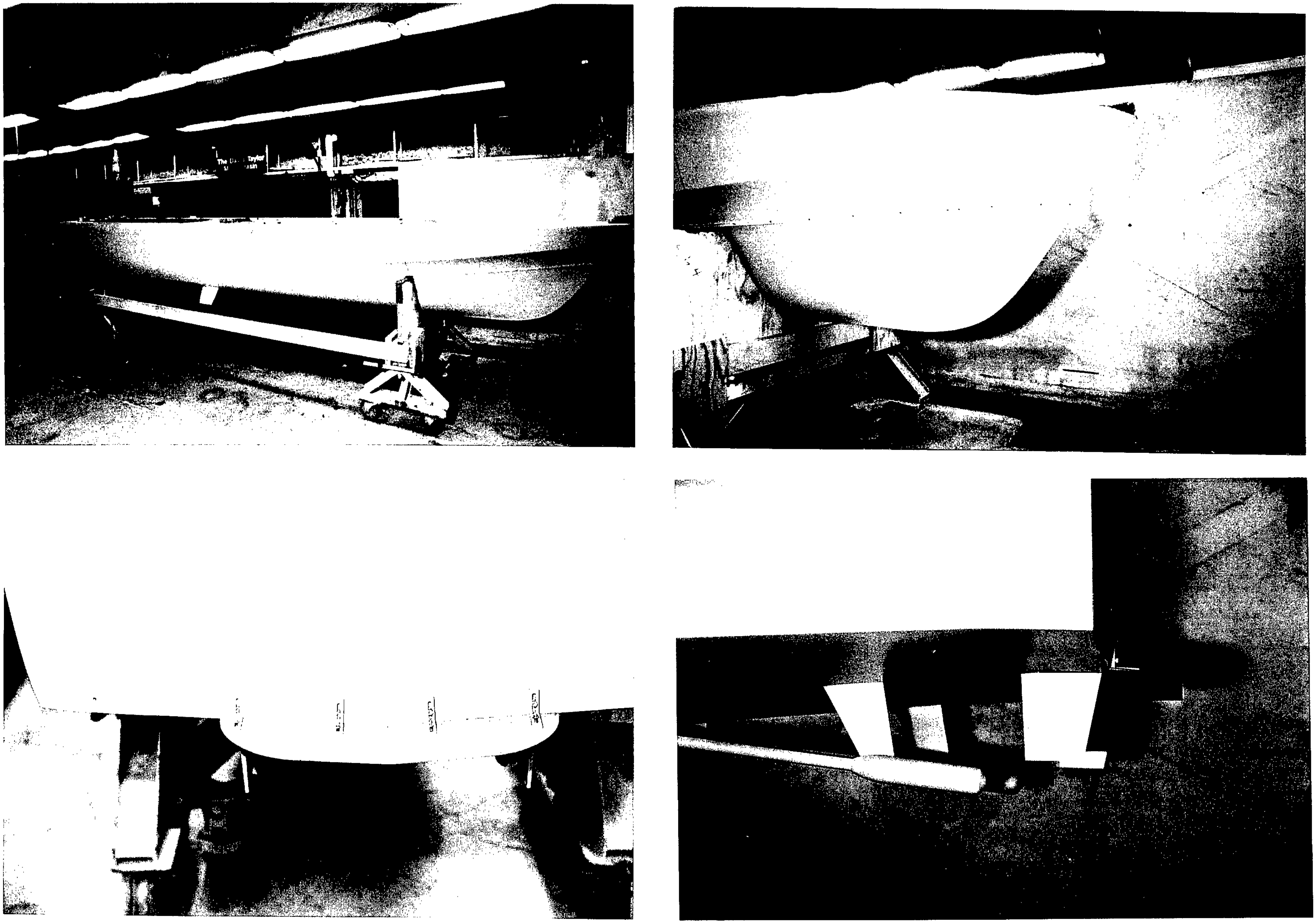


Fig A1. Photographs of Island Class Model 5526 and appendages, model tested stern flaps, "bow spray rails", and stern flap installation and testing hardware

Difference Between Actual and Desired Model Offsets

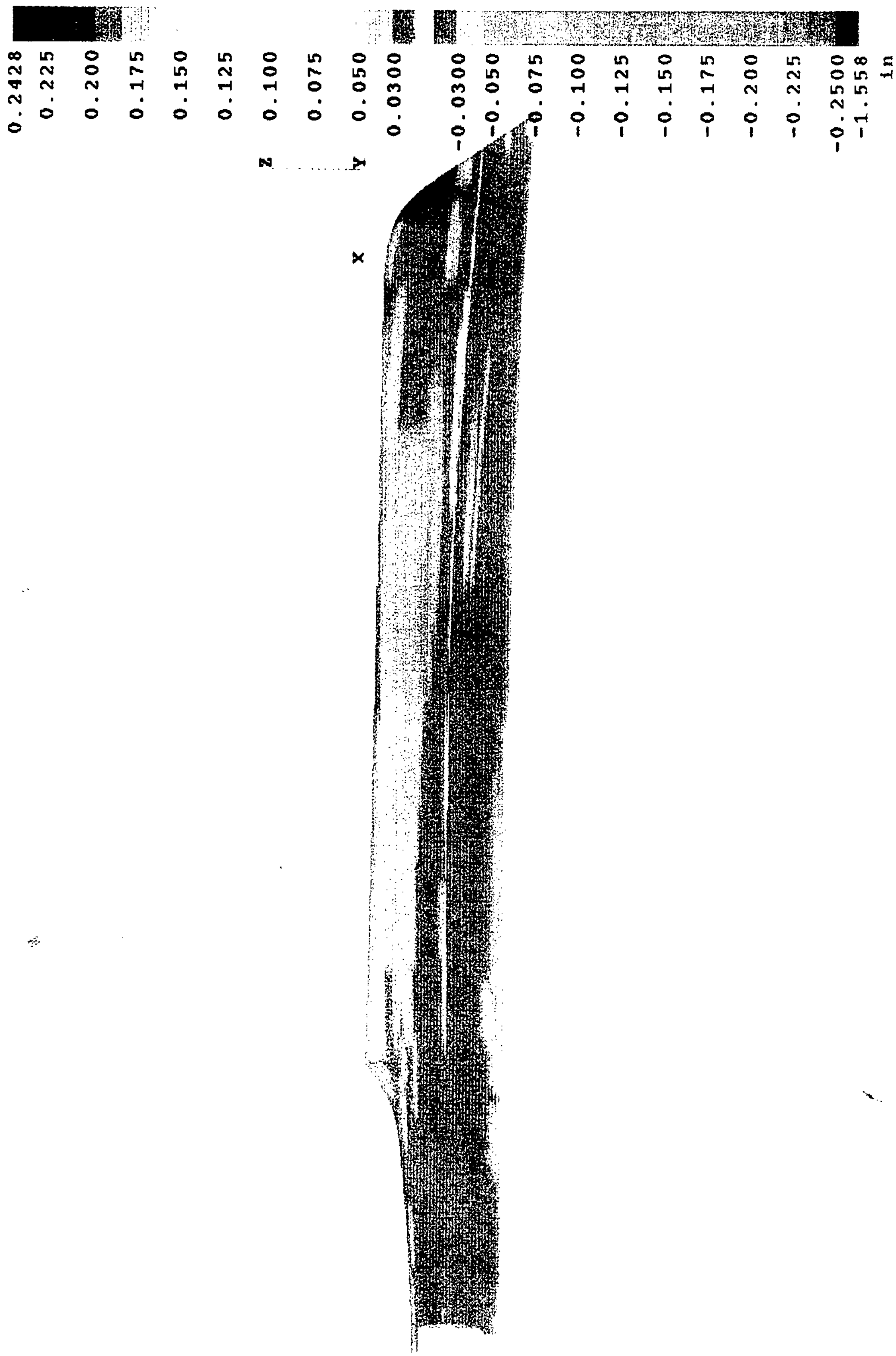


Fig A2. Island Class Model 5526, graphic depiction of model surface inspection

Difference Between Actual and Desired Model Offsets

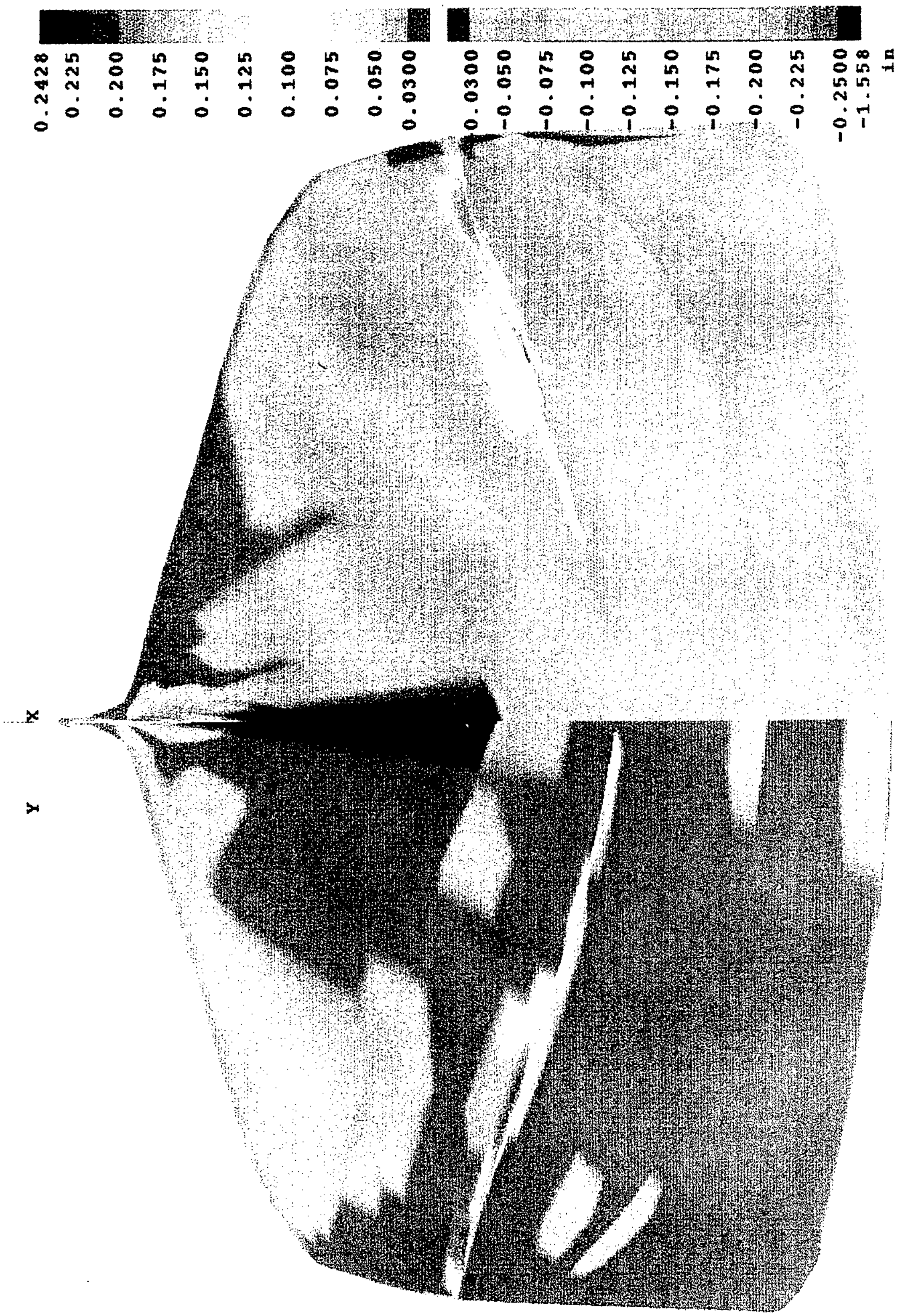


Fig A2. Island Class Model 5526, graphic depiction of model surface inspection (cont.)

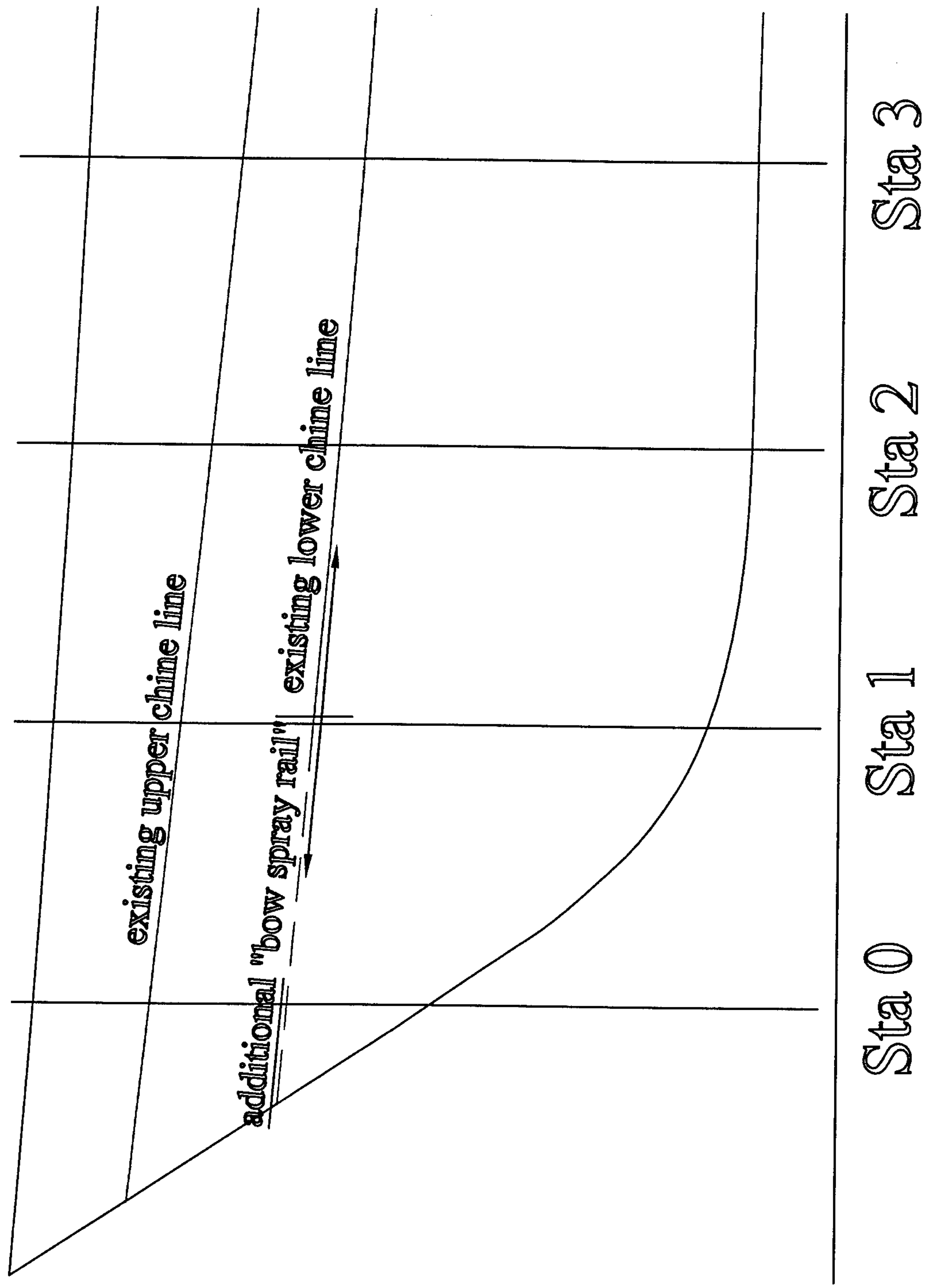
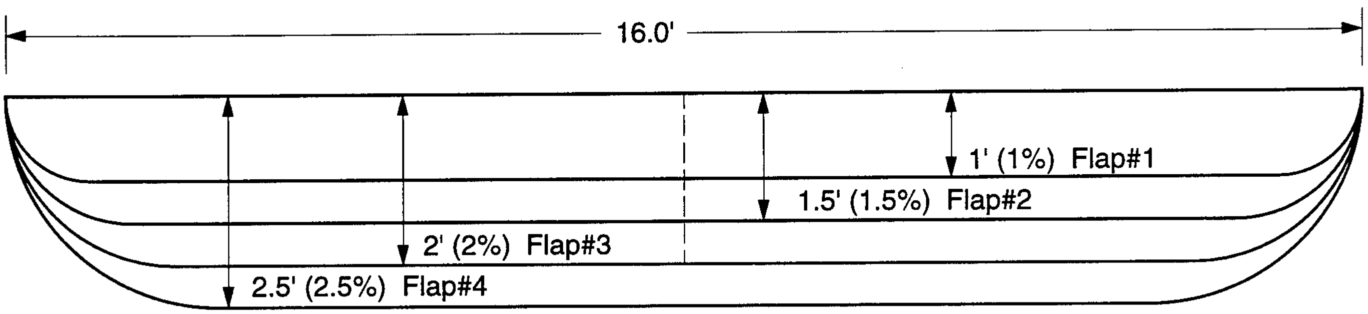


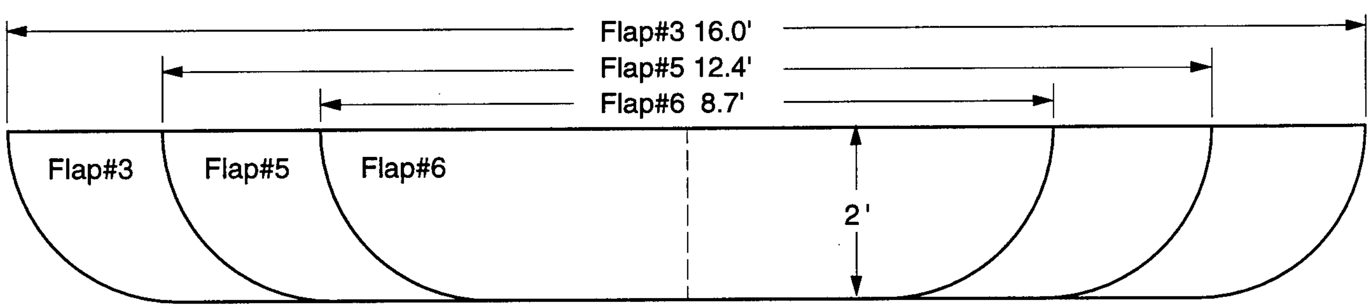
Figure A3. Island Class Model 5526, Chine Rail and Bow Spray Rail Installation

Island Class 110 WPB Stern Flaps **Model 5526** $\lambda = 5.706$

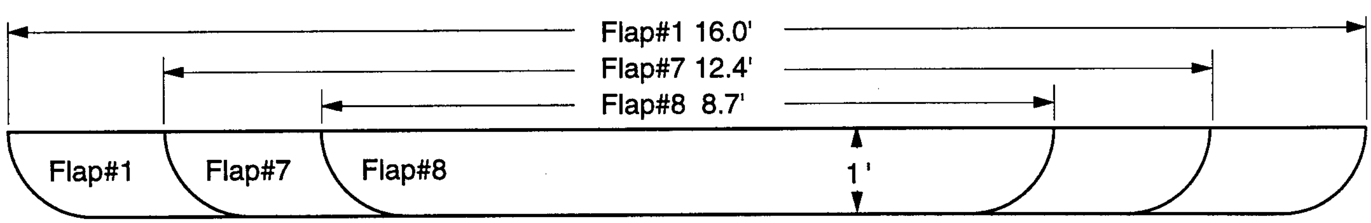
	Ship Scale Dimensions				
Flap#	Chord Length (ft)	Span (ft)	Planform Area (sq. ft)	Series	Comments
1	1	16	15.6	chord series @16' span, span series @1' chord	Area Equivalent to #6
2	1.5	16	23.0	chord series @16' span	Area Equivalent to #5
3	2	16	30.3	chord series @16' span, span series @2' chord	
4	2.5	16	37.3	chord series @16' span	Longest Chord
5	2	12.4	23.0	span series @2' chord	Area Equivalent to #2
6	2	8.7	15.6	span series @2' chord	Area Equivalent to #1
7	1	12.4	11.9	span series @1' chord	
8	1	8.7	8.2	span series @1' chord	Smallest flap



Flaps #1, #2, #3 and #4: Equivalent 16' Span, Variations in Chord Length

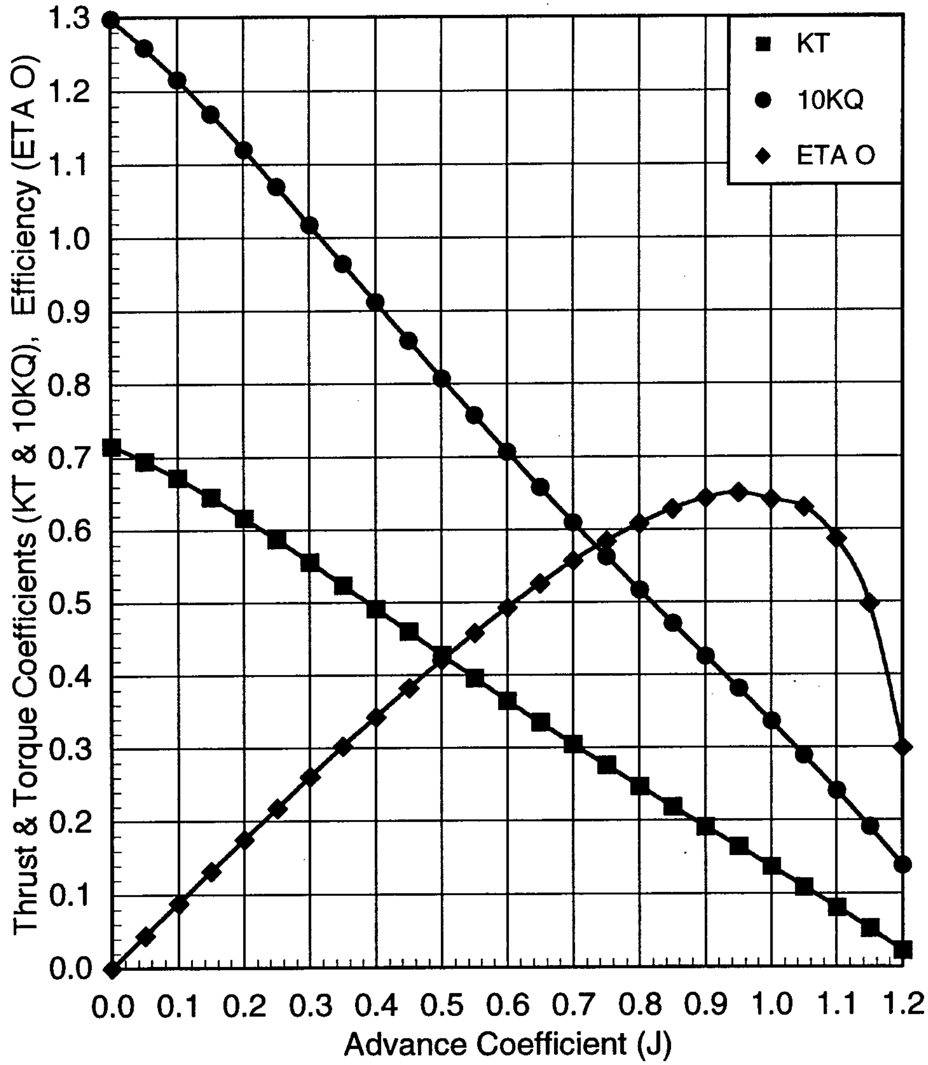


Flaps #3, #5, and #6: Equivalent 2' Chord Length, Variations in Span



Flaps #1, #7, and #8: Equivalent 1' Chord Length, Variations in Span

Fig A4. Geometry of model tested stern flaps



FAIRED OPEN WATER COEFFICIENTS
COAST GUARD CAVITATION PROPELLER 5128
2/6/90 EXP NO. 1.00

J	KT	10KQ	ETAO
0.000	0.716	1.298	0.000
0.050	0.695	1.259	0.044
0.100	0.672	1.216	0.088
0.150	0.645	1.169	0.132
0.200	0.617	1.120	0.175
0.250	0.587	1.070	0.218
0.300	0.556	1.018	0.261
0.350	0.524	0.965	0.303
0.400	0.492	0.913	0.343
0.450	0.460	0.860	0.383
0.500	0.428	0.808	0.421
0.550	0.396	0.757	0.458
0.600	0.365	0.707	0.493
0.650	0.335	0.658	0.526
0.700	0.305	0.610	0.557
0.750	0.276	0.563	0.584
0.800	0.247	0.517	0.608
0.850	0.219	0.471	0.628
0.900	0.191	0.426	0.643
0.950	0.164	0.381	0.650
1.000	0.137	0.336	0.641
1.050	0.109	0.289	0.630
1.100	0.081	0.241	0.587
1.150	0.052	0.191	0.497
1.200	0.022	0.138	0.299

DIAMETER 15.502 in — CHORD LENGTH (0.7R) 9.190 in

P/D (0.7R) 1.238 — NO. BLADES 5 — ROTATION RH

Fig A5. Representative Island Class propeller open water characteristics used in delivered power estimates, as determined on cavitation-sized model propeller 5128

163Lton LCG: 4.65ft aft midships
VCG: 8.88ft above BL

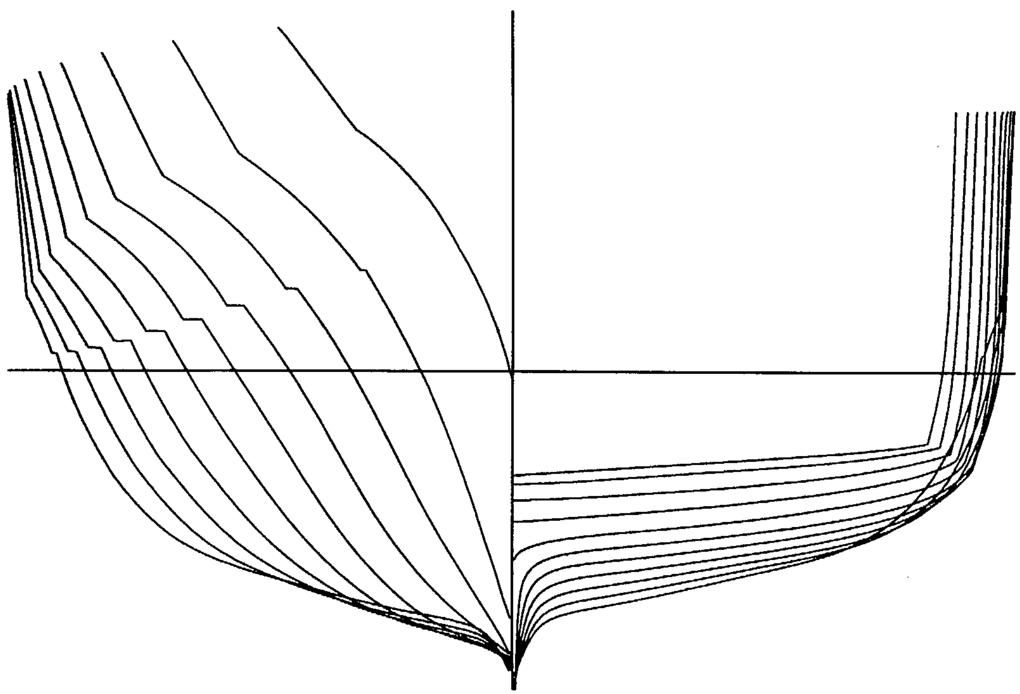


Table A1. Island Class, bare hull hydrostatic calculations at tested loading conditions

Principal Dimensions

Length (LBP)	102.44ft (31.22m)
Length (LWL)	104.3ft (31.80m)
Beam (Bx)	21.07ft (6.42m)
Draft FP (Tfp)	7.66ft (2.33m)
Draft AP (Tap)	6.85ft (2.09m)
Displacement	163.38Lt (166.04MT)
Wetted Surface	2242sqft (208.3sqm)

Model Scale Properties

Scale Ratio	5.706
Length (LBP)	17.95ft (5.47m)
Length (LWL)	18.28ft (5.57m)
Beam (Bx)	3.69ft (1.13m)
Draft FP (Tfp)	1.34ft (.41m)
Draft AP (Tap)	1.20ft (.37m)
Displacement	0.88Lt (.89MT)
Wetted Surface	68.88sqft (6.4sqm)

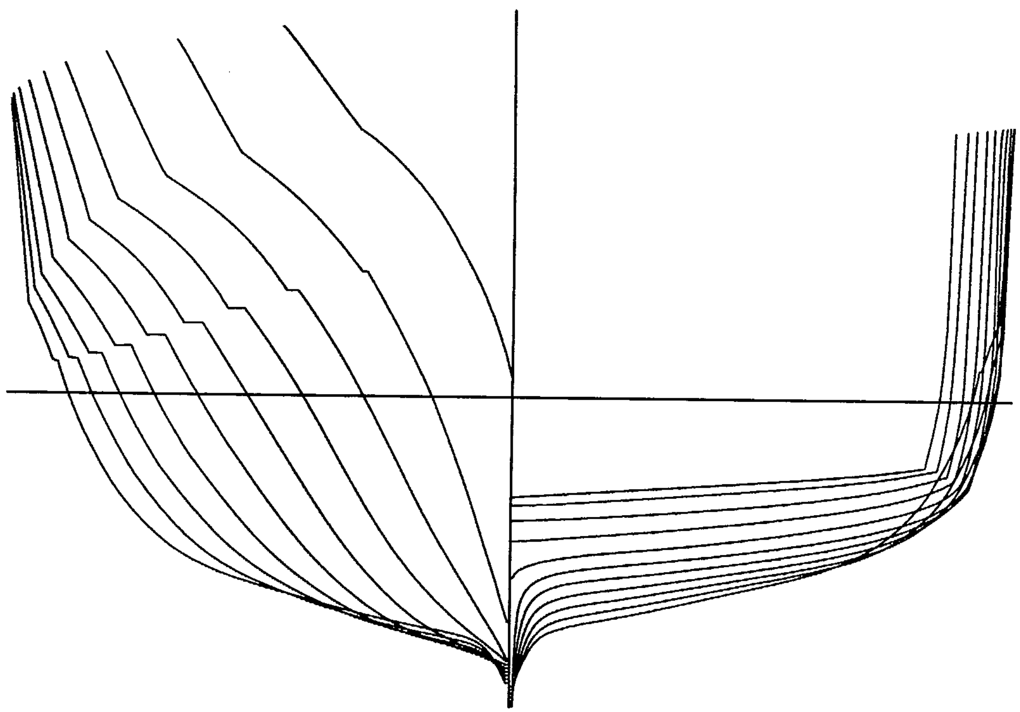
Coefficients

Cp .691	Cwp .783
Cb .402	

Naval Surface WarfareCenter
Resistance & Propulsion

title: USCG Island Class 110 WPB		
surface file: CG110WPB.SRF	drawn by: Liam O'Connell	
model number: 5526	scale factor: 5.706	date: 4/5/99

151Lton LCG: 5.09ft aft midships
VCG: 9.11ft above BL



Principal Dimensions

Length (LBP)	102.44ft (31.22m)
Length (LWL)	103.67ft (31.60m)
Beam (Bx)	21.07ft (6.42m)
Draft FP (Tfp)	7.18ft (2.19m)
Draft AP (Tap)	6.74ft (2.05m)
Displacement	151.0Lt (153.46MT)
Wetted Surface	2175sqft (202.1sqm)

Model Scale Properties

Scale Ratio	5.706
Length (LBP)	17.95ft (5.47m)
Length (LWL)	18.17ft (5.54m)
Beam (Bx)	3.69ft (1.13m)
Draft FP (Tfp)	1.26ft (.38m)
Draft AP (Tap)	1.18ft (.36m)
Displacement	0.81Lt (.83MT)
Wetted Surface	66.82sqft (6.2sqm)

Coefficients

Cp .69	Cwp .778
Cb .386	

Naval Surface WarfareCenter
Resistance & Propulsion

title: USCG Island Class 110 WPB		
surface file: CG110WPB.SRF		drawn by: Liam O'Connell
model number: 5526	scale factor: 5.706	date: 4/5/99

Table A1. Island Class, bare hull hydrostatic calculations at tested loading conditions (cont.)

144Lton LCG: 5.253ft aft midships
VCG: 9.373ft above BL

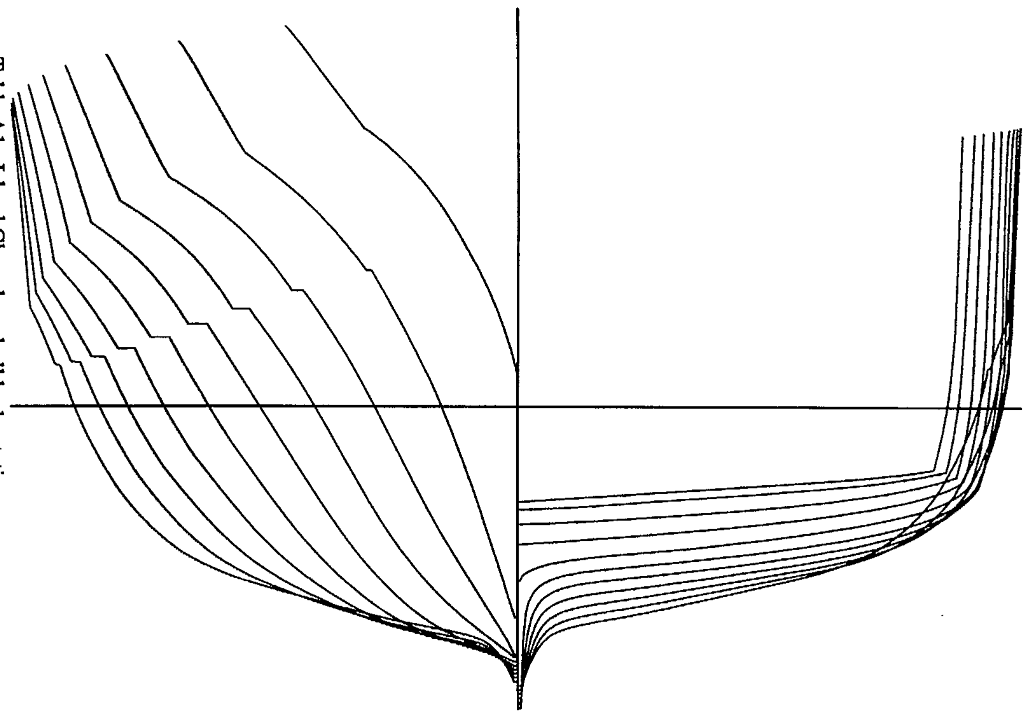


Table A1. Island Class, bare hull hydrostatic calculations at tested loading conditions (cont.)

Principal Dimensions

Length (LBP)	102.44ft (31.22m)
Length (LWL)	103.61ft (31.58m)
Beam (Bx)	21.07ft (6.42m)
Draft FP (Tfp)	6.93ft (2.11m)
Draft AP (Tap)	6.66ft (2.03m)
Displacement	143.6Lt (145.94MT)
Wetted Surface	2136sqft (198.5sqm)

Model Scale Properties

Scale Ratio	5.706
Length (LBP)	17.95ft (5.47m)
Length (LWL)	18.16ft (5.53m)
Beam (Bx)	3.69ft (1.13m)
Draft FP (Tfp)	1.21ft (.37m)
Draft AP (Tap)	1.17ft (.36m)
Displacement	0.77Lt (.79MT)
Wetted Surface	65.62sqft (6.1sqm)

Coefficients

Cp .688	Cwp .776
Cb .376	

Naval Surface WarfareCenter
Resistance & Propulsion

title: USCG Island Class 110 WPB

surface file:	drawn by:	
CG110WPB.SRF	Liam O'Connell	
model number:	scale factor:	date:
5526	5.706	4/5/99

APPENDIX B

MODEL EXPERIMENTS AND ANALYSIS

- APPENDIX B -

Model scale data and analysis pertaining to the evaluation, selection, and performance of a stern flap design for the U.S. Coast Guard Island Class 110 WPB patrol boats are contained within this appendix.

Hardware and Procedures

The Test Agenda, which includes a list of experimental numbers and corresponding ship/model conditions, is presented in Table B1. All data contained herein was collected on Carriage 1 in the deep water basin of DTMB. Model 5526 was ballasted to three different representative displacements and loading conditions for this test series. A Ship Trials loading condition of 151 L. tons, LCG = 5.09ft (1.55m) aft of midships, static trim = -1.0°, was utilized for the ship/model comparison between the standardization trials on the BAINBRIDGE ISLAND (WPB 1343) and powering estimates on Model 5526. The stern flap evaluation, selection, and performance, was determined at the Full Load condition of 163.39 L. tons, LCG = 4.645ft (1.42m) aft of midships. Stern flap performance at a second condition of Min-Ops loading 143.61 L. tons, LCG = 5.253ft (1.6m) aft of midships, was also determined. The Model 5526 displacements, appended wetted surfaces, drafts, and other related quantities, pertaining to the three tested loading conditions, are presented in Table B2.

The model was restrained in surge, sway, and yaw, but was free to pitch, heave, and roll. Data measurements were made using DTMB standard instrumentation. Model resistance was measured using a 200 lbf (890 N) capacity 4 inch (10.16 cm) block gauge. The linear bearing, floating platform tow post system was utilized; Cusanelli and Bradel [6]. The static location of the model tow point was at 81.5 inches aft of the FP, parallel to, and at the same level as, the water surface. Side force was measured with a 20 lbf (89 N) capacity 4 inch (10.16 cm) block gauge. Dynamic running rise/sinkage was determined at the forward and aft perpendiculars by wire potentiometers. Resistance experiments, to determine stern flap performance, were conducted nominally at two knot (ship scale) increments over the full range of ship speeds from 12 through 32 knots. Model data was collected over smaller speed increments when determined necessary. Stern flap evaluation/optimization experiments were conducted at six speeds, in 4 knot increments over the speed range, (12, 16, 20, 24, 28, 32 knots). The ship/model comparison experiments were conducted at the corresponding ship speeds measured during the standardization trials on the BAINBRIDGE ISLAND (WPB 1343). The appropriate force measurements and/or coefficients were monitored and/or plotted throughout the experiments, until the Project Manager (Model Test) determined that necessary and sufficient measurements had been collected to fulfill the experimental agenda.

In order to induce turbulent flow over the length of the model hull, one-eighth inch (0.318 cm) diameter by one-tenth inch (0.254 cm) height turbulence stimulator studs were placed aft of the stem at approximately 1 percent of the waterline length, spaced 1 inch (2.54 cm) apart.

Measurement Uncertainty

Resistance measurement uncertainties (precision errors) were examined on Model 5526 at two ship speeds, 16 and 24 knots. The precision error, also known as random or repeatability error, is an indicator of the "scatter" in the data. Table B3 summarizes the measured uncertainty (precision errors) in resistance measurements for the present Model 5526 experiments. For Island Class Model 5526, the uncertainty is in the range of $\pm$ 0.5 ~ 1.0 percent of the nominal resistance measurement. Precision error is a function of the unsteadiness of the phenomenon being measured, and the instability of test equipment. For the reported uncertainty analysis, the precision error limit values were determined directly from repeated model test measurements. A minimum sample size of 12 individual data spots was utilized for each analysis. These are first-order precision limits, reflecting the scatter in a data set collected over the time span of a single experiment, with the identical model, equipment, and instrumentation, utilized throughout the model experiments reported herein.

Data Analysis

Resistance and powering data presented in this report are for the full scale Island Class 110 WPB patrol boats operating in smooth, deep salt water with a uniform standard temperature of 59^0 Fahrenheit (15^0 Celsius). The 1957 ITTC Model-Ship Correlation Line was used for the frictional resistance calculations. Stern flap performance, as determined from resistance and estimated powering results, are presented at one knot (ship scale) increments over the full range of ship speeds from 12 through 32 knots. Stern flap evaluation/optimization experiments are presented at six speeds, in 4 knot increments over the speed range. The ship/model comparison is presented at the corresponding ship speeds as measured during the standardization trials on the BAINBRIDGE ISLAND (WPB 1343).

Full scale Island Class effective power (P_E) predictions were determined directly from resistance experiments conducted on DTMB Model 5526. Model self-propulsion (powering) experiments were not conducted on Model 5526 at this time. Estimates of the Island Class delivered power (P_D), propeller RPM, with and without stern flap, were made by the combination of the following elements:

- Effective Power (P_E) from the present resistance experiments on Model 5526.
- Representative class propeller open water performance data, as measured on a single 15.502 inch (39.37 cm) cavitation-sized model propeller 5128. Model 5526 propulsion-sized propellers, which would have a model scale diameter of 8.7 inches (22.1 cm), do not exist for the Island Class.
- Assumed propeller-hull interaction coefficients of 1-t, $1-W_T$, and η_R, representative of similar patrol craft, and iterated to values which best matched estimated model powering data to full scale powering data.

Ship/Model Comparison - Correlation Allowance Estimate

Prior to the stern flap evaluation and selection, it was necessary to perform a ship/model comparison between Model 5526 and standardization trials results from the BAINBRIDGE ISLAND (WPB 1343). This comparison was made in order to estimate the ship/model correlation allowance for the new Model

5526. A ship/model correlation insures that the most accurate assessment of ship performance will be achieved. Powering performance trials were conducted on the BAINBRIDGE ISLAND (WPB 1343), off the coast of Cape Henry, Virginia, in 1991; Haupt and Puckette [4]. An excerpt from this powering trials report is presented as Table B4. This table contains the propulsion performance data at a loading condition of 151 long tons, LCG of 5.09' aft of midships, static trim of -1.0°. This loading condition was chosen by USCG ELC-024, for the ship/model comparison, because it was the most representative of the intended Island Class full load condition of 163 long tons (nominal).

Model scale powering experiments, which are necessary for a formal and precise determination of correlation allowance, were not performed on Model 5526. Instead, model resistance predictions, representative class propeller open water performance data, and assumed propeller-hull interaction coefficients, were utilized to estimate Island Class powering data for comparison to the ship trials results. Since powering experiments were not conducted on Model 5526, the standard methods by which ship/model correlation coefficients are determined could not be utilized. A method relating model resistance predictions to ship trials powering data had to be developed. A powering estimate for the Island Class, at the trials loading condition, was prepared by DTMB. It was desired that this powering estimate reflect the exact speeds, delivered powers, and propeller RPMs measured during the WPB-1343 standardization trials of Table B4. Propeller-hull interaction coefficients of 1-t , $1\text{-}W_T$, and η_R, representative of similar patrol craft, were then assumed, and propeller efficiency was calculated from the trials RPM and the open water coefficients from model propeller 5128. An iterative process of "fairing", or smoothing, of the assumed and/or calculated coefficients was necessary in order to retain all values within reasonable bounds for similar craft. Ultimately, ship resistance predicted from the Model 5526 experiments was utilized with the presumed propeller-hull interaction coefficients, to estimate full scale powering data. The ship/model powering correlation allowance was determined by solving for the value of C_A which, when used with the standard DTMB powering prediction method, Grant and Wilson [7], results in the best agreement between the ship standardization trial measured delivered power and the estimated delivered power from model experiments, Hadler, et al. [8]. Due to variations of C_A correlation with speed, some engineering judgment is used to select the best value. Though the full scale trial data often includes slow speed measurements, in practice, the correlation is done for the speeds where sufficient power is developed for accurate measurements. The highest speeds are generally of the most interest, because the high speed data for both model and ship is considered more accurate, and the prediction of maximum speed and power is a primary concern. However, for the Island Class at full power, the ship propellers exhibit characteristics of propeller cavitation. Comparison of full scale data at speeds where the ship propeller exhibits cavitation, to that of the (non-cavitation corrected) model predictions, would result in an erroneous correlation allowance.

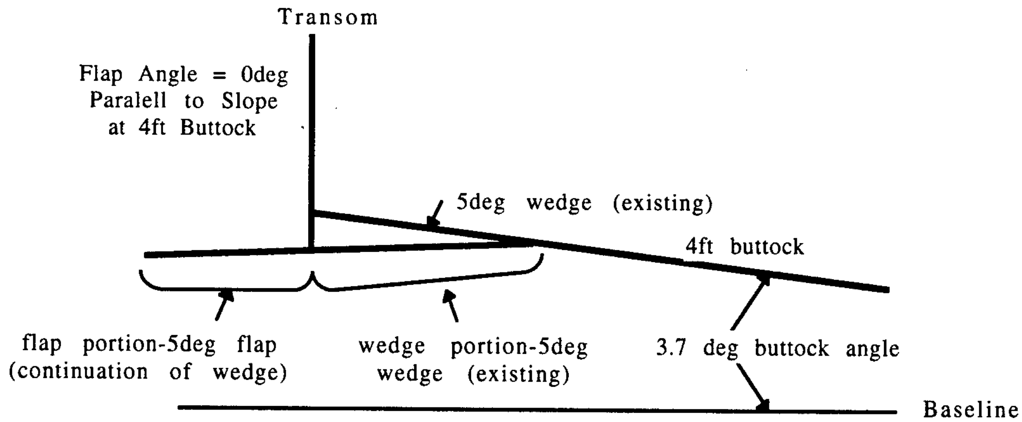
Table B5 presents the ship/model powering comparison between BAINBRIDGE ISLAND(WPB 1343) and Model 5526, at the 151 L. ton loading condition, with variations in correlation allowance. The comparisons, between ship trials measured delivered power and estimated model delivered power, are presented in DTMB standard form utilized for formal ship/model correlations: Power correlation C_P, and RPM correlation, C_N, which are defined as non-dimensional coefficients of: trial measurement / model prediction. It is recommended that the value of $C_A = 0.0003$ be considered the appropriate correlation allowance for the Island Class 110 WPB. The complete model resistance and powering (no flap), at 151 L. ton load condition, at $C_A = 0.0003$, are presented in Tables B6 and B7, and compared to the BAINBRIDGE ISLAND trials results in Figure B1. The stated correlation allowance, $C_A = 0.0003$, for the Island Class and the present ship/model comparison on the Bainbridge Island, should be viewed only as a model testing adjustment factor which brings the present model resistance predictions, utilized to estimate ship powering, in line with the measured ship trials data. At this time, any comparison to the NAVSEA Correlation Data Base [5] on other U.S. Navy ships, should be done with great caution. Prior to adding this Island Class correlation allowance to the data base, it is recommended that an effort be made to determine the ship model correlation allowance through a traditional model powering test series.

Stern Flap Evaluation and Selection

The stern flap optimization and selection experiments were conducted at an equivalent Full Load condition of 163.39 L. tons, LCG = 4.645' aft of midships, for six speeds, in 4 knot increments over the speed range, (12, 16, 20, 24, 28, 32 knots). Eight stern flaps were manufactured for the present Model 5526 experiments. Small-scale sketches and principal dimensions were presented in Figure A3. These stern flaps were designed as a series to systematically investigate variations in flap dimensions of chord length, span, angle, and planform area distribution. All eight flaps were evaluated over a range of angles, nominally in 2.5 degree increments, from 0 to 10 degrees trailing edge down. Stern flap design is affected greatly by mission requirements and selection criteria, as well as hullform design. Stern flaps exhibit specific resistance performance trends with respect to the design parameters. Increasing flap chord length or angle generally reduces the low speed performance, but improves the high speed resistance reduction. A compromise must customarily be reached between high and low speed performance, with the particular ship's operating profile indicating the relative importance of each. For the Island Class design, particular attention was also made as to the effects of the stern flap designs on ship running trim. Increasing flap chord length or angle tends to increase the magnitude of the generated bow down trim moment.

Stern Flap Coordinate System: The coordinate system used to define the stern flap angle (see following diagram) is referenced to the local run angle near the transom along the 4 ft (1.22 m) buttock. A zero degree (0°) stern flap is one which is a continuation of (or parallel to) this run angle. Flap angle is increased by rotating the flap trailing edge downward (TED). The run angle, on the Island Class 110 WPB, is 3.7° relative to the ship baseline. Ship drawings specify the angle of the transom wedge (inlayed into the present hull design) to be 5° at the 4 ft (1.22 m) buttock. In the defined coordinate system, a 5° flap angle would be a continuation (continuous parallel bottom surface) of the 5° wedge angle, whereas, a

0° flap angle would be parallel to local run angle. The 4 ft (1.22 m) buttock was selected as the position for measuring the flap and wedge angles because it was the position at which the transom wedge angle was specified in the full scale drawings. (For reference, the bottom surface of the present 5° wedge is 1.3° TED, relative to the ship baseline.)



The selection criteria for the Island Class 110 WPB final stern flap design was prescribed by USCG ELC-024. Stern flap selection was based upon maximizing power reductions at high speeds, while satisfying secondary powering criteria prescribed at cruising speed and best economic speed, and upon limits set on maximum ship trim modification. The stern flap selection criteria, as prescribed by ELC-024, was stated specifically in terms of ship powering. However, the scope of the present model tests did not include model self-propulsion (powering) experiments. The prescribed criteria for the Island Class stern flap design selection were evaluated through model resistance experiments only. It is assumed that the stern flap configuration which exhibited the lowest resistance at the critical speeds would also have the lowest delivered power. In general, delivered power reductions average a few percent greater than resistance reductions during model powering tests with stern flaps. An examination of the historical data base of model stern flap experiments shows that stern flaps can cause an improvement in propulsive efficiency, due to reductions in wake factor and increases in propulsion efficiency. Therefore, model stern flap effective power performance is considered indicative of delivered power performance, and in most cases, represents the lower bounds of the powering reduction potential. The model scale predicted resistance for the Island Class with each of the eight stern flap designs at all tested flap angles, were compared to the baseline (no flap) predicted resistance, at each of the six tested ship speeds. Likewise, the ship dynamic running trim for each flap case was compared to the baseline configuration. By this method, a direct stern flap performance can be determined. The prescribed criteria for the Island Class stern flap design were as follows:

Selection criteria for the Island Class 110 WPB final stern flap design -

- Maximize reduction in ship powering over high speed range of 28 to 32 knots.
- Disallow any increase in ship powering at cruising speed, as indicated by performance at 24 knots.
- Limit ship running trim modification (bow down) to 1.0 degrees, at all speeds.

Comparisons of the effective power performances and trim modifications of the eight tested stern flap designs, at all tested flap angles and optimization speeds, are presented in Table B8. Results of the stern flap optimization experiments, depicted graphically as effects on resistance and ship running trim, for all variations in flap chord length, span, and angle, are presented in Figure B2.

All tested flaps were able to satisfy the secondary powering criteria prescribed at cruising speed and best economic speed. Many of the stern flap designs exhibited resistance reductions from ship speeds of 12 up to 28 or 30 knots. However, none of the designs, at any tested flap angle, appeared to have a potential for substantial resistance reduction at the top speed tested, 32 knots. Increasing flap angle to 10°, tended to result in the lowest resistance in the range of 20 knots, however, dramatically increased the 32 knot resistance. Flap angles of 10°, for all but the two smallest flaps, exceeded the maximum allowable ship running trim modification. Several of the larger flap designs also exceeded the trim criteria at angles of 7.5°. The performance of the tested series of flaps can be summarized as follows:

- Flap chord variations at constant span of 16 ft (4.9 m): For flap angles of 0° and 5°, the chord variations resulted in minimal (± 1.0%) resistance differences. At a flap angle of 10°, lengthening the chord resulted in reduced resistance at 20 knots (-3%), but resulted in an equivalent increase in resistance at 32 knots.
- Flap span variations at constant chord length of 2 ft (0.61 m) or constant chord length of 1 ft (0.3 m): In general, for all angles tested, trends indicated that increasing span resulted in reduced resistance at 12 ~ 20 knots, but resulted in increased resistance at 24 ~ 32 knots.

Severe deck-wetting resulted from any ship running trim modification (bow down) that exceed approximately 1.2 degrees. At the top speed tested, 32 knots, severe deck-wetting occurred whenever the ship running trim modification reached approximately 1.0 degrees. A effort was made to insure that the Island Class 110 WPB selected stern flap design did not approach the originally stated 1.0 degree ship running trim modification criteria. Note: The subsequent bow spray rail design effort successfully reduced the bow spray sheet which resulted in the aforementioned deck-wetting at high speeds.

Model stern Flap #6 at 7.5 degrees exhibited the greatest reduction in high speed ship resistance while still satisfying the secondary resistance and trim modification criteria. This design represents a full scale stern flap with chord length 2 ft (0.61 m), span of 8.7 ft (2.7 m), and an angle of 7.5° trailing edge down relative to the local slope (run) at the 4 ft (1.22 m) buttock.

Stern Flap Performance

Performance predictions are for the selected Island Class 110 WPB stern flap with chord length 2 ft (0.61 m), span of 8.7 ft (2.7 m), and an angle of 7.5° trailing edge down.

Resistance and Delivered Power Performance

The selected stern flap resistance performance on the Island Class 110 WPB patrol boats, over the entire speed range of 10 through 32 knots, was predicted from experiments on Model 5526. Resistance predictions were made at both the Full Load condition of 163.39 L. tons, LCG = 4.645' aft of midships, and at a second condition of Min-Ops loading 143.61 L. tons, LCG = 5.253' aft of midships. Island Class effective power (P_E) predictions, both with and without the stern flap installed, for both loading conditions, are presented in Tables B9 through B12. The P_E predictions were determined directly from resistance experiments conducted on DTMB Model 5526.

The model resistance predictions were then used to estimate powering with and without the stern flap, by the technique detailed previously. Island Class estimated delivered power (P_D), propeller RPM, and other related quantities, both with and without the stern flap installed, for both loading conditions, are presented in Tables B13 through B16, and summarized in Table B17. The model scale performance of the Island Class stern flap design, in terms of resistance, delivered power, and propeller RPM, is depicted in Figure B3 for full load, and Figure B4 for min-ops. Data is presented as ratios, defined as value required with the stern flap installed divided by value required for the baseline (no flap) configuration, as a function of ship speed. A ratio value below 1.0 denotes a reduction due to the stern flap.

Projected Full Scale Stern Flap Performance

While significant powering improvement is indicated from these Model 5526 stern flap experiments, the actual full scale stern flap on the Island Class would generally be expected to exceed the performance on the model. Prior to any full scale stern flap installation, an appropriate stern flap design is determined through model experiments and CFD calculations. While significant powering improvement is indicated from these model experiments, the actual performance of the full scale prototype stern flap generally exceeds that of the model predictions, Cusanelli [3]. Ship trials indicate that the model experiments were under-predicting the stern flap performance in the range of roughly 2% to as much as 12%. Closer examination of these trials shows that the major improvement in ship performance due to the flap that is not duplicated at model scale tends to occur at lower speeds. Stern flap ship trials have shown no adverse affect on ship powering at any speed tested, indicating that the low speed powering penalty of model stern flaps may be attributable to model scale phenomena. These circumstances lead the designer to conclude that, as a consequence of the smaller scale, the flow conditions around the model stern flap are not truly representative of that on the ship. Indications are that the stern flap scale effect might have a strong

Reynolds Number dependency. Therefore, stern flap performance may not extrapolate correctly by the standard techniques. Although the stern flap is itself a source of drag, its interaction with the ship's hull results in a net decrease in effective power. The drag on the model stern flap may be disproportionately large, as evidenced by the increase in resistance measured at low speeds. This may be due to incorrect scaling of drag associated with interference, separation, or interaction of the stern flap induced flow with the afterbody flow patterns, or any combination of these and other effects. Because of these issues, it became necessary to modify the standard techniques for extrapolation of model scale stern flap data to ship performance.

Three sets of ship trials, and recent testing on various size models, have been conducted with and without the stern flaps, in an effort to better understand the stern flap scale effect. Computational efforts for studying this scale effect have been made possible by the recent emergence of improved computers and flow codes that can perform calculations at full scale Reynolds numbers. Great strides have been made, towards verification and explanation of performance and flow observations of stern flaps, through the combination of these full scale, model scale, and computational efforts; Cusanelli et. al. [9]. This unique data set has been used to develop a simple quantitative empirical "performance projection tool", for estimating the magnitude of the stern flap scale effect. This performance adjustment tool loosely simulates the full scale experience, i.e., indicating greater model data adjustments at lower speeds and at increasing model scale ratio. Performance projections, adjusting model data for scaling effects by the performance adjustment tool, were compared to the stern flap ship trials performances [9]. The developed performance adjustment tool did tend to bring the model data more in line with the full scale results. However, the adjustment tool needs to be used with some attentiveness, as stern flaps on ships still performed better than the model data indicated at several speeds, even with adjustments to model scale data.

The performance adjustment tool was utilized to calculate new projections of Island Class 110 WPB full scale stern flap performance, from the Model 5526 data. These new stern flap performance projections, adjusted for scaling effects, are presented in Tables B18 and B19, and Figures B5 and B6, for both load conditions. The performance projections are summarized in Table B20. The presented Island Class performances do not account for propeller cavitation.

Performance within Engine Operating Envelope

Projected shaft powering comparisons were made to the Island Class main propulsion engine operating envelope, Figures B7 through B9. Island Class 110 WPB C series Caterpillar 3516 main propulsion engines were utilized for this comparison. Data pertaining to the engine operating envelope was supplied by USCG ELC-024. The depicted engine envelope represents the "upper curve" on engine brake horsepower, BHP, defined by the equation: BHP = (engine RPM / 1910)^2.7 * 2730. This curve of engine brake horsepower vs. engine speed has typically been referred to as the engine performance curve. A transmission gear loss of 3% was utilized for the conversion between BHP and delivered shaft horsepower, SHP. The transmission gear ratio between engine RPM and shaft RPM is 2.33:1. Also depicted on these figures is the engine maximum power, with bands representing $\pm$ 3% on maximum power.

The BAINBRIDGE ISLAND (WPB 1343) ship trials data and Model 5526 powering data (at the estimated correlation allowance $C_A = 0.0003$) are compared to the engine operating envelope, for the trials 151 L. ton load condition, in Figure B7. As shown by this figure, the WPB 1343 trials data, except for the two lowest speeds, exhibits delivered power vs. engine speed requirements in excess of the stated Caterpillar 3516 engine operating envelope (exceeding specified engine performance curve). This has resulted in the inability of this particular engine design, as installed in the WPB 1343, to reach full engine RPM. The data spot depicting maximum ship speed attained, 29.2 knots, falls slightly below the engine maximum power, but within the - 3% power band.

Island Class projected shaft powering at both full load and min-ops, with/without stern flap installed, are compared to the operating envelope, in Figures B8 and B10. As was the case at 151 L. tons, the data at both the higher full load (163 L. tons) and lower min-ops (144 L. tons), indicate delivered power vs. engine speed requirements higher than that of the stated Caterpillar 3516 engine operating envelope (exceeding specified engine lug curve), over most of the speed range. The installation of the stern flap shifts the projected powering curve closer to the defined engine operating envelope. However, an even greater reduction in the ship's power vs. speed relationship is necessary for the performance to remain within the envelope.

Ship Maximum Speed Determination

The Island Class projected maximum speeds, at both full load and min-ops, with/without stern flap installed, were determined from the comparison of the projected powering to the Caterpillar 3516 engine operating envelope. Maximum SHP and engine RPM were determined where the projected powering curve intersected the line defining the engine maximum power. Maximum ship speed was then determined at this powering point. For the full load condition, the maximum attainable speed, for the Island Class 110 WPB patrol boats with the stern flap installed, is projected to be 27.85 knots, at a total shaft power of 2583 hP, with a propeller speed of 786.3 RPM (engine speed 1832 RPM). This represents an increase in top speed of 0.80 knots over the existing boats. At min-ops, the maximum attainable speed, with the stern flap installed, is projected to be 30.38 knots, at a total shaft power of 2635 hP, with a propeller speed of 812.9 RPM (engine speed 1894 RPM). This represents an increase in top speed of 0.38 knots.

Savings Potential

The installation of a stern flap on the Island Class 110 WPB results in the capability to maintain ship speed with less delivered power, and lower shaft speed, and therefore, represents a potential for propulsion fuel reduction. Data pertaining to the fuel consumption rates, of the Island Class 110 WPB C series Caterpillar 3516 main propulsion engines, was collected during the standardization trials on the BAINBRIDGE ISLAND (WPB-1343). Fuel consumption rates were recorded for ship speeds in the range of 15 through 29 knots, at a loading condition of 151 long tons, LCG of 5.09' aft of midships, static trim of -1.0°. These fuel rates were utilized to estimate fuel consumption (gal/hr.) at the full load and min-ops conditions, with and without the flap. An estimated speed-time profile was supplied by USCG ELC-024, based on 3000 annual operational hours. Summation of the weighted time at speed and the estimated fuel consumption rates, yields an estimate of the annual fuel consumption of the Island Class at each loading condition, with and without the stern flap, Table B21. It is assumed that the time-at-speed for the class with the stern flap installed will be equivalent to that of the present ship. The estimated average reduction in annual fuel consumption, provided for by the installation of the stern flap, is 4.5 percent when operating at full load, and 3.9 percent for min-ops. Fuel savings was estimated assuming a split of 2/3 time (2000 hr.) at full load, and 1/3 time (1000 hr.) at min-ops. The annual fuel savings, resulting from a stern flap installation of the Island Class 110 WPB, would amount to 13,328 gallons, or approximately $13,000 per ship / per year, on average.

Effects on Ship Running Trim

Ship sinkage at both the forward and aft perpendiculars, and the ship trim, for the Island Class with and without the stern flap installed, for both the full load and min-ops conditions, are presented in Figures B10 and B11. The effect of the stern flap on ship trim was then determined. The Island Class ship running trim, at both full load and min-ops, was affected very similarly by the stern flap. The net change in bow down trim angle, resulting from the stern flap, increased as ship speed increased. The change in trim angle remained within 0.6 degrees over the range of ship operational speeds (12 ~ 30 knots). Therefore, the selected stern flap satisfied the design criteria of ship running trim modification (bow down) not to exceed 1.0 degrees, at any speed.

Effects on Stern Waves

Wave breaking, eddy-making, and turbulence, represent lost energy in the local transom flow of a vessel. A great deal of 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 localized waves generated at the transom. Transom flow can be categorized by three simplified descriptions. At slower speeds, the transom and flap are fully wetted and the flow is said to be "attached". Resistance is increased by the added wetted surface 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 transom and flap then rolling forward to wet them again. At some greater speed, the flow detaches cleanly or "breaks-away" from the 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 stern flap. The effect of the stern flap on the localized flow around the transom, and its effects on the ship speed at which the stern flow breaks away from the transom, is carefully observed and photographed at model scale.

Visual observations and photographs were taken of the local transom flow generated behind Model 5526, with and without the stern flap installed, at full load, for 2 knot increments of ship speed, from 10 to 32 knots, Figure B12. The character of the transom flow was considerably altered by the stern flap over the speed range of 12 ~ 20 knots. Within these speeds, the transom flow appears to be decreased in both wave height and overall width by the stern flap. The ship speed at which the transom flow detaches (break-away) was reduced from approximately 17 knots for the baseline hull to 15 knots when the stern flap was installed. Referring to the comparison photographs at 16 knots, the baseline hull still exhibits attached flow, while the stern flap case exhibits fully detached flow. At this speed, the stern flap exhibited the greatest modification to the transom flow. Coincidentally, the stern flap also exhibited its maximum powering reduction at this 16 knot speed.

For speeds in excess of 22 knots, there appears to be little visual difference in the local transom flow generated behind Model 5526 with or without the stern flap installed. However, at these higher speeds, the stern flap does appear to reduce the visual wake deficit behind the twin rudders. This stern flap effect had not previously been documented.

Spray Rail Installation

During the initial model testing, observations of the flow patterns off the model lower chine, lead the test engineers to conclude that proper flow separation was not being achieved over this region at model scale. In order to promote a cleaner flow separation along this chine, a model scale chine rails were installed. Plexi-glass spray rails were installed on both port and starboard sides of the model, following the contour indicated by the existing lower chine line The spray rails extended the lower chine 1/4 inch (0.64 cm) beyond the existing hull lines. This is a technique used at model scale only, in order to promote flow separation similar to that of the full scale ship along the existing ship lower chine. This model scale spray rail is not to be interpreted as an additional hull treatment or appendage necessary for flow separation at full scale. These spray rails were installed on the model for all of the experiments reported herein.

However, it was further noted during the stern flap evaluation and selection phase of the model testing, that a significant amount of spray was being generated from the bow region at ship speeds in excess of 24 knots. This spray resulted in a serious amount of model deck-wetting at still higher speeds. This was not believed to be solely a model scale flow separation phenomena. Representatives of the USCG ELC-024, present at the model testing, reported that similar spray patterns - leading to forward deck-wetting, have been observed at full scale. The flow streamlines, which appear to generate this spray, originate in the region of the bow between the forwardmost edge of the bow stem and the ship's existing lower chine.

Since there is nothing in the hull lines to deflect these flow streamlines (either at ship or model scale), the water tends to cling to the hull and progress upwards. At speeds of 24 ~ 28 knots, the flow appears to separate off the upper chine. At higher speeds, the flow progress upwards all the way to the deck line before separating. Once at the upper chine or deck level, the flow separates in a spray sheet which increases in size as speed increases.

It was suggested by the DTMB test engineers to add "bow spray rails" as a continuation of the model scale chine rails forward to the bow stem. It was believed that spray rails in this forwardmost bow region would promote separation of the flow streamlines which appeared to generate the spray sheet. In contrast to the chine rails, this addition of the "bow spray rails" forward of the existing hull chine, does represent a modification to the existing Island Class hull. At ship scale, the bow spray rails extend 7.25 ft (2.2 m) from the bow stem, following the contour indicated by the existing lower chine line. The bow spray rails extend off the hull (thickness) approximately 1.5 inches (3.8 cm). Model scale experiments were conducted at full load, with and without the bow spray rails. Effective power predictions showed a relatively small increase (0.2 to 1.3%) over the very small speed range of 14 ~ 19 knots. However, as can be seen in the comparison photographs of Figure B13, the bow spray rails effected a very significant reduction in the amount of spray generated by the bow. In fact, with the bow spray rails installed, throughout the speed range tested there was not any significant amount of spray or forward deck-wetting observed. It was recommended by the DTMB test engineers that bow spray rails remain installed at model scale for all of the subsequent model experiments with and without the selected stern flap. Continuation of the model testing, with bow spray rails installed, was agreed to by the representatives of the USCG ELC-024.

It is recommended that "bow spray rails" be installed in the Island Class. The bow spray rails extend aft 7.25 ft (2.2 m) from the bow stem, following the contour indicated by the existing lower chine line, and extend off the hull (thickness) approximately 1.5 inches (3.8 cm).

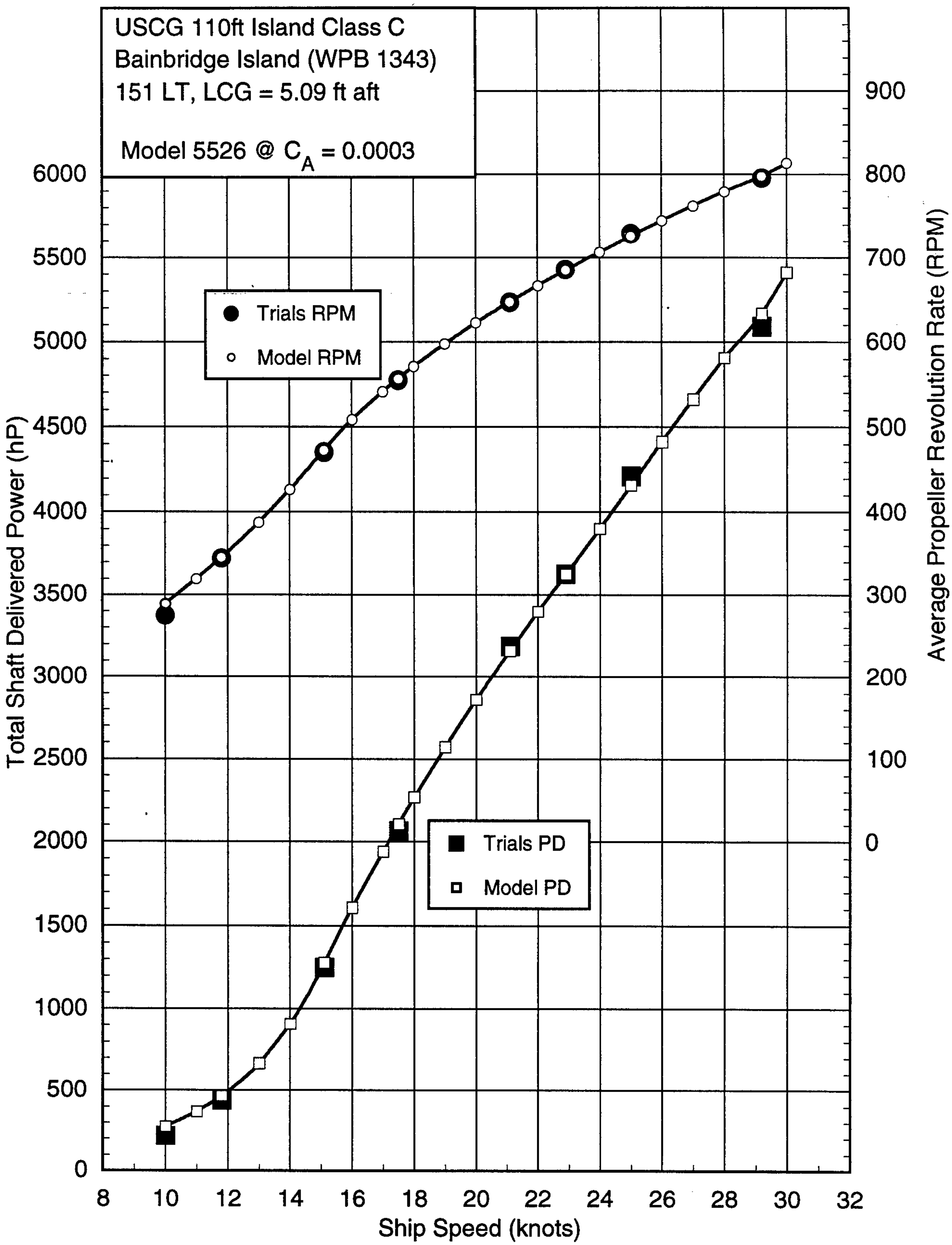


Fig B1. Ship/Model comparison between BAINBRIDGE ISLAND (WPB 1343) and Model 5526, 151 L. ton load condition, at estimated correlation allowance C_A = 0.0003

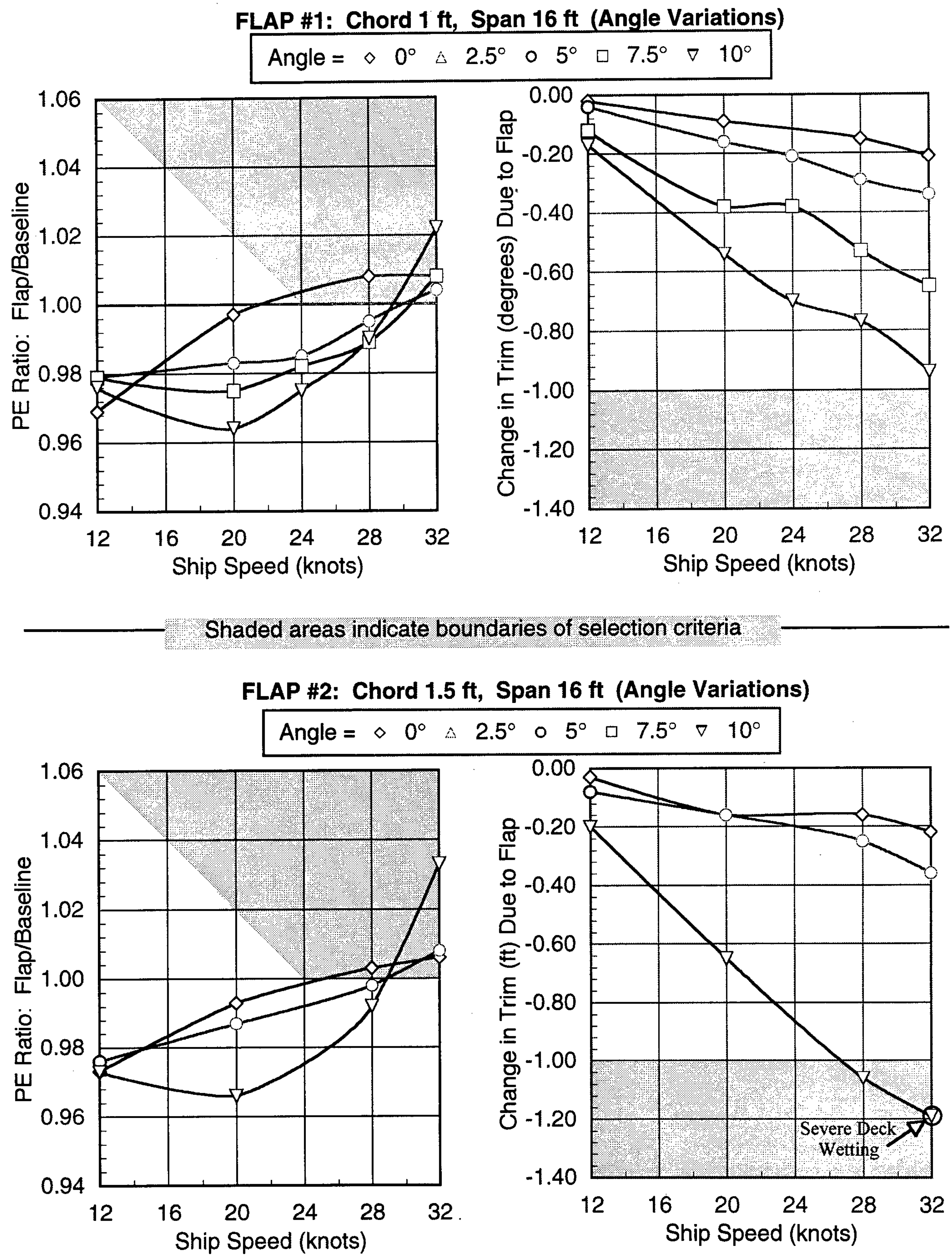


Fig B2. Stern flap optimization, effects on resistance and ship trim, for variations in flap chord length, span, and angle

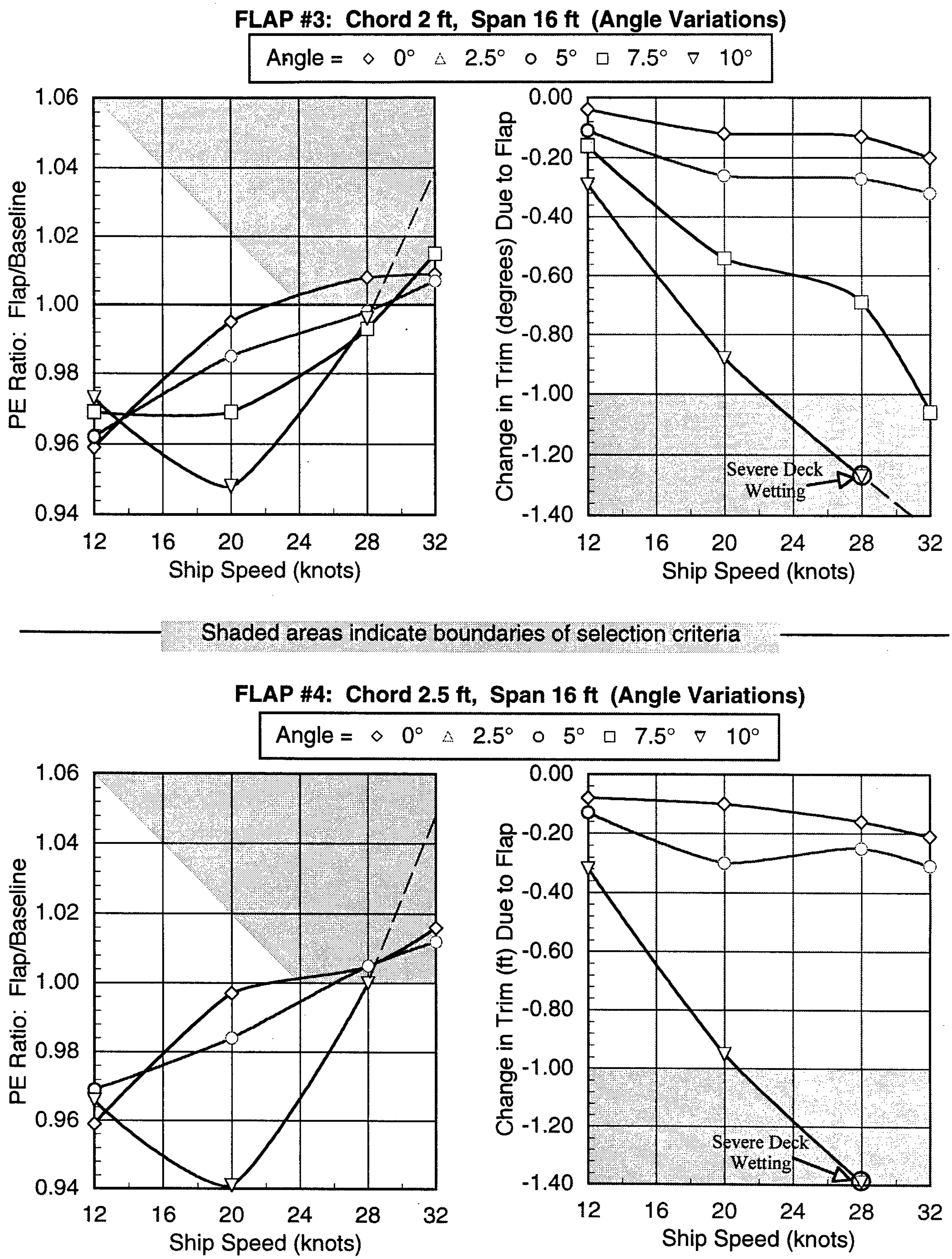
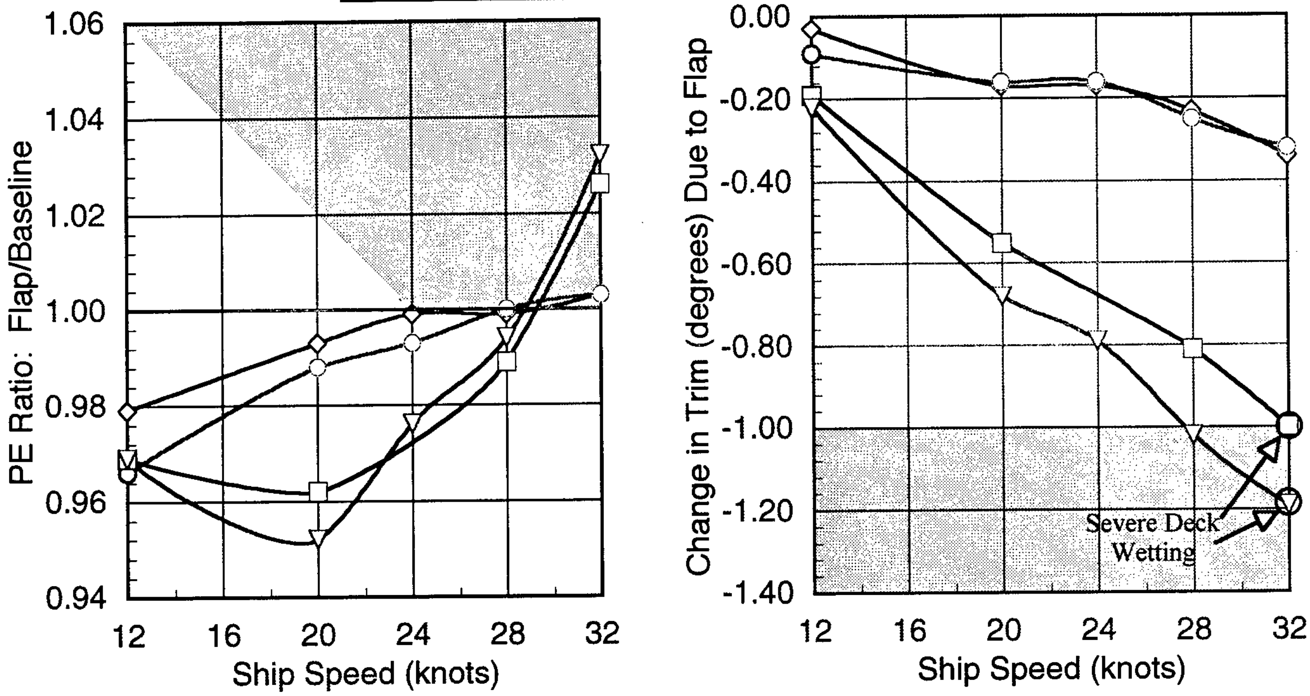


Fig B2. Stern flap optimization, effects on resistance and ship trim, for variations in flap chord length, span, and angle (continued)

FLAP #5: Chord 2 ft, Span 12.4 ft (Angle Variations)

Angle = ◇ 0° △ 2.5° ○ 5° □ 7.5° ▽ 10°



Shaded areas indicate boundaries of selection criteria

FLAP #6: Chord 2 ft, Span 8.7 ft (Angle Variations)

Angle = ◇ 0° △ 2.5° ○ 5° □ 7.5° ▽ 10°

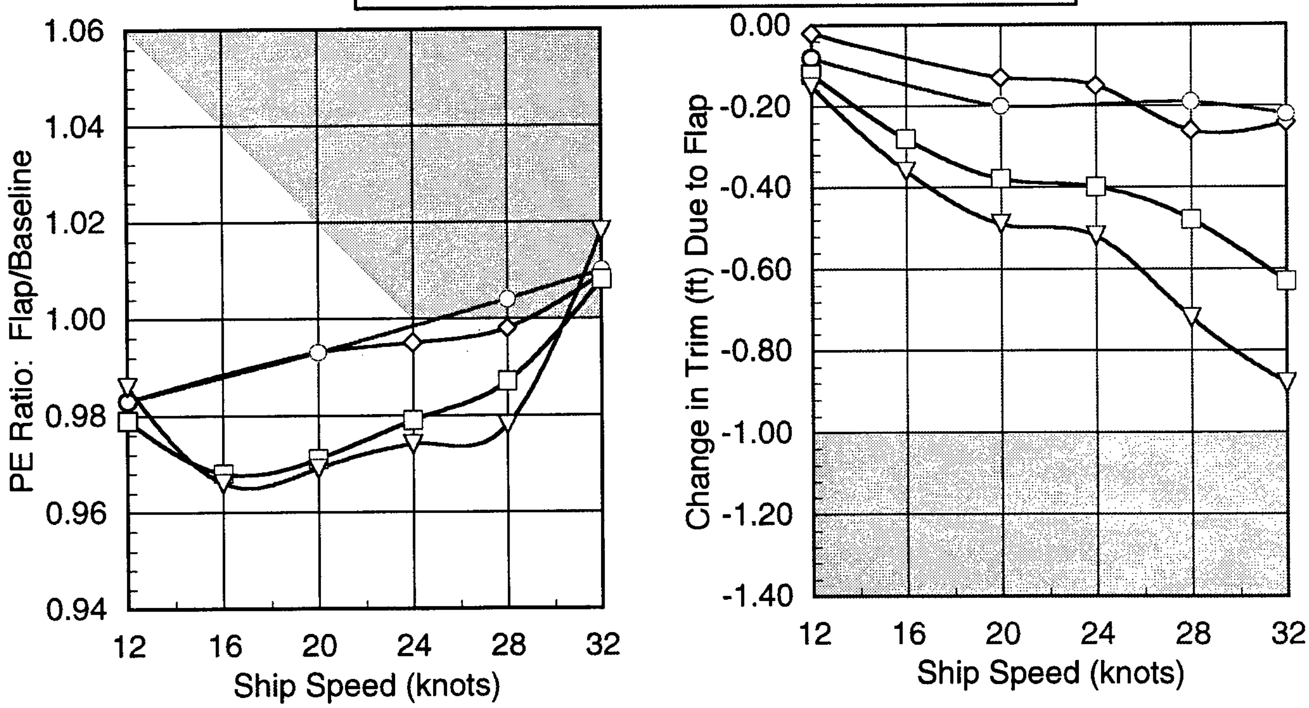
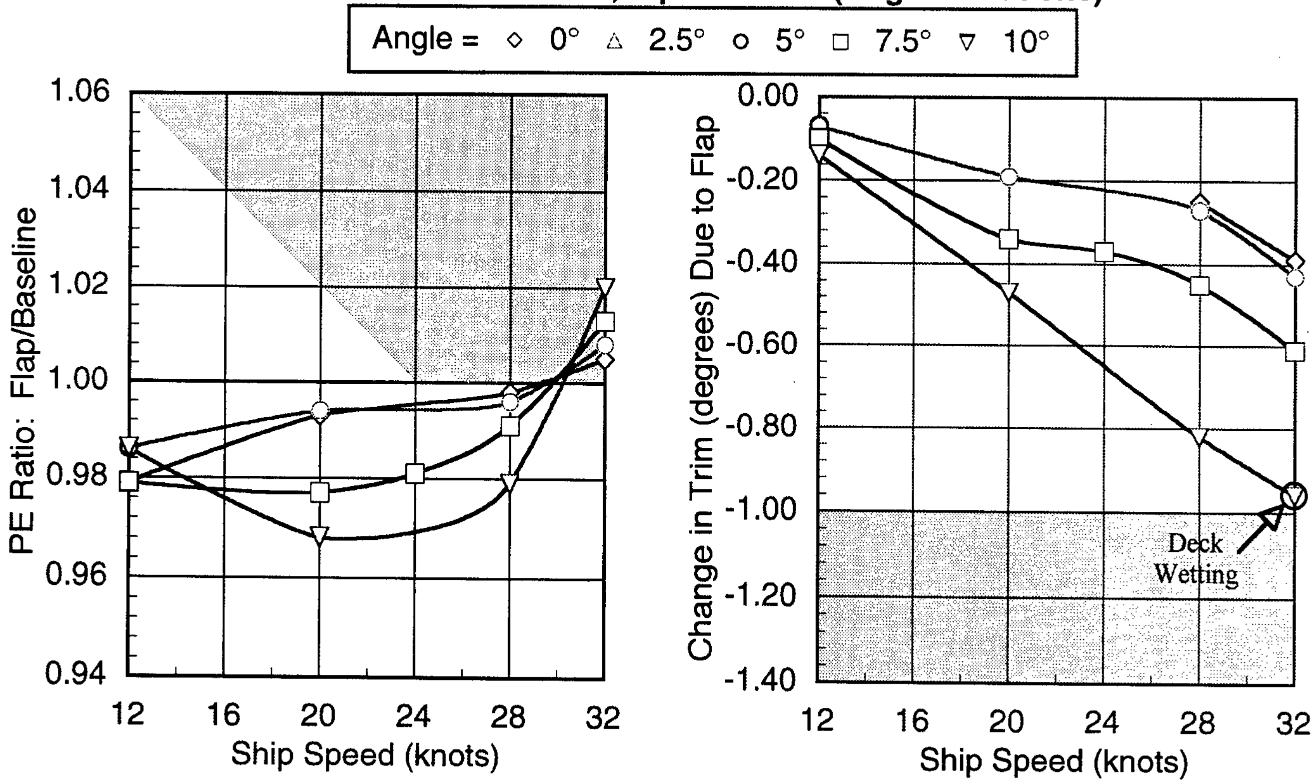


Fig B2. Stern flap optimization, effects on resistance and ship trim, for variations in flap chord length, span, and angle (continued)

FLAP #7: Chord 1 ft, Span 12.4 ft (Angle Variations)



Shaded areas indicate boundaries of selection criteria

FLAP #8: Chord 1 ft, Span 8.7 ft (Angle Variations)

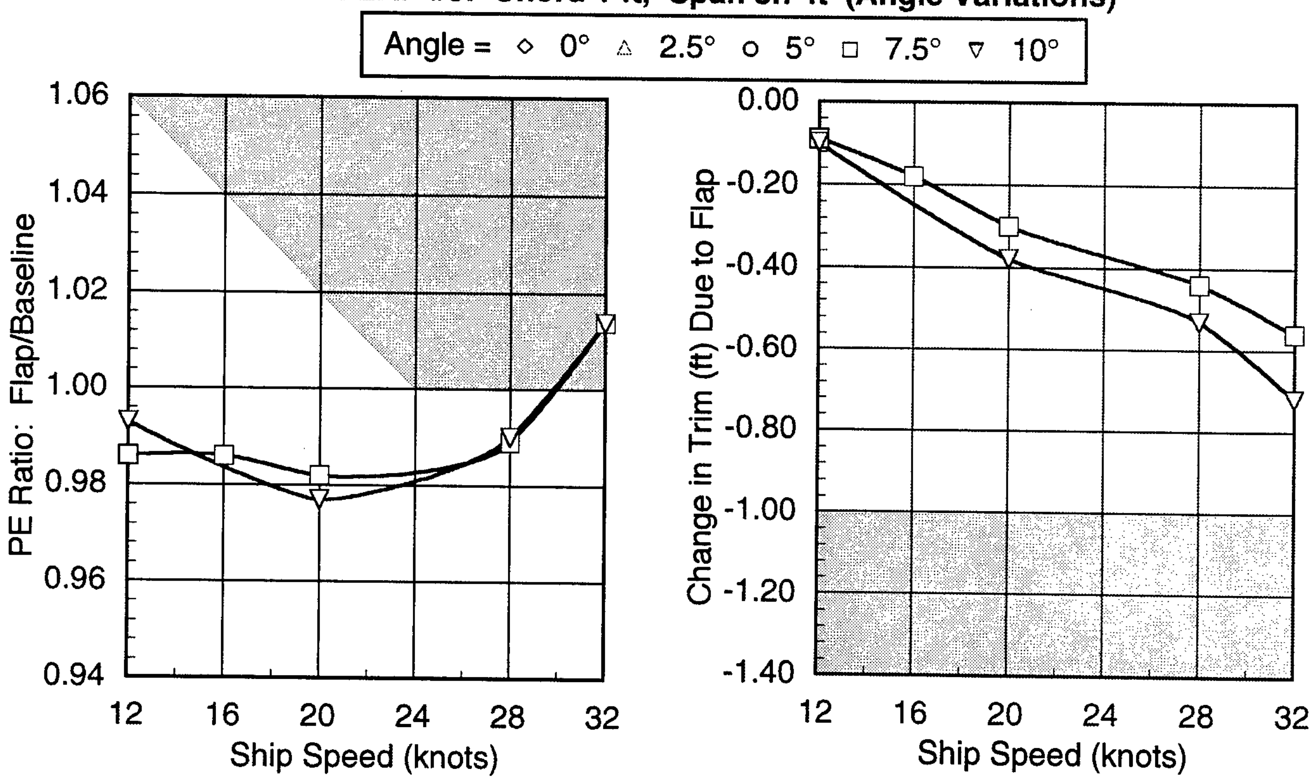
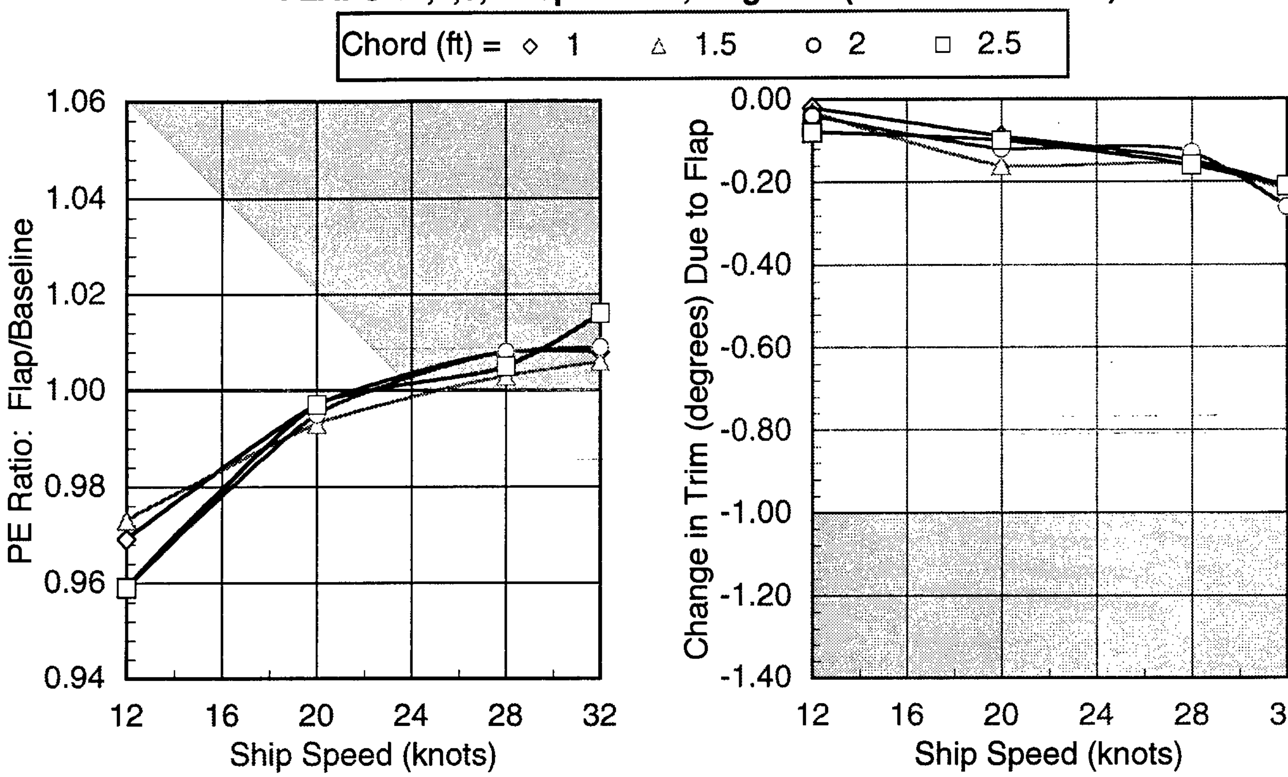


Fig B2. Stern flap optimization, effects on resistance and ship trim, for variations in flap chord length, span, and angle (continued)

FLAPS #1,2,3,4: Span 16 ft, Angle 0° (Chord Variations)



Shaded areas indicate boundaries of selection criteria

FLAPS #1,2,3,4: Span 16 ft, Angle 5° (Chord Variations)

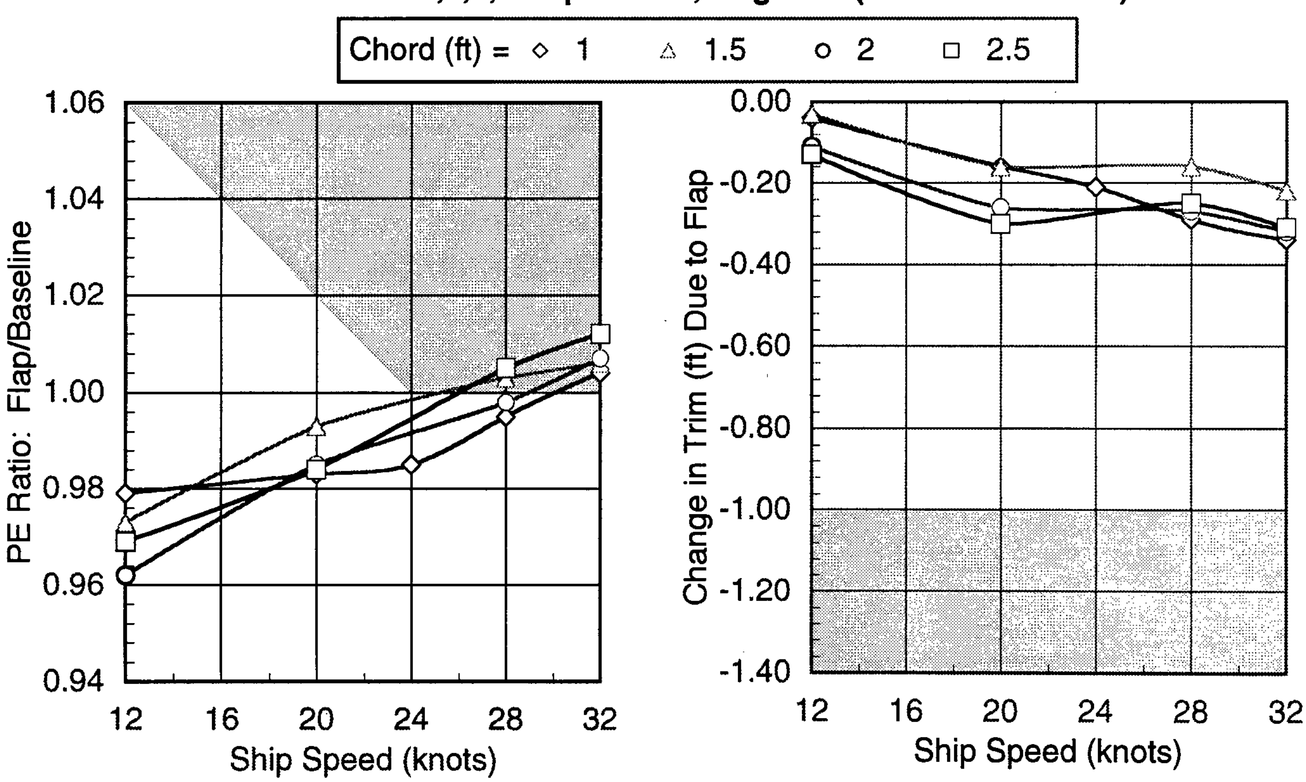


Fig B2. Stern flap optimization, effects on resistance and ship trim, for variations in flap chord length, span, and angle (continued)

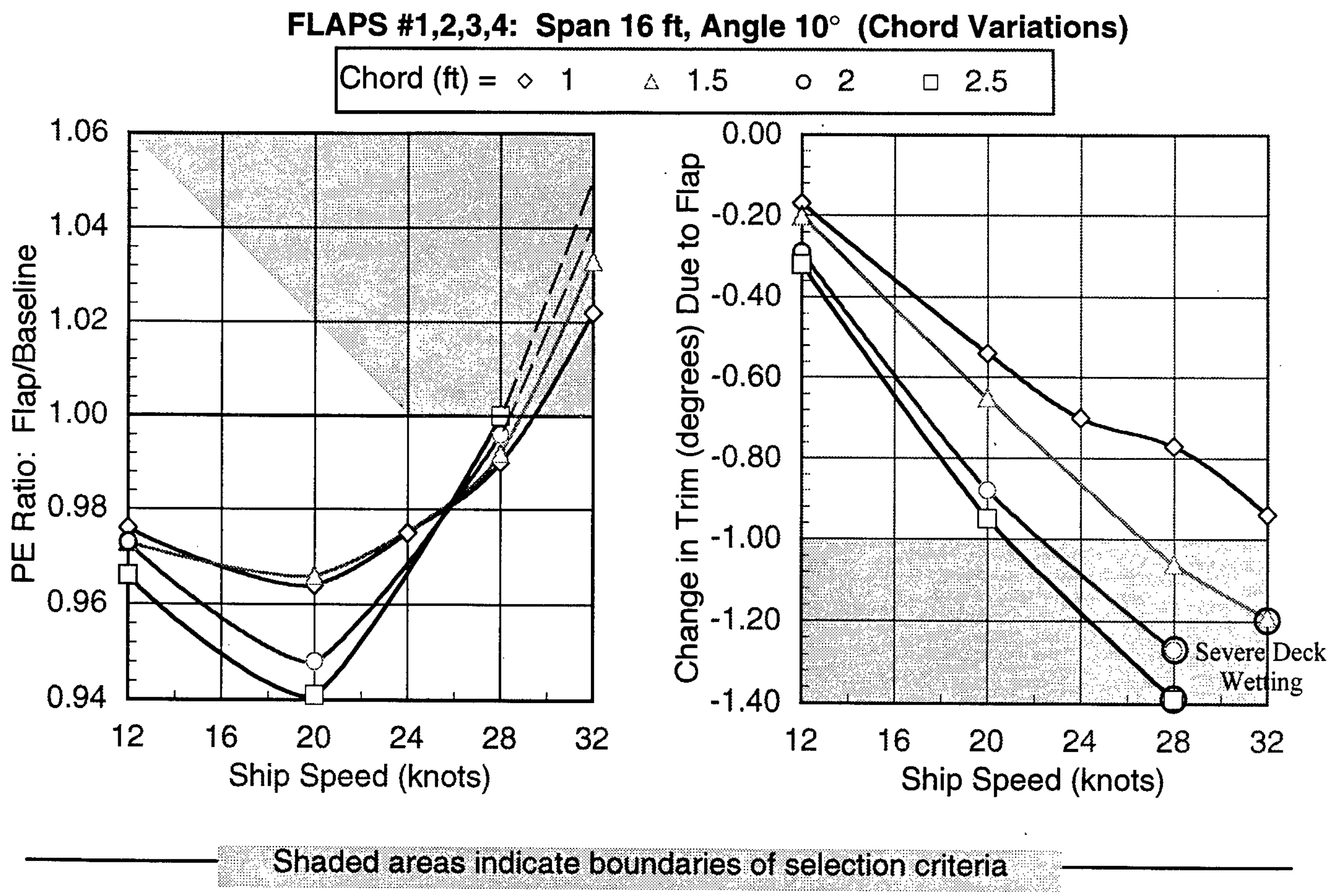


Fig B2. Stern flap optimization, effects on resistance and ship trim, for variations in flap chord length, span, and angle (continued)

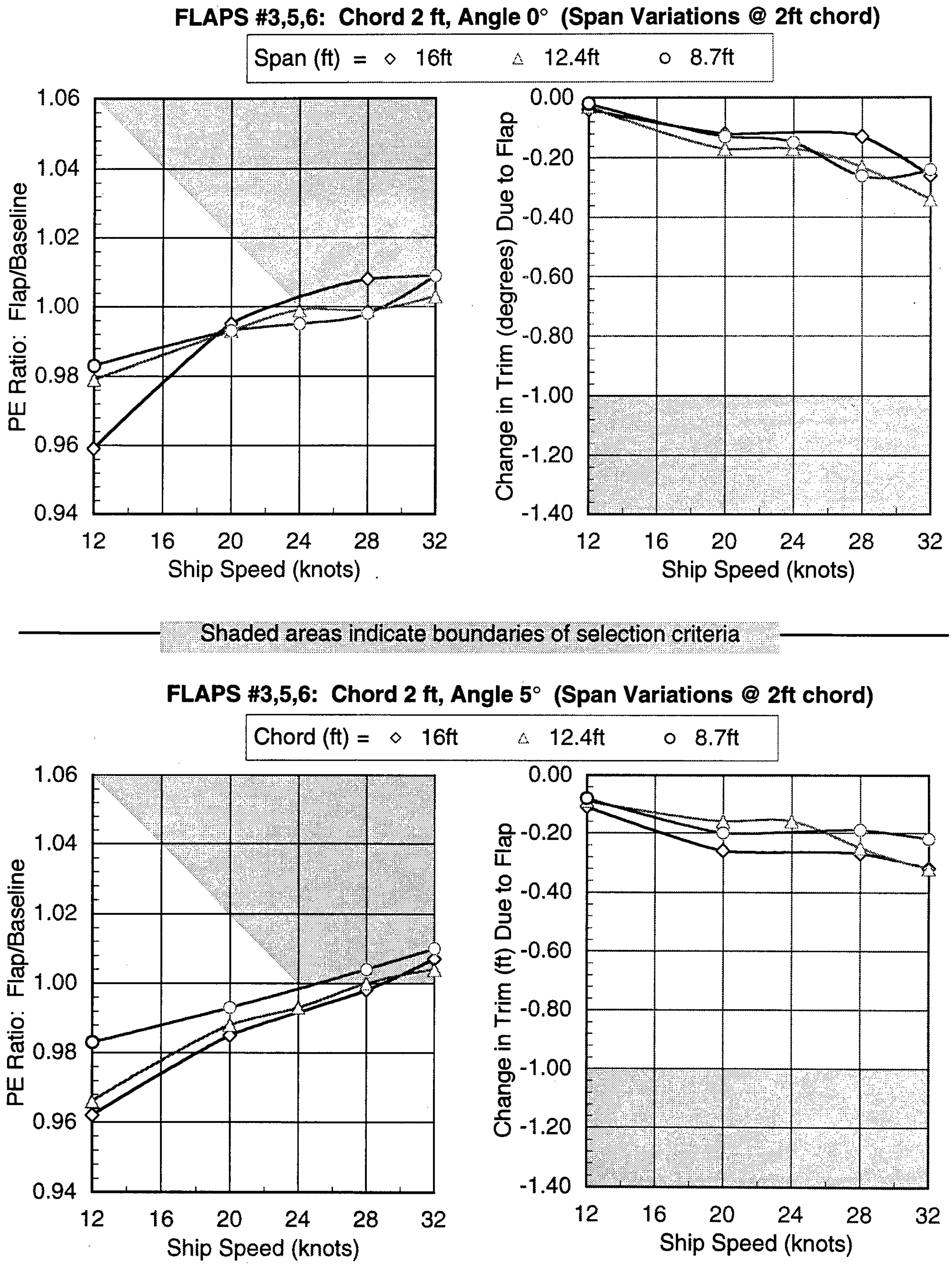
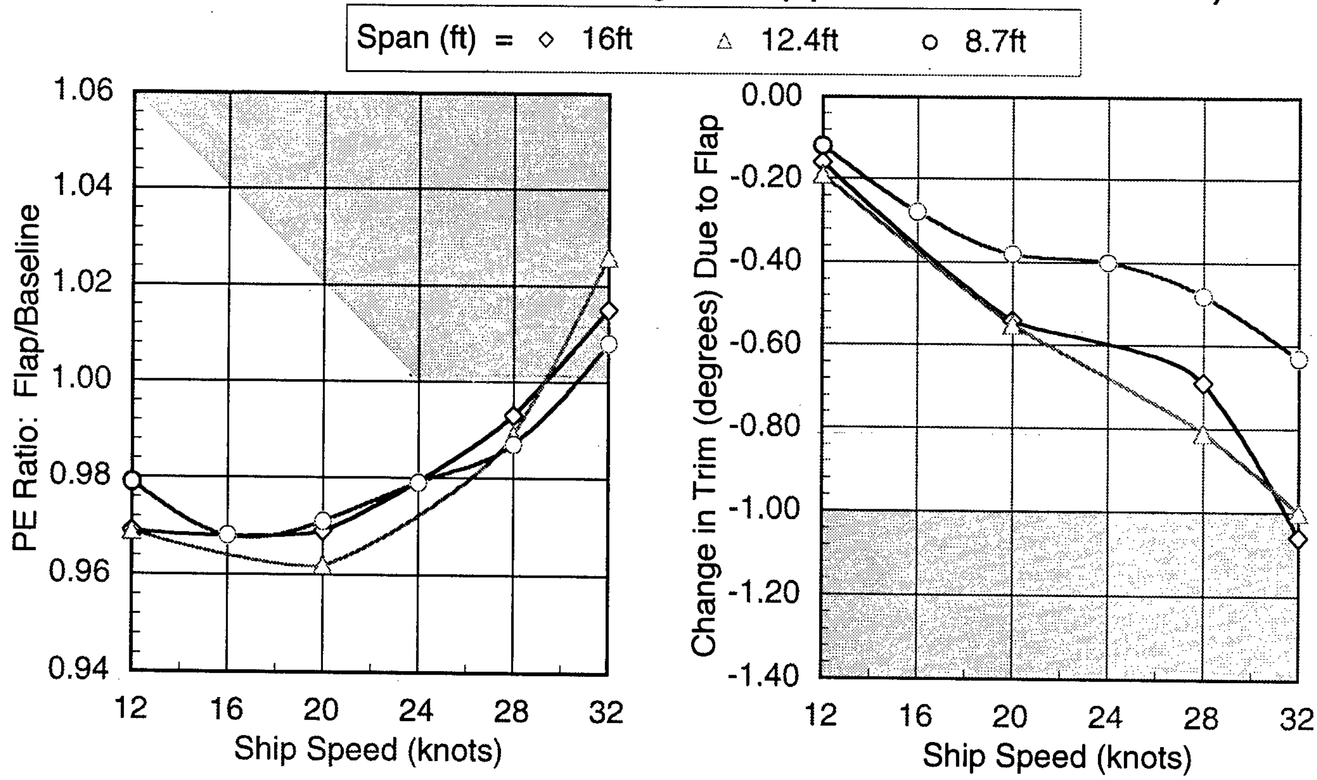


Fig B2. Stern flap optimization, effects on resistance and ship trim, for variations in flap chord length, span, and angle (continued)

FLAPS #3,5,6: Chord 2 ft, Angle 7.5° (Span Variations @ 2ft chord)



Shaded areas indicate boundaries of selection criteria

FLAPS #3,5,6: Chord 2 ft, Angle 10° (Span Variations @ 2ft chord)

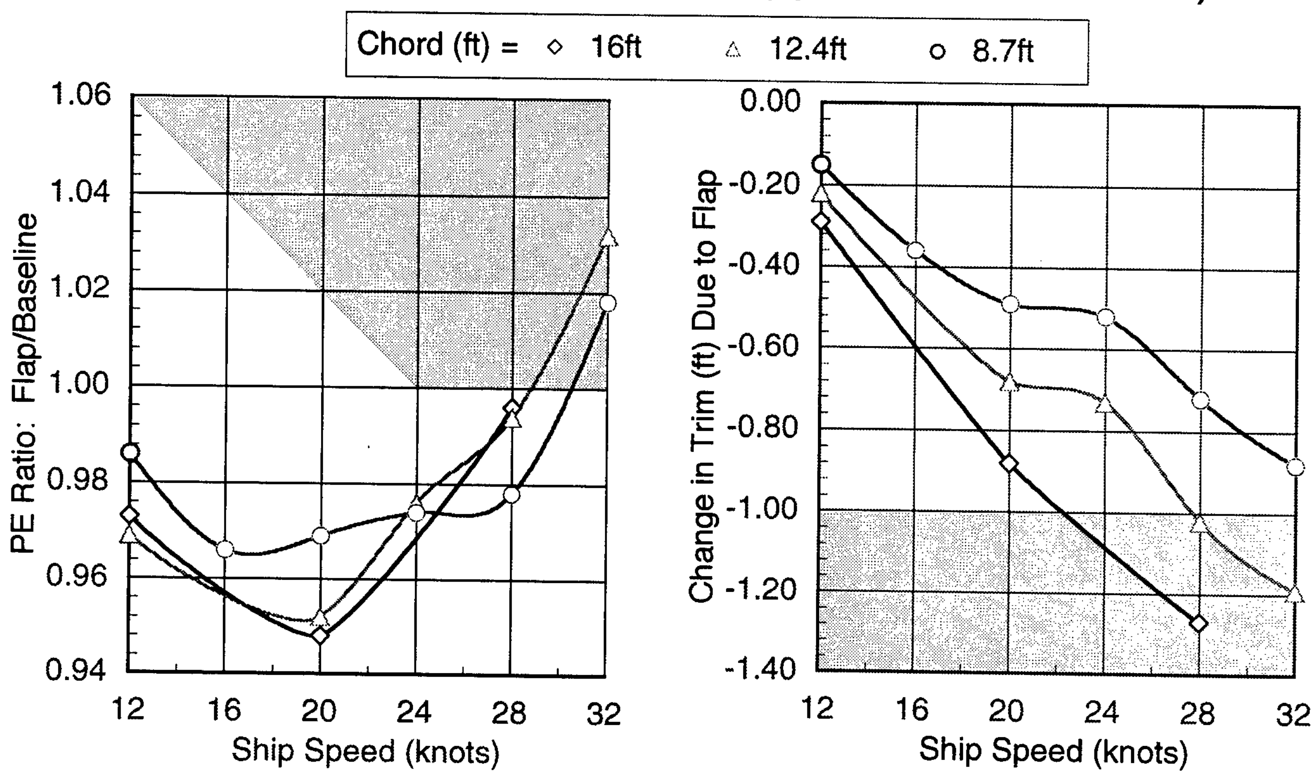


Fig B2. Stern flap optimization, effects on resistance and ship trim, for variations in flap chord length, span, and angle (continued)

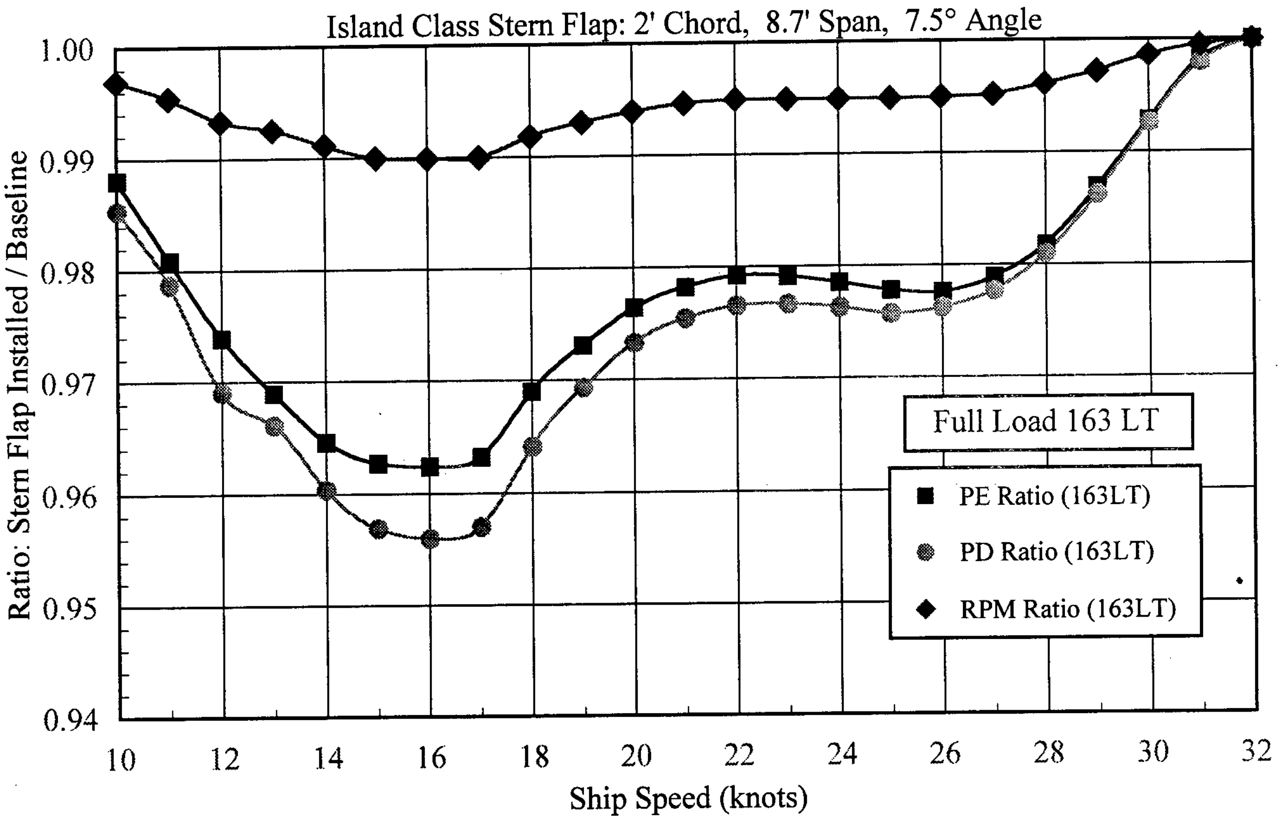


Fig B3. Island Class, comparisons of model scale resistance and powering with/without stern flap installed, full load 163 L. tons (adjusted for stern flap scale effects)

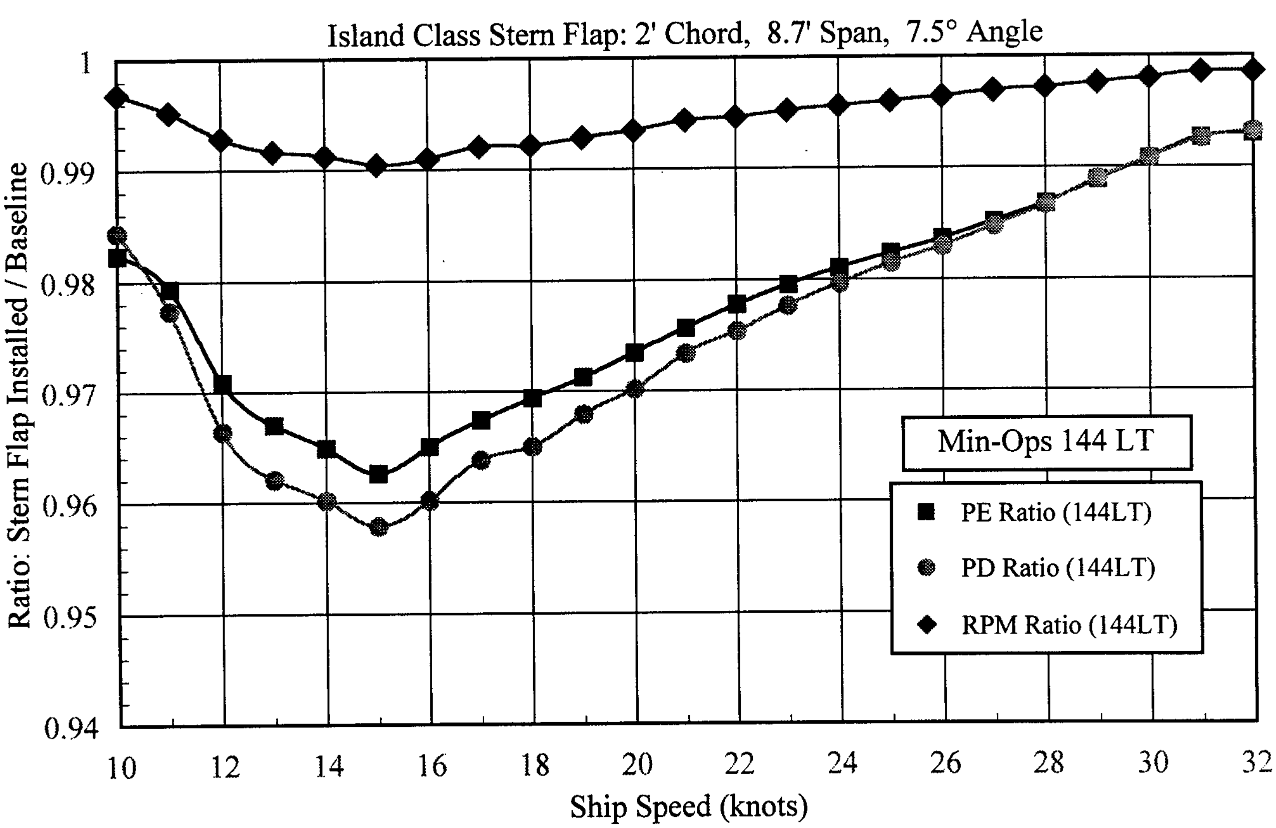


Fig B4. Island Class, comparisons of model scale resistance and powering with/without stern flap installed, min-ops 144 L. tons (adjusted for stern flap scale effects)

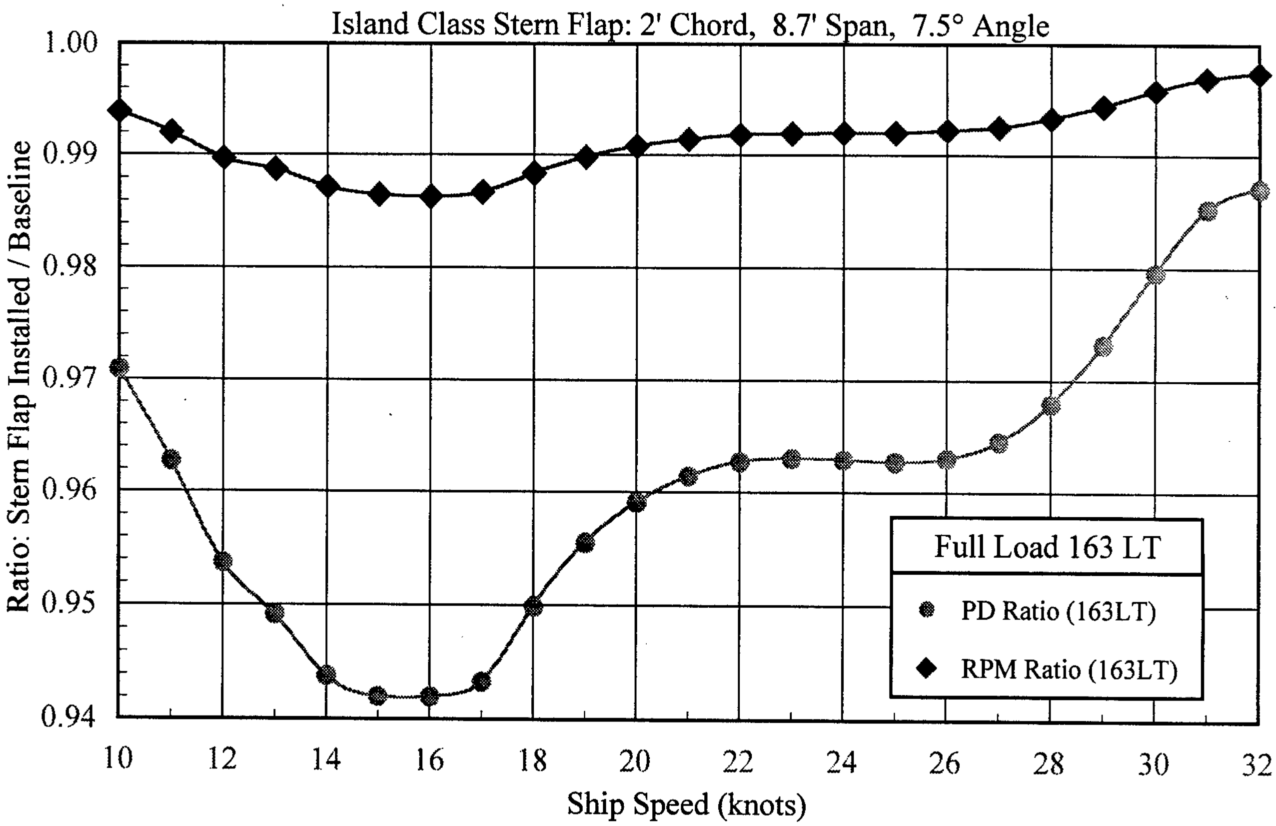


Fig B5. Projected full scale stern flap performance on Island Class 110 WPB, full load 163 L. tons (adjusted for stern flap scale effects)

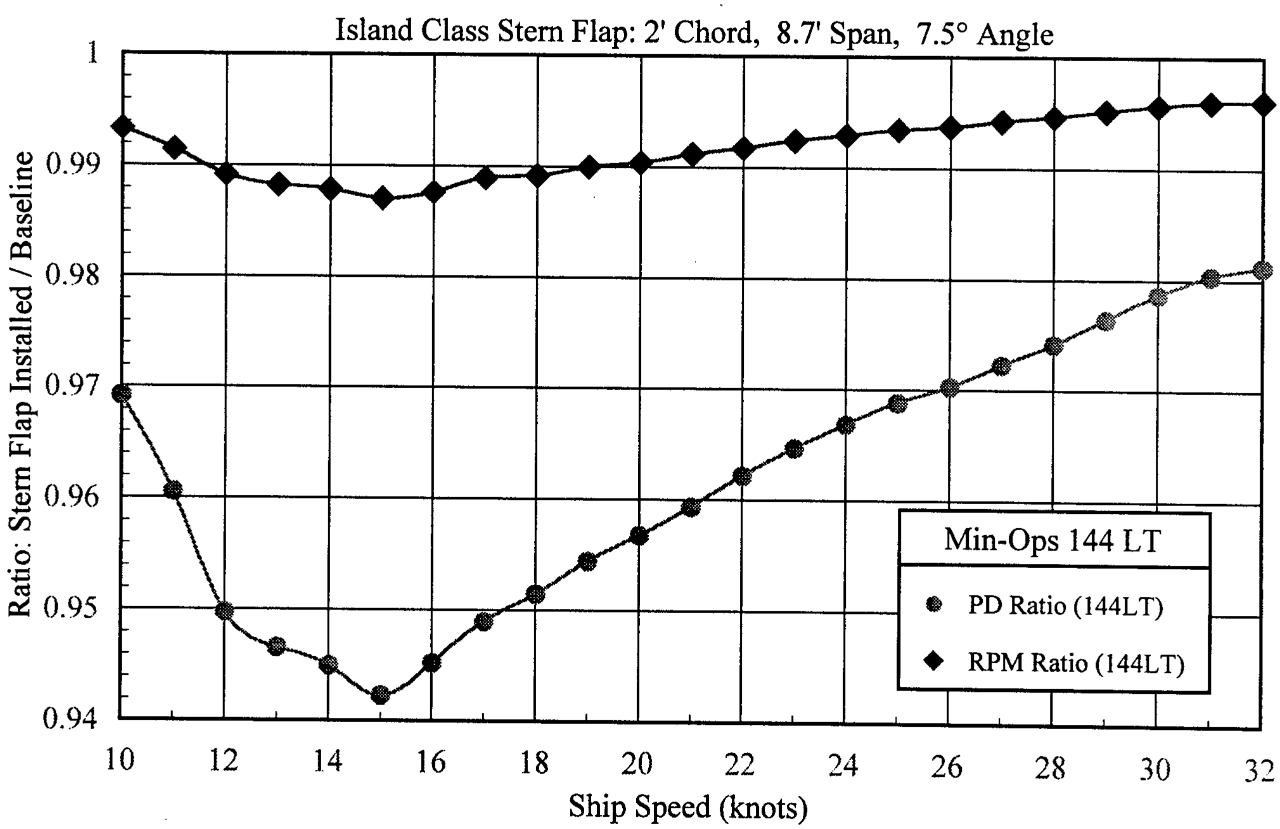


Fig B6. Projected full scale stern flap performance on Island Class 110 WPB, min-ops 144 L. tons (adjusted for stern flap scale effects)

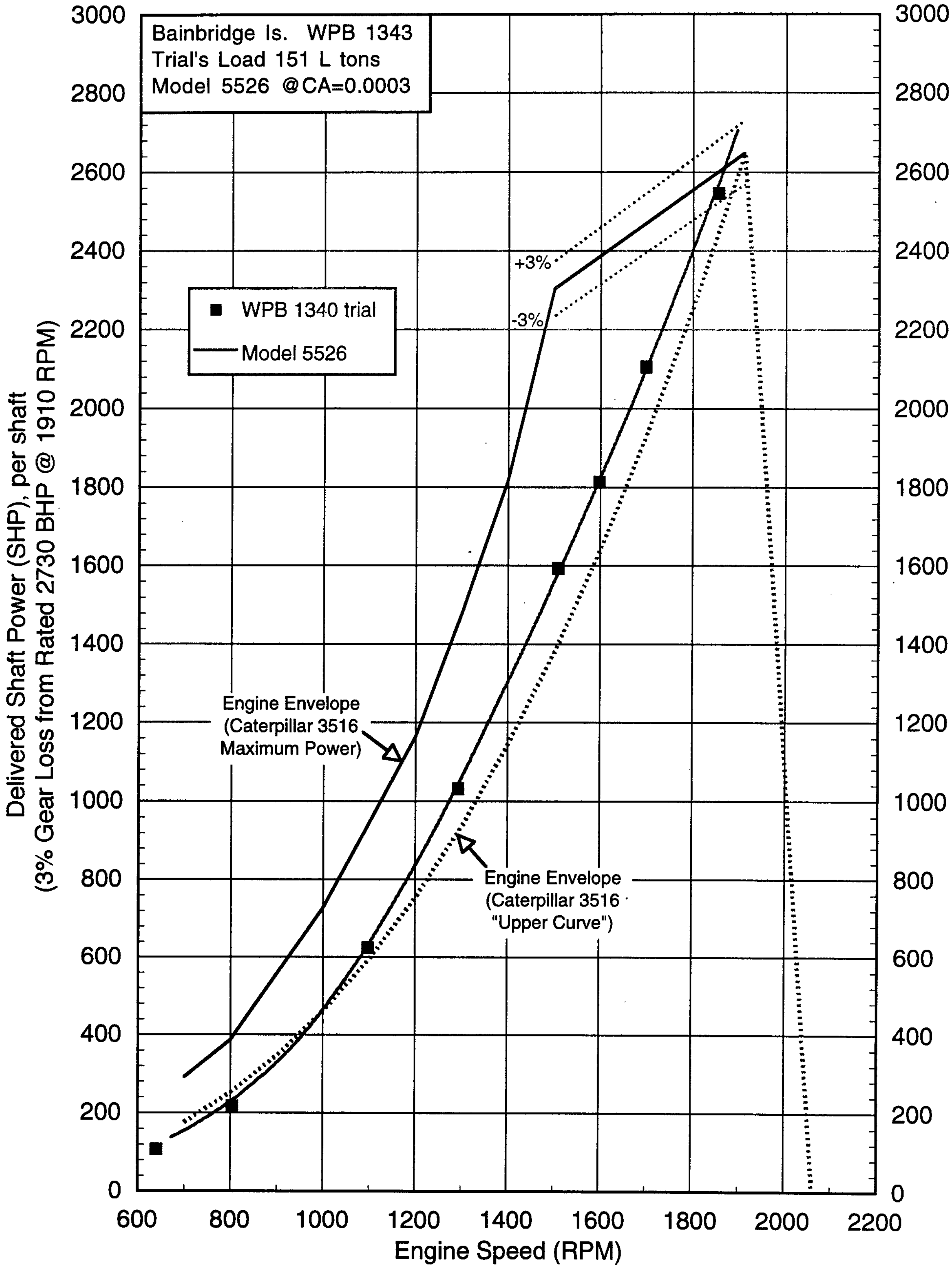


Fig B7. Ship/Model powering comparison to main engine operating envelope (Caterpillar 3516), 151 L. ton load condition, at estimated correlation allowance $C_A = 0.0003$

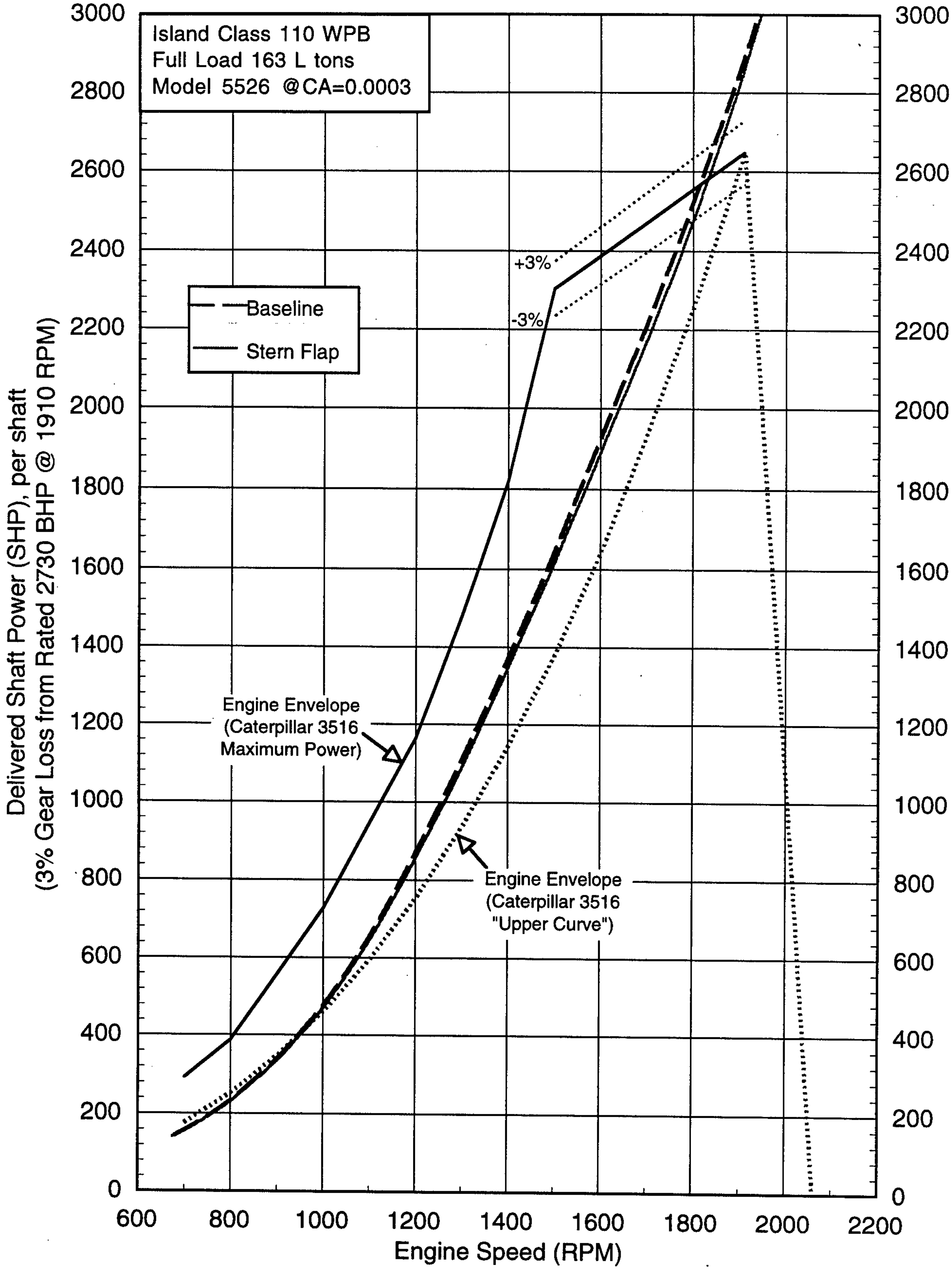


Fig B8. Island Class 110 WPB, projected shaft powering comparison to main engine operating envelope (Caterpillar 3516), with/without stern flap installed, full load

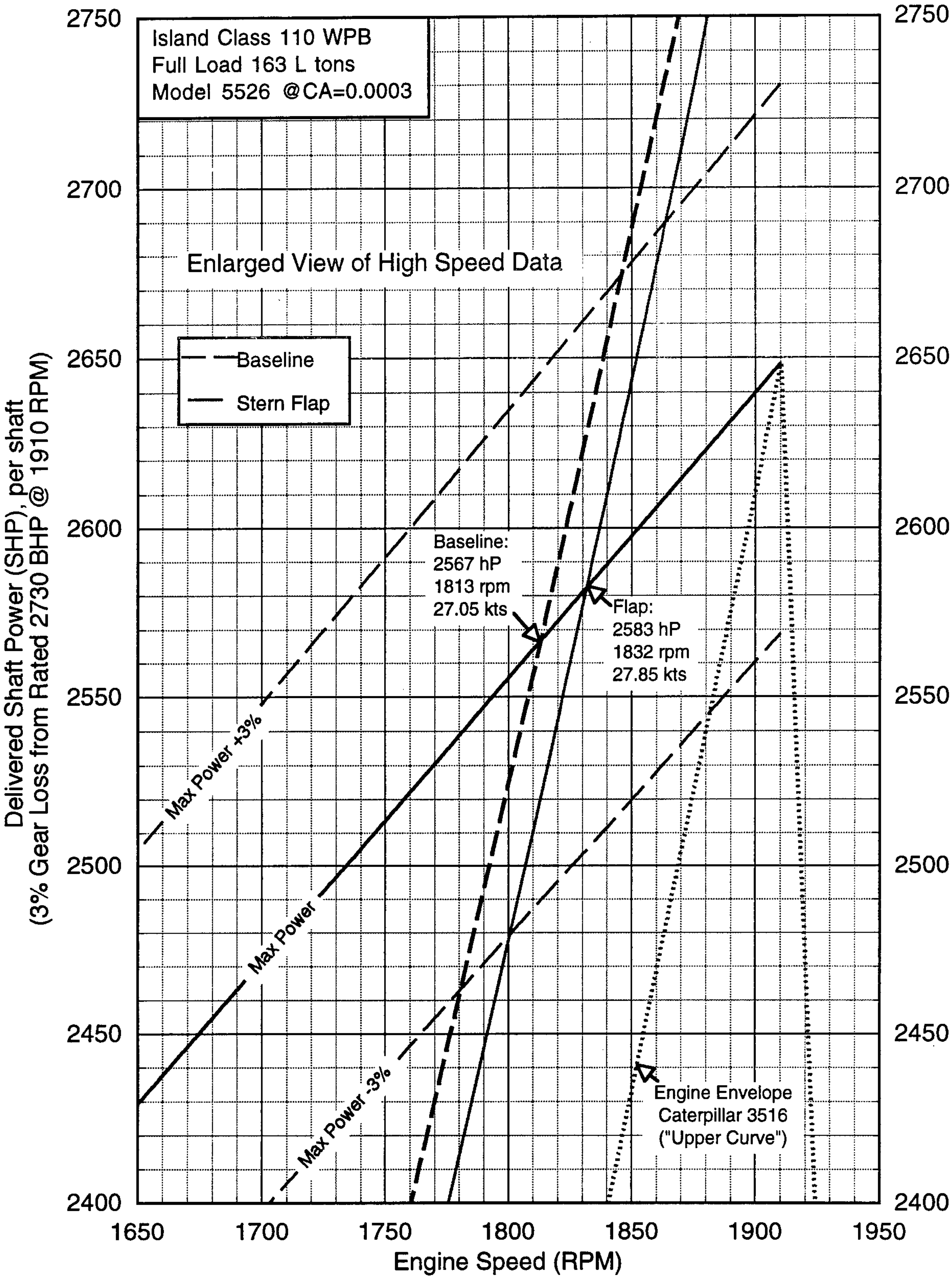


Fig B8. Island Class 110 WPB, projected shaft powering comparison to main engine operating envelope (Caterpillar 3516), with/without stern flap installed, full load (continued)

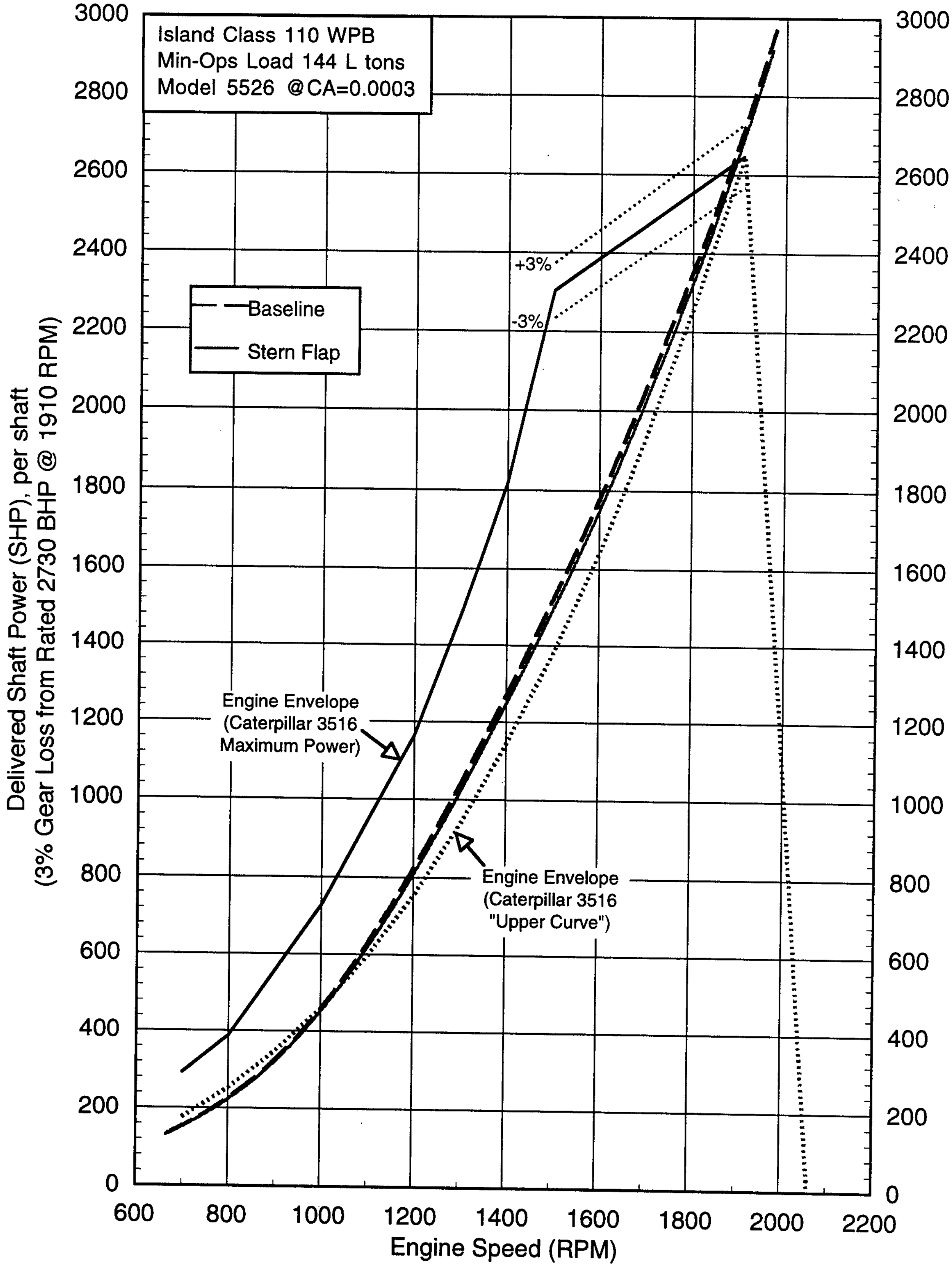


Fig B9. Island Class 110 WPB, projected shaft powering comparison to main engine operating envelope (Caterpillar 3516), with/without stern flap installed, min-ops load

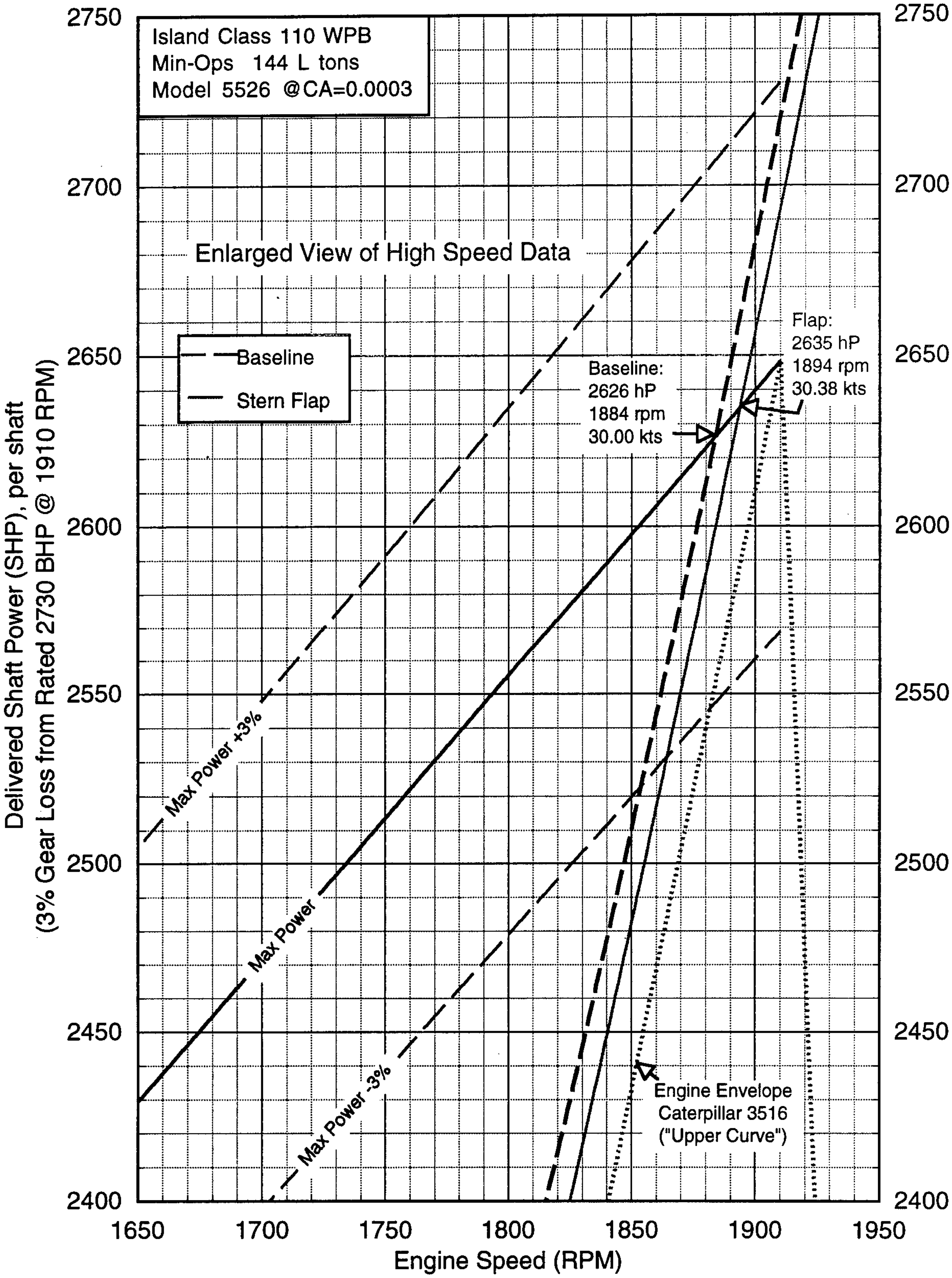


Fig B9. Island Class 110 WPB, projected shaft powering comparison to main engine operating envelope (Caterpillar 3516), with/without stern flap installed, min-ops load (continued)

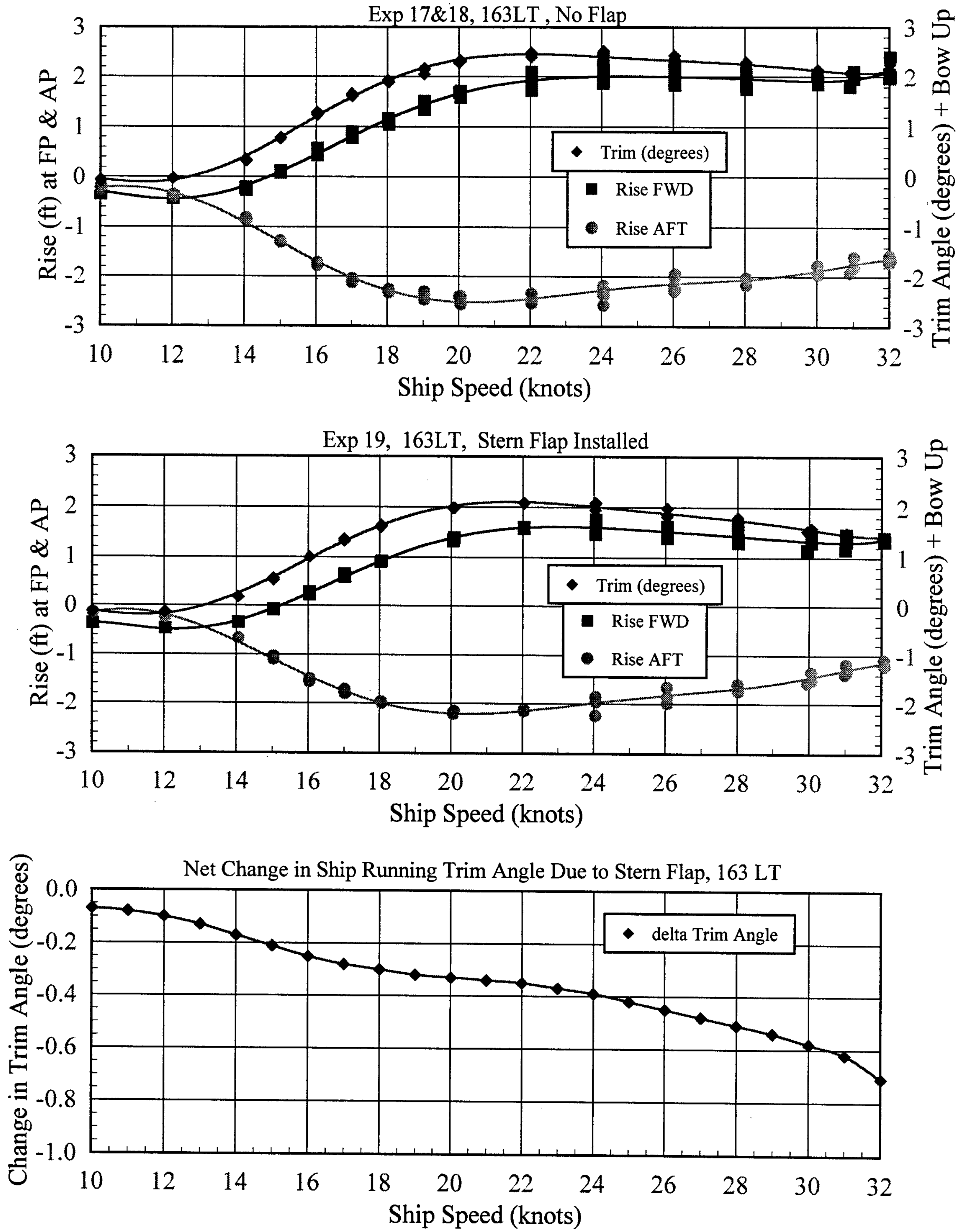
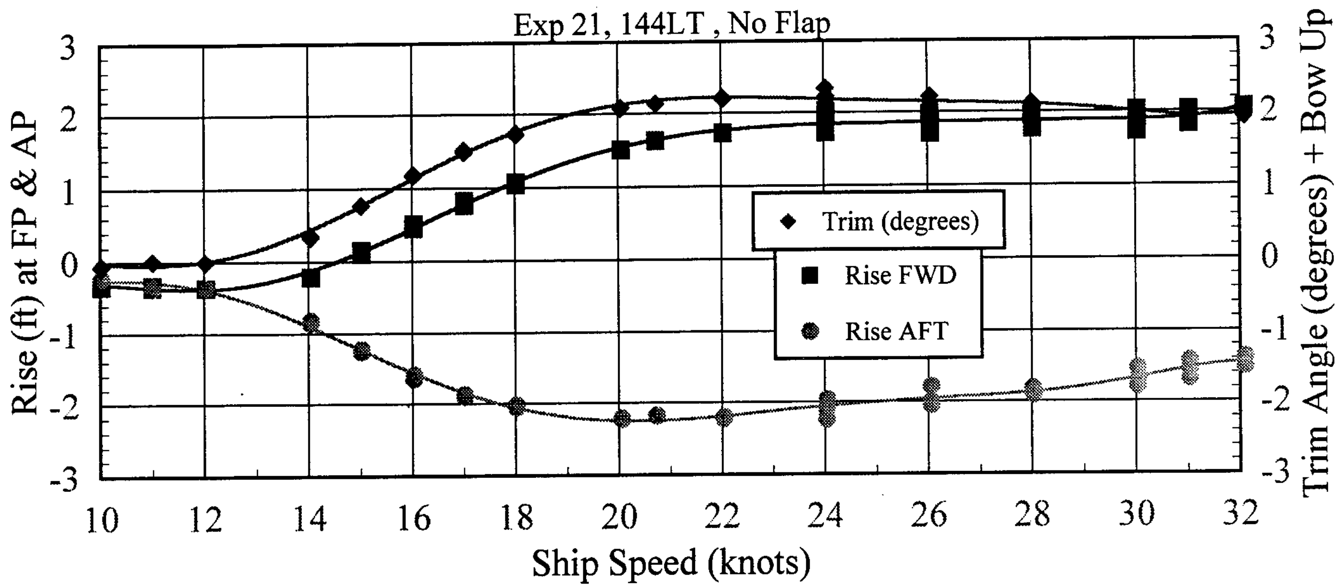
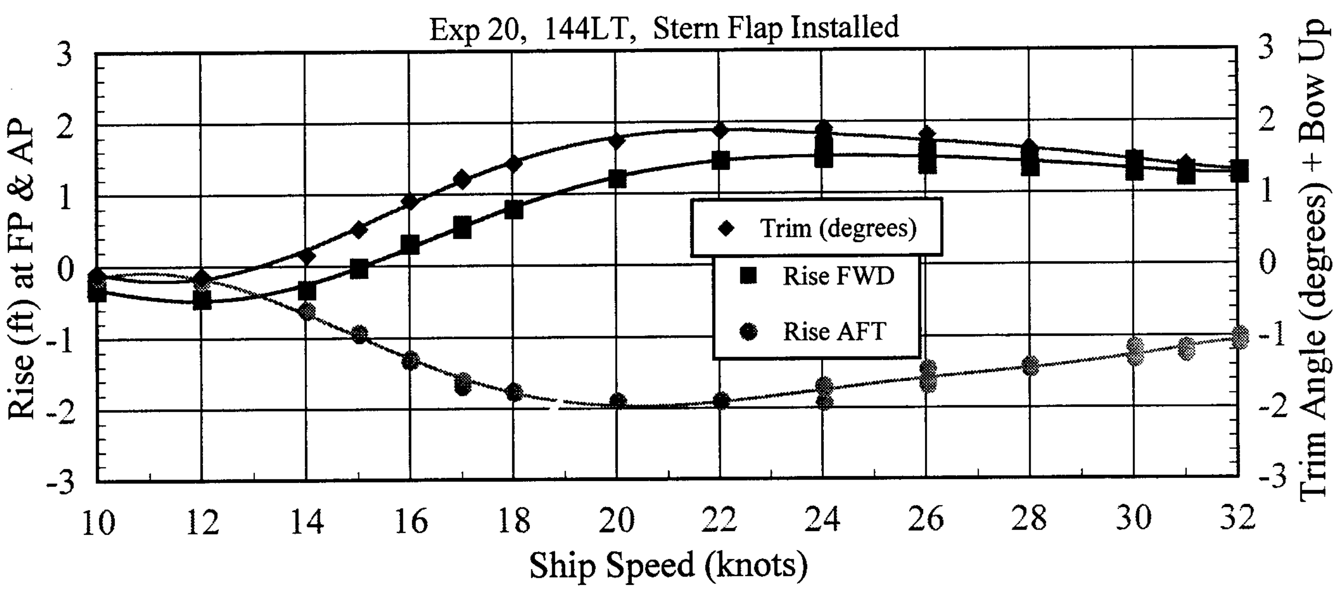


Fig B10. Island Class, comparisons of model scale dynamic running trim with/without stern flap installed, full load 163 L. tons





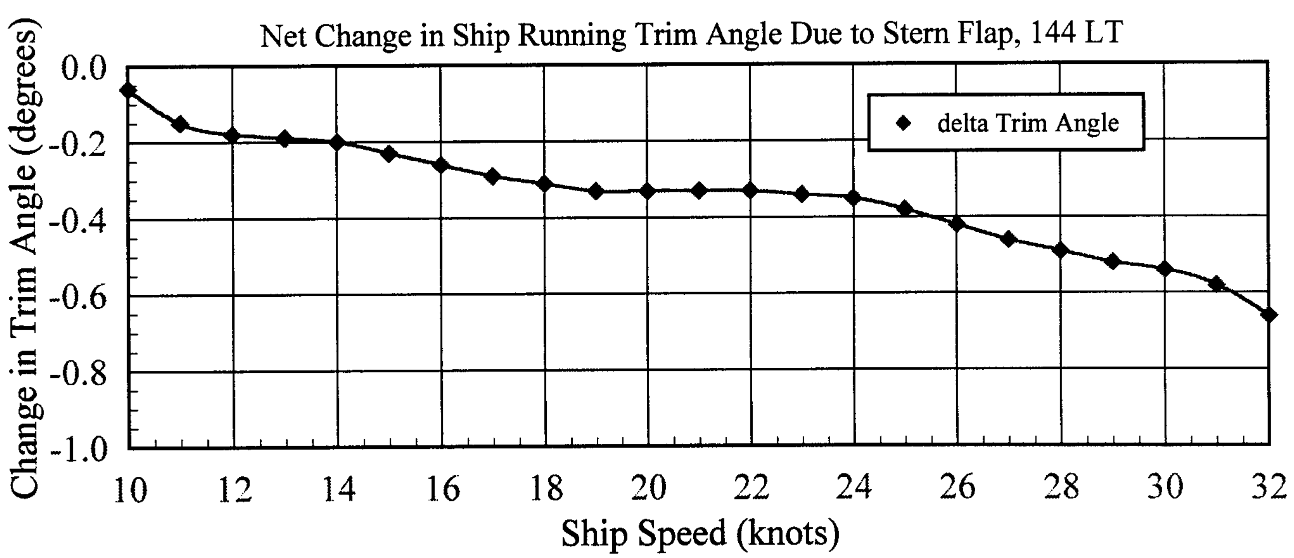


Fig B11. Island Class; comparisons of model scale dynamic running trim with/without stern flap installed, min-ops 144 L. tons

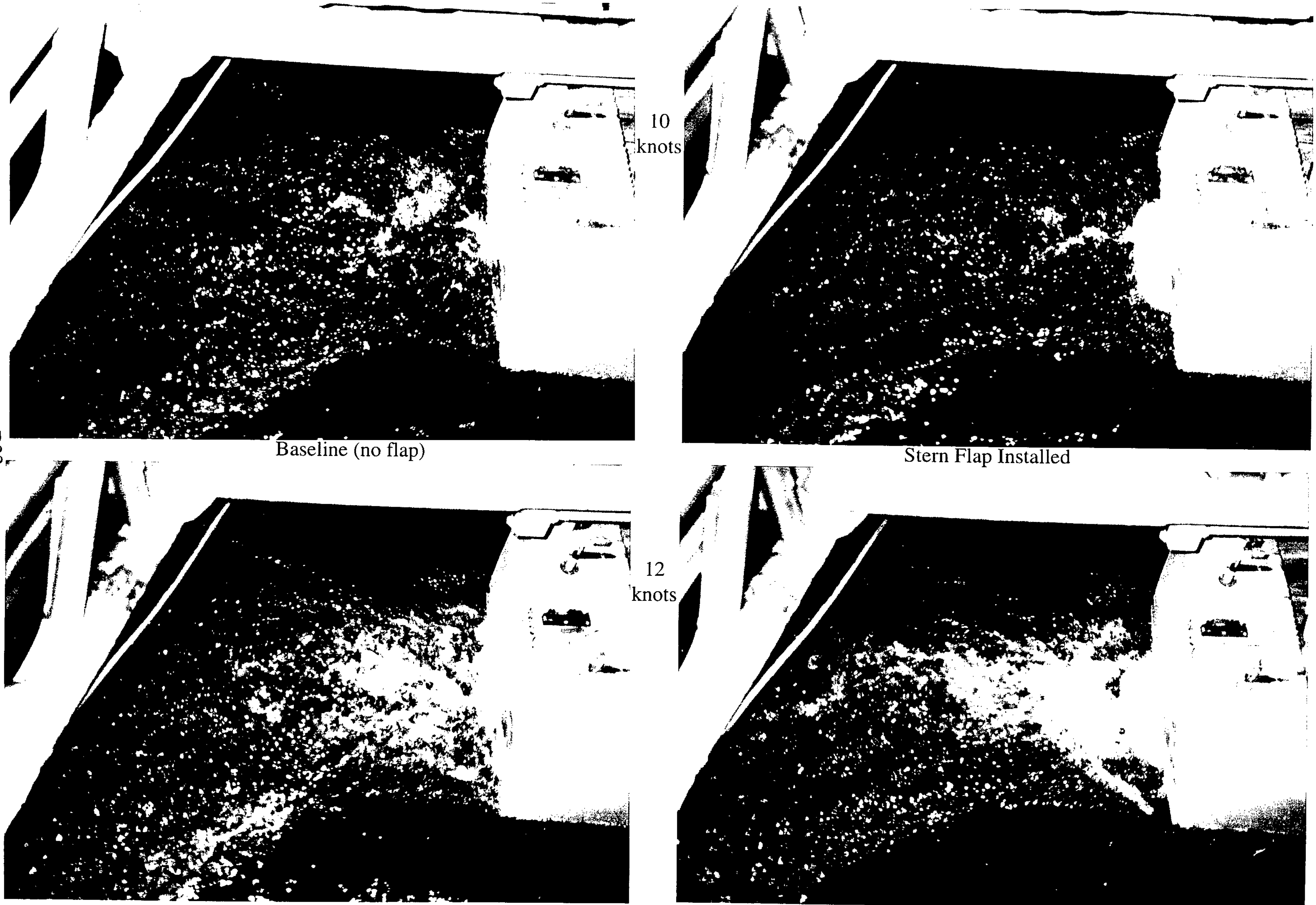


Fig B12. Local transom flow comparisons, with/without stern flap installed, full load 163 L. tons

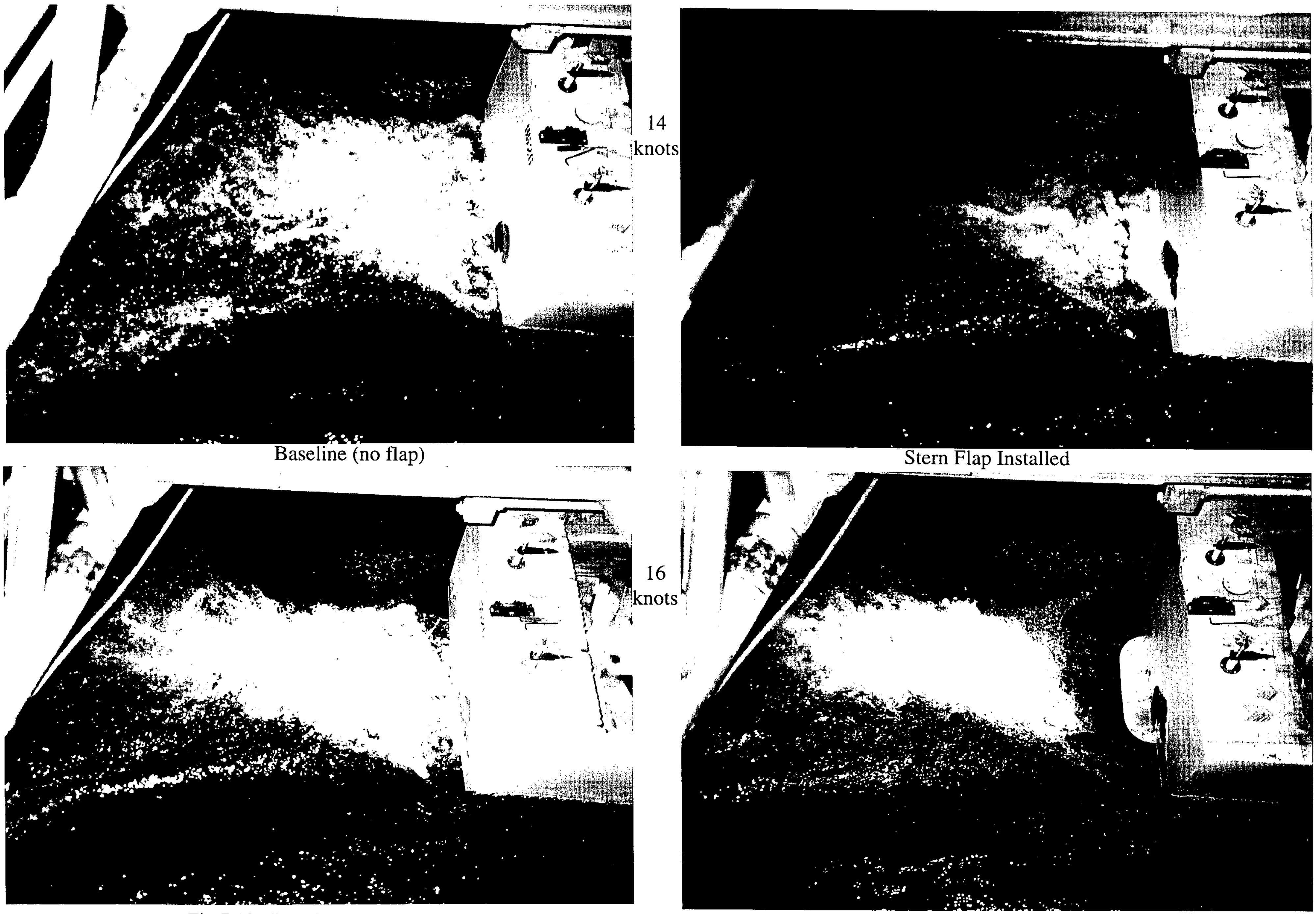


Fig B12. Local transom flow comparisons, with/without stern flap installed, full load 163 L. tons (continued)

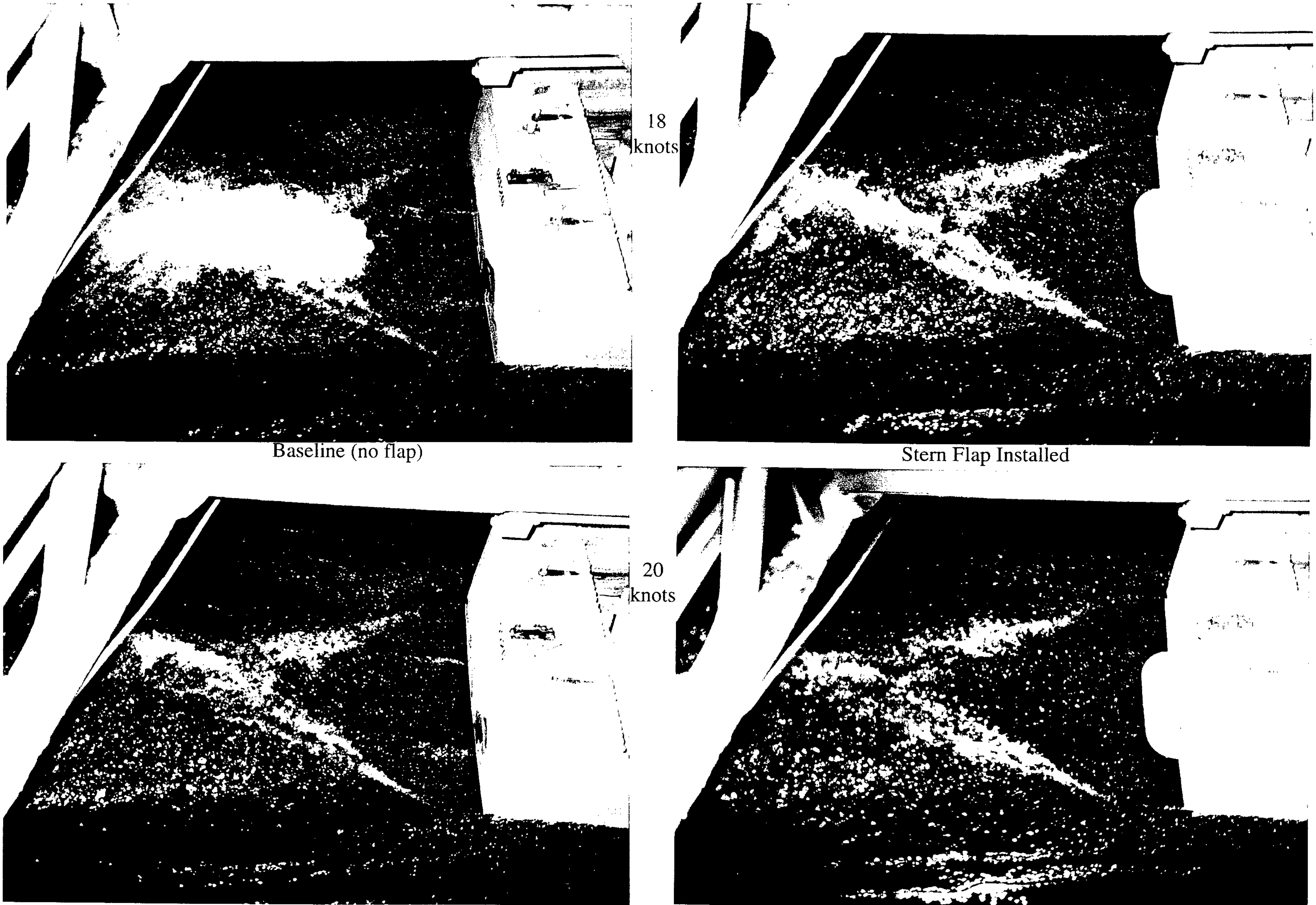


Fig B12. Local transom flow comparisons, with/without stern flap installed, full load 163 L. tons (continued)

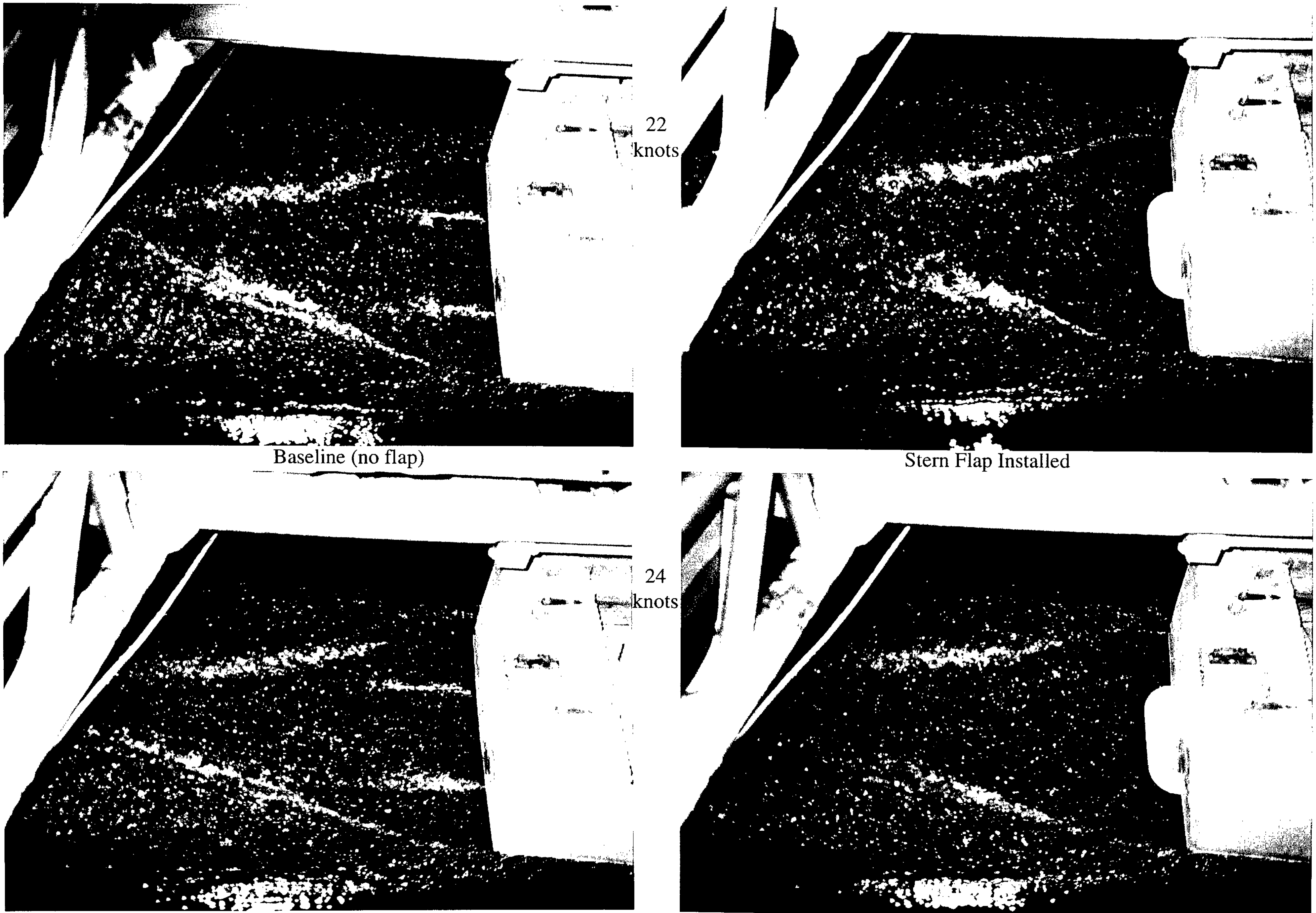
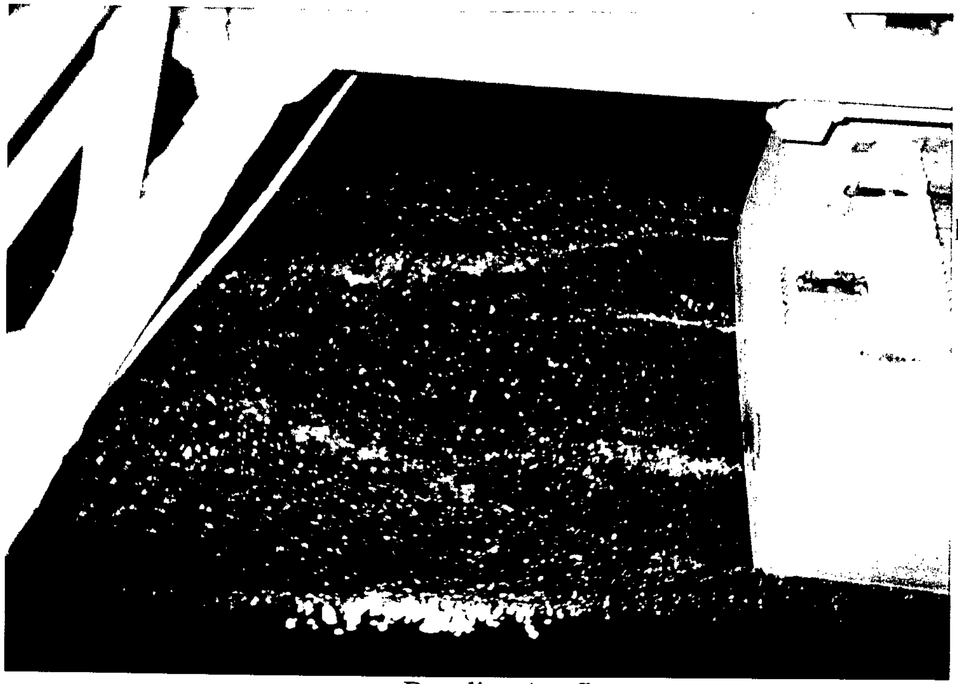


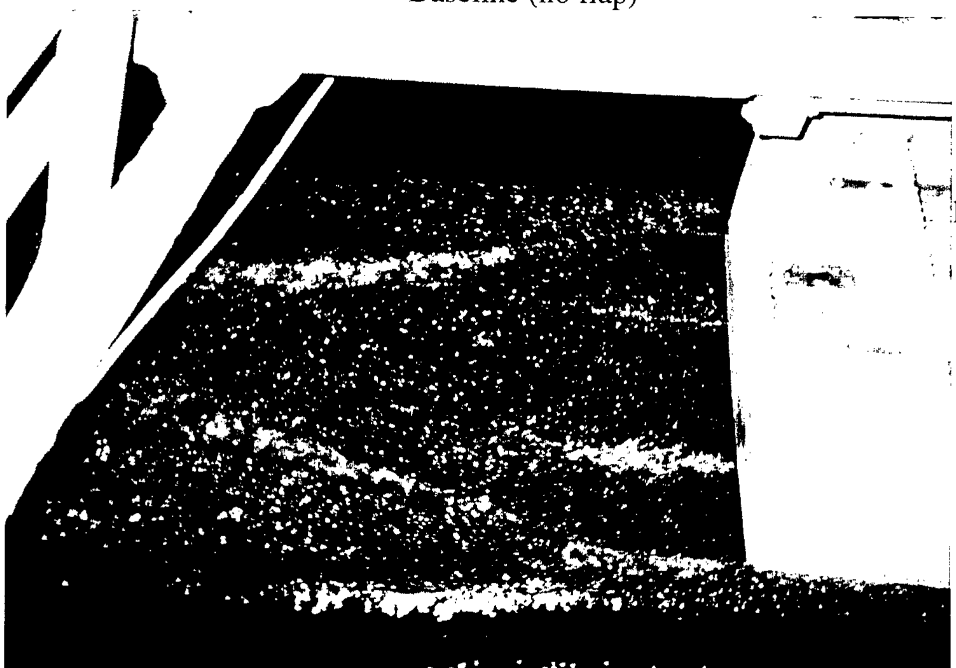
Fig B12. Local transom flow comparisons, with/without stern flap installed, full load 163 L. tons (continued)



26 knots

Baseline (no flap)

Stern Flap Installed



28 knots

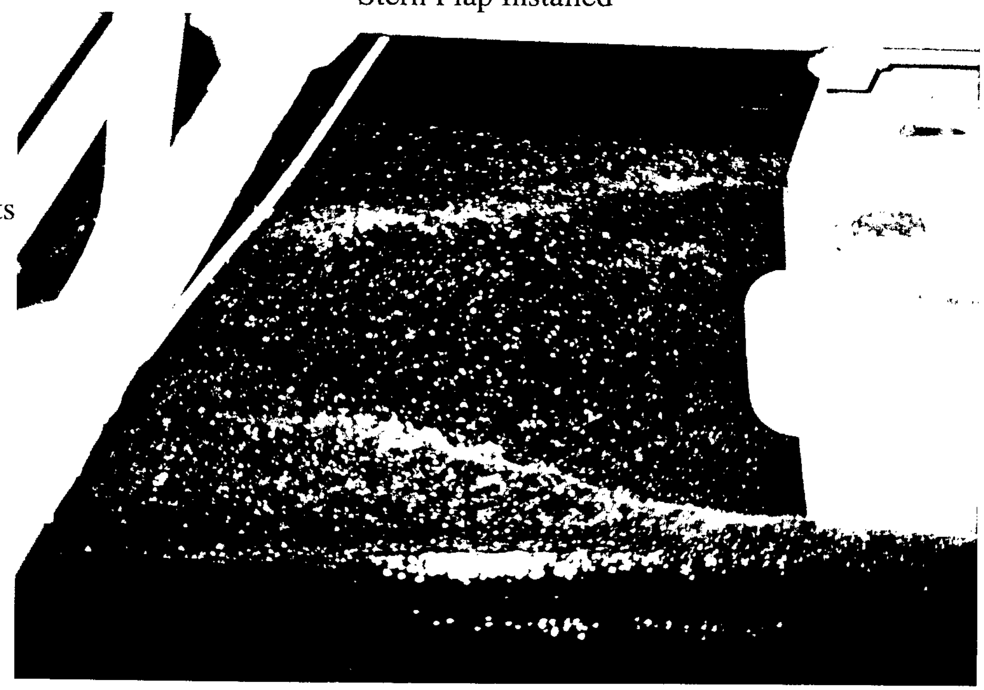


Fig B12. Local transom flow comparisons, with/without stern flap installed, full load 163 L. tons (continued)

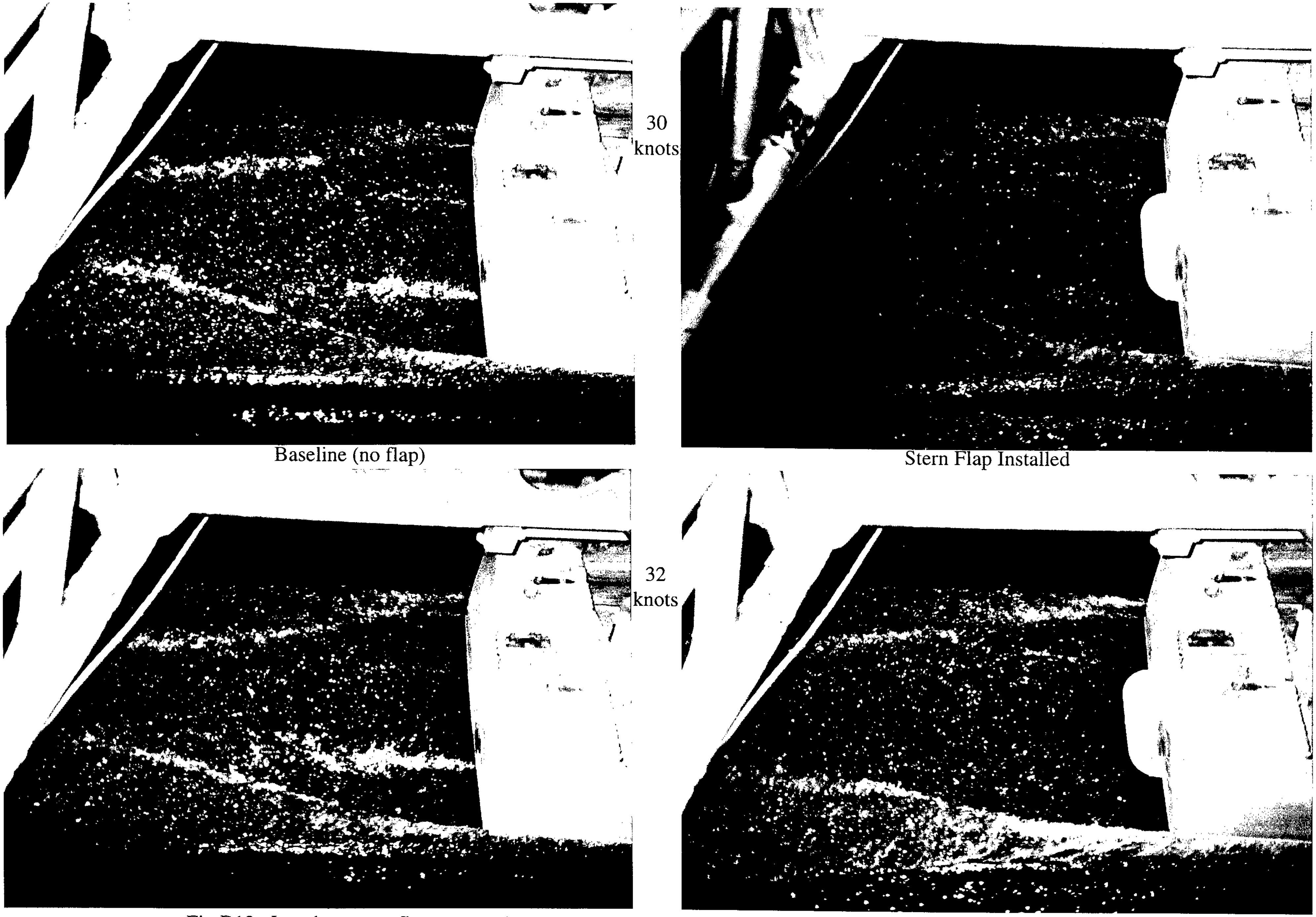


Fig B12. Local transom flow comparisons, with/without stern flap installed, full load 163 L. tons (continued)

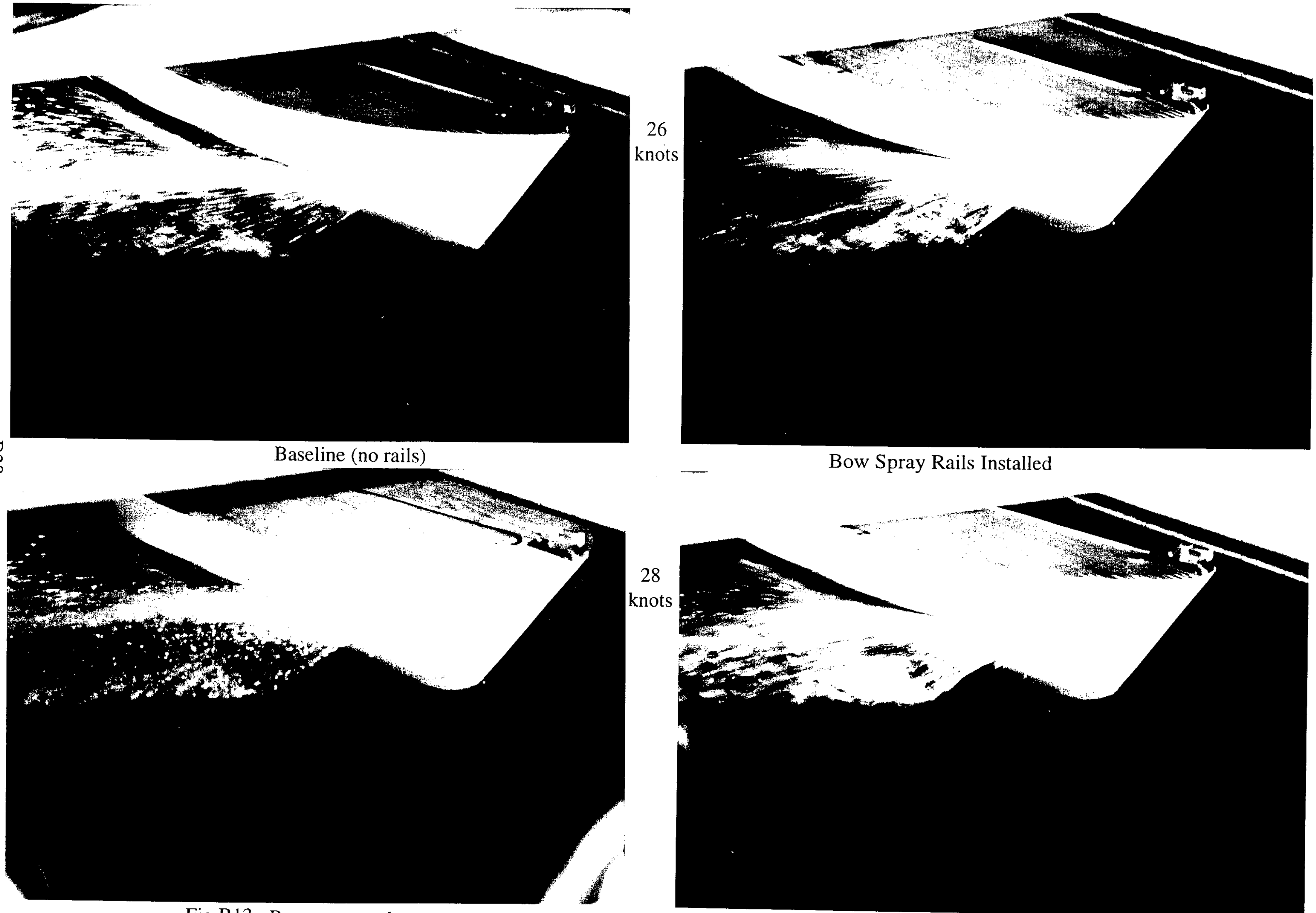
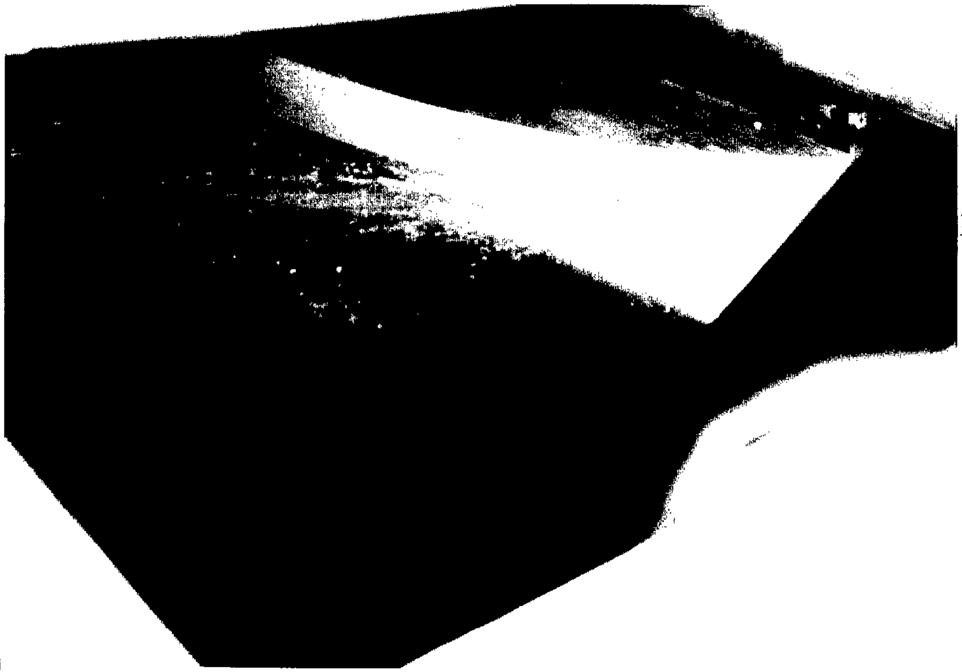


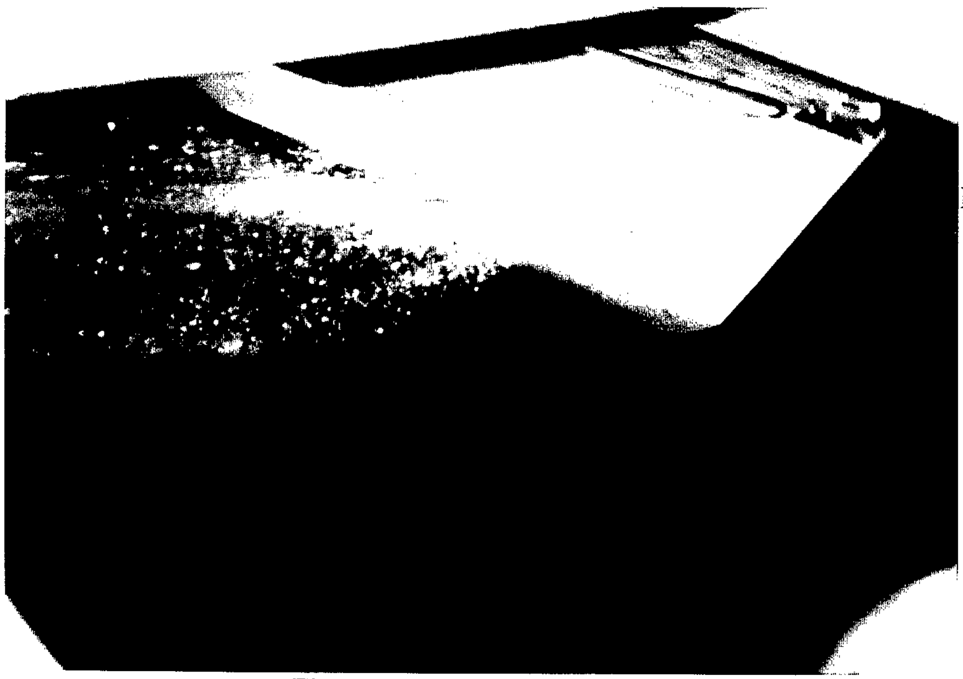
Fig B13. Bow wave and spray comparisons, with/without bow spray rails, full load 163 L. tons



30 knots

Baseline (no rails)

Bow Spray Rails Installed



32 knots

Fig B13. Bow wave and spray comparisons, with/without bow spray rails, full load 163 L. tons (continued)

Table B1. Test Agenda: USCG Island Class 110 WPB Model 5526 stern flap evaluation and selection

Experiments Conducted 4/22/99 - 4/27/99

Test #	Test Type	Loading	Long Tons	Appendages	Stern Flap	Speeds (knots)	Comments/Description
1	Set-Up/Trials	Corr	151	S&S, R, RS	NO flap	16, 20, 24	Yaw angle adjustments to zero side force
2	Uncertainty	Corr	151	S&S, R, RS	NO flap	16, 24	Data Collect for Uncertainty Analysis
3	Correlation	Corr	151	S&S, R, RS	NO flap	trials speeds	determine CA vs. Bainbridge Island ship trials
4	PE Resistance	Full Load	163.39	S&S, R, RS	NO flap	12-32 (4kt Incs)	Baseline (no flap) speeds for flap comparisons
5	Flap Evaluation	Full Load	163.39	S&S, R, RS	Flap #1	12-32 (4kt Incs)	Flap angle optimization

First series of experiments aborted after Test 5. Model 5526 was returned to woodshop for repairs to keel.

Spray Rail Installed: 1/4" thick plexi-glass rail along 8' of lower chine to promote cleaner flow/spray separation at chine.

Experiments Conducted 5/3/99 - 5/13/99.

Test #	Test Type	Loading	Long Tons	Appendages	Stern Flap	Speeds (knots)	Comments/Description
6	Correlation	Corr	151	S&S, R, RS	NO flap	trials speeds	correlate vs. Bainbridge Is. trials, repeat Test 3 w/chine rail
7	PE Resistance	Full Load	163.39	S&S, R, RS	NO flap	12-32 (4kt Incs)	Baseline (no flap) speeds for flap comparisons
8	Flap Evaluation	Full Load	163.39	S&S, R, RS	Flap #1	12-32 (4kt Incs)	Lc=1ft, Span=16ft, angle optimization (0°, 5°, 10°)
9	Flap Evaluation	Full Load	163.39	S&S, R, RS	Flap #2	12-32 (4kt Incs)	Lc=1.5ft, Span=16ft, angle optimization (0°, 5°, 10°)
10	Flap Evaluation	Full Load	163.39	S&S, R, RS	Flap #3	12-32 (4kt Incs)	Lc=2ft, Span=16ft, angle optimization (0°, 5°, 10°)
11	Flap Evaluation	Full Load	163.39	S&S, R, RS	Flap #4	12-32 (4kt Incs)	Lc=2.5ft, Span=16ft, angle optimization (0°, 5°, 10°)
12	Flap Evaluation	Full Load	163.39	S&S, R, RS	Flap #5	12-32 (4kt Incs)	Lc=2ft, Span=12.4ft, angle optimization (0°, 5°, 7.5°, 10°)
13	Flap Evaluation	Full Load	163.39	S&S, R, RS	Flap #6	12-32 (4kt Incs)	Lc=2ft, Span=8.7ft, angle optimization (0°, 5°, 7.5°, 10°)
14	Flap Evaluation	Full Load	163.39	S&S, R, RS	Flap #1,3	12-32 (4kt Incs)	Angle optimization (Re-Tests at additional 7.5° angle)
15	Flap Evaluation	Full Load	163.39	S&S, R, RS	Flap #7	12-32 (4kt Incs)	Lc=1ft, Span=12.4ft, angle optimization (0°, 5°, 7.5°, 10°)
16	Flap Evaluation	Full Load	163.39	S&S, R, RS	Flap #8	12-32 (4kt Incs)	Lc=1ft, Span=8.7ft, angle optimization (7.5°, 10°)
17	PE Resistance	Full Load	163.39	S&S, R, RS	NO flap	12 through 32	Baseline (no flap) PE Experiment, entire speed range
	Spray Rail extended forward to bow stem for all remaining experiments of this series.						
18	PE Resistance	Full Load	163.39	S&S, R, RS	NO flap	12 through 32	PE Experiment to determine effect of extending spray rail
19	PE Resistance	Full Load	163.39	S&S, R, RS	Flap#6 @7.5°	12 through 32	Selected Flap PE Experiment
20	PE Resistance	Min-Ops	143.61	S&S, R, RS	Flap#6 @7.5°	12 through 32	Selected Flap PE Experiment, alternate loading
21	PE Resistance	Min-Ops	143.61	S&S, R, RS	NO flap	12 through 32	PE Experiment (no flap), alternate loading

Appendages: Shafting and struts (S&S), rudders (R), roll stabilizers (RS)

Table B2. Island Class Model 5526, displacements, appended wetted surfaces, drafts, and other related quantities, tested loading conditions

Model 5526 LAMDA = 5.706

	condition number 1 USCG Island Class Trial Condition 151 LT		condition number 2 USCG Island Class Min-Ops 143.61 LT		condition number 3 USCG Island Class Full Load 163.39 LT	
	SHIP	MODEL	SHIP	MODEL	SHIP	MODEL
LBP (ft)	102.44	17.953	102.44	17.953	102.44	17.953
LWL (ft)	103.67	18.169	103.61	18.158	104.30	18.279
WET SURF HULL(sq ft)	2175	66.803	2136	65.605	2242	68.861
WET SURF APP(sq ft)	123.7	3.8	123.7	3.8	123.7	3.8
TOTAL WET SURF(sq ft)	2298.7	70.602	2259.7	69.404	2365.7	72.660
DISPLACE (ton, lbs)	151	1770	143.61	1684	163.39	1916
BOW DRAFT (ft)	7.18	1.258	6.93	1.215	7.66	1.342
STERN DRAFT (ft)	6.74	1.181	6.66	1.167	6.85	1.200
SHIP TRIM (+ft bow up)	-0.44	-0.077	-0.27	-0.047	-0.81	-0.142
BEAM (ft)	21.07	3.693	21.07	3.693	21.07	3.693
TEMP (F)	59	68	59	68	59	68
RHO	1.9905	1.9367	1.9905	1.9367	1.9905	1.9367
NU	1.2817	1.0836	1.2817	1.0836	1.2817	1.0836
Bow Deck/Keel (ft)	15.4	2.695	15.4	2.695	15.4	2.695
Mid-Ship Deck/Keel (ft)	-	-	-	-	-	-
Stern Deck/Keel (ft)	15.4	2.695	15.4	2.695	15.4	2.695
BOW HOOK SET (ft)	-	1.437	-	1.480	-	1.353
MID HOOK SET (ft)	-		-		-	
STERN HOOK SET (ft)	-	1.514	-	1.528	-	1.495
PROP #, port	-	-	-	-	-	-
PROP #, stbd	-	-	-	-	-	-
PROP DIA (in)	-	-	-	-	-	-
PROP ROTATION	-	-	-	-	-	-
SPEED RANGE, low (kts)	12.0	5.02	12.0	5.02	12.0	5.02
high (kts)	32.0	13.40	32.0	13.40	32.0	13.40
MODEL DISP total (lbs)	-	1770	-	1684	-	1916
MODEL WEIGHT (lbs)	-	1456	-	1456	-	1456
Floating Platform (lbs)		45		45		45
BALLAST needed (lbs)	-	269	-	183	-	415
APPENDAGES, ws (sqft)	61.07	1.876	61.07	1.876	61.07	1.876
Stabilizer Fins (2)	40	1.228	40	1.228	40	1.228
Rudders (2)	21	0.648	21	0.648	21	0.648

Table B3. Model 5526 uncertainty in resistance measurements

Ship Speed (knots)	Measure-ment	Units	Nominal Mean	Bias Limit (±)	Precision Limit (±)	Uncertainty* units (±)	Uncertainty percent (±)
16	Rt	lbf	97.05	0.17	0.446	0.477	0.49%
24	Rt	lbf	166.27	0.17	1.584	1.593	0.96%

* Overall Uncertainty has been determined by combining the bias and precision limits using the root-sum-square (RSS) method for a 95 percent confidence level.

Model Measurements for Precision Error

Spot	Vsk	Rt	Vsk	Rt	
1	24.06	165.66	16.02	97.071	
2	24.06	166.62	16.03	96.862	
3	24.06	166.97	16.02	96.916	
4	24.06	165.61	16.02	96.843	
5	24.06	166.86	16.02	96.664	
6	24.06	166.8	16.02	97.067	
7	24.05	164.84	16.02	97.081	
8	24.05	167.17	16.02	97.403	
9	24.06	165.53	16.02	97.13	
10	24.05	166.3	16.02	97.271	
11	24.05	166.09	16.02	97.062	
12	24.05	166.83	16.02	97.234	
		166.27		97.050	Average (Nominal Mean)
		0.727		0.205	Standard Deviation
		1.584		0.446	t dist * Std Dev = Precision (Units)

Table B4. BAINBRIDGE ISLAND (WPB 1343) performance trials results, 151 L. ton load condition

Performance Trials Results BAINBRIDGE ISLAND (WPB 1343) 151 LT, LCG = 5.09 ft. Aft of Midships, Static Trim = -1.0°												
Run Number	Average Speed (Knots)	Shaft Speed (RPM)			Engine Speed (RPM)	Shaft Torque (Ft- Lbs)		Shaft Horsepower			Propulsion Fuel Consumption	Running Trim, Ref. B.L. (Degrees)
		Port	Stbd	Average	Average	Port	Stbd	Port	Stbd	Total	Total (GPH)	
1\2	10.0	275	275	275	640	2086	2054	109	108	217	-	-1.2
3\4	11.8	344	345	345	803	3346	3299	219	217	436	-	-1
5\6	15.1	472	469	471	1097	7132	6817	641	609	1250	69.6	-0.2
7\8	17.5	555	554	555	1292	9958	9605	1052	1013	2065	114.0	0.8
9\10	21.1	646	648	647	1508	13201	12663	1624	1562	3187	163.2	1.5
11\12	22.9	683	688	686	1597	14193	13609	1845	1782	3627	188.3	1.7
13\14	25.0	728	729	729	1698	15657	14707	2172	2041	4213	215.2	1.6
15\16	29.2	790	801	796	1854	16927	16687	2547	2545	5092	276.0	1.3

Reproduced from Table 3.1.3. of NSCSES Report No. 60-264; Haupt and Puckette [4]

Table B5. Ship/model comparison between BAINBRIDGE ISLAND (WPB 1343) and Model 5526, 151 L. ton load condition, variations in correlation allowance

Performance Trials Results BAINBRIDGE ISLAND (WPB 1343)
151 LT, LCG = 5.09 ft. Aft of Midships, Static Trim = -1.0°

FULL SCALE TRIALS DATA			
Speed No.	Ship Speed (knots)	Shaft Speed RPM (avg)	Shaft Power Total (hP)
1	10.0	275.0	217
2	11.8	344.5	436
3	15.1	470.5	1250
4	17.5	554.5	2065
5	21.1	647.0	3187
6	22.9	685.5	3627
7	25.0	728.5	4213
8	29.2	795.5	5092

SELECTED CORRELATION ALLOWANCE

MODEL DATA		CA = 0.0003		
Ship Speed (knots)	Shaft Speed RPM	Shaft Power PD (hP)	Correlation Cn Ship/Model	Correlation Cp Ship/Model
10.0	288.8	275	0.952	0.787
11.8	345.5	466	0.997	0.936
15.1	473.1	1278	0.995	0.978
17.5	556.4	2105	0.997	0.981
21.1	647.3	3160	1.000	1.009
22.9	684.9	3626	1.001	1.000
25.0	725.9	4159	1.004	1.012
29.2	797.9	5167	0.997	0.985
Cn and Cp averages (speeds 3 - 7) =>			**0.999**	**0.998**

MODEL DATA			CA = 0.0002		
Speed No.	Ship Speed (knots)	Shaft Speed RPM	Shaft Power PD (hP)	Correlation Cn Ship/Model	Correlation Cp Ship/Model
1	10.0	287.9	271	0.955	0.799
2	11.8	344.5	459	1.000	0.950
3	15.1	471.9	1263	0.997	0.989
4	17.5	555.0	2083	0.999	0.992
5	21.1	645.6	3122	1.002	1.021
6	22.9	683.0	3579	1.004	1.013
7	25.0	723.8	4102	1.006	1.027
8	29.2	795.4	5087	1.000	1.001
	Cn and Cp averages (speeds 3 - 7) =>			**1.002**	**1.008**

MODEL DATA		CA = 0.00025		
Ship Speed (knots)	Shaft Speed RPM	Shaft Power PD (hP)	Correlation Cn Ship/Model	Correlation Cp Ship/Model
10.0	288.4	273	0.954	0.793
11.8	345.0	462	0.999	0.943
15.1	472.5	1271	0.996	0.983
17.5	555.7	2094	0.998	0.986
21.1	646.5	3141	1.001	1.015
22.9	684.0	3602	1.002	1.007
25.0	724.8	4130	1.005	1.020
29.2	796.6	5127	0.999	0.993
Cn and Cp averages (speeds 3 - 7) =>			**1.000**	**1.002**

MODEL DATA			CA = 0.00035		
Speed No.	Ship Speed (knots)	Shaft Speed RPM	Shaft Power PD (hP)	Correlation Cn Ship/Model	Correlation Cp Ship/Model
1	10.00	289.3	278	0.951	0.781
2	11.80	346.1	469	0.995	0.929
3	15.10	473.7	1285	0.993	0.972
4	17.50	557.0	2117	0.996	0.976
5	21.10	648.2	3179	0.998	1.003
6	22.90	685.8	3649	1.000	0.994
7	25.00	726.9	4188	1.002	1.006
8	29.20	799.1	5207	0.995	0.978
	Cn and Cp averages (speeds 3 - 7) =>			**0.998**	**0.990**

MODEL DATA		CA = 0.0004		
Ship Speed (knots)	Shaft Speed RPM	Shaft Power PD (hP)	Correlation Cn Ship/Model	Correlation Cp Ship/Model
10.00	289.8	280	0.949	0.775
11.80	346.6	472	0.994	0.923
15.10	474.3	1293	0.992	0.967
17.50	557.7	2128	0.994	0.971
21.10	649.0	3198	0.997	0.997
22.90	686.8	3672	0.998	0.988
25.00	728.0	4216	1.001	0.999
29.20	800.4	5248	0.994	0.970
Cn and Cp averages (speeds 3 - 7) =>			**0.996**	**0.984**

Table B6. Island Class, resistance prediction (no flap), ship trials load condition 151 L. tons, Exp. 6

MODEL CONDITION = "Exp6 Model 5526 @151LT, No Flap, w/Rail"

EHP RESULTS FROM EXPERIMENT NUMBER = 6
DTRC MODEL NUMBER = 5526 DTRC DSC 14-May-99

	SHIP		MODEL	
LENGTH	102.44 FT	(31.2 M)	17.95 FT	(5.472 M)
WETTED SURFACE	2299.SQ FT	(214. SQ M)	70.60 SQ FT	(6.56 SQ M)
DISPLACEMENT	151.TONS	(153. T)	0.79 TONS	(0.80 T)
RHO	1.9905	(31.885 N SXX2/MXX4)	1.9369	(31.026 N SXX2/MXX4)
NU (E+5)	1.2817	(0.11907 SQ M/SEC)	1.0983	(0.10204 SQ M/SEC)

LINEAR RATIO 5.706
ITTC FRICTION LINE
CORRELATION ALLOWANCE (CA) 0.00030

VS		PE		FRICTIONAL POWER		FN	V-L	1000CR
KNOTS	M/S	HP	KW	HP	KW			
10.00	5.14	144.8	108.0	45.9	34.2	0.294	0.988	4.945
11.00	5.66	197.9	147.6	60.4	45.0	0.323	1.087	5.165
11.80	6.07	252.3	188.1	73.9	55.1	0.347	1.166	5.428
12.00	6.17	268.3	200.0	77.6	57.9	0.353	1.186	5.517
13.00	6.69	363.3	270.9	97.7	72.9	0.382	1.284	6.044
14.00	7.20	494.8	369.0	121.0	90.2	0.412	1.383	6.812
15.00	7.72	673.1	501.9	147.5	110.0	0.441	1.482	7.786
15.10	7.77	692.4	516.4	150.4	112.2	0.444	1.492	7.872
16.00	8.23	869.6	648.4	177.7	132.5	0.470	1.581	8.446
17.00	8.75	1053.4	785.5	211.6	157.8	0.500	1.680	8.567
17.50	9.00	1145.0	853.8	230.1	171.6	0.514	1.729	8.536
18.00	9.26	1235.3	921.2	249.5	186.1	0.529	1.778	8.452
19.00	9.77	1411.7	1052.7	291.6	217.5	0.559	1.877	8.165
20.00	10.29	1582.1	1179.8	338.1	252.1	0.588	1.976	7.775
21.00	10.80	1747.8	1303.3	389.2	290.2	0.617	2.075	7.335
21.10	10.85	1764.0	1315.4	394.6	294.3	0.620	2.085	7.289
22.00	11.32	1910.7	1424.8	445.1	331.9	0.647	2.174	6.882
22.90	11.78	2057.7	1534.4	499.7	372.6	0.673	2.263	6.487
23.00	11.83	2074.1	1546.6	506.0	377.4	0.676	2.272	6.444
24.00	12.35	2241.5	1671.5	572.2	426.7	0.706	2.371	6.038
25.00	12.86	2415.5	1801.3	643.7	480.0	0.735	2.470	5.670
26.00	13.38	2599.0	1938.1	720.9	537.6	0.764	2.569	5.343
27.00	13.89	2793.7	2083.3	803.9	599.4	0.794	2.668	5.055
28.00	14.40	3000.6	2237.6	892.9	665.8	0.823	2.766	4.801
29.00	14.92	3219.1	2400.5	988.1	736.8	0.853	2.865	4.574
29.20	15.02	3264.5	2434.3	1007.9	751.6	0.858	2.885	4.532
30.00	15.43	3450.5	2573.0	1089.7	812.6	0.882	2.964	4.372

Table B7. Island Class, estimated powering (no flap), ship trials load condition 151 L. tons

```
WPB1343 estimate 151LT Ca=0.0003
SHIP LENGTH               102.4 FEET   (  31.2 METERS)
SHIP DISPLACEMENT          151. TONS   (  153. METRIC TONS)
SHIP WETTED SURFACE       2299. SQFT   (  214. SQ METERS)
CORRELATION ALLOWANCE .00030           ITTC FRICTION USED
```

SHIP SPEED (KTS)	SHIP SPEED (M/S)	RESIDUARY RES.COEF. (CR*1000)	EFFECTIVE POWER- PE (HP)	EFFECTIVE POWER- PE (kW)	DELIVERED POWER- PD (HP)	DELIVERED POWER- PD (kW)	PROPELLER REV. PER MINUTE
10.0	5.14	4.945	144.8	108.0	275.4	205.3	288.8
11.8	6.07	5.428	252.3	188.1	465.7	347.2	345.5
12.0	6.17	5.517	268.3	200.0	494.5	368.8	352.4
14.0	7.20	6.812	494.8	369.0	906.6	676.1	426.5
15.1	7.77	7.872	692.4	516.4	1278.0	953.0	473.1
16.0	8.23	8.446	869.6	648.4	1608.9	1199.7	508.3
17.5	9.00	8.536	1145.0	853.8	2105.4	1570.0	556.4
18.0	9.26	8.452	1235.3	921.2	2266.2	1689.9	570.9
20.0	10.29	7.775	1582.1	1179.8	2860.5	2133.1	622.5
21.1	10.85	7.289	1764.0	1315.4	3159.9	2356.3	647.3
22.0	11.32	6.882	1910.7	1424.8	3397.4	2533.4	666.7
22.9	11.78	6.487	2057.7	1534.4	3625.5	2703.5	684.9
24.0	12.35	6.038	2241.5	1671.5	3902.1	2909.8	706.6
25.0	12.86	5.670	2415.5	1801.3	4159.0	3101.3	725.9
26.0	13.38	5.343	2599.0	1938.1	4414.6	3292.0	744.6
28.0	14.40	4.801	3000.6	2237.6	4905.0	3657.7	779.3
29.2	15.02	4.532	3264.5	2434.3	5167.2	3853.2	797.9
30.0	15.43	4.372	3450.5	2573.0	5410.8	4034.9	813.3

SHIP SPEED (KTS)	EFFICIENCIES (ETA) ETAD	ETAO	ETAH	ETAR	ETAB	THRUST DEDUCTION AND WAKE FACTORS 1-THDF	1-WFTT	1-WFTQ	ADVANCE COEF. ADVC
10.0	0.525	0.635	0.810	1.025	0.650	0.825	1.015	1.030	0.860
11.8	0.540	0.630	0.820	1.050	0.660	0.835	1.020	1.050	0.855
12.0	0.540	0.630	0.820	1.050	0.665	0.835	1.025	1.055	0.855
14.0	0.545	0.620	0.825	1.065	0.660	0.850	1.030	1.070	0.830
15.1	0.540	0.615	0.830	1.065	0.655	0.860	1.040	1.080	0.810
16.0	0.540	0.610	0.830	1.065	0.650	0.865	1.040	1.085	0.805
17.5	0.545	0.610	0.840	1.060	0.650	0.880	1.050	1.090	0.810
18.0	0.545	0.615	0.840	1.055	0.650	0.885	1.050	1.090	0.810
20.0	0.555	0.620	0.850	1.045	0.650	0.900	1.055	1.085	0.830
21.1	0.560	0.625	0.855	1.040	0.650	0.905	1.055	1.080	0.845
22.0	0.560	0.630	0.865	1.035	0.650	0.915	1.060	1.080	0.855
22.9	0.570	0.635	0.870	1.030	0.650	0.920	1.055	1.075	0.865
24.0	0.575	0.640	0.880	1.025	0.655	0.930	1.055	1.070	0.880
25.0	0.580	0.640	0.890	1.020	0.655	0.935	1.050	1.065	0.890
26.0	0.590	0.640	0.900	1.020	0.655	0.940	1.045	1.060	0.895
28.0	0.610	0.645	0.925	1.030	0.660	0.955	1.030	1.045	0.910
29.2	0.630	0.645	0.945	1.040	0.670	0.960	1.015	1.035	0.910
30.0	0.640	0.645	0.955	1.040	0.670	0.965	1.015	1.035	0.915

Table B8. Stern flap optimization and selection, model resistance experiments

Exp8 RESISTANCE: Flap#1, Chord 1 ft, Span 16 ft

Speed (knots)	Baseline Full Load PE (hP)	Flap Angle 0° PE (hP)	Flap Angle 5° PE (hP)	Flap Angle 7.5° PE (hP)	Flap Angle 10° PE (hP)
12	292	283	286	286	285
16	966				
20	1775	1770	1745	1730	1711
24	2478		2444	2434	2415
28	3313	3339	3298	3275	3281
32	4385	4420	4403	4420	4482

Speed (knots)	PE Ratio	PE Ratio 0°	PE Ratio 5°	PE Ratio 7.5°	PE Ratio 10°
12	-	0.969	0.979	0.979	0.976
16	-				
20	-	0.997	0.983	0.975	0.964
24	-		0.986	0.982	0.975
28	-	1.008	0.995	0.989	0.990
32	-	1.008	1.004	1.008	1.022

Exp8 TRIM: Flap#1, Chord 1 ft, Span 16 ft

Speed (knots)	Baseline Full Load Trim Angle	Flap Angle 0° Trim Angle	Flap Angle 5° Trim Angle	Flap Angle 7.5° Trim Angle	Flap Angle 10° Trim Angle
12	-0.02	-0.04	-0.07	-0.14	-0.19
16	1.24				
20	2.33	2.24	2.17	1.95	1.79
24	2.42		2.21	2.04	1.72
28	2.26	2.11	1.97	1.73	1.49
32	2.08	1.87	1.74	1.43	1.13

Speed (knots)	Δ Angle	Δ Angle 0°	Δ Angle 5°	Δ Angle 7.5°	Δ Angle 10°
12	-	-0.02	-0.04	-0.12	-0.17
16	-				
20	-	-0.09	-0.16	-0.38	-0.54
24	-		-0.21	-0.38	-0.70
28	-	-0.15	-0.29	-0.53	-0.77
32	-	-0.21	-0.34	-0.65	-0.94

Exp9 RESISTANCE: Flap#2, Chord 1.5 ft, Span 16 ft

Speed (knots)	Baseline Full Load PE (hP)	Flap Angle 0° PE (hP)	Flap Angle 5° PE (hP)	Flap Angle 7.5° PE (hP)	Flap Angle 10° PE (hP)
12	292	284	285		284
16	966				
20	1775	1762	1752		1715
24	2478				
28	3313	3323	3307		3286
32	4385	4411	4422		4530

Speed (knots)	PE Ratio	PE Ratio 0°	PE Ratio 5°	PE Ratio 7.5°	PE Ratio 10°
12	-	0.973	0.976		0.973
16	-				
20	-	0.993	0.987		0.966
24	-				
28	-	1.003	0.998		0.992
32	-	1.006	1.008		1.033

Exp9 TRIM: Flap#2, Chord 1.5 ft, Span 16 ft

Speed (knots)	Baseline Full Load Trim Angle	Flap Angle 0° Trim Angle	Flap Angle 5° Trim Angle	Flap Angle 7.5° Trim Angle	Flap Angle 10° Trim Angle
12	-0.02	-0.05	-0.10		-0.22
16	1.24				
20	2.33	2.17	2.17		1.68
24	2.42				
28	2.26	2.10	2.02		1.20
32	2.08	1.85	1.82		0.89

Speed (knots)	Δ Angle	Δ Angle 0°	Δ Angle 5°	Δ Angle 7.5°	Δ Angle 10°
12	-	-0.03	-0.08		-0.20
16	-				
20	-	-0.16	-0.16		-0.65
24	-				
28	-	-0.16	-0.25		-1.06
32	-	-0.22	-0.26		-1.19

Table B8. Stern flap optimization and selection, model resistance experiments (continued)

Exp10 RESISTANCE: Flap#3, Chord 2 ft, Span 16 ft

Speed (knots)	Baseline Full Load PE (hP)	Flap Angle 0° PE (hP)	Flap Angle 5° PE (hP)	Flap Angle 7.5° PE (hP)	Flap Angle 10° PE (hP)
12	292	280	281	283	284
16	966				
20	1775	1767	1749	1720	1682
24	2478				
28	3313	3338	3308	3290	3300
32	4385	4423	4415	4452	

Speed (knots)	PE Ratio	PE Ratio 0°	PE Ratio 5°	PE Ratio 7.5°	PE Ratio 10°
12	-	0.959	0.962	0.969	0.973
16	-				
20	-	0.995	0.985	0.969	0.948
24	-				
28	-	1.008	0.998	0.993	0.996
32	-	1.009	1.007	1.015	

Exp10 TRIM: Flap#3, Chord 2 ft, Span 16 ft

Speed (knots)	Baseline Full Load Trim Angle	Flap Angle 0° Trim Angle	Flap Angle 5° Trim Angle	Flap Angle 7.5° Trim Angle	Flap Angle 10° Trim Angle
12	-0.02	-0.07	-0.13	-0.18	-0.31
16	1.24				
20	2.33	2.21	2.07	1.79	1.45
24	2.42				
28	2.26	2.13	1.99	1.57	0.99
32	2.08	1.81	1.76	1.02	

Speed (knots)	Δ Angle	Δ Angle 0°	Δ Angle 5°	Δ Angle 7.5°	Δ Angle 10°
12	-	-0.04	-0.11	-0.16	-0.29
16	-				
20	-	-0.12	-0.26	-0.54	-0.88
24	-				
28	-	-0.13	-0.27	-0.69	-1.27
32	-	-0.26	-0.32	-1.06	

Exp11 RESISTANCE: Flap#4, Chord 2.5 ft, Span 16 ft

Speed (knots)	Baseline Full Load PE (hP)	Flap Angle 0° PE (hP)	Flap Angle 5° PE (hP)	Flap Angle 7.5° PE (hP)	Flap Angle 10° PE (hP)
12	292	280	283		282
16	966				
20	1775	1770	1746		1670
24	2478				
28	3313	3330	3330		3313
32	4385	4453	4437		

Speed (knots)	PE Ratio	PE Ratio 0°	PE Ratio 5°	PE Ratio 7.5°	PE Ratio 10°
12	-	0.959	0.969		0.966
16	-				
20	-	0.997	0.984		0.941
24	-				
28	-	1.005	1.005		1.000
32	-	1.016	1.012		

Exp11 TRIM: Flap#4, Chord 2.5 ft, Span 16 ft

Speed (knots)	Baseline Full Load Trim Angle	Flap Angle 0° Trim Angle	Flap Angle 5° Trim Angle	Flap Angle 7.5° Trim Angle	Flap Angle 10° Trim Angle
12	-0.02	-0.10	-0.16		-0.34
16	1.24				
20	2.33	2.23	2.03		1.38
24	2.42				
28	2.26	2.10	2.01		0.88
32	2.08	1.86	1.76		

Speed (knots)	Δ Angle	Δ Angle 0°	Δ Angle 5°	Δ Angle 7.5°	Δ Angle 10°
12	-	-0.08	-0.13		-0.32
16	-				
20	-	-0.10	-0.30		-0.95
24	-				
28	-	-0.16	-0.25		-1.39
32	-	-0.21	-0.31		

Table B8. Stern flap optimization and selection, model resistance experiments (continued)

Exp12 RESISTANCE: Flap#5, Chord 2 ft, Span 12.4 ft

Speed (knots)	Baseline Full Load PE (hP)	Flap Angle 0° PE (hP)	Flap Angle 5° PE (hP)	Flap Angle 7.5° PE (hP)	Flap Angle 10° PE (hP)
12	292	286	282	283	283
16	966				
20	1775	1762	1754	1707	1690
24	2478	2476	2460		2418
28	3313	3309	3313	3275	3294
32	4385	4398	4401	4498	4527

Speed (knots)	PE Ratio	PE Ratio 0°	PE Ratio 5°	PE Ratio 7.5°	PE Ratio 10°
12	-	0.979	0.966	0.969	0.969
16	-				
20	-	0.993	0.988	0.962	0.952
24	-	0.999	0.993		0.976
28	-	0.999	1.000	0.989	0.994
32	-	1.003	1.004	1.026	1.032

Exp12 TRIM: Flap#5, Chord 2 ft, Span 12.4 ft

Speed (knots)	Baseline Full Load Trim Angle	Flap Angle 0° Trim Angle	Flap Angle 5° Trim Angle	Flap Angle 7.5° Trim Angle	Flap Angle 10° Trim Angle
12	-0.02	-0.06	-0.11	-0.21	-0.24
16	1.24				
20	2.33	2.16	2.17	1.78	1.65
24	2.42	2.25	2.26		1.69
28	2.26	2.03	2.02	1.45	1.25
32	2.08	1.74	1.76	1.07	0.89

Speed (knots)	Δ Angle	Δ Angle 0°	Δ Angle 5°	Δ Angle 7.5°	Δ Angle 10°
12	-	-0.03	-0.09	-0.19	-0.22
16	-				
20	-	-0.17	-0.16	-0.55	-0.68
24	-	-0.17	-0.16		-0.73
28	-	-0.23	-0.25	-0.81	-1.02
32	-	-0.34	-0.32	-1.00	-1.19

Exp13 RESISTANCE: Flap#6, Chord 2 ft, Span 8.7 ft

Speed (knots)	Baseline Full Load PE (hP)	Flap Angle 0° PE (hP)	Flap Angle 5° PE (hP)	Flap Angle 7.5° PE (hP)	Flap Angle 10° PE (hP)
12	292	287	287	286	288
16	966			935	933
20	1775	1763	1763	1723	1720
24	2478	2465		2425	2413
28	3313	3307	3325	3270	3240
32	4385	4425	4430	4420	4462

Speed (knots)	PE Ratio	PE Ratio 0°	PE Ratio 5°	PE Ratio 7.5°	PE Ratio 10°
12	-	0.983	0.983	0.979	0.986
16	-			0.968	0.966
20	-	0.993	0.993	0.971	0.969
24	-	0.995		0.979	0.974
28	-	0.998	1.004	0.987	0.978
32	-	1.009	1.010	1.008	1.018

Exp13 TRIM: Flap#6, Chord 2 ft, Span 8.7 ft

Speed (knots)	Baseline Full Load Trim Angle	Flap Angle 0° Trim Angle	Flap Angle 5° Trim Angle	Flap Angle 7.5° Trim Angle	Flap Angle 10° Trim Angle
12	-0.02	-0.04	-0.10	-0.14	-0.17
16	1.24			0.96	0.88
20	2.33	2.20	2.13	1.95	1.84
24	2.42	2.27		2.02	1.90
28	2.26	2.00	2.07	1.79	1.54
32	2.08	1.84	1.85	1.45	1.20

Speed (knots)	Δ Angle	Δ Angle 0°	Δ Angle 5°	Δ Angle 7.5°	Δ Angle 10°
12	-	-0.02	-0.08	-0.12	-0.15
16	-			-0.28	-0.36
20	-	-0.13	-0.20	-0.38	-0.49
24	-	-0.15		-0.40	-0.52
28	-	-0.26	-0.19	-0.48	-0.72
32	-	-0.24	-0.22	-0.63	-0.88

Table B8. Stern flap optimization and selection, model resistance experiments (continued)

Exp15 RESISTANCE: Flap#7, Chord 1 ft, Span 12.4 ft

Speed (knots)	Baseline Full Load PE (hP)	Flap Angle 0° PE (hP)	Flap Angle 5° PE (hP)	Flap Angle 7.5° PE (hP)	Flap Angle 10° PE (hP)
12	292	286	288	286	288
16	966				
20	1775	1763	1764	1734	1719
24	2478			2430	
28	3313	3308	3299	3284	3242
32	4385	4409	4419	4440	4473

Speed (knots)	PE Ratio	PE Ratio 0°	PE Ratio 5°	PE Ratio 7.5°	PE Ratio 10°
12	-	0.979	0.986	0.979	0.986
16	-				
20	-	0.993	0.994	0.977	0.968
24	-			0.981	
28	-	0.998	0.996	0.991	0.979
32	-	1.005	1.008	1.013	1.020

Exp15 TRIM: Flap#7, Chord 1 ft, Span 12.4 ft

Speed (knots)	Baseline Full Load Trim Angle	Flap Angle 0° Trim Angle	Flap Angle 5° Trim Angle	Flap Angle 7.5° Trim Angle	Flap Angle 10° Trim Angle
12	-0.02		-0.09	-0.12	-0.16
16	1.24				
20	2.33		2.14	1.99	1.86
24	2.42			2.05	
28	2.26	2.01	1.99	1.81	1.44
32	2.08	1.69	1.65	1.47	1.12

Speed (knots)	Δ Angle	Δ Angle 0°	Δ Angle 5°	Δ Angle 7.5°	Δ Angle 10°
12	-		-0.07	-0.10	-0.14
16	-				
20	-		-0.19	-0.34	-0.47
24	-			-0.37	
28	-	-0.25	-0.27	-0.45	-0.82
32	-	-0.39	-0.43	-0.61	-0.96

Exp16 RESISTANCE: Flap#8, Chord 1 ft, Span 8.7 ft

Speed (knots)	Baseline Full Load PE (hP)	Flap Angle 0° PE (hP)	Flap Angle 5° PE (hP)	Flap Angle 7.5° PE (hP)	Flap Angle 10° PE (hP)
12	292			288	290
16	966			952	
20	1775			1743	1735
24	2478				
28	3313			3275	3279
32	4385			4445	4446

Speed (knots)	PE Ratio	PE Ratio 0°	PE Ratio 5°	PE Ratio 7.5°	PE Ratio 10°
12	-	0.000	0.000	0.986	0.993
16	-			0.986	
20	-			0.982	0.977
24	-				
28	-			0.989	0.990
32	-			1.014	1.014

Exp15 TRIM: Flap#8, Chord 1 ft, Span 8.7ft

Speed (knots)	Baseline Full Load Trim Angle	Flap Angle 0° Trim Angle	Flap Angle 5° Trim Angle	Flap Angle 7.5° Trim Angle	Flap Angle 10° Trim Angle
12	-0.02			-0.11	-0.12
16	1.24			1.06	
20	2.33			2.03	1.95
24	2.42				
28	2.26			1.82	1.73
32	2.08			1.52	1.36

Speed (knots)	Δ Angle	Δ Angle 0°	Δ Angle 5°	Δ Angle 7.5°	Δ Angle 10°
12	-	0.02	0.02	-0.09	-0.10
16	-			-0.18	
20	-			-0.30	-0.38
24	-				
28	-			-0.44	-0.53
32	-			-0.56	-0.72

Table B9a. Island Class, resistance prediction (no flap), full load 163 L. tons, original model configuration without spray rail extension, Exp. 17

```
MODEL CONDITION    =    "Exp17,163LT, No Flap, no ExtRails"

EHP RESULTS FROM EXPERIMENT NUMBER = 17
DTRC MODEL NUMBER = 5526  DTRC    DSC     5-19-99

SHIP                                  MODEL
LENGTH             102.44 FT ( 31.2 M)                 17.95 FT     ( 5.472 M)
WETTED SURFACE    2366.SQ FT (  220. SQ M)             72.66 SQ FT ( 6.75  SQ M)
DISPLACEMENT       163.TONS  (   166. T    )            0.86 TONS ( 0.87  T)
RHO                  1.9905  ( 31.885 N SXX2/MXX4)      1.9369      ( 31.026 N SXX2/MXX4)
NU (E+5)             1.2817  ( 0.11907 SQ M/SEC)        1.0983      ( 0.10204 SQ M/SEC)

                      LINEAR RATIO                   5.706
                      ITTC FRICTION LINE
                      CORRELATION ALLOWANCE (CA)     0.00030
```

VS		PE		FRICTIONAL POWER		FN	V-L	1000CR
KNOTS	M/S	HP	KW	HP	KW			
10.00	5.14	150.9	112.5	47.3	35.2	0.294	0.988	5.035
11.00	5.66	209.8	156.5	62.2	46.4	0.323	1.087	5.390
12.00	6.17	291.0	217.0	79.9	59.5	0.353	1.186	5.936
13.00	6.69	402.1	299.8	100.6	75.0	0.382	1.284	6.668
14.00	7.20	549.8	410.0	124.5	92.8	0.412	1.383	7.531*
15.00	7.72	743.0	554.1	151.8	113.2	0.441	1.482	8.510*
16.00	8.23	963.5	718.5	182.9	136.4	0.470	1.581	9.260*
17.00	8.75	1177.6	878.2	217.8	162.4	0.500	1.680	9.492*
18.00	9.26	1379.3	1028.5	256.8	191.5	0.529	1.778	9.351*
19.00	9.77	1576.9	1175.9	300.1	223.8	0.559	1.877	9.044*
20.00	10.29	1764.2	1315.6	348.0	259.5	0.588	1.976	8.601
21.00	10.80	1943.0	1448.9	400.6	298.7	0.617	2.075	8.092
22.00	11.32	2116.3	1578.1	458.1	341.6	0.647	2.174	7.566
23.00	11.83	2288.5	1706.6	520.8	388.4	0.676	2.272	7.059
24.00	12.35	2464.2	1837.5	588.9	439.1	0.706	2.371	6.591
25.00	12.86	2648.0	1974.6	662.5	494.0	0.735	2.470	6.174
26.00	13.38	2843.3	2120.3	741.9	553.2	0.764	2.569	5.809
27.00	13.89	3053.0	2276.6	827.3	616.9	0.794	2.668	5.494
28.00	14.40	3278.3	2444.6	918.9	685.2	0.823	2.766	5.222
29.00	14.92	3518.7	2623.9	1016.9	758.3	0.853	2.865	4.984
30.00	15.43	3776.1	2815.9	1121.5	836.3	0.882	2.964	4.777
31.00	15.95	4052.8	3022.2	1232.9	919.4	0.911	3.063	4.599
32.00	16.46	4355.9	3248.2	1351.3	1007.6	0.941	3.162	4.455

* Only at these speeds does the addition of the "bow spray rails" affect the resistance.

Table B9b. Island Class, resistance prediction (no flap), full load 163 L. tons. Exp. 18 with "bow spray rails"

```
MODEL CONDITION    =    "Exp18, Baseline 163LT, No Flap, ExtRails"

EHP RESULTS FROM EXPERIMENT NUMBER = 18
DTRC MODEL NUMBER = 5526  DTRC    DSC     5-19-99

SHIP                                MODEL
LENGTH              102.44 FT ( 31.2 M)                17.95 FT    ( 5.472 M)
WETTED SURFACE     2366.SQ FT (  220. SQ M)            72.66 SQ FT ( 6.75  SQ M)
DISPLACEMENT        163.TONS  (   166. T     )          0.86 TONS ( 0.87  T)
RHO                   1.9905  ( 31.885 N SXX2/MXX4)     1.9369      ( 31.026 N SXX2/MXX4)
NU  (E+5)             1.2817  ( 0.11907 SQ M/SEC)       1.0983      ( 0.10204 SQ M/SEC)

                     LINEAR RATIO                    5.706
                     ITTC FRICTION LINE
                     CORRELATION ALLOWANCE (CA)      0.00030
```

VS		PE		FRICTIONAL POWER		FN	V-L	1000CR
KNOTS	M/S	HP	KW	HP	KW			
10.00	5.14	150.9	112.5	47.3	35.2	0.294	0.988	5.035
11.00	5.66	209.8	156.5	62.2	46.4	0.323	1.087	5.390
12.00	6.17	291.0	217.0	79.9	59.5	0.353	1.186	5.936
13.00	6.69	402.1	299.8	100.6	75.0	0.382	1.284	6.668
14.00	7.20	550.3	410.4	124.5	92.8	0.412	1.383	7.540*
15.00	7.72	749.9	559.2	151.8	113.2	0.441	1.482	8.610*
16.00	8.23	976.2	727.9	182.9	136.4	0.470	1.581	9.410*
17.00	8.75	1182.5	881.8	217.8	162.4	0.500	1.680	9.540*
18.00	9.26	1382.7	1031.1	256.8	191.5	0.529	1.778	9.380*
19.00	9.77	1578.3	1177.0	300.1	223.8	0.559	1.877	9.054*
20.00	10.29	1764.2	1315.6	348.0	259.5	0.588	1.976	8.601
21.00	10.80	1943.0	1448.9	400.6	298.7	0.617	2.075	8.092
22.00	11.32	2116.3	1578.1	458.1	341.6	0.647	2.174	7.566
23.00	11.83	2288.5	1706.6	520.8	388.4	0.676	2.272	7.059
24.00	12.35	2464.2	1837.5	588.9	439.1	0.706	2.371	6.591
25.00	12.86	2648.0	1974.6	662.5	494.0	0.735	2.470	6.174
26.00	13.38	2843.3	2120.3	741.9	553.2	0.764	2.569	5.809
27.00	13.89	3053.0	2276.6	827.3	616.9	0.794	2.668	5.494
28.00	14.40	3278.3	2444.6	918.9	685.2	0.823	2.766	5.222
29.00	14.92	3518.7	2623.9	1016.9	758.3	0.853	2.865	4.984
30.00	15.43	3776.1	2815.9	1121.5	836.3	0.882	2.964	4.777
31.00	15.95	4052.8	3022.2	1232.9	919.4	0.911	3.063	4.599
32.00	16.46	4355.9	3248.2	1351.3	1007.6	0.941	3.162	4.455

* Only at these speeds does the addition of the "bow spray rails" affect the resistance.

Table B10. Island Class, resistance prediction (no flap), min-ops 144 L. tons, Exp. 21

MODEL CONDITION = "Exp21, 144LT, No Flap, ExtRails"

EHP RESULTS FROM EXPERIMENT NUMBER = 21
DTRC MODEL NUMBER = 5526 DTRC DSC 5-19-99

	SHIP	MODEL
LENGTH	102.44 FT (31.2 M)	17.95 FT (5.472 M)
WETTED SURFACE	2260.SQ FT (210. SQ M)	69.40 SQ FT (6.45 SQ M)
DISPLACEMENT	144.TONS (146. T)	0.75 TONS (0.76 T)
RHO	1.9905 (31.885 N SXX2/MXX4)	1.9369 (31.026 N SXX2/MXX4)
NU (E+5)	1.2817 (0.11907 SQ M/SEC)	1.0983 (0.10204 SQ M/SEC)

LINEAR RATIO 5.706
ITTC FRICTION LINE
CORRELATION ALLOWANCE (CA) 0.00030

VS		PE		FRICTIONAL POWER		FN	V-L	1000CR
KNOTS	M/S	HP	KW	HP	KW			
10.00	5.14	142.4	106.2	45.1	33.7	0.294	0.988	4.945
11.00	5.66	194.5	145.1	59.4	44.3	0.323	1.087	5.165
12.00	6.17	261.6	195.1	76.3	56.9	0.353	1.186	5.455
13.00	6.69	351.7	262.3	96.0	71.6	0.382	1.284	5.920
14.00	7.20	479.1	357.3	118.9	88.7	0.412	1.383	6.677
15.00	7.72	649.8	484.5	145.0	108.2	0.441	1.482	7.607
16.00	8.23	832.0	620.4	174.7	130.3	0.470	1.581	8.163
17.00	8.75	1003.4	748.2	208.0	155.1	0.500	1.680	8.234
18.00	9.26	1172.3	874.2	245.3	182.9	0.529	1.778	8.085
19.00	9.77	1339.3	998.7	286.7	213.8	0.559	1.877	7.806
20.00	10.29	1503.2	1120.9	332.4	247.9	0.588	1.976	7.444
21.00	10.80	1664.0	1240.9	382.6	285.3	0.617	2.075	7.038
22.00	11.32	1822.8	1359.2	437.6	326.3	0.647	2.174	6.617
23.00	11.83	1981.7	1477.8	497.5	371.0	0.676	2.272	6.205
24.00	12.35	2143.7	1598.5	562.5	419.4	0.706	2.371	5.818
25.00	12.86	2311.9	1724.0	632.8	471.9	0.735	2.470	5.466
26.00	13.38	2489.6	1856.5	708.6	528.4	0.764	2.569	5.154
27.00	13.89	2680.5	1998.9	790.2	589.3	0.794	2.668	4.885
28.00	14.40	2886.7	2152.6	877.7	654.5	0.823	2.766	4.655
29.00	14.92	3109.3	2318.6	971.3	724.3	0.853	2.865	4.459
30.00	15.43	3348.9	2497.3	1071.2	798.8	0.882	2.964	4.291
31.00	15.95	3603.5	2687.2	1177.6	878.2	0.911	3.063	4.142
32.00	16.46	3870.8	2886.5	1290.7	962.5	0.941	3.162	4.005

Table B11. Island Class, resistance prediction with stern flap, full load 163 L. tons, Exp. 19

```
MODEL CONDITION    =    "Exp19, 163LT, Stern Flap, ExtRails"

EHP RESULTS FROM EXPERIMENT NUMBER = 19
DTRC MODEL NUMBER = 5526  DTRC    DSC    5-19-99

                    SHIP                                  MODEL
LENGTH             102.44 FT ( 31.2 M)                   17.95 FT     ( 5.472 M)
WETTED SURFACE    2366.SQ FT (  220. SQ M)               72.66 SQ FT ( 6.75  SQ M)
DISPLACEMENT       163.TONS  (  166. T     )              0.86 TONS ( 0.87  T)
RHO                  1.9905  ( 31.885 N SXX2/MXX4)        1.9369      ( 31.026 N SXX2/MXX4)
NU (E+5)             1.2817  ( 0.11907 SQ M/SEC)          1.0983      ( 0.10204 SQ M/SEC)

                      LINEAR RATIO                  5.706
                      ITTC FRICTION LINE
                      CORRELATION ALLOWANCE (CA)    0.00030
```

VS		PE		FRICTIONAL POWER		FN	V-L	1000CR
KNOTS	M/S	HP	KW	HP	KW			
10.00	5.14	149.1	111.2	47.3	35.2	0.294	0.988	4.949
11.00	5.66	205.8	153.4	62.2	46.4	0.323	1.087	5.242
12.00	6.17	283.4	211.4	79.9	59.5	0.353	1.186	5.724
13.00	6.69	389.6	290.5	100.6	75.0	0.382	1.284	6.392
14.00	7.20	530.8	395.8	124.5	92.8	0.412	1.383	7.195
15.00	7.72	721.9	538.3	151.8	113.2	0.441	1.482	8.206
16.00	8.23	939.5	700.6	182.9	136.4	0.470	1.581	8.975
17.00	8.75	1139.0	849.4	217.8	162.4	0.500	1.680	9.110
18.00	9.26	1339.9	999.2	256.8	191.5	0.529	1.778	9.023
19.00	9.77	1535.8	1145.3	300.1	223.8	0.559	1.877	8.753
20.00	10.29	1722.6	1284.5	348.0	259.5	0.588	1.976	8.348
21.00	10.80	1900.7	1417.3	400.6	298.7	0.617	2.075	7.870
22.00	11.32	2072.2	1545.2	458.1	341.6	0.647	2.174	7.365
23.00	11.83	2240.7	1670.9	520.8	388.4	0.676	2.272	6.868
24.00	12.35	2411.3	1798.1	588.9	439.1	0.706	2.371	6.405
25.00	12.86	2589.2	1930.7	662.5	494.0	0.735	2.470	5.991
26.00	13.38	2779.6	2072.8	741.9	553.2	0.764	2.569	5.633
27.00	13.89	2988.6	2228.6	827.3	616.9	0.794	2.668	5.335
28.00	14.40	3218.6	2400.1	918.9	685.2	0.823	2.766	5.090
29.00	14.92	3472.6	2589.5	1016.9	758.3	0.853	2.865	4.892
30.00	15.43	3748.9	2795.6	1121.5	836.3	0.882	2.964	4.728
31.00	15.95	4045.4	3016.7	1232.9	919.4	0.911	3.063	4.587
32.00	16.46	4355.9	3248.2	1351.3	1007.6	0.941	3.162	4.455

* Addition of "bow spray rails" results in a change in Cr over full speed range.

Table B12. Island Class, resistance prediction with stern flap, min-ops 144 L. tons, Exp. 20

MODEL CONDITION = "Exp20, 144LT, Stern Flap, ExtRails"

EHP RESULTS FROM EXPERIMENT NUMBER = 20
DTRC MODEL NUMBER = 5526 DTRC DSC 5-19-99

	SHIP		MODEL	
LENGTH	102.44 FT	(31.2 M)	17.95 FT	(5.472 M)
WETTED SURFACE	2260.SQ FT	(210. SQ M)	69.40 SQ FT	(6.45 SQ M)
DISPLACEMENT	144.TONS	(146. T)	0.75 TONS	(0.76 T)
RHO	1.9905	(31.885 N SXX2/MXX4)	1.9369	(31.026 N SXX2/MXX4)
NU (E+5)	1.2817	(0.11907 SQ M/SEC)	1.0983	(0.10204 SQ M/SEC)

LINEAR RATIO 5.706
ITTC FRICTION LINE
CORRELATION ALLOWANCE (CA) 0.00030

VS		PE		FRICTIONAL POWER		FN	V-L	1000CR
KNOTS	M/S	HP	KW	HP	KW			
10.00	5.14	139.9	104.3	45.1	33.7	0.294	0.988	4.820
11.00	5.66	190.5	142.0	59.4	44.3	0.323	1.087	5.010
12.00	6.17	254.0	189.4	76.3	56.9	0.353	1.186	5.232
13.00	6.69	340.1	253.6	96.0	71.6	0.382	1.284	5.650
14.00	7.20	462.3	344.8	118.9	88.7	0.412	1.383	6.366
15.00	7.72	625.5	466.4	145.0	108.2	0.441	1.482	7.241
16.00	8.23	802.9	598.7	174.7	130.3	0.470	1.581	7.801
17.00	8.75	971.7	724.6	208.0	155.1	0.500	1.680	7.906
18.00	9.26	1136.4	847.4	245.3	182.9	0.529	1.778	7.772
19.00	9.77	1300.9	970.1	286.7	213.8	0.559	1.877	7.521
20.00	10.29	1463.4	1091.2	332.4	247.9	0.588	1.976	7.191
21.00	10.80	1623.6	1210.7	382.6	285.3	0.617	2.075	6.816
22.00	11.32	1782.4	1329.1	437.6	326.3	0.647	2.174	6.424
23.00	11.83	1941.3	1447.6	497.5	371.0	0.676	2.272	6.036
24.00	12.35	2103.2	1568.3	562.5	419.4	0.706	2.371	5.669
25.00	12.86	2271.3	1693.7	632.8	471.9	0.735	2.470	5.334
26.00	13.38	2449.1	1826.3	708.6	528.4	0.764	2.569	5.037
27.00	13.89	2640.7	1969.2	790.2	589.3	0.794	2.668	4.782
28.00	14.40	2848.7	2124.3	877.7	654.5	0.823	2.766	4.567
29.00	14.92	3074.8	2292.9	971.3	724.3	0.853	2.865	4.387
30.00	15.43	3318.2	2474.3	1071.2	798.8	0.882	2.964	4.233
31.00	15.95	3577.2	2667.5	1177.6	878.2	0.911	3.063	4.097
32.00	16.46	3843.7	2866.3	1290.7	962.5	0.941	3.162	3.963

Table B13. Island Class, estimated powering (no flap), full load 163 L. tons

WPB estimate 163LT No Flap, including "bow spray rails"

SHIP LENGTH	102.4 FEET	(31.2 METERS)	
SHIP DISPLACEMENT	163. TONS	(166. METRIC TONS)	
SHIP WETTED SURFACE	2366. SQFT	(220. SQ METERS)	
CORRELATION ALLOWANCE	.00030		ITTC FRICTION USED

SHIP SPEED (KTS)	SHIP SPEED (M/S)	RESIDUARY RES.COEF. (CR*1000)	EFFECTIVE POWER- PE (HP)	EFFECTIVE POWER- PE (kW)	DELIVERED POWER- PD (HP)	DELIVERED POWER- PD (kW)	PROPELLER REV. PER MINUTE
10.0	5.14	5.041	151.0	112.6	288.4	215.1	291.7
11.0	5.66	5.396	210.0	156.6	394.5	294.2	324.3
12.0	6.17	5.937	291.0	217.0	541.8	404.0	359.4
13.0	6.69	6.666	402.0	299.8	745.8	556.1	397.5
14.0	7.20	7.534	550.0	410.1	1023.3	763.1	438.1
15.0	7.72	8.611	750.0	559.3	1404.8	1047.5	482.1
16.0	8.23	9.408	976.0	727.8	1839.1	1371.4	524.0
17.0	8.75	9.545	1183.0	882.2	2221.2	1656.3	557.9
18.0	9.26	9.382	1383.0	1031.3	2581.9	1925.3	587.9
19.0	9.77	9.052	1578.0	1176.7	2924.7	2180.9	615.2
20.0	10.29	8.600	1764.0	1315.4	3239.6	2415.8	639.9
21.0	10.80	8.092	1943.0	1448.9	3532.5	2634.2	662.2
22.0	11.32	7.565	2116.0	1577.9	3809.7	2840.9	683.4
23.0	11.83	7.061	2289.0	1706.9	4074.5	3038.3	703.3
24.0	12.35	6.590	2464.0	1837.4	4327.8	3227.3	722.3
25.0	12.86	6.174	2648.0	1974.6	4592.5	3424.6	741.1
26.0	13.38	5.808	2843.0	2120.0	4857.7	3622.4	759.5
27.0	13.89	5.494	3053.0	2276.6	5119.5	3817.6	777.2
28.0	14.40	5.221	3278.0	2444.4	5379.3	4011.4	794.2
29.0	14.92	4.985	3519.0	2624.1	5627.6	4196.5	810.4
30.0	15.43	4.777	3776.0	2815.8	5935.4	4426.0	828.8
31.0	15.95	4.599	4053.0	3022.3	6293.9	4693.3	848.9
32.0	16.46	4.455	4356.0	3248.3	6692.6	4990.7	869.6

SHIP SPEED (KTS)	EFFICIENCIES (ETA) ETAD	ETAO	ETAH	ETAR	ETAB	THRUST DEDUCTION AND WAKE FACTORS 1-THDF	1-WFTT	1-WFTQ	ADVANCE COEF. ADVC
10.0	0.525	0.630	0.810	1.025	0.645	0.825	1.015	1.030	0.850
11.0	0.530	0.630	0.815	1.040	0.655	0.830	1.020	1.045	0.845
12.0	0.535	0.625	0.820	1.050	0.655	0.835	1.025	1.055	0.835
13.0	0.540	0.620	0.820	1.060	0.655	0.845	1.030	1.065	0.825
14.0	0.535	0.610	0.825	1.065	0.650	0.850	1.030	1.075	0.810
15.0	0.535	0.605	0.830	1.065	0.645	0.860	1.035	1.085	0.790
16.0	0.530	0.600	0.830	1.065	0.640	0.865	1.040	1.090	0.780
17.0	0.535	0.600	0.835	1.060	0.635	0.875	1.045	1.090	0.780
18.0	0.535	0.605	0.840	1.055	0.635	0.885	1.050	1.090	0.790
19.0	0.540	0.605	0.845	1.050	0.640	0.890	1.055	1.090	0.795
20.0	0.545	0.610	0.850	1.045	0.640	0.900	1.055	1.090	0.810
21.0	0.550	0.620	0.855	1.040	0.640	0.905	1.055	1.085	0.820
22.0	0.555	0.625	0.865	1.035	0.645	0.915	1.060	1.080	0.835
23.0	0.560	0.630	0.870	1.030	0.645	0.920	1.055	1.075	0.845
24.0	0.570	0.630	0.880	1.025	0.645	0.930	1.055	1.070	0.860
25.0	0.575	0.635	0.890	1.020	0.650	0.935	1.050	1.065	0.870
26.0	0.585	0.640	0.900	1.020	0.650	0.940	1.045	1.060	0.880
27.0	0.595	0.640	0.910	1.025	0.655	0.950	1.040	1.055	0.885
28.0	0.610	0.640	0.925	1.030	0.660	0.955	1.030	1.045	0.890
29.0	0.625	0.640	0.940	1.035	0.665	0.960	1.020	1.040	0.895
30.0	0.635	0.640	0.955	1.040	0.670	0.965	1.015	1.035	0.900
31.0	0.645	0.645	0.960	1.040	0.670	0.970	1.010	1.035	0.905
32.0	0.650	0.645	0.970	1.045	0.670	0.975	1.010	1.030	0.910

Table B14. Island Class, estimated powering (no flap), min-ops 144 L. tons

WPB estimate 144LT No Flap, including "bow spray rails"
SHIP LENGTH 102.4 FEET (31.2 METERS)
SHIP DISPLACEMENT 144. TONS (146. METRIC TONS)
SHIP WETTED SURFACE 2260. SQFT (210. SQ METERS)
CORRELATION ALLOWANCE .00030 ITTC FRICTION USED

SHIP SPEED (KTS)	SHIP SPEED (M/S)	RESIDUARY RES.COEF. (CR*1000)	EFFECTIVE POWER- PE (HP)	EFFECTIVE POWER- PE (kW)	DELIVERED POWER- PD (HP)	DELIVERED POWER- PD (kW)	PROPELLER REV. PER MINUTE
10.0	5.14	4.927	142.0	105.9	269.5	200.9	287.5
11.0	5.66	5.183	195.0	145.4	363.3	270.9	318.6
12.0	6.17	5.467	262.0	195.4	481.7	359.2	350.4
13.0	6.69	5.926	352.0	262.5	641.9	478.7	384.8
14.0	7.20	6.675	479.0	357.2	873.9	651.7	423.1
15.0	7.72	7.610	650.0	484.7	1191.3	888.3	464.6
16.0	8.23	8.163	832.0	620.4	1529.1	1140.3	502.5
17.0	8.75	8.230	1003.0	747.9	1835.5	1368.8	534.3
18.0	9.26	8.082	1172.0	874.0	2133.6	1591.0	563.3
19.0	9.77	7.804	1339.0	998.5	2422.5	1806.4	589.9
20.0	10.29	7.443	1503.0	1120.8	2699.4	2012.9	614.7
21.0	10.80	7.038	1664.0	1240.8	2965.2	2211.2	637.4
22.0	11.32	6.618	1823.0	1359.4	3225.5	2405.3	659.4
23.0	11.83	6.206	1982.0	1478.0	3476.1	2592.1	679.9
24.0	12.35	5.819	2144.0	1598.8	3720.2	2774.2	699.6
25.0	12.86	5.466	2312.0	1724.1	3970.7	2961.0	719.0
26.0	13.38	5.155	2490.0	1856.8	4221.8	3148.2	737.8
27.0	13.89	4.886	2681.0	1999.2	4469.0	3332.5	755.7
28.0	14.40	4.656	2887.0	2152.8	4715.8	3516.6	773.1
29.0	14.92	4.458	3109.0	2318.4	4953.6	3693.9	789.6
30.0	15.43	4.291	3349.0	2497.3	5251.4	3916.0	808.4
31.0	15.95	4.143	3604.0	2687.5	5590.4	4168.8	828.7
32.0	16.46	4.005	3871.0	2886.6	5947.6	4435.1	849.1

SHIP SPEED (KTS)	EFFICIENCIES (ETA) ETAD	ETAO	ETAH	ETAR	ETAB	THRUST DEDUCTION AND WAKE FACTORS 1-THDF	1-WFTT	1-WFTQ	ADVANCE COEF. ADVC
10.0	0.525	0.635	0.810	1.025	0.650	0.825	1.015	1.030	0.865
11.0	0.535	0.635	0.815	1.040	0.660	0.830	1.020	1.045	0.860
12.0	0.545	0.630	0.820	1.050	0.665	0.835	1.025	1.055	0.860
13.0	0.550	0.630	0.820	1.060	0.665	0.845	1.030	1.065	0.850
14.0	0.550	0.625	0.825	1.065	0.665	0.850	1.030	1.070	0.835
15.0	0.545	0.615	0.830	1.065	0.660	0.860	1.035	1.080	0.820
16.0	0.545	0.615	0.830	1.065	0.655	0.865	1.040	1.085	0.815
17.0	0.545	0.615	0.835	1.060	0.655	0.875	1.045	1.085	0.815
18.0	0.550	0.620	0.840	1.055	0.655	0.885	1.050	1.085	0.820
19.0	0.555	0.620	0.845	1.050	0.655	0.890	1.055	1.085	0.830
20.0	0.555	0.625	0.850	1.045	0.655	0.900	1.055	1.085	0.840
21.0	0.560	0.630	0.855	1.040	0.655	0.905	1.055	1.080	0.855
22.0	0.565	0.635	0.865	1.035	0.655	0.915	1.060	1.080	0.865
23.0	0.570	0.635	0.870	1.030	0.655	0.920	1.055	1.075	0.875
24.0	0.575	0.640	0.880	1.025	0.655	0.930	1.055	1.070	0.885
25.0	0.580	0.640	0.890	1.020	0.655	0.935	1.050	1.065	0.895
26.0	0.590	0.645	0.900	1.020	0.655	0.940	1.045	1.060	0.905
27.0	0.600	0.645	0.910	1.025	0.660	0.950	1.040	1.050	0.910
28.0	0.610	0.645	0.925	1.030	0.660	0.955	1.030	1.045	0.915
29.0	0.630	0.645	0.940	1.035	0.665	0.960	1.020	1.040	0.920
30.0	0.640	0.645	0.955	1.040	0.670	0.965	1.015	1.035	0.920
31.0	0.645	0.645	0.960	1.040	0.670	0.970	1.010	1.030	0.925
32.0	0.650	0.645	0.970	1.045	0.670	0.975	1.010	1.030	0.930

Table B15. Island Class, estimated powering with stern flap, full load 163 L. tons

WPB estimate 163LT Stern Flap, including "bow spray rails"
SHIP LENGTH 102.4 FEET (31.2 METERS)
SHIP DISPLACEMENT 163. TONS (166. METRIC TONS)
SHIP WETTED SURFACE 2366. SQFT (220. SQ METERS)
CORRELATION ALLOWANCE .00030 ITTC FRICTION USED

SHIP SPEED (KTS)	SHIP SPEED (M/S)	RESIDUARY RES.COEF. (CR*1000)	EFFECTIVE POWER- PE (HP)	EFFECTIVE POWER- PE (kW)	DELIVERED POWER- PD (HP)	DELIVERED POWER- PD (kW)	PROPELLER REV. PER MINUTE
10.0	5.14	4.943	149.0	111.1	284.2	211.9	290.8
11.0	5.66	5.250	206.0	153.6	386.1	287.9	322.8
12.0	6.17	5.712	283.0	211.0	525.0	391.5	357.0
13.0	6.69	6.401	390.0	290.8	720.5	537.3	394.5
14.0	7.20	7.198	531.0	396.0	982.8	732.9	434.2
15.0	7.72	8.208	722.0	538.4	1344.3	1002.4	477.3
16.0	8.23	8.981	940.0	701.0	1760.5	1312.8	518.7
17.0	8.75	9.110	1139.0	849.4	2125.6	1585.1	552.3
18.0	9.26	9.024	1340.0	999.2	2489.1	1856.1	583.1
19.0	9.77	8.754	1536.0	1145.4	2834.9	2114.0	610.9
20.0	10.29	8.351	1723.0	1284.8	3153.2	2351.4	636.0
21.0	10.80	7.872	1901.0	1417.6	3445.5	2569.3	658.6
22.0	11.32	7.364	2072.0	1545.1	3720.2	2774.2	679.9
23.0	11.83	6.869	2241.0	1671.1	3979.0	2967.2	699.7
24.0	12.35	6.404	2411.0	1797.9	4225.2	3150.7	718.6
25.0	12.86	5.990	2589.0	1930.6	4481.1	3341.6	737.3
26.0	13.38	5.634	2780.0	2073.0	4741.9	3536.0	755.7
27.0	13.89	5.336	2989.0	2228.9	5005.3	3732.4	773.5
28.0	14.40	5.091	3219.0	2400.4	5277.1	3935.1	791.1
29.0	14.92	4.893	3473.0	2589.8	5550.3	4138.9	808.1
30.0	15.43	4.728	3749.0	2795.6	5891.2	4393.1	827.6
31.0	15.95	4.586	4045.0	3016.4	6281.0	4683.8	848.5
32.0	16.46	4.455	4356.0	3248.3	6692.6	4990.7	869.6

SHIP SPEED (KTS)	EFFICIENCIES (ETA) ETAD	ETAO	ETAH	ETAR	ETAB	THRUST DEDUCTION AND WAKE FACTORS 1-THDF	1-WFTT	1-WFTQ	ADVANCE COEF. ADVC
10.0	0.525	0.630	0.810	1.025	0.645	0.825	1.015	1.030	0.855
11.0	0.535	0.630	0.815	1.040	0.655	0.830	1.020	1.045	0.850
12.0	0.540	0.625	0.820	1.050	0.660	0.835	1.025	1.055	0.840
13.0	0.540	0.620	0.820	1.060	0.660	0.845	1.030	1.065	0.830
14.0	0.540	0.615	0.825	1.065	0.655	0.850	1.030	1.075	0.815
15.0	0.535	0.610	0.830	1.065	0.650	0.860	1.035	1.080	0.800
16.0	0.535	0.605	0.830	1.065	0.640	0.865	1.040	1.090	0.785
17.0	0.535	0.605	0.835	1.060	0.640	0.875	1.045	1.090	0.790
18.0	0.540	0.605	0.840	1.055	0.640	0.885	1.050	1.090	0.795
19.0	0.540	0.610	0.845	1.050	0.640	0.890	1.055	1.090	0.800
20.0	0.545	0.615	0.850	1.045	0.645	0.900	1.055	1.085	0.815
21.0	0.550	0.620	0.855	1.040	0.645	0.905	1.055	1.085	0.825
22.0	0.555	0.625	0.865	1.035	0.645	0.915	1.060	1.080	0.840
23.0	0.565	0.630	0.870	1.030	0.645	0.920	1.055	1.075	0.850
24.0	0.570	0.635	0.880	1.025	0.650	0.930	1.055	1.070	0.865
25.0	0.580	0.635	0.890	1.020	0.650	0.935	1.050	1.065	0.875
26.0	0.585	0.640	0.900	1.020	0.650	0.940	1.045	1.060	0.885
27.0	0.595	0.640	0.910	1.025	0.655	0.950	1.040	1.055	0.890
28.0	0.610	0.640	0.925	1.030	0.660	0.955	1.030	1.045	0.895
29.0	0.625	0.640	0.940	1.035	0.665	0.960	1.020	1.040	0.895
30.0	0.635	0.640	0.955	1.040	0.670	0.965	1.015	1.035	0.900
31.0	0.645	0.645	0.960	1.040	0.670	0.970	1.010	1.035	0.905
32.0	0.650	0.645	0.970	1.045	0.670	0.975	1.010	1.030	0.910

Table B16. Island Class, estimated powering with stern flap, min-ops 144 L. tons

WPB estimate 144LT Stern Flap, including "bow spray rails"
SHIP LENGTH 102.4 FEET (31.2 METERS)
SHIP DISPLACEMENT 144. TONS (146. METRIC TONS)
SHIP WETTED SURFACE 2260. SQFT (210. SQ METERS)
CORRELATION ALLOWANCE .00030 ITTC FRICTION USED

SHIP SPEED (KTS)	SHIP SPEED (M/S)	RESIDUARY RES.COEF. (CR*1000)	EFFECTIVE POWER- PE (HP)	EFFECTIVE POWER- PE (kW)	DELIVERED POWER- PD (HP)	DELIVERED POWER- PD (kW)	PROPELLER REV. PER MINUTE
10.0	5.14	4.825	140.0	104.4	265.3	197.8	286.6
11.0	5.66	5.030	191.0	142.4	355.1	264.8	317.1
12.0	6.17	5.231	254.0	189.4	465.5	347.1	347.9
13.0	6.69	5.648	340.0	253.5	617.6	460.6	381.6
14.0	7.20	6.360	462.0	344.5	839.1	625.7	419.4
15.0	7.72	7.249	626.0	466.8	1141.2	851.0	460.2
16.0	8.23	7.802	803.0	598.8	1468.2	1094.8	498.0
17.0	8.75	7.909	972.0	724.8	1770.8	1320.5	530.1
18.0	9.26	7.768	1136.0	847.1	2059.0	1535.4	558.9
19.0	9.77	7.522	1301.0	970.2	2344.7	1748.5	585.7
20.0	10.29	7.189	1463.0	1091.0	2618.9	1952.9	610.7
21.0	10.80	6.818	1624.0	1211.0	2886.2	2152.2	633.8
22.0	11.32	6.422	1782.0	1328.8	3146.1	2346.0	655.9
23.0	11.83	6.035	1941.0	1447.4	3398.5	2534.3	676.7
24.0	12.35	5.668	2103.0	1568.2	3644.6	2717.8	696.6
25.0	12.86	5.333	2271.0	1693.5	3897.1	2906.1	716.2
26.0	13.38	5.037	2449.0	1826.2	4150.1	3094.8	735.2
27.0	13.89	4.783	2641.0	1969.4	4401.1	3281.9	753.4
28.0	14.40	4.568	2849.0	2124.5	4653.2	3469.9	771.0
29.0	14.92	4.387	3075.0	2293.0	4899.3	3653.4	787.8
30.0	15.43	4.233	3318.0	2474.2	5203.1	3879.9	806.9
31.0	15.95	4.097	3577.0	2667.4	5549.3	4138.1	827.5
32.0	16.46	3.963	3844.0	2866.5	5907.2	4405.0	847.9

SHIP SPEED (KTS)	EFFICIENCIES (ETA) ETAD	ETAO	ETAH	ETAR	ETAB	THRUST DEDUCTION AND WAKE FACTORS 1-THDF	1-WFTT	1-WFTQ	ADVANCE COEF. ADVC
10.0	0.530	0.635	0.810	1.025	0.650	0.825	1.015	1.030	0.870
11.0	0.540	0.635	0.815	1.040	0.660	0.830	1.020	1.045	0.865
12.0	0.545	0.635	0.820	1.050	0.665	0.835	1.025	1.055	0.865
13.0	0.550	0.630	0.820	1.060	0.670	0.845	1.030	1.065	0.860
14.0	0.550	0.625	0.825	1.065	0.665	0.850	1.030	1.070	0.845
15.0	0.550	0.620	0.830	1.065	0.660	0.860	1.035	1.080	0.830
16.0	0.545	0.615	0.830	1.065	0.655	0.865	1.040	1.085	0.820
17.0	0.550	0.620	0.835	1.060	0.655	0.875	1.045	1.085	0.820
18.0	0.550	0.620	0.840	1.055	0.655	0.885	1.050	1.085	0.830
19.0	0.555	0.625	0.845	1.050	0.655	0.890	1.055	1.085	0.835
20.0	0.560	0.630	0.850	1.045	0.655	0.900	1.055	1.085	0.845
21.0	0.565	0.630	0.855	1.040	0.655	0.905	1.055	1.080	0.860
22.0	0.565	0.635	0.865	1.035	0.655	0.915	1.060	1.080	0.870
23.0	0.570	0.640	0.870	1.030	0.655	0.920	1.055	1.075	0.880
24.0	0.575	0.640	0.880	1.025	0.655	0.930	1.055	1.070	0.890
25.0	0.585	0.640	0.890	1.020	0.655	0.935	1.050	1.065	0.900
26.0	0.590	0.645	0.900	1.020	0.655	0.940	1.045	1.060	0.905
27.0	0.600	0.645	0.910	1.025	0.660	0.950	1.040	1.050	0.915
28.0	0.610	0.645	0.925	1.030	0.660	0.955	1.030	1.045	0.915
29.0	0.630	0.645	0.940	1.035	0.665	0.960	1.020	1.040	0.920
30.0	0.640	0.645	0.955	1.040	0.670	0.965	1.015	1.035	0.925
31.0	0.645	0.645	0.960	1.040	0.670	0.970	1.010	1.030	0.930
32.0	0.650	0.645	0.970	1.045	0.670	0.975	1.010	1.030	0.930

Table B17. Summary of model scale stern flap and "bow spray rails" performance on Island Class

RESISTANCE: Full Load 163.39 LT						
VS	Exp17, Baseline 163LT, No Flap	Exp18, Baseline 163LT, No Flap, ExtRails	PE ratio Exp18/17, Extended Spray Rail Effects	Exp19, 163LT, Stern Flap, ExtRails	PE ratio Exp19/18, Stern Flap Effects	PE ratio Exp19/18, Stern Flap Effects
10	151	151	1.0	149	0.988	-1.19
11	210	210	1.0	206	0.981	-1.91
12	291	291	1.0	283	0.974	-2.61
13	402	402	1.0	390	0.969	-3.11
14	550	550	1.001	531	0.965	-3.54
15	743	750	1.009	722	0.963	-3.73
16	964	976	1.013	940	0.962	-3.76
17	1178	1183	1.004	1139	0.963	-3.68
18	1379	1383	1.002	1340	0.969	-3.10
19	1577	1578	1.001	1536	0.973	-2.69
20	1764	1764	1.0	1723	0.976	-2.36
21	1943	1943	1.0	1901	0.978	-2.18
22	2116	2116	1.0	2072	0.979	-2.08
23	2289	2289	1.0	2241	0.979	-2.09
24	2464	2464	1.0	2411	0.979	-2.15
25	2648	2648	1.0	2589	0.978	-2.22
26	2843	2843	1.0	2780	0.978	-2.24
27	3053	3053	1.0	2989	0.979	-2.11
28	3278	3278	1.0	3219	0.982	-1.82
29	3519	3519	1.0	3473	0.987	-1.31
30	3776	3776	1.0	3749	0.993	-0.72
31	4053	4053	1.0	4045	0.998	-0.18
32	4356	4356	1.0	4356	1.000	0.00

RESISTANCE: Min-Ops 143.61 LT				
VS	Exp21, 144LT, No Flap, ExtRails	Exp20, 144LT, Stern Flap, ExtRails	PE ratio Exp20/21, Stern Flap Effects, ExtRails	PE ratio Exp20/21, Stern Flap Effects, ExtRails
10	142	140	0.982	-1.76
11	195	191	0.979	-2.06
12	262	254	0.971	-2.91
13	352	340	0.967	-3.30
14	479	462	0.965	-3.51
15	650	626	0.963	-3.74
16	832	803	0.965	-3.50
17	1003	972	0.968	-3.16
18	1172	1136	0.969	-3.06
19	1339	1301	0.971	-2.87
20	1503	1463	0.974	-2.65
21	1664	1624	0.976	-2.43
22	1823	1782	0.978	-2.22
23	1982	1941	0.980	-2.04
24	2144	2103	0.981	-1.89
25	2312	2271	0.982	-1.76
26	2490	2449	0.984	-1.63
27	2681	2641	0.985	-1.48
28	2887	2849	0.987	-1.32
29	3109	3075	0.989	-1.11
30	3349	3318	0.991	-0.92
31	3604	3577	0.993	-0.73
32	3871	3844	0.993	-0.70

Table B17. Summary of model scale stern flap and "bow spray rails" performance on Island Class (continued)

POWERING: Full Load 163.39 LT						
VS	Baseline 163LT, No Flap, PD	Baseline 163LT, No Flap, RPM	163LT, Stern Flap, PD	163LT, Stern Flap, RPM	Stern Flap Effects, PD Ratio	Stern Flap Effects, RPM Ratio
10	288	291.7	284	290.8	0.985	0.997
11	395	324.3	386	322.8	0.979	0.995
12	542	359.4	525	357	0.969	0.993
13	746	397.5	721	394.5	0.966	0.992
14	1023	438.1	983	434.2	0.960	0.991
15	1405	482.1	1344	477.3	0.957	0.990
16	1839	524.0	1761	518.7	0.957	0.990
17	2221	557.9	2126	552.3	0.957	0.990
18	2582	587.9	2489	583.1	0.964	0.992
19	2925	615.2	2835	610.9	0.969	0.993
20	3240	639.9	3153	636	0.973	0.994
21	3533	662.2	3446	658.6	0.975	0.995
22	3810	683.4	3720	679.9	0.977	0.995
23	4075	703.3	3979	699.7	0.977	0.995
24	4328	722.3	4225	718.6	0.976	0.995
25	4593	741.1	4481	737.3	0.976	0.995
26	4858	759.5	4742	755.7	0.976	0.995
27	5120	777.2	5005	773.5	0.978	0.995
28	5379	794.2	5277	791.1	0.981	0.996
29	5628	810.4	5550	808.1	0.986	0.997
30	5935	828.8	5891	827.6	0.993	0.999
31	6294	848.9	6281	848.5	0.998	1.000
32	6693	869.6	6693	869.6	1.000	1.000

POWERING: Min-Ops 143.61 LT						
VS	144LT, No Flap, PD	144LT, No Flap, RPM	144LT, Stern Flap, PD	144LT, Stern Flap, RPM	Stern Flap Effects, PD Ratio	Stern Flap Effects, RPM Ratio
10	270	287.5	265	286.6	0.984	0.997
11	363	318.6	355	317.1	0.977	0.995
12	482	350.4	466	347.9	0.966	0.993
13	642	384.8	618	381.6	0.962	0.992
14	874	423.1	839	419.4	0.960	0.991
15	1191	464.6	1141	460.2	0.958	0.991
16	1529	502.5	1468	498.0	0.960	0.991
17	1836	534.3	1771	530.1	0.965	0.992
18	2134	563.3	2059	558.9	0.965	0.992
19	2423	589.9	2345	585.7	0.968	0.993
20	2699	614.7	2619	610.7	0.970	0.993
21	2965	637.4	2886	633.8	0.973	0.994
22	3226	659.4	3146	655.9	0.975	0.995
23	3476	679.9	3399	676.7	0.978	0.995
24	3720	699.6	3645	696.6	0.980	0.996
25	3971	719.0	3897	716.2	0.981	0.996
26	4222	737.8	4150	735.2	0.983	0.996
27	4469	755.7	4401	753.4	0.985	0.997
28	4716	773.1	4653	771.0	0.987	0.997
29	4954	789.6	4899	787.8	0.989	0.998
30	5251	808.4	5203	806.9	0.991	0.998
31	5590	828.7	5549	827.5	0.993	0.999
32	5948	849.1	5907	847.9	0.993	0.999

Table B18. Projected full scale stern flap powering on Island Class 110 WPB, full load 163 L. tons

WPB estimate 163LT Stern Flap (fs projected)

SHIP LENGTH	102.4 FEET	(31.2 METERS)	
SHIP DISPLACEMENT	163. TONS	(166. METRIC TONS)	
SHIP WETTED SURFACE	2366. SQFT	(220. SQ METERS)	
CORRELATION ALLOWANCE	.00030	ITTC FRICTION USED	

SHIP SPEED (KTS)	SHIP SPEED (M/S)	RESIDUARY RES.COEF. (CR*1000)	EFFECTIVE POWER- PE (HP)	EFFECTIVE POWER- PE (kW)	DELIVERED POWER- PD (HP)	DELIVERED POWER- PD (kW)	PROPELLER REV. PER MINUTE
10.0	5.14	4.846	147.0	109.6	280.0	208.8	289.9
11.0	5.66	5.141	203.0	151.4	379.8	283.2	321.7
12.0	6.17	5.599	279.0	208.1	516.7	385.3	355.7
13.0	6.69	6.268	384.0	286.3	707.9	527.9	393.0
14.0	7.20	7.056	523.0	390.0	965.8	720.2	432.5
15.0	7.72	8.064	712.0	530.9	1322.8	986.4	475.6
16.0	8.23	8.826	927.0	691.3	1732.4	1291.8	516.8
17.0	8.75	8.971	1125.0	838.9	2095.3	1562.5	550.5
18.0	9.26	8.882	1323.0	986.6	2452.6	1828.9	581.1
19.0	9.77	8.620	1517.0	1131.2	2794.5	2083.9	608.9
20.0	10.29	8.217	1701.0	1268.4	3107.1	2316.9	634.0
21.0	10.80	7.746	1877.0	1399.7	3396.0	2532.4	656.5
22.0	11.32	7.245	2046.0	1525.7	3667.7	2735.0	677.8
23.0	11.83	6.757	2213.0	1650.2	3923.7	2925.9	697.6
24.0	12.35	6.299	2381.0	1775.5	4167.4	3107.6	716.5
25.0	12.86	5.891	2557.0	1906.8	4421.1	3296.8	735.2
26.0	13.38	5.537	2745.0	2046.9	4677.9	3488.3	753.6
27.0	13.89	5.242	2951.0	2200.6	4937.9	3682.2	771.4
28.0	14.40	5.000	3178.0	2369.8	5206.5	3882.4	788.9
29.0	14.92	4.805	3429.0	2557.0	5476.8	4084.0	805.9
30.0	15.43	4.644	3702.0	2760.6	5814.5	4335.9	825.3
31.0	15.95	4.505	3995.0	2979.1	6201.1	4624.1	846.3
32.0	16.46	4.374	4301.0	3207.3	6606.3	4926.3	867.3

SHIP SPEED (KTS)	EFFICIENCIES (ETA) ETAD	ETAO	ETAH	ETAR	ETAB	THRUST DEDUCTION AND WAKE FACTORS 1-THDF	1-WFTT	1-WFTQ	ADVANCE COEF. ADVC
10.0	0.525	0.630	0.810	1.025	0.650	0.825	1.015	1.030	0.860
11.0	0.535	0.630	0.815	1.040	0.655	0.830	1.020	1.045	0.855
12.0	0.540	0.625	0.820	1.050	0.660	0.835	1.025	1.055	0.845
13.0	0.540	0.625	0.820	1.060	0.660	0.845	1.030	1.065	0.835
14.0	0.540	0.615	0.825	1.065	0.655	0.850	1.030	1.075	0.820
15.0	0.540	0.610	0.830	1.065	0.650	0.860	1.035	1.080	0.800
16.0	0.535	0.605	0.830	1.065	0.645	0.865	1.040	1.090	0.790
17.0	0.535	0.605	0.835	1.060	0.640	0.875	1.045	1.090	0.790
18.0	0.540	0.605	0.840	1.055	0.640	0.885	1.050	1.090	0.795
19.0	0.545	0.610	0.845	1.050	0.640	0.890	1.055	1.090	0.805
20.0	0.545	0.615	0.850	1.045	0.645	0.900	1.055	1.085	0.815
21.0	0.555	0.620	0.855	1.040	0.645	0.905	1.055	1.085	0.830
22.0	0.560	0.625	0.865	1.035	0.645	0.915	1.060	1.080	0.840
23.0	0.565	0.630	0.870	1.030	0.650	0.920	1.055	1.075	0.855
24.0	0.570	0.635	0.880	1.025	0.650	0.930	1.055	1.070	0.865
25.0	0.580	0.635	0.890	1.020	0.650	0.935	1.050	1.065	0.875
26.0	0.585	0.640	0.900	1.020	0.655	0.940	1.045	1.060	0.885
27.0	0.600	0.640	0.910	1.025	0.655	0.950	1.040	1.055	0.890
28.0	0.610	0.640	0.925	1.030	0.660	0.955	1.030	1.045	0.895
29.0	0.625	0.640	0.940	1.035	0.665	0.960	1.020	1.040	0.900
30.0	0.635	0.645	0.955	1.040	0.670	0.965	1.015	1.035	0.905
31.0	0.645	0.645	0.960	1.040	0.670	0.970	1.010	1.035	0.905
32.0	0.650	0.645	0.970	1.045	0.670	0.975	1.010	1.030	0.910

Table B19. Projected full scale stern flap powering on Island Class 110 WPB, min-ops 144 L. tons

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WPB estimate 144LT Stern Flap (fs projected)
SHIP LENGTH              102.4 FEET   (  31.2 METERS)
SHIP DISPLACEMENT         144. TONS   (  146. METRIC TONS)
SHIP WETTED SURFACE      2260. SQFT   (  210. SQ METERS)
CORRELATION ALLOWANCE .00030          ITTC FRICTION USED
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SHIP SPEED (KTS)	SHIP SPEED (M/S)	RESIDUARY RES.COEF. (CR*1000)	EFFECTIVE POWER- PE (HP)	EFFECTIVE POWER- PE (kW)	DELIVERED POWER- PD (HP)	DELIVERED POWER- PD (kW)	PROPELLER REV. PER MINUTE
10.0	5.14	4.723	138.0	102.9	261.2	194.8	285.6
11.0	5.66	4.915	188.0	140.2	349.0	260.2	315.9
12.0	6.17	5.114	250.0	186.4	457.5	341.1	346.6
13.0	6.69	5.532	335.0	249.8	607.6	453.1	380.3
14.0	7.20	6.249	456.0	340.0	826.8	616.6	418.0
15.0	7.72	7.113	617.0	460.1	1122.6	837.1	458.6
16.0	8.23	7.666	792.0	590.6	1445.3	1077.7	496.3
17.0	8.75	7.785	960.0	715.9	1745.8	1301.9	528.4
18.0	9.26	7.646	1122.0	836.7	2030.2	1513.9	557.2
19.0	9.77	7.403	1285.0	958.2	2312.2	1724.2	584.0
20.0	10.29	7.074	1445.0	1077.5	2582.9	1926.0	608.8
21.0	10.80	6.703	1603.0	1195.4	2844.9	2121.5	631.8
22.0	11.32	6.317	1760.0	1312.4	3103.7	2314.5	654.0
23.0	11.83	5.934	1917.0	1429.5	3353.4	2500.6	674.8
24.0	12.35	5.573	2077.0	1548.8	3597.0	2682.3	694.7
25.0	12.86	5.242	2243.0	1672.6	3847.1	2868.8	714.3
26.0	13.38	4.947	2418.0	1803.1	4096.3	3054.6	733.2
27.0	13.89	4.698	2608.0	1944.8	4345.4	3240.4	751.4
28.0	14.40	4.484	2813.0	2097.7	4594.2	3425.9	769.0
29.0	14.92	4.306	3036.0	2263.9	4837.3	3607.2	785.8
30.0	15.43	4.155	3277.0	2443.7	5139.5	3832.5	804.9
31.0	15.95	4.020	3532.0	2633.8	5481.0	4087.2	825.4
32.0	16.46	3.889	3796.0	2830.7	5835.9	4351.8	845.8

SHIP SPEED (KTS)	EFFICIENCIES (ETA) ETAD	ETAO	ETAH	ETAR	ETAB	THRUST DEDUCTION AND WAKE FACTORS 1-THDF	1-WFTT	1-WFTQ	ADVANCE COEF. ADVC
10.0	0.530	0.635	0.810	1.025	0.650	0.825	1.015	1.030	0.870
11.0	0.540	0.635	0.815	1.040	0.660	0.830	1.020	1.040	0.870
12.0	0.545	0.635	0.820	1.050	0.670	0.835	1.025	1.055	0.870
13.0	0.550	0.635	0.820	1.060	0.670	0.845	1.030	1.065	0.860
14.0	0.550	0.630	0.825	1.065	0.670	0.850	1.030	1.070	0.845
15.0	0.550	0.620	0.830	1.065	0.665	0.860	1.035	1.080	0.830
16.0	0.550	0.620	0.830	1.065	0.660	0.865	1.040	1.085	0.825
17.0	0.550	0.620	0.835	1.060	0.655	0.875	1.045	1.085	0.825
18.0	0.555	0.620	0.840	1.055	0.655	0.885	1.050	1.085	0.830
19.0	0.555	0.625	0.845	1.050	0.660	0.890	1.055	1.085	0.840
20.0	0.560	0.630	0.850	1.045	0.660	0.900	1.055	1.085	0.850
21.0	0.565	0.635	0.855	1.040	0.655	0.905	1.055	1.080	0.860
22.0	0.565	0.635	0.865	1.035	0.655	0.915	1.060	1.075	0.870
23.0	0.570	0.640	0.870	1.030	0.655	0.920	1.055	1.075	0.885
24.0	0.575	0.640	0.880	1.025	0.655	0.930	1.055	1.070	0.895
25.0	0.585	0.645	0.890	1.020	0.655	0.935	1.050	1.065	0.900
26.0	0.590	0.645	0.900	1.020	0.655	0.940	1.045	1.060	0.910
27.0	0.600	0.645	0.910	1.025	0.660	0.950	1.040	1.050	0.915
28.0	0.610	0.645	0.925	1.030	0.660	0.955	1.030	1.045	0.920
29.0	0.630	0.645	0.940	1.035	0.665	0.960	1.020	1.040	0.920
30.0	0.640	0.645	0.955	1.040	0.670	0.965	1.015	1.035	0.925
31.0	0.645	0.645	0.960	1.040	0.670	0.970	1.010	1.030	0.930
32.0	0.650	0.645	0.970	1.045	0.670	0.975	1.010	1.030	0.935

Table B20. Stern flap on Island Class 110 WPB: Summary of full scale projected performance (indluding flap scale effects)

POWERING: Full Load 163.39 LT						
VS	Baseline 163LT, No Flap, PD	Baseline 163LT, No Flap, RPM	163LT, Stern Flap, PD	163LT, Stern Flap, RPM	Stern Flap Effects, PD Ratio	Stern Flap Effects, RPM Ratio
10	288	291.7	280	289.9	0.971	0.994
11	395	324.3	380	321.7	0.963	0.992
12	542	359.4	517	355.7	0.954	0.990
13	746	397.5	708	393.0	0.949	0.989
14	1023	438.1	966	432.5	0.944	0.987
15	1405	482.1	1323	475.6	0.942	0.987
16	1839	524.0	1732	516.8	0.942	0.986
17	2221	557.9	2095	550.5	0.943	0.987
18	2582	587.9	2453	581.1	0.950	0.988
19	2925	615.2	2795	608.9	0.955	0.990
20	3240	639.9	3107	634.0	0.959	0.991
21	3533	662.2	3396	656.5	0.961	0.991
22	3810	683.4	3668	677.8	0.963	0.992
23	4075	703.3	3924	697.6	0.963	0.992
24	4328	722.3	4167	716.5	0.963	0.992
25	4593	741.1	4421	735.2	0.963	0.992
26	4858	759.5	4678	753.6	0.963	0.992
27	5120	777.2	4938	771.4	0.965	0.993
28	5379	794.2	5207	788.9	0.968	0.993
29	5628	810.4	5477	805.9	0.973	0.994
30	5935	828.8	5815	825.3	0.980	0.996
31	6294	848.9	6201	846.3	0.985	0.997
32	6693	869.6	6606	867.3	0.987	0.997

POWERING: Min-Ops 143.61 LT						
VS	144LT, No Flap, PD	144LT, No Flap, RPM	144LT, Stern Flap, PD	144LT, Stern Flap, RPM	Stern Flap Effects, PD Ratio	Stern Flap Effects, RPM Ratio
10	270	287.5	261	285.6	0.9692	0.9934
11	363	318.6	349	315.9	0.9606	0.9915
12	482	350.4	458	346.6	0.9498	0.9892
13	642	384.8	608	380.3	0.9466	0.9883
14	874	423.1	827	418.0	0.9461	0.9879
15	1191	464.6	1123	458.6	0.9423	0.9871
16	1529	502.5	1445	496.3	0.9452	0.9877
17	1836	534.3	1746	528.4	0.9511	0.9890
18	2134	563.3	2030	557.2	0.9515	0.9892
19	2423	589.9	2312	584.0	0.9545	0.9900
20	2699	614.7	2583	608.8	0.9568	0.9904
21	2965	637.4	2845	631.8	0.9594	0.9912
22	3226	659.4	3104	654.0	0.9622	0.9918
23	3476	679.9	3353	674.8	0.9647	0.9925
24	3720	699.6	3597	694.7	0.9669	0.9930
25	3971	719.0	3847	714.3	0.9689	0.9935
26	4222	737.8	4096	733.2	0.9703	0.9938
27	4469	755.7	4345	751.4	0.9723	0.9943
28	4716	773.1	4594	769.0	0.9742	0.9947
29	4954	789.6	4837	785.8	0.9765	0.9952
30	5251	808.4	5140	804.9	0.9787	0.9957
31	5590	828.7	5481	825.4	0.9804	0.9960
32	5948	849.1	5836	845.8	0.9812	0.9961

Table B21. Estimate of Island Class main propulsion engine fuel consumption rates. with/without stern flap installed (both include effect of "bow spray rails")

BASELINE (No Flap), Full Load (163 L tons)

Based on 2000 Annual Operational hours

Speed (knots)	Total Power PD (hP)	Fuel Consumption (gal/hr)	Speed-Time Profile (% time)	Annual Fuel Consumption (gal/yr)
12	542	33.4	40	26747
13	746	45.1		
14	1023	60.3		
15	1405	79.9	25	39935
16	1839	100.9		
17	2221	118.8		
18	2582	135.5	10	27095
19	2925	151.5		
20	3240	166.6		
21	3533	181.2	5	18117
22	3810	195.6		
23	4075	210.2	5	21015
24	4328	224.9		
25	4593	241.2	5	24117
26	4858	258.6		
27	5120	277.1	10	55423
28	5379	296.8		
29	5628	316.9		
30	5935	344.0		
Total Annual Fuel Consumption (gallons/yr):				212449

STERN FLAP, Full Load (163 L tons)

Based on 2000 Annual Operational hours

Speed (knots)	Total Power PD (hP)	Fuel Consumption (gal/hr)	Speed-Time Profile (% time)	Annual Fuel Consumption (gal/yr)
12	517	32.0	40	25564
13	708	43.0		
14	966	57.2		
15	1323	75.8	25	37881
16	1732	95.8		
17	2095	112.9		
18	2453	129.5	10	25898
19	2795	145.4		
20	3107	160.2		
21	3396	174.3	5	17430
22	3668	188.1		
23	3924	201.8	5	20178
24	4167	215.4		
25	4421	230.5	5	23049
26	4678	246.7		
27	4938	264.2	10	52833
28	5207	283.5		
29	5477	304.5		
30	5815	333.1		
Total Annual Fuel Consumption (gallons/yr):				202832
Annual Fuel Savings (gallons/yr):				9617
				4.5%

BASELINE (No Flap), Min-Ops (144 L tons)

Based on 1000 Annual Operational hours

Speed (knots)	Total Power PD (hP)	Fuel Consumption (gal/hr)	Speed-Time Profile (% time)	Annual Fuel Consumption (gal/yr)
12	482	29.9	40	11952
13	642	39.2		
14	874	52.2		
15	1191	69.1	25	17265
16	1529	86.0		
17	1836	100.7		
18	2134	114.7	10	11472
19	2423	128.1		
20	2699	140.9		
21	2965	153.4	5	7670
22	3226	165.9		
23	3476	178.3	5	8916
24	3720	190.9		
25	3971	204.4	5	10218
26	4222	218.6		
27	4469	233.4		
28	4716	249.1		
29	4954	265.3		
30	5251	286.9	10	28693
Total Annual Fuel Consumption (gallons/yr):				96186

STERN FLAP, Min-Ops (144 L tons)

Based on 1000 Annual Operational hours

Speed (knots)	Total Power PD (hP)	Fuel Consumption (gal/hr)	Speed-Time Profile (% time)	Annual Fuel Consumption (gal/yr)
12	458	28.4	40	11374
13	608	37.3		
14	827	49.6		
15	1123	65.5	25	16375
16	1445	81.9		
17	1746	96.5		
18	2030	109.9	10	10990
19	2312	123.0		
20	2583	135.5		
21	2845	147.7	5	7387
22	3104	160.0		
23	3353	172.2	5	8609
24	3597	184.5		
25	3847	197.6	5	9881
26	4096	211.4		
27	4345	225.9		
28	4594	241.3		
29	4837	257.3		
30	5140	278.6	10	27858
Total Annual Fuel Consumption (gallons/yr):				92475
Annual Fuel Savings (gallons/yr):				3711
				3.9%

Based on 3000 Annual Operating hours: 2/3 (2000 hrs) at Full Load, 1/3 (1000 hrs) at Min-Ops

Stern Flap Annual Fuel Savings (gallons/yr):	13328
Stern Flap Fuel Reduction (%):	**4.3%**
Annual Fuel Cost Savings ($1/gallon):	**$13,328**

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