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Bethesda, Maryland 20084–5000

EFFECTIVE POWER PREDICTIONS FOR DDG 51 WITH A PARAMETRIC SERIES OF LARGE SONAR DOMES AND THE ADDITION OF A 40 FOOT PARALLEL MIDDLE BODY

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DEPARTMENTAL REPORT

EFFECTIVE POWER PREDICTIONS FOR DDG 51 WITH A PARAMETRIC SERIES OF LARGE SONAR DOMES AND THE ADDITION OF A 40 FOOT PARALLEL MIDDLE BODY

By

Peter A. Chang, III

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The following modifications to the DDG-51 Flight I design are under consideration for the DDG-51 Flight III design: (1) addition of a 40 foot (12.19 m) parallel middle body and (2) replacing the 53 foot (16.15 m) dome by an alternative larger dome. The effects of these changes on the ship resistance and on the flow streamlines over the forward portion of the hull were evaluated using the Ship Wave Inviscid Flow Theory (SWIFT) computer program.

The effect of the parallel middle body addition on resistance is speed dependent with a 13 percent increase at 24 knots and a 12 percent decrease at 30 knots. The combined effect of the addition of the parallel middle body and the 125 foot (38.10 m) dome is to increase resistance at 24 knots by 37 percent and to decrease the 32 knot resistance by 6 percent.

The flow streamline locations for all configurations with a dome are very nearly the same and indicate that the bubble sweepdown performance will remain unchanged for the calm water, zero yaw condition.

The dome length variations were obtained by adding parallel middle body to the existing dome shapes. It is recommended that the domes be optimized for minimum resistance.

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NOMENCLATURE

Where possible the notations used in this document are consistent with the International Towing Tank Conference (ITTC) Standard Symbols* .

ENGLISH STANDARD AND METRIC EQUIVALENTS

ENGLISH STANDARD	METRIC
1 inch	25.400 millimeter {0.0254 m (meter)}
1 foot	0.3048 m (meter)
1 foot per second	0.3048 m/s (meter per second)
1 knot	0.5144 m/s (meter per second)
1 pound (force)	4.4480 N (newtons)
1 degree (angle)	0.01745 rad (radians)
1 horsepower	0.7457 kW (kilowatts)
1 long ton	1.016 tonnes, 1.016 metric tons, or 1016.0 kilograms
1 inch water (60°F)	248.8 pa (pascals)

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* International Towing Tank Conference Standard Symbols 1976, The British Ship Research Association, BSRA Technical Memorandum No. 500 (May 1976).

ABSTRACT

The following modifications to the DDG-51 Flight I design are under consideration for the DDG-51 Flight III design: (1) addition of a 40 foot (12.19 m) parallel middle body and (2) replacing the 53 foot (16.15 m) dome by an alternative larger dome. The effects of these changes on the ship resistance and on the flow streamlines over the forward portion of the hull were evaluated using the Ship Wave Inviscid Flow Theory (SWIFT) computer program.

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The flow streamline locations for all configurations with a dome are very nearly the same and indicate that the bubble sweepdown performance will remain unchanged for the calm water, zero yaw condition.

The dome length variations were obtained by adding parallel middle body to the existing dome shapes. It is recommended that the domes be optimized for minimum resistance.

ADMINISTRATIVE INFORMATION

The work reported herein was performed at the David Taylor Research and Development Center (DTRC) and was authorized by the Naval Sea Systems Command (NAVSEA 55W32) in accordance with Work Request Number 10470AA, Program Element 63564N, Task Area S0408080, Work Unit Number 1-1522-835.

INTRODUCTION

NAVSEA has requested that DTRC use analytical techniques for determining the hydrodynamic effects on the DDG-51 resulting from the addition of a 40 foot (12.19 m) parallel middle body and from lengthening the existing dome. This is part of the preliminary design effort for the DDG-51 Flight III [1*] . This report is an assessment of the impact that these changes will have on the effective power and flow characteristics around the dome.

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* References are listed on page 22.

It is expected that lengthening the existing dome may significantly affect the speed and power of DDG-51 Flight III. An overview study by Oakley[2], based on experimental data, shows that large, unconventional sonar domes can significantly increase the effective power, especially around a Froude number of 0.27. One of the speeds that is of greatest importance to the DDG 51 is 20 knots which corresponds to a Froude number of 0.265*.

The ability to conduct sonar operations can be dependent upon the flow around the dome. For instance, flow noise, due to turbulence and cavitation, and bubble sweepdown may limit the speeds at which sonar operations can take place. Since the lengthened domes extend further aft, there is concern that there would be a higher probability of problems associated with bubble sweepdown. These bubbles can come from a variety of sources which include surface bubble entrainment and stem cavitation. Bubble tubes or "hawse pipes" with bubbles from free surface air entrainment have been shown to affect bottom mounted sonar domes[3]. In this report predictions are made for flow streamlines emanating at the free surface and the stem.

In this report, the existing hull will be referred to as the "Flight I" or "baseline" hull. The AN/SQS-26/53C dome will be referred to as the "baseline" or "53 foot" dome. The "Flight III" hull refers to the Flight I hull which has had a 40 foot (12.19 m) parallel middle body inserted 244 feet (74.4 m) aft of the forward perpendicular.

The free surface potential flow code (SWIFT) was used to predict the wavemaking resistance and streamlines for various configurations of DDG-51. Five configurations were analyzed: 1) Flight I hull with baseline dome 2) Flight III with baseline dome 3) Flight III with 77 foot (23.47 m) dome 4) Flight III with 101 foot (30.78 m) dome and 5) Flight III with 125 foot (38.10 m) dome. The lengths of the domes were chosen to correspond to lengths of ship construction modules. The domes are based on the baseline dome section shapes, but were lengthened by adding a parallel section at the deepest point of the dome.

DESCRIPTION OF ANALYTICAL MODEL

The SWIFT computer code, as documented in Kim, Kim and Lucas[4], is a higher order panel method. It was used to make wavemaking resistance coefficient and form factor predictions. SWIFT can model the hull as quadratically curved panels with linearly varying source strengths. In this study, the zeroeth order, flat panel with constant source strength, approximation was used.

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* Based on a 506 foot L_{pp} of the Flight III hull

The wave resistance coefficients were computed by integrating the pressures over the hull. The 1+k form factors were computed using a method by Granville, documented in Cheng[5]. A form factor for each hull/dome configuration was obtained by averaging over speed all the values predicted for each configuration. Note that at 20 knots the effective power due to the form factor only amounts to about 3 percent of the total. The frictional resistance accounts for 50 percent of the total effective power, wave resistance 40 percent and a correlation allowance of 0.0004 about 7 percent.

Bubble sweepdown was analyzed by computing the streamlines which originated at the free surface and at the stem. SWIFT uses a Runge-Kutta solver which computes the trajectory of the streamlines on the hull surface. Predictions are made for the ship in a zero yaw angle, calm water condition.

Past experience with SWIFT, as well as other panel method codes, has shown that these methods are excellent for evaluating hull form changes, especially those which have a great impact on wave resistance. The predictions herein are for use in the feasibility study phase of ship design and the complexity and extent of the calculations have been designed for good comparisons among the various ship configurations. Thus, effective powering comparisons, in terms of ratios, with the baseline hull form, have been included in this report.

DESCRIPTION OF NUMERICAL MODELS

The "baseline", or Flight I hull which was modelled is the 466 foot (142.0 m) DDG-51 hull with a small stern wedge. The 3 foot, 2 inch (0.97 m) long, "small" stern wedge is shown in Borda, Figure 6*. The baseline or "53 foot" dome is the AN/SQS-26/53C dome.

The Flight III hull has a parallel section, 40 feet long (12.19 m), inserted aft of Frame 244 (244 feet (74.4 m) aft of FP).

Using the 53 foot (16.15 m) baseline dome, a parametric family of domes was constructed. The family of domes all have the same forebody and afterbody but have been lengthened by adding parallel sections. The parallel sections were added at the point of maximum depth, 16.9 feet (5.15 m) aft of the forward perpendicular. In this way, the maximum depth and beam were left

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* Borda, Gary C., David Taylor Research Center, as reported in a document of higher classification.

unchanged. The six configurations, as panelled, are shown in Figure 1. As shown in Figure 2, the change in volume of the domes with respect to the Flight III hull with *stem* bow, varies linearly from 2 percent for the 53 foot (16.15 m) dome to 6 percent for the 125 foot (38.10 m) dome. The additional surface area of the domes vary from 4.5 to 12.5 percent, for the 53 to 125 foot (16.15 to 38.10 m) domes, respectively.

The calm water draft for all configurations is 20.8 feet (6.34 m). The DDG-51 *Flight I* model experiments were conducted at this draft. It will be noted that the design draft for the DDG-51 Flight III has been estimated by NAVSEA to be 22.25 feet (6.78 m). The 20.8 foot (6.34 m) still water draft was kept constant for this study so that only the effects of bow dome and parallel middle body could be assessed. The surface areas and displacements for all the hull/dome configurations are shown in Table 1.

The various hull and dome configurations were numerically modelled using approximately 230 panels for the hull and 120 panels for the dome. The free surface was panelled with two blocks of panels, one in front and to the side and one aft of the transom. A total of about 1200 panels for the hull and free surface were used. For the 18 to 32 knot speed range, for which these calculations were made, the transom was assumed to be dry†.

DISCUSSION OF RESULTS

In this section the effects of the parallel middle body and dome length on the *total* effective power and on bubble sweepdown are discussed. Predictions of the wave resistance coefficients and wavemaking resistance are found in Appendix A.

EFFECT OF PARALLEL MIDDLE BODY (PMB) ADDITION ON EFFECTIVE POWER

The 40 foot parallel middle body addition increases the wetted surface area by 10.1 percent. This increases the frictional resistance by a constant 9.0 percent .

Figure 3 shows the ratios of the total effective power for the Flight III and Flight I hulls (the Flight III, 53' Dome curve). Below 26.5 knots SWIFT predicts that the effective power will increase. The maximum increase, occuring at 24 knots, is 13 percent. Above 26.5 knots the effect of the hull length increase on the wavemaking resistance overcomes the increase in frictional

† During model experiments, it was observed that the transom flow breaks free at 20-21 knots. At full scale, however, the speed of breakaway can be substantially less.

resistance and the total effective power decreases. The maximum decrease is 11.7 percent at 30 knots.

EFFECT OF BOW DOME LENGTH VARIATION ON EFFECTIVE POWER

The following the table shows the increase in the frictional drag due to the increase in wetted surface areas of the lengthened domes.

Increase in frictional resistance due to the lengthening of bow dome

DDG-51 Flight III Dome Configuration	Percent increase in frictional resistance with respect to Flight III with 53 ft (16.15 m) Dome
77 ft (23.47 m) Dome	2.6
101 ft (30.78 m) Dome	5.4
125 ft (38.10 m) Dome	7.8

The changes in effective power due just to change in dome length are shown in Figure 4. The curves are with respect to the 506 foot (154.2 m) Flight III hull with 53 foot (16.15 m) baseline dome. At none of the speeds analyzed does an increase in dome length lead to a decrease in effective power. As shown in Appendix A this is due to the large increase in wavemaking resistance as dome length increases, particularly around 24-25 knots.

The maximum increases in total effective power occur at about 25 knots and are approximately 5, 12, and 22 percent for the 77 foot (23.47 m), 101 foot (30.78 m) and the 125 foot (38.10 m) domes, respectively.

Figure 5 shows plots of the changes in frictional, wave and total resistance as functions of dome length, at 24 and 30 knots. The numbers in Figure 5 are the component resistances (i.e. due to friction, wavemaking and total) for the 77 foot (23.47 m), 101 foot (30.78 m) and the 125 foot (38.10 m) domes divided by the component resistances for Flight III with baseline, 53 foot (16.15 m) foot dome.

COMBINED EFFECT OF BOW DOME LENGTH VARIATION AND PMB ADDITION ON EFFECTIVE POWER

Figure 3 shows the change in total effective power due to the increase in dome length *and* the addition of the parallel middle body. All predictions are with respect to the baseline configuration (Flight I hull with 53 foot (16.15 m) dome). The following table shows the increases in frictional resistance due to both the PMB addition and the lengthened domes.

Increase in frictional resistance due to the lengthening of hull and bow dome

Addition to DDG-51 Baseline Configuration	Percent increase in frictional resistance with respect to Baseline configuration
Parallel Middle Body (PMB)	9.0
PMB and 77 ft (23.47 m) Dome	11.8
PMB and 101 ft (30.78 m) Dome	14.9
PMB and 125 ft (38.10 m) Dome	17.5

The maximum effective power increases for all the dome length variations occur at 24 knots. The increases are 18 percent, 27 percent and 37 percent for the 77 foot (23.47 m), 101 foot (30.78 m) and the 125 foot (38.10 m) domes, respectively. As shown in Appendix A, both the addition of the forty foot parallel middle body and the increase in dome length have their maximum increases in wavemaking resistance at this speed.

The speeds at which the hull length addition overcomes the increase in wavemaking resistance of the lengthened domes and the additional wetted surface are approximately 26.9, 27.3, and 27.7 knots, for the three dome lengths additions, respectively. The maximum decreases in total effective power are 10.6, 9.1, and 6.0 percent for the three dome length configurations, respectively.

All of the longer domes, by themselves, without the PMB, decrease the maximum speed. However, with the addition of the PMB, the maximum speed with any of the domes, will be greater than that of the DDG-51 baseline configuration.

BUBBLE SWEEPDOWN

Streamline predictions for the Flight III hull with 53 and 125 foot (16.15 m and 38.10 m, respectively) domes are shown in Figures 6 and 7 respectively. Figure 8 is a transverse cut 125 feet (38.10 m) aft of the forward perpendicular. The streamlines originate at the free surface, 20 feet (6.1 m) aft of the forward perpendicular. Figure 8 shows that streamlines originating at the free surface will not impinge on the domes. However, as the domes get longer, the streamlines tend to come closer to the centerline. This could have an impact on the performance of a keel dome mounted aft of the bow dome.

Figure 9, a transverse section cut 77 feet (23.47 m) aft of the forward perpendicular, shows how the change in dome length affects the transverse locations of the streamlines originating at the stem. The streamlines, originating slightly above the hull/dome juncture move down and toward the centerline, unless "trapped" by the hull/dome juncture. The fairing of the hull/dome junction may be important in the minimization of the adverse effects that stem cavitation has on sonar dome noise.

CONCLUSIONS

The three dimensional free surface Rankine source potential flow code, SWIFT, was used to make effective power predictions for DDG-51 with a family of bow domes and a forty foot parallel middle body. The domes varied in length from 53 feet to 125 feet (16.15 m and 38.10 m), respectively. The impacts on effective power and bubble sweepdown, due to these changes, were predicted. The following conclusions can be made:

1) The 40 foot (12.19 m) parallel middle body addition will add a maximum of 13 percent to the total effective power. Above 26.5 knots the parallel middle body decreases the effective power, with a maximum decrease of 12 percent, at 30 knots.

2) The increase in dome length, without the parallel middle body length change, will increase the effective power over the 18 to 32 knot speed range. The effective power will increase at most by 5 percent for the 77 foot (23.47 m) dome, 12 percent for the 101 foot (30.78 m) dome and 22 percent for the 125 foot (38.10 m) dome.

3) The combined effect of adding both a forty foot parallel middle body and lengthening the dome will be to increase the effective power at intermediate speeds, while decreasing it at high speeds. The maximum increases in effective power occuring at about 24 knots, will be 18 percent for the 77 foot (23.47 m) dome, 27 percent for the 101 foot (30.78 m) dome and 37

percent for the 125 foot (38.10 m) dome. Above about 27 knots, the effective power is lower than for the baseline configuration.

4) It is predicted that streamlines emanating from the free surface will not impinge on the lengthened domes for the ship operating in calm water and zero yaw angle. However, streamlines originating at the stem come close to the lengthened domes.

RECOMMENDATIONS

The following recommendations are for further hydrodynamic design and analysis in support of the Flight III hull and sonar dome design.

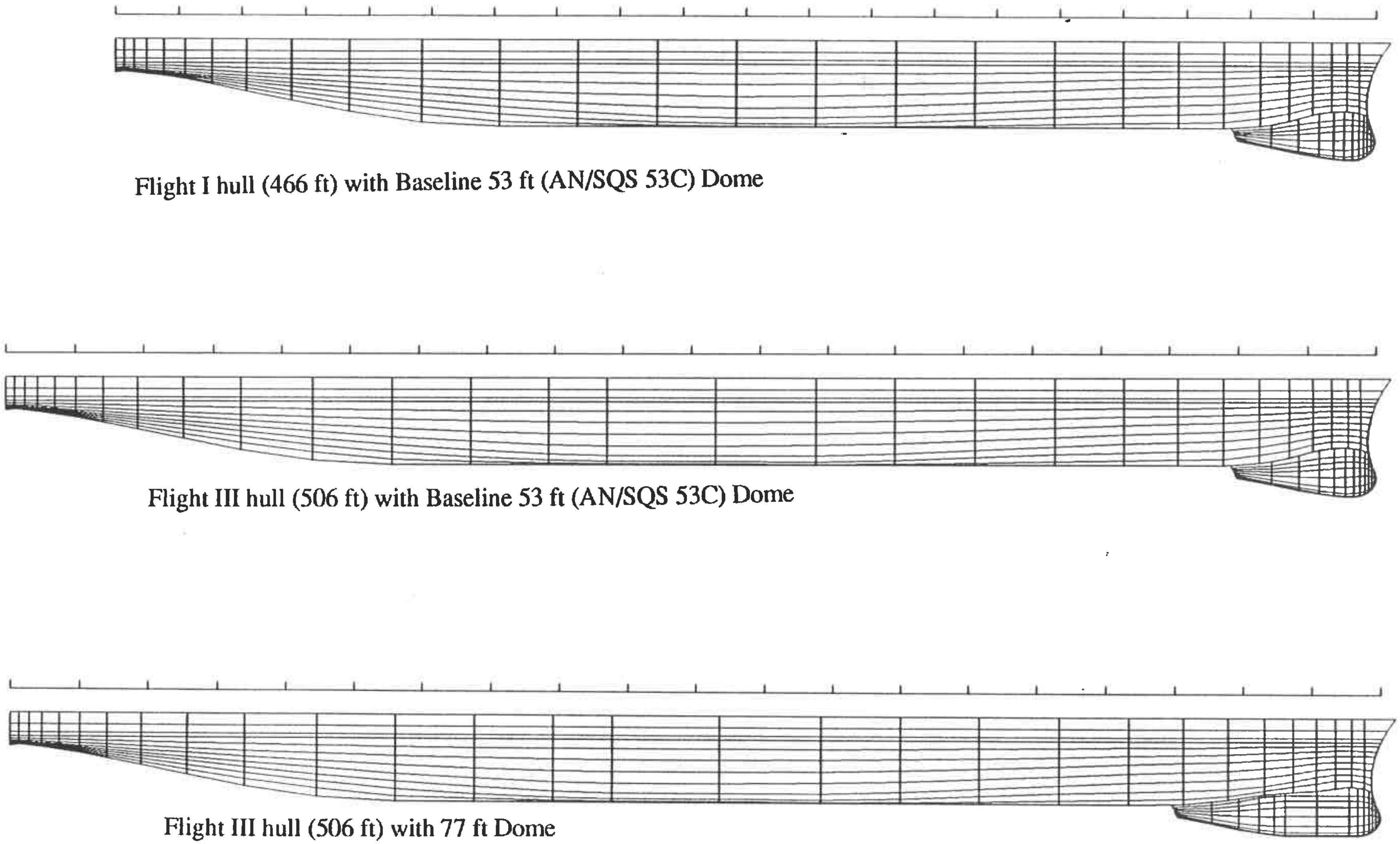
1) The dome designs considered in this report are simple parallel middle body extensions of the current dome. They will have a significant impact on effective power. It is recommended that the shape of the domes be optimized for minimum resistance.

2) The streamlines predicted in this report were for the zero yaw condition. Bubble sweepdown problems may be worst when the ship is at a yaw angle. It is recommended that capabilities be developed to predict the streamlines for a ship in a yawed condition. This can be done by modifying the potential flow code, SWIFT, to handle ships in asymmetric, lifting flows.

3) Flow noise over the dome causes degradation in sonar operations as ship speed increases. Work needs to be done to design a dome which minimizes flow noise. This can be done with the Reynold's Averaged Navier-Stokes code, RANS, a viscous flow code which is capable of predicting boundary layer characteristics. This predictive tool would provide insight into separated flow and vortices induced by hull and bowdome geometry.

ACKNOWLEDGEMENTS

The author wishes to express his appreciation to Dr. Yoon-Ho Kim for his technical insights and assistance in running SWIFT and interpreting the results. The author would also like to thank Mr. Gabor Karafiath for his guidance and editorial comments.

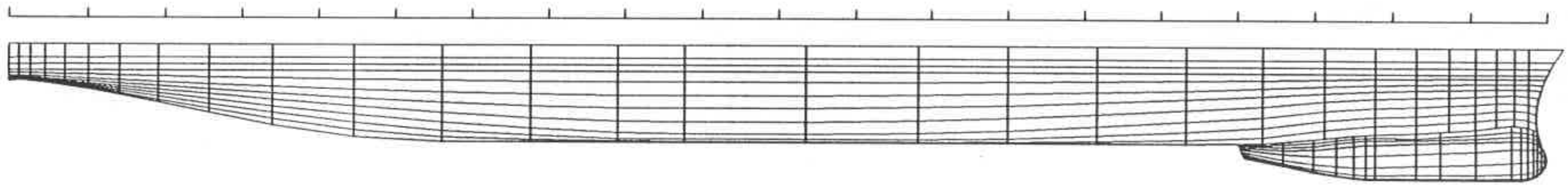


Flight I hull (466 ft) with Baseline 53 ft (AN/SQS 53C) Dome

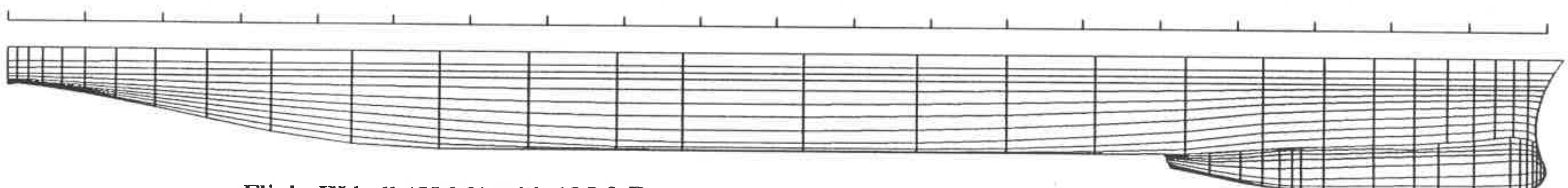
Flight III hull (506 ft) with Baseline 53 ft (AN/SQS 53C) Dome

Flight III hull (506 ft) with 77 ft Dome

Fig 1. Profile views of DDG-51 Baseline and Flight III with parametrically varying domes, as panelled for SWIFT.

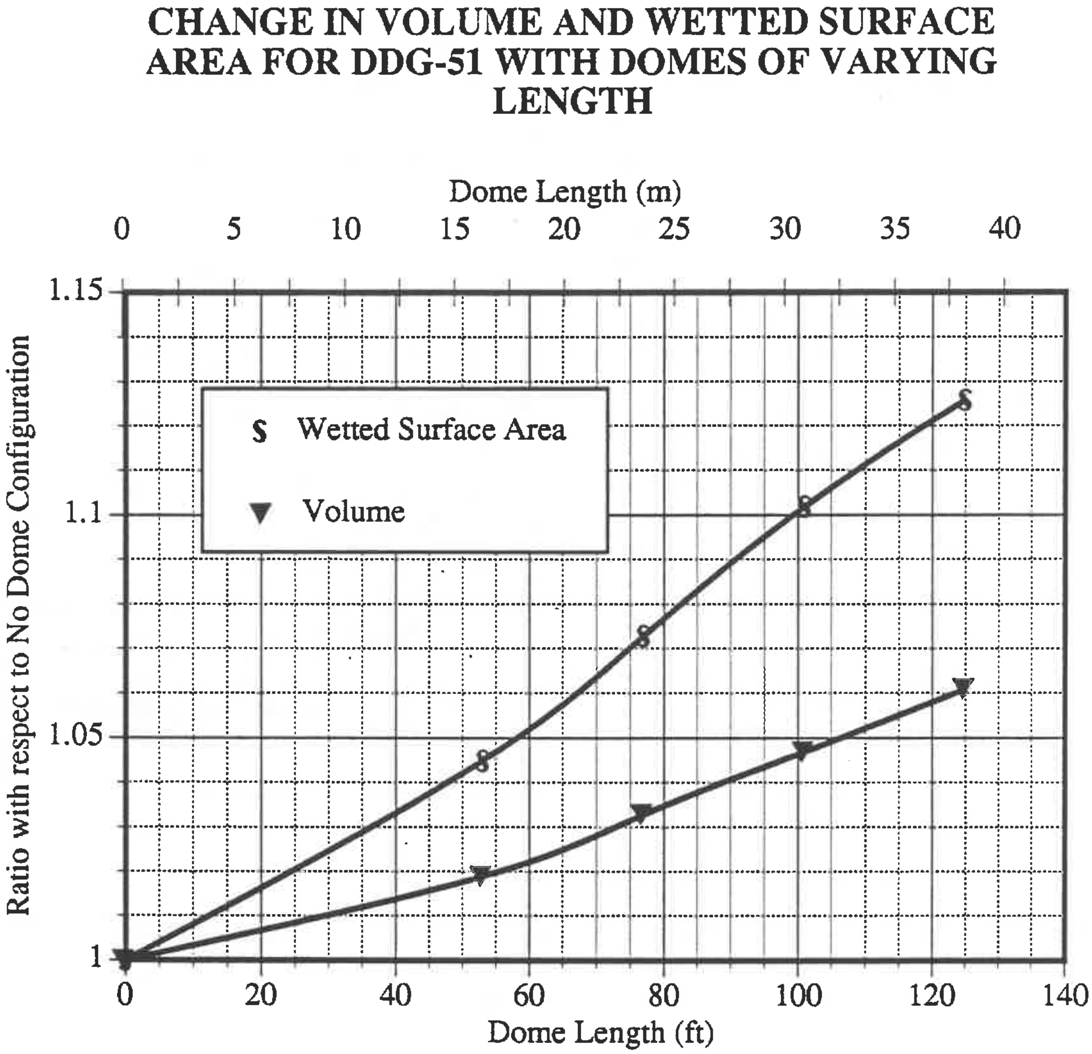


Flight III hull (506 ft) with 101 ft Dome



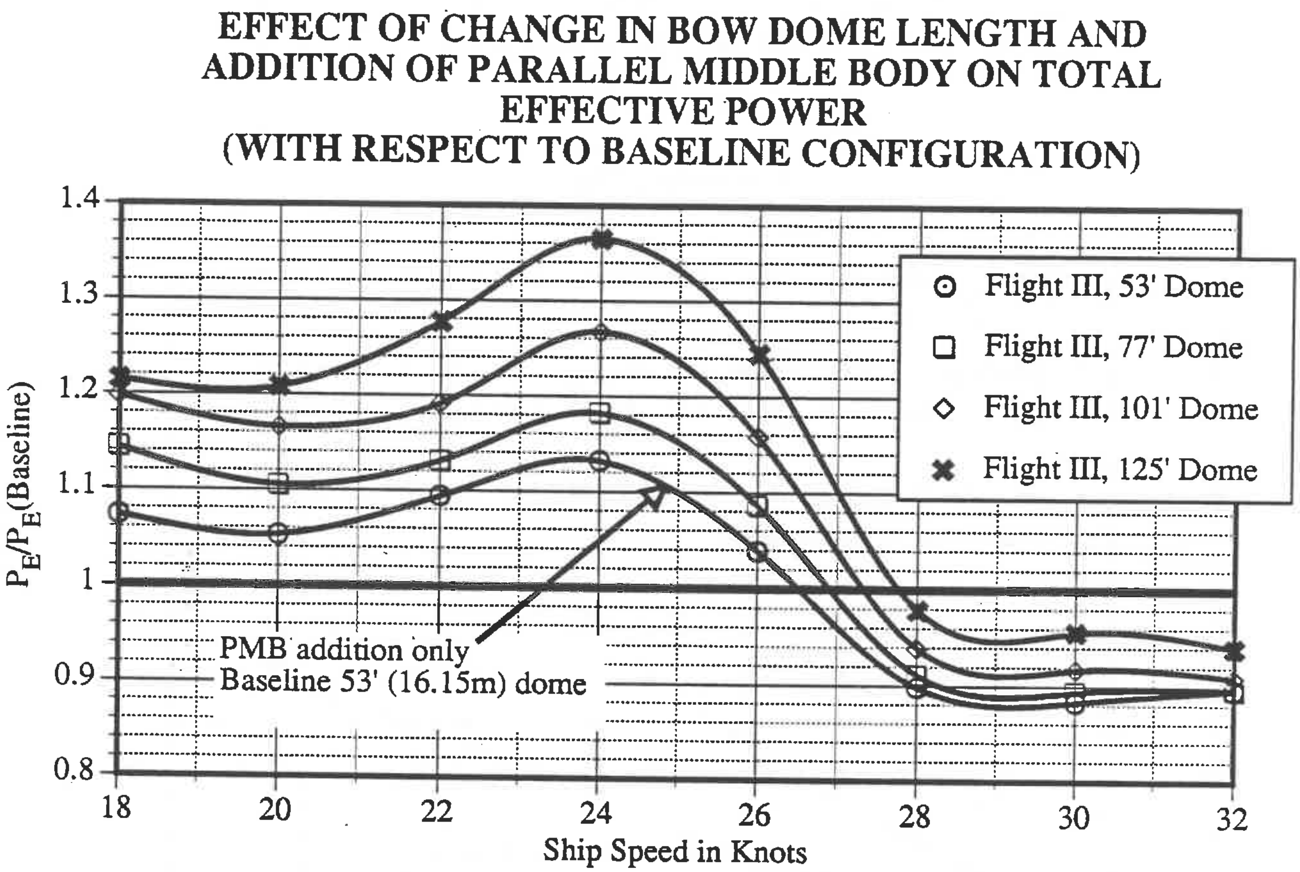
Flight III hull (506 ft) with 125 ft Dome

Fig 1. (continued)



DDG-51 Flight III has a 40 foot (12.2 m) parallel middle body inserted at Frame 244
Still Water Draft = 20.8 feet (6.34 m) Even Keel

Fig. 2. Change in wetted surface area and volume for DDG-51 Flight III, with respect to the Flight III No Dome configuration, for bow domes of varying length.

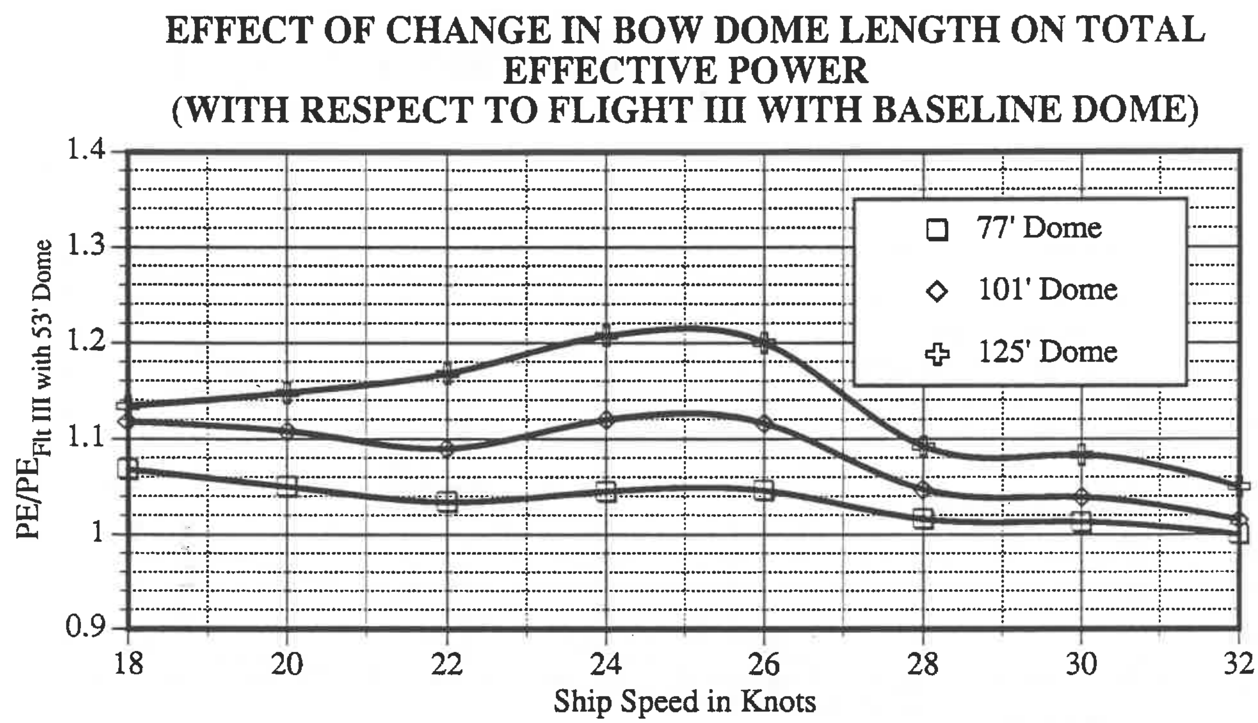


Wave resistance coefficients and Form Factors (1+k) predicted by SWIFT, Free to sink and trim
CA = 0.0004, ITTC Ship-Model Correlation Line
SW Draft = 20.8 ft (6.34 m), EK

Baseline Configuration: 466 ft (142.0 m) Hull with 53 ft (16.15 m) (AN/SQS-53C) Dome

Flight III hull has a 40 ft (12.19 m) Parallel Middle Body inserted at Frame 244

Fig. 3. Predicted change in total effective power due to increase in dome length, with respect to Baseline (Flight I with 53 ft (16.15 m) dome) configuration.



Wave resistance coefficients and Form Factors (1+k) predicted by SWIFT, Free to sink and trim
CA = 0.0004, ITTC Ship-Model Correlation Line
SW Draft = 20.8 ft (6.34 m), EK

Flight III hull has a 40 ft (12.19 m) Parallel Middle Body inserted at Frame 244

Fig. 4. Predicted change in total effective power due to increase in dome length, with respect to Flight III with 53 ft (16.15 m) dome

CHANGE IN COMPONENT EFFECTIVE POWER FOR DDG-51 FLIGHT III, AS A FUNCTION OF BOW DOME LENGTH (NO CHANGE IN HULL LENGTH)

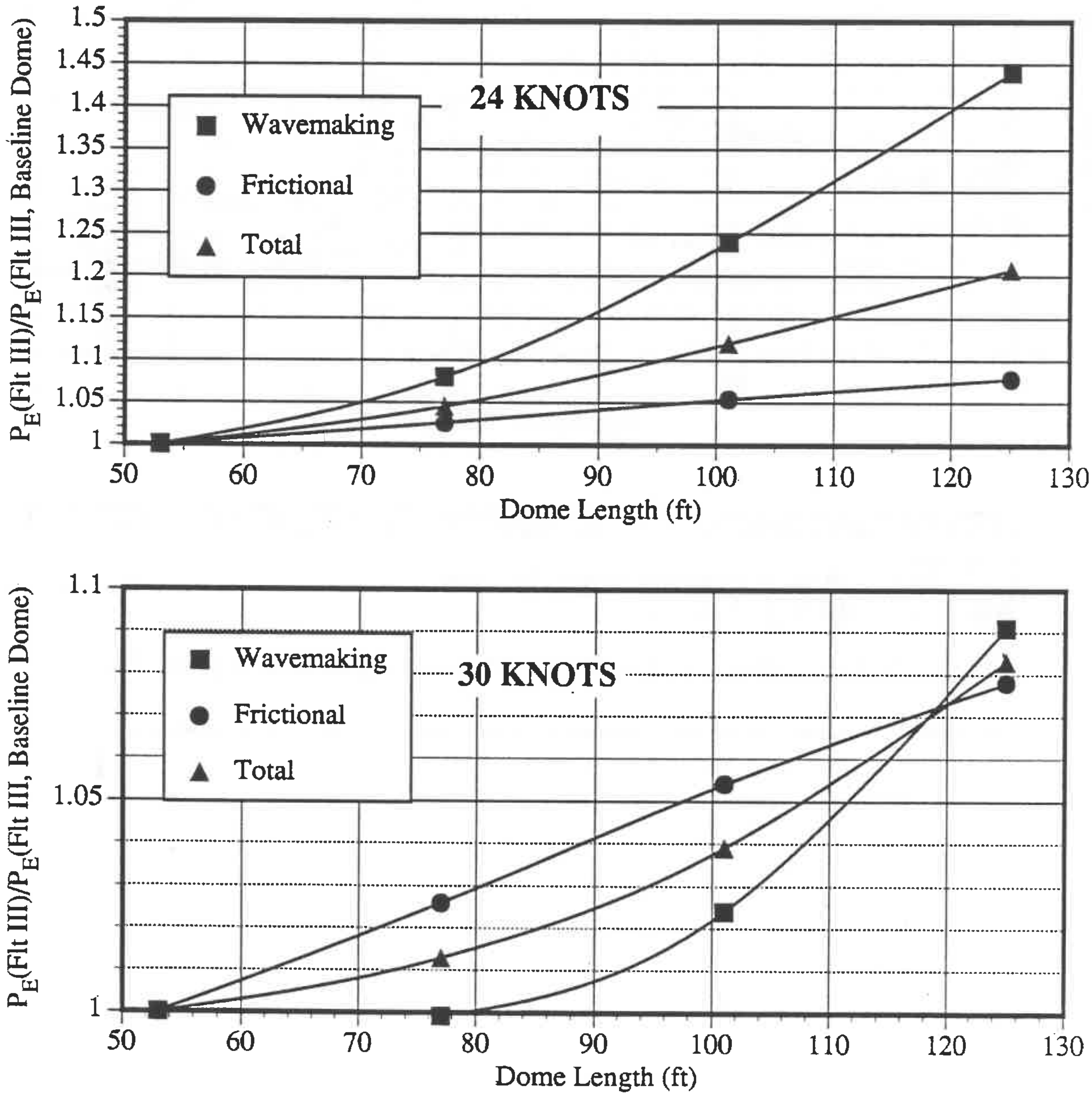


Fig. 5. Change in component effective power for DDG-51 Flight III, as a function of bow dome length.

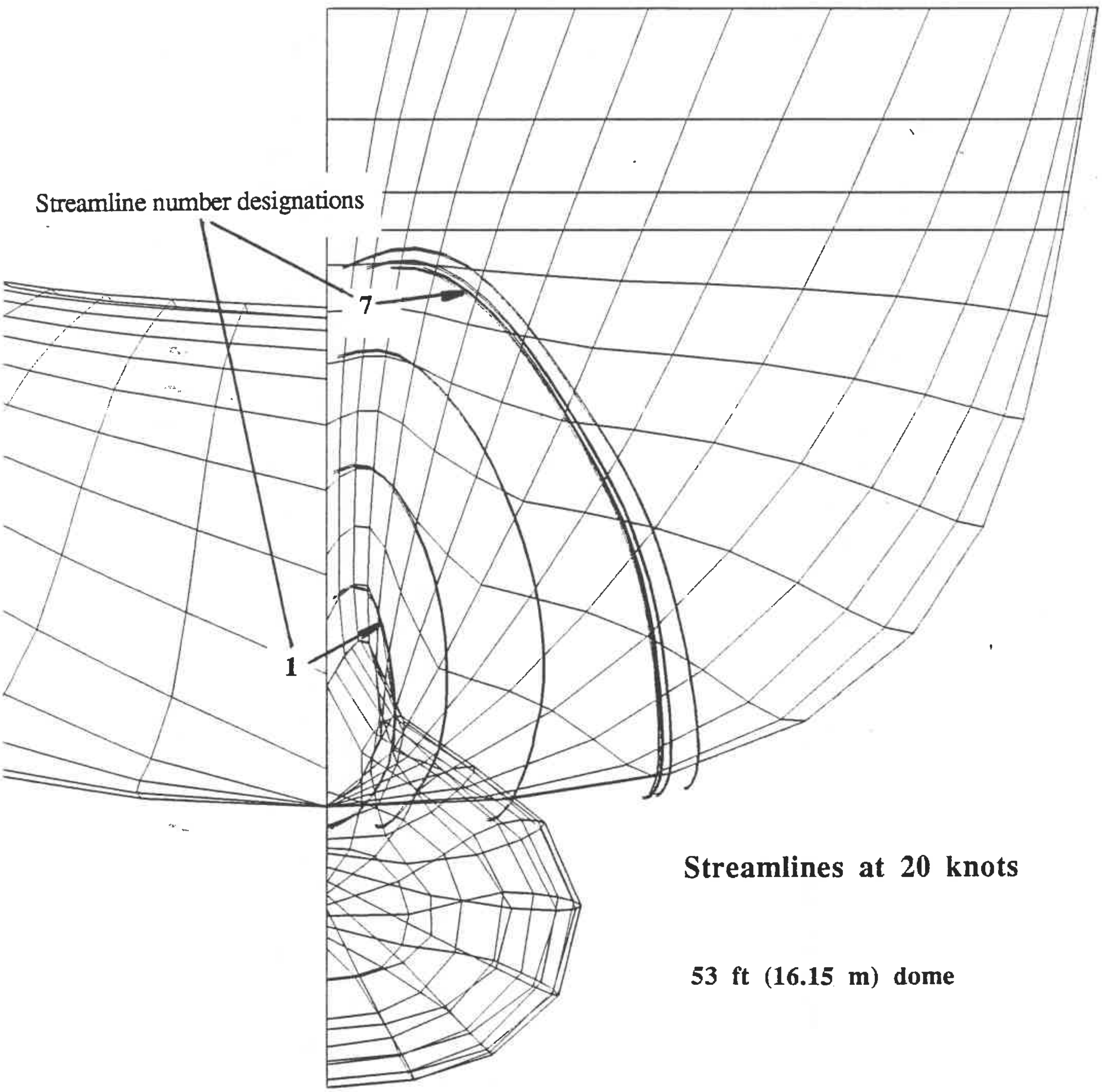
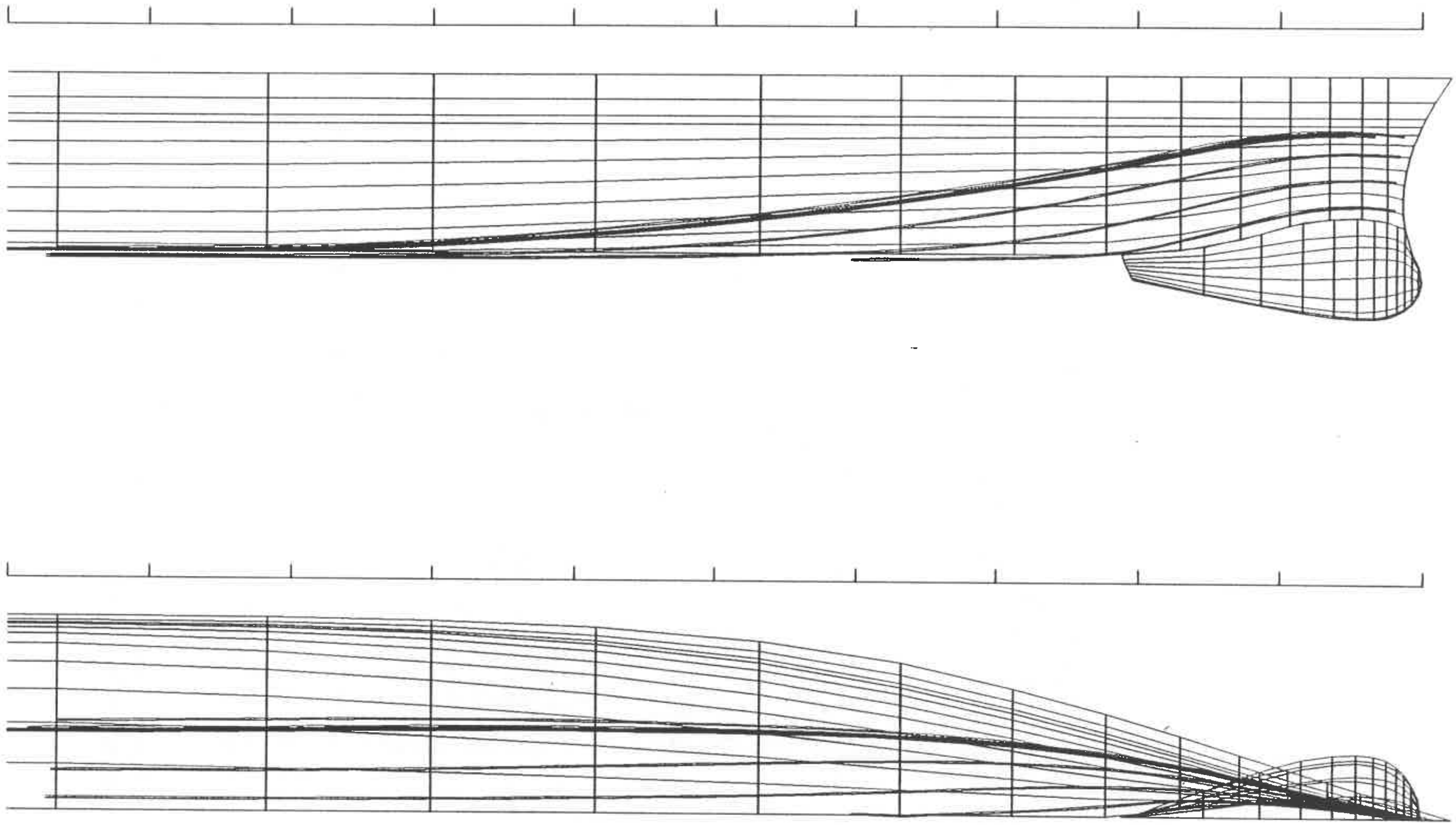


Fig 6. Potential flow streamlines at 20 knots for DDG-51 Flight III hull with 53 foot dome as predicted by SWIFT.



53 ft (16.15 m) dome

Fig 6. (continued)

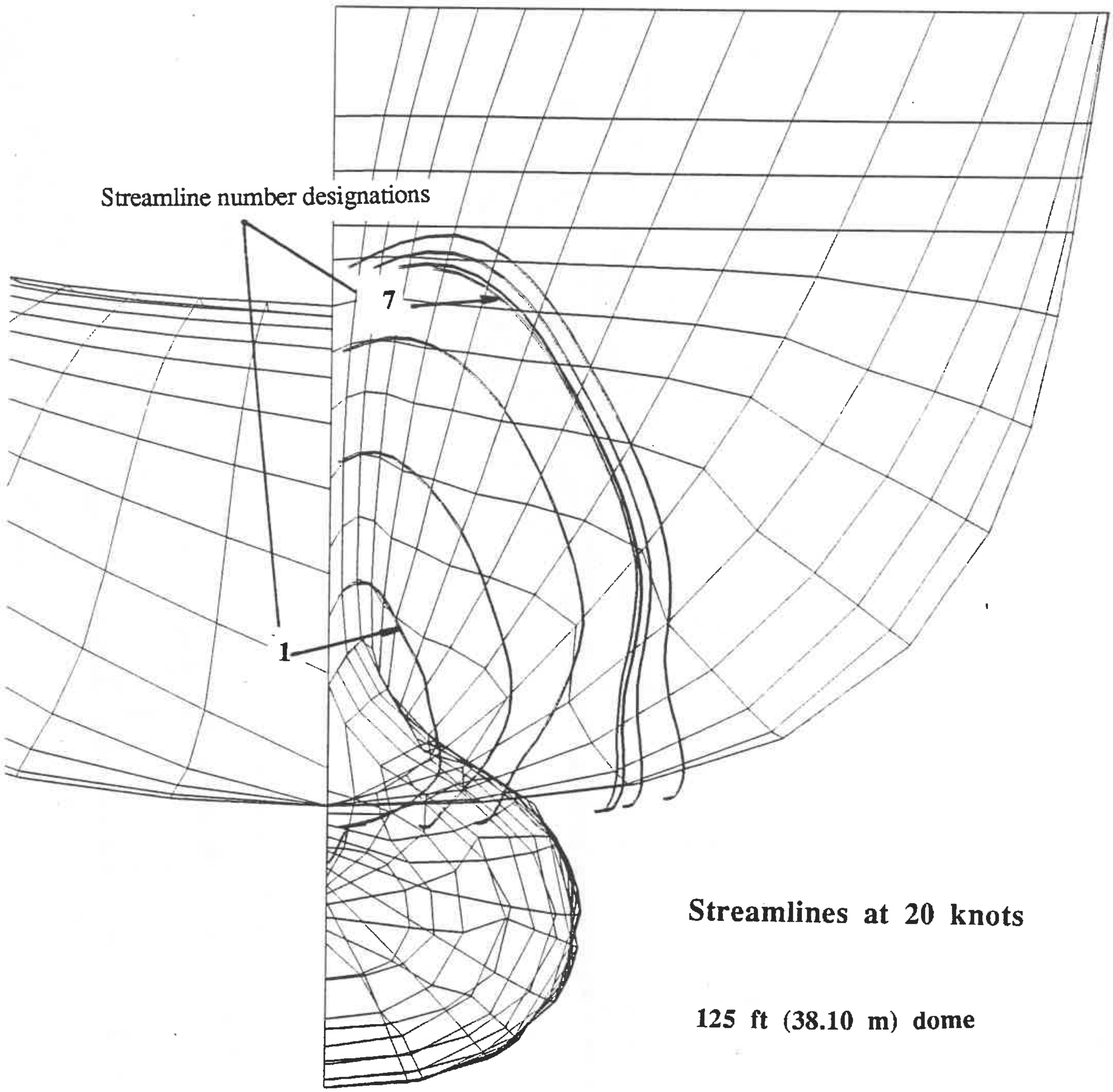
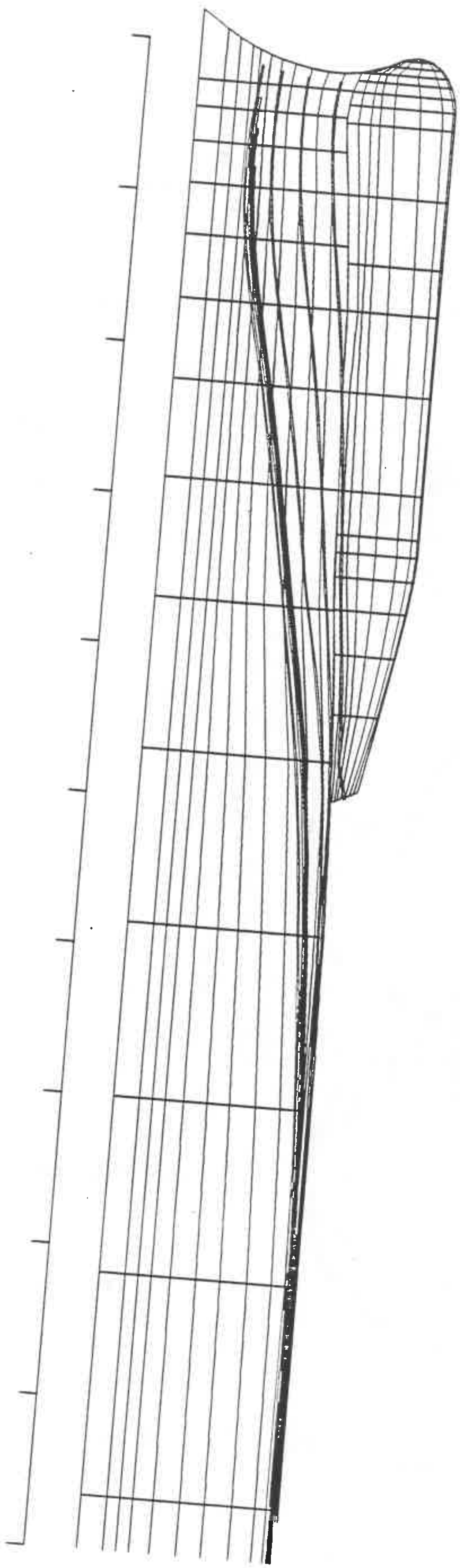
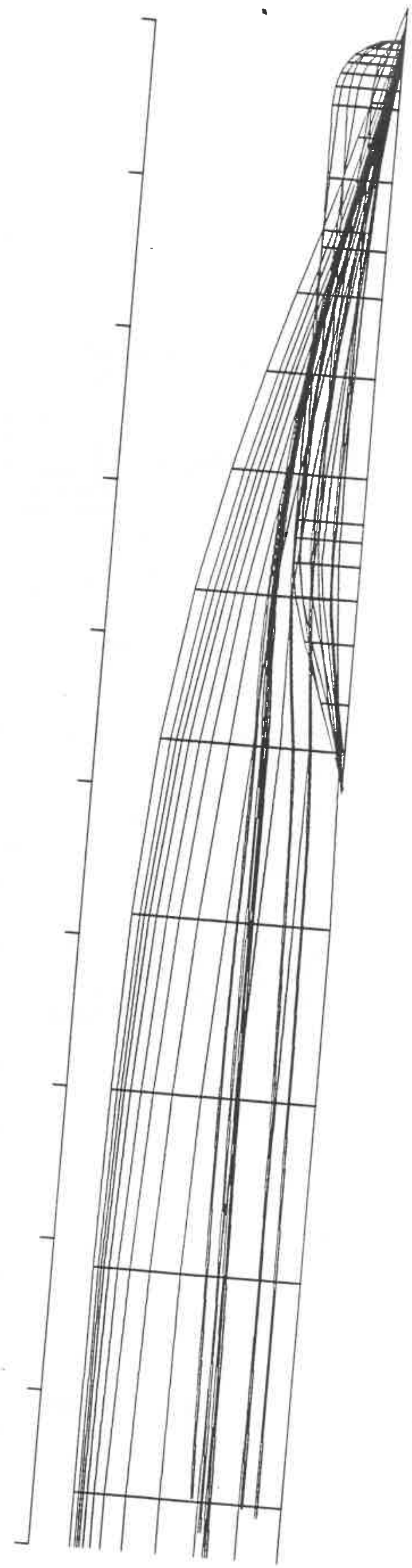


Fig 7. Potential flow streamlines at 20 knots for DDG-51 Flight III hull with 125 foot dome as predicted by SWIFT.





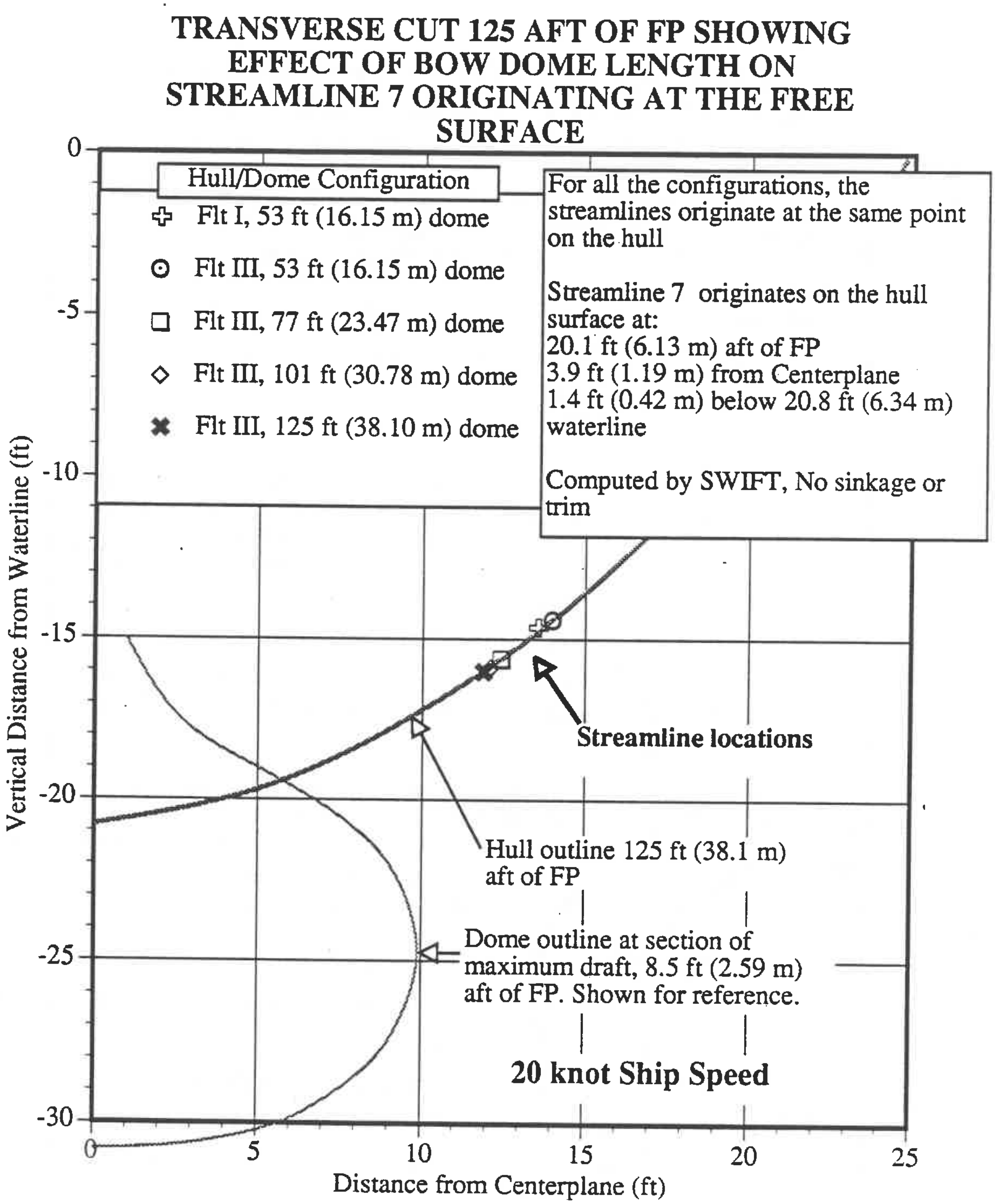


Fig. 8 Transverse cut at Frame 125 (125 feet (38.10 m) aft of FP) showing how the change in bow dome length affects a streamline originating at the free surface.

TRANSVERSE CUT 77 FEET (23.47 m) AFT OF FP SHOWING EFFECT OF BOW DOME LENGTH ON STREAMLINE 1 ORIGINATING AT THE STEM

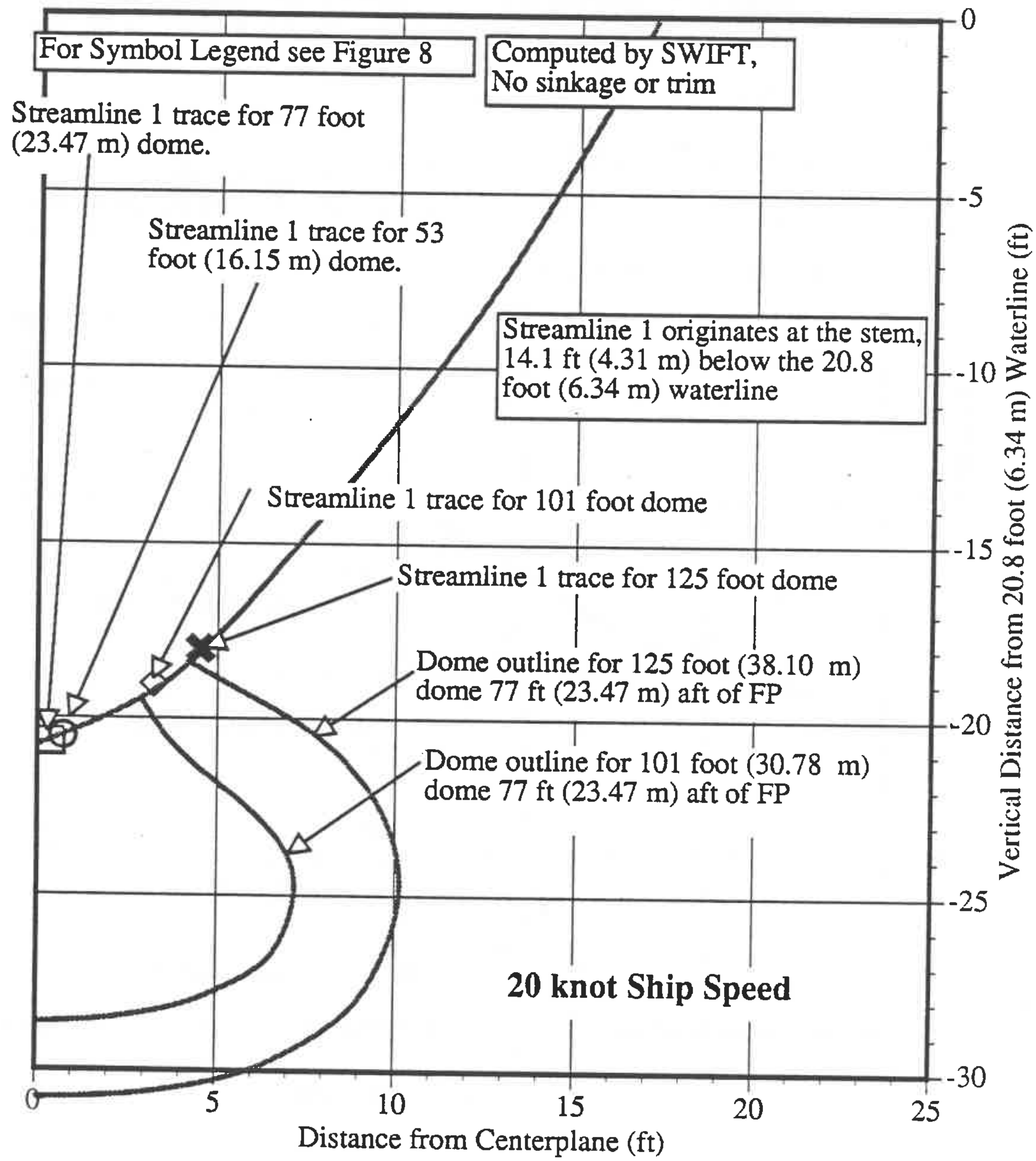


Fig. 9. Transverse cut at Frame 77 (77 feet (23.47 m) aft of the FP) showing how the change in bow dome length affects a streamline originating at the stem

TABLE 1. Displacements and wetted surface areas for DDG-51 configurations

Hull Configuration	Hull Length L_{pp} (ft)	Dome Length (ft)	Displacement (LT)	Displacement LT (tonnes)	Wetted Surface Area (ft^2)	Wetted Surface Area (m^2)
Baseline	466	No Dome	8243	8375	29990	2786
Baseline	**466**	**53**	**8409**	**8544**	**31523**	**2928**
Flight III	506	No Dome	9466	9617	33353	3098
Flight III	506	53	9644	9798	34909	3243
Flight III	506	77	9778	9934	35829	3329
Flight III	506	101	9910	10069	36725	3412
Flight III	506	125	10143	10305	37550	3488

All figures for a 20.8 foot (6.34 m) even keel, still water draft

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REFERENCES

1. "DDG-51 Flight III Feasability Study," NAVSEA/041-501-TN-0077 (Jul 1989).

2. Oakley, O.H., "Suggested Guidance for EHP Estimation for DD Type Hull Forms with Large Unconventional Sonar Domes," ORI/2405 (Feb 1985).

3. Rubin, M.B., "Predicted Streamlines and Minimum Pressures for the Oceanographic Survey Ship T-AGS 39 as Represented by Model 9027-3 and 9027-4 (with and without Bulb)," DTRC/SHD-1178-03 (Sep 1987).

4. Kim, Y.-H., S.-H. Kim and T. Lucas, "Advanced Panel Method for Ship Wave Inviscid Flow Theory (SWIFT)," DTRC/89/029 (Nov 1989).

5. Cheng, H. and J.S. Dean, "User's Manual for the XYZ Free Surface Program," DTRC/86/029 (June 1986).

6. Fisher, S.C., "Resistance Reduction for the DDG 51 Through Changes in the Sonar Dome Volume and Location (Model 5422)," DTNSRDC/SPD-0200-21 (May 1985).

7. Saunders, H.E., Hydrodynamics in Ship Design, SNAME, New York, NY (1957).

APPENDIX A: WAVEMAKING RESISTANCE PREDICTIONS

This appendix describes the wavemaking resistance coefficients predicted using SWIFT and the changes in wavemaking resistance due to the addition of a forty foot parallel middle body and lengthened bow domes.

COMPARISON WITH MEASURED VALUES

Figure A1 compares wavemaking resistance coefficients predicted by SWIFT with those determined from longitudinal wavecut experiments[6]. It shows that agreement between predictions and experiments is very good above 22 knots. Below 22 knots the curves diverge, with SWIFT overpredicting the wavemaking resistance coefficients. Since the SWIFT predictions were made assuming a dry transom, this low speed divergence is to be expected. It is important to note that the *shapes* of the curves are the same above 22 knots, which lends confidence to the predictions for the increase in hull and dome lengths.

WAVEMAKING RESISTANCE COEFFICIENT PREDICTIONS

Figure A2 shows the wavemaking resistance coefficients (C_w) as a function of speed for DDG-51 Flight I and Flight III hulls. The C_w values for the Flight III hull are lower than for the Flight I hull for speeds greater than 25 knots. The relative locations of the humps and hollows of the wave resistance coefficient as shown in Figure A2 are in basic agreement with wave resistance considerations from Saunders[7]. The addition of the PMB, resulting in increased length, should shift humps and hollows in the wave resistance coefficient curve to higher speeds. Examination of the humps and hollows of the PMB wave resistance coefficient curve shows that the hump at 22 knots and the hollow at 24 knots have been shifted about 2 knots due to the PMB.

WAVEMAKING RESISTANCE PREDICTIONS

Figure A3 (curve labelled "Flt III, 53' Dome") shows the changes in wavemaking resistance due to the addition of the PMB. At 24 knots the addition of the PMB adds 23 percent to the wavemaking resistance. At 28 knots, it decreases the wavemaking resistance by 27 percent.

Figure A4 shows changes in wavemaking resistance due just to addition of dome length. Thus, the curves are with respect to the 506 foot (154.2 m) Flight III hull with 53 foot (16.15 m) baseline dome. The curves show that except at the highest speeds the increase in dome length increases the wavemaking resistance. The increases are maximum at 18 and 24 knot greater than 28 knots however, the increases in wavemaking resistance are quite sma instance, at 30 knots, the wavemaking resistance increases by 0, 2.4, and 9.1 percent dome length additions, respectively.

Figure A3 shows the combined effect of the parallel middle body addition and the addition. The maximum increases in wavemaking resistance for *both* the dome length middle body additions occur in the 24-25 knot speed range. Taken in combination, th considerable increases in wave resistance in this speed range. The increases are 33 pe percent and 77 percent for the 77 foot (23.47 m), 101 foot (30.78 m) and the 125 foo domes, respectively.

The speeds at which the dome length and parallel middle body additions lead to a de the wavemaking resistance are approximately 26.3, 26.7, and 27.2 knots, for the three lengths additions, respectively. The maximum decreases in wavemaking resistance at th speeds are substantial. The decreases at 28.5 knots are approximately 29, 28, and 24 pe the three dome length additions, respectively.

TOTAL EFFECTIVE POWER (P_E) PREDICTIONS

This is addressed in the main text of the report.

SUMMARY

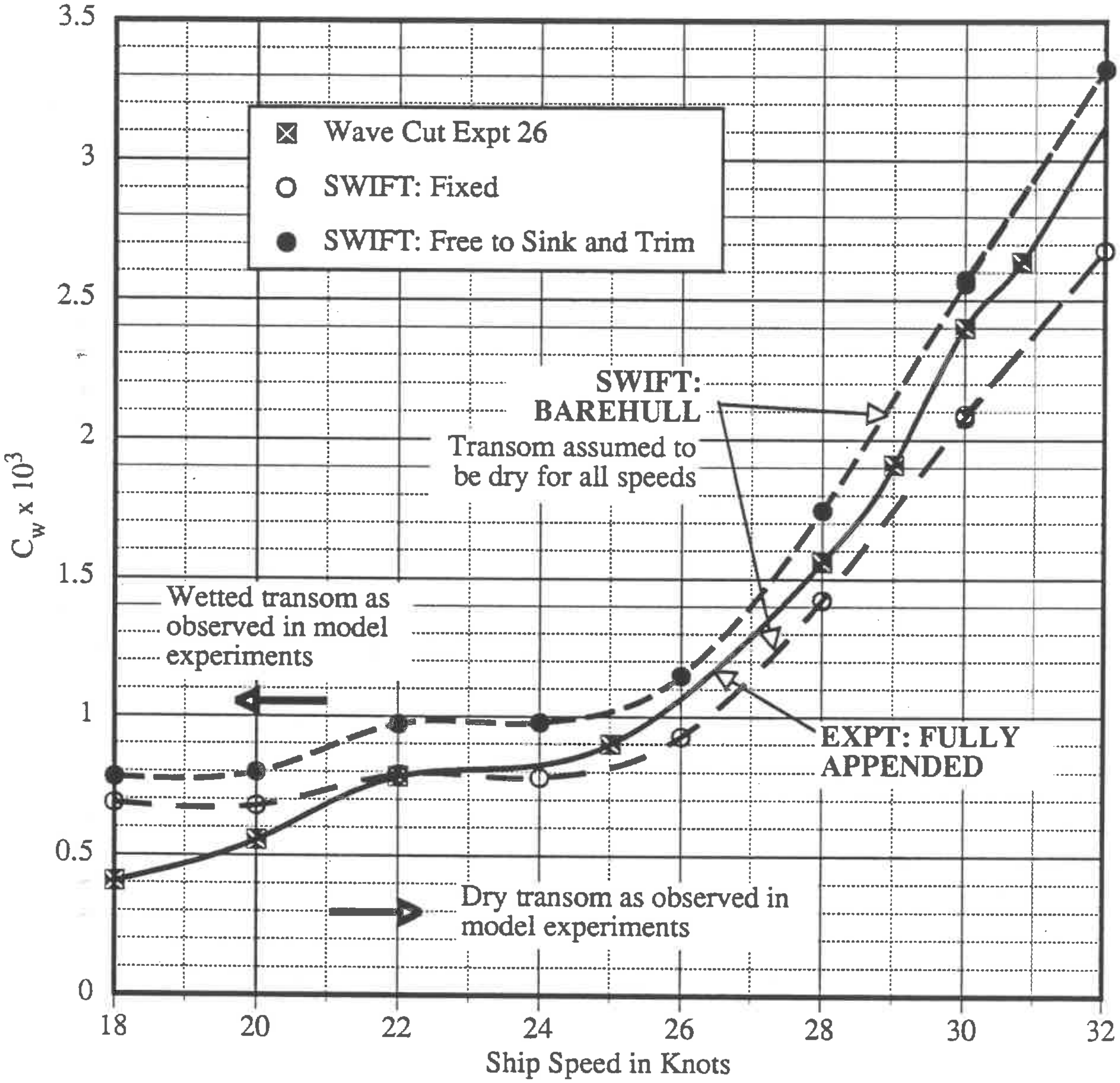
(1) The addition of the parallel middle body will substantially increase the wavemak resistance at medium speeds while decreasing it substantially at high speeds. The maximu increase, at 24 knots, is 23 percent. The maximum decrease, at 28 knots, is 28 percent. T effect on the *total* effective power is a maximum increase, at 24 knots, of 13 percent and a maximum decrease, at 30 knots, of 12 percent. Thus, even though the PMB adds 9 percen frictional resistance, the longer hull length leads to substantially decreased effective power a higher speeds.

(2) The effect just of increasing the length of the bow dome will be to increase the wavemaking resistance over the 18-32 knot speed range, particularly in the 24- 25 knot rang 25 knots the increases are 9, 26, 47 percent for the 77 foot (23.47 m), 101 foot (30.78 m), 125 foot (30.78 m) domes, respectively.

(3) Both the increase in dome length and the parallel middle body addition have their max effective power increases in the 24-25 knot speed range. When the two modifications are ta

together this results in dramatic increases in wavemaking resistance at 24 knots. These increases could be offset by wavemaking resistance optimization of the dome geometry and/or careful selection of the increase in hull length.

WAVEMAKING RESISTANCE COEFFICIENTS FOR DDG-51 BASELINE CONFIGURATION PREDICTED BY SWIFT AND MEASURED IN EXPERIMENTS



Wavecut experiment 26 performed on Model 5422 with baseline (6'-6", 1.98 m) wedge FULLY APPENDED with Rudders and CRP shafts and struts. From Ref. 6 (Fisher) Table 2.

SWIFT predictions computed for BAREHULL with short (3'-2", 0.97 m) wedge.

Fig. A1. Comparison of wave resistance coefficients predicted by SWIFT and from model experiments.

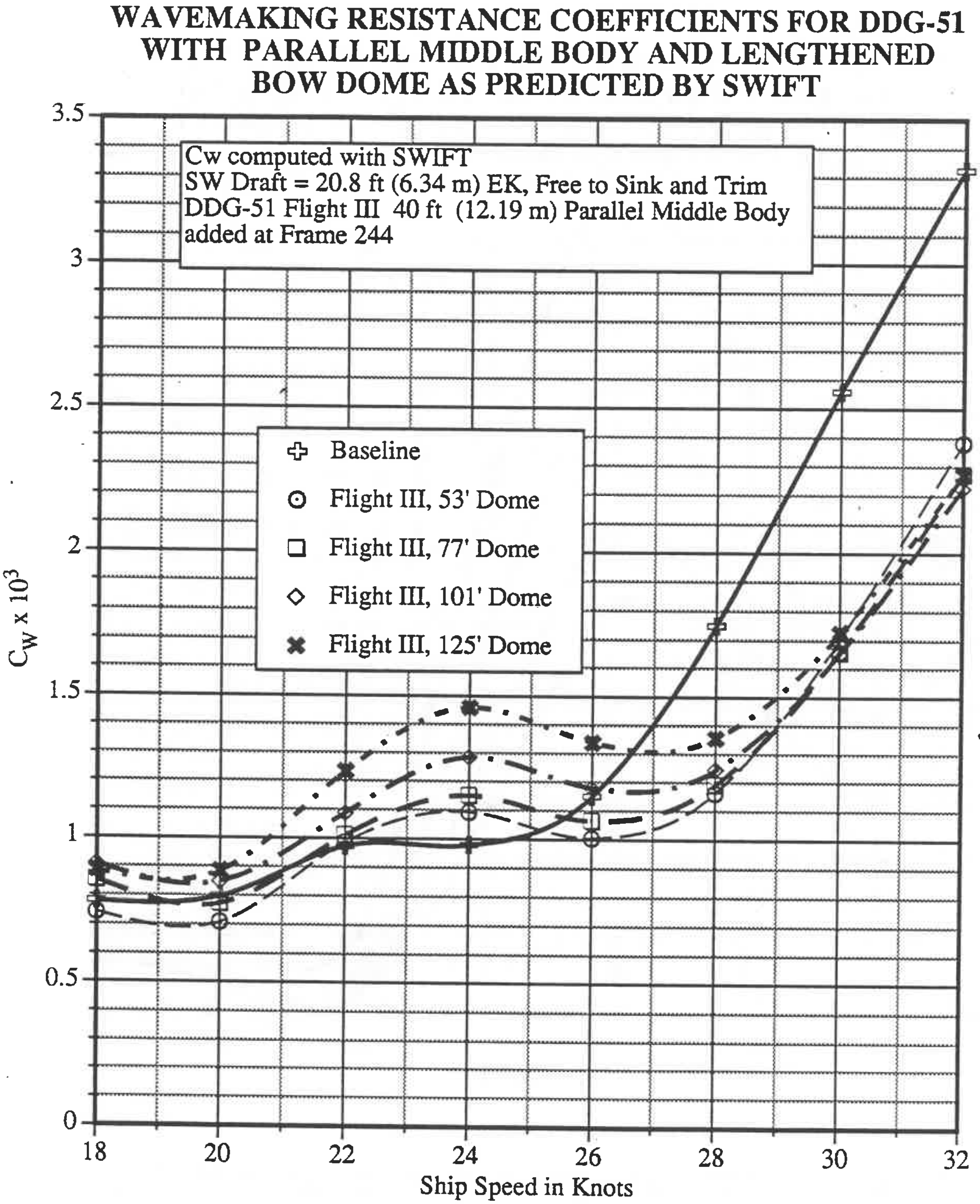
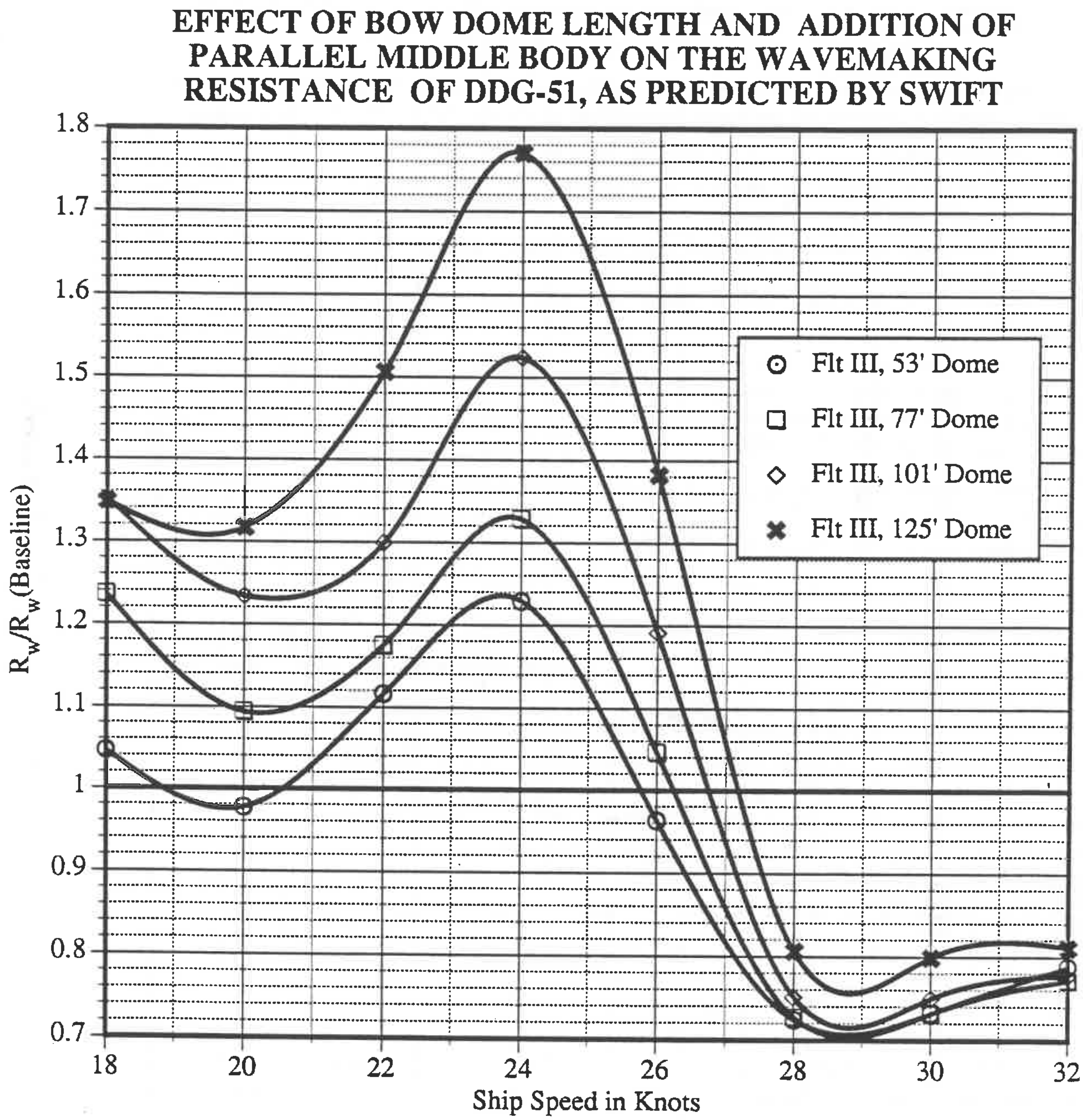


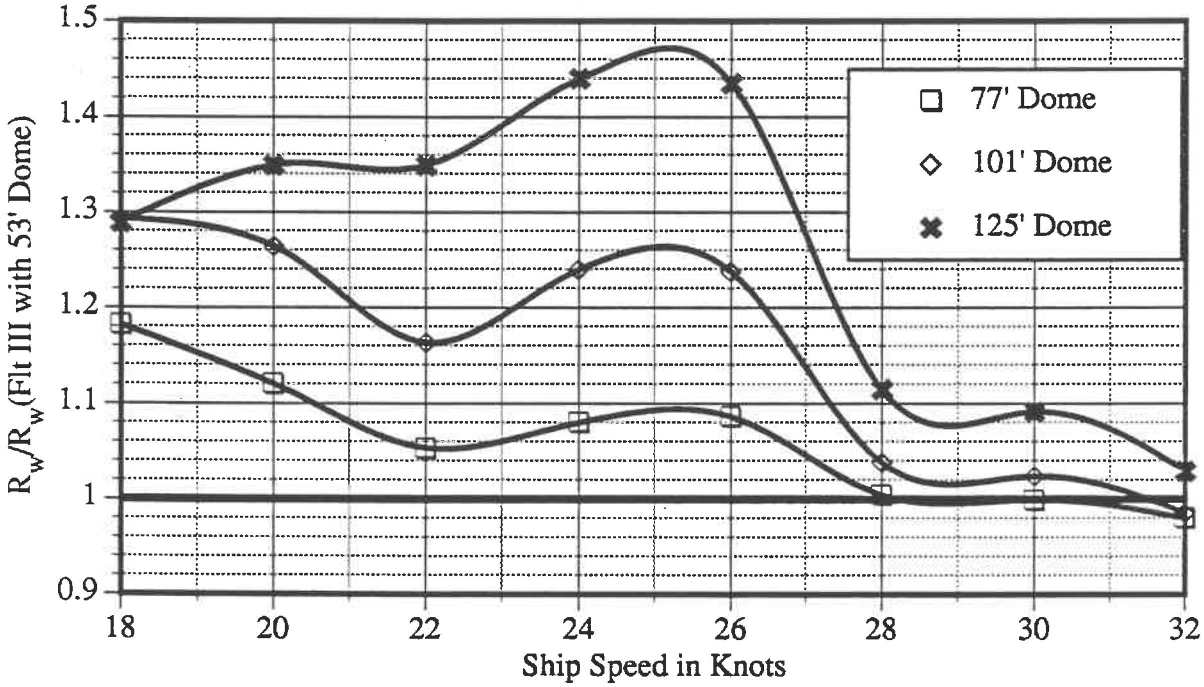
Fig. A2. Effect of change in dome length on DDG-51 Flight III wave resistance coefficients as predicted by SWIFT.



Wave resistance coefficients predicted by SWIFT, Free to sink and trim
Baseline configuration: 466 ft (142.0 m) hull with 53 ft (16.15 m) Dome
Flight III hull is the Flight I hull with a 40 ft (12.19 m) Parallel Middle Body inserted at Frame 244

Fig. A3. Predicted change in wavemaking resistance due to increase in dome length and addition of parallel middle body with respect to Baseline (Flight I with 53 foot (16.15 m) Dome) configuration.

EFFECT OF CHANGE IN BOW DOME LENGTH ON WAVEMAKING RESISTANCE OF DDG-51, AS PREDICTED BY SWIFT



Wave resistance coefficients predicted by SWIFT, Free to sink and trim
Flight III hull is the Flight I hull with a 40 ft (12.19 m) Parallel Middle Body inserted at Frame 244

Fig. A4. Predicted change in wavemaking resistance due to increase in dome length with respect to Flight III hull with 53 foot (16.15 m) dome.