NAVY DEPARTMENT

THE DAVID W. TAYLOR MODEL BASIN

WASHINGTON 7, D.C.

SS PENNSYLVANIA

STANDARDIZATION TRIAL ANALYSIS

AND

COMPARISON WITH MODEL TEST RESULTS

By

J. B. Hadler
C. J. Wilson

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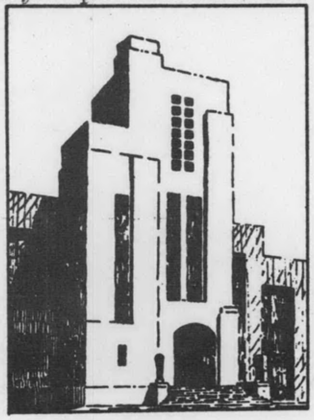

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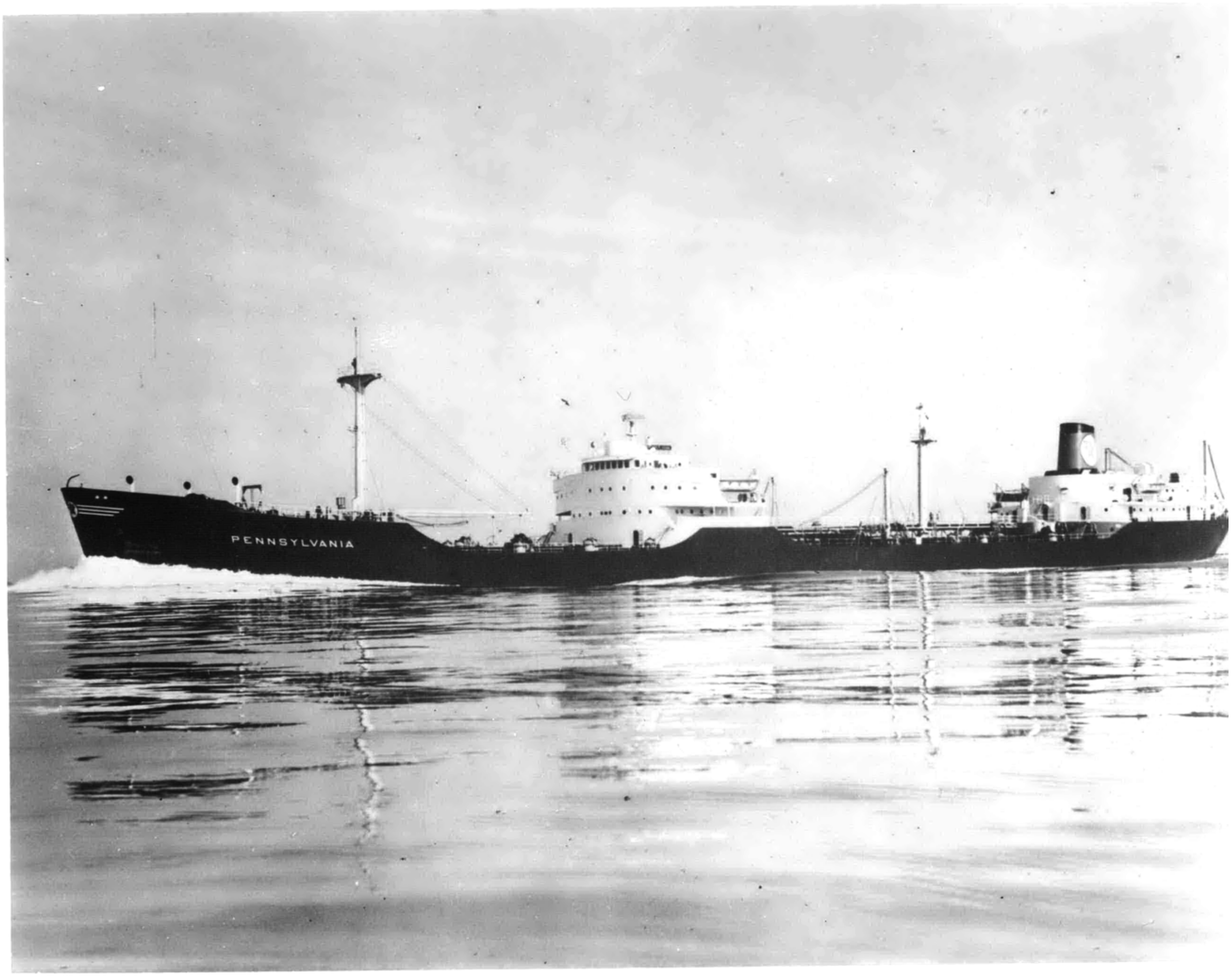

SS PENNSYLVANIA
During Standardization Trials

SS PENNSYLVANIA STANDARDIZATION TRIAL
ANALYSIS AND COMPARISON WITH MODEL TEST RESULTS

INTRODUCTION

As a part of the David Taylor Model Basin's efforts to obtain as much reliable full scale trial data as practicable for the purpose of improving the accuracy of model test predictions the Quincy yard of the Bethlehem Steel Company was requested (1)* to permit the Taylor Model Basin to observe the trials of the SS PENNSYLVANIA. The PENNSYLVANIA was the first ship of a 28,000 ton DWT single-screw tanker class built by the Quincy yard. The frontispiece is a photograph of the vessel during standardization trials on the Rockland, Maine measured mile course. The trials were conducted by the Central Technical Department of the Shipbuilding Division, Bethlehem Steel Company on 2, 3 and 4 August 1949.

A model of the PENNSYLVANIA, 22 feet in length, TMB Model No. 4057, was tested self-propelled in the deep water basin of the Taylor Model Basin at drafts corresponding as nearly as practicable to the trial conditions.

The ship trial data have been analyzed and reduced to standard model basin conditions for comparison with the performance predicted for the ship from self-propulsion tests No. 4 and No. 10 of Model 4057. Test No. 4 (2) represented the heavy-displacement trial condition. Test No. 10 was run at the conditions prevailing during light-displacement trials.

APPARATUS AND METHODS FOR OBSERVING TRIAL DATA

In accordance with the present practice of conducting standardization trials, measurements were made of revolutions per minute, shaft horsepower and speed while traversing the measured mile.

The interval required by the vessel to traverse the measured mile during each run was timed by three observers on the bridge, each equipped with a stop watch. The average of the three stop-watch times was used in calculating the average speed over the measured mile. The revolutions per mile of the propeller shaft were indicated by a Smith-Cummings counter operated by an observer on the bridge. The revolutions per mile were divided by the elapsed time of this observer to obtain the revolutions per minute (RPM). The torque in the propeller shaft was measured by a recently purchased Siemens-Ford A.C. torsionmeter.

Shaft horsepower (SHP) was computed from the shaft torque and RPM. Relative wind data were recorded for the individual runs with a propeller type Friez anemometer electrically connected to a velocity and direction indicator on the bridge. The anemometer was located at the top of the foremast.

SHIP TRIAL AND MODEL TEST CONDITIONS

The underwater hull was sand blasted and painted before trials. Conventional marine anti-fouling painting was used consisting of three undercoats of combination red lead-zinc chromate, one anti-corrosive coat and one resin-type anti-foulin coat. An examination of the underwater body by Bethlehem Steel Company personnel disclosed the surface to be "extremely smooth.

The ship was steered over the standardization course by gyro. Rudder angles varied up to about 3 degrees and infrequent went as high as 5 and 6 degrees. A straight approach run of thr miles was made for all runs.

The principal dimensions and characteristics of the ship and model are given in Table 1. Table 1 also gives information on the conditions prevailing during the standardization trials. Figure 1 is a photograph of the stern of the model as fitted with the propeller for these tests.

A 5-ft. length superstructure model, TMB Model 4197, representing the PENNSYLVANIA with all of the major appendages above the design waterline was constructed. This model was test in the 8 x 10 ft. wind tunnel at the Taylor Model Basin to determine the resistance due to wind at varying angles of attack. Figure 2 is a picture of the model as tested in the wind tunnel.

TABLE 1

Ship and Model Characteristics and Test Conditions

	SS PENNSYLVANIA	MODEL 4057
Length on Waterline (LWL)	608.00 ft.	21.919 ft.
Max. Beam at LWL	84.00 ft.	3.028 ft.
Linear Ratio		27.74
Appendages	Rudder and Bilge Keels	
No. of Props.	1	1
Model Prop. No.		3055
Prop. Plans *	CTD 4467-E-91	C-3055
Des. Prop. Dia.	22.00 ft.	9.517 in.
Des. Prop. Pitch at 0.7 Rad.	17.75 ft.	7.678 in.
No. of Blades	4	
Direction of Rotation	Right Hand	
P/D	0.807	
MWR	0.227	
BTF	Variable	
Propeller Area/Disk Area	0.420	

* Ship and model propeller designs have identical characteristi

	SS PENNSYLVANIA		SHIP CONDITIONS FOR MODEL	
	Heavy Displ.	Light Displ.	Heavy Displ.	Light Displ
ıl Course	Rockland, Me.	Rockland, Me.	-	-
ıgth of Trial ›urse	6080 ft.	6080 ft.	-	-
›placement	36289 tons	25945 tons	36100 tons	25710 tons
;e of Test	2 Aug 49	3, 4 Aug 49	8 Sep 48	24 Aug 49
ın Draft	33.19 ft.	24.50 ft.	33.00 ft.	24.31 ft.
ım	Even Keel	8.00 ft. by stern	Even Keel	8.00 ft. by stern
;ted Surface	74965 sq. ft.	63665 sq. ft.	74760 sq. ft.	63410 sq. f
's out of dock	2	3, 4	-	-
›th of Water	204 ft.	204 ft.	610 ft.	610 ft. (Basin depth 22 ft.)
ıp. of water	56° F.	58° F.	*	*
ıd (Beaufort scale)	2	1 - 3	-	-
;tom Paint	Resin-Type Anti-Fouling		Enamel	
›cific Gravity ' water	1.024 assumed	1.024 assumed	**	**

* Model test predictions have been corrected to a standard temperature of 59.0° F.

** Model test predictions have been corrected to standard sea water specific gravity of 1.028.

DISCUSSION OF TRIAL AND MODEL TEST RESULTS

Three runs were made over the measured mile at each of the various speeds tested. Elapsed time over the mile, the propeller shaft RPM, propeller shaft torque and relative wind direction and velocity were recorded by Bethlehem Steel Company personnel (4). These data are given in Appendix 1. Appendix 2 contains the information for calculating SHP from torque and RPM.

The data from the full-scale trials have been reduced to standard model basin conditions of zero wind and current by using Eggert's power method as described by Pitrie (3). This method is outlined in some detail in Appendix 3. Curves of SHP, RPM, true slip, apparent slip and wake fraction for model and ship are presented in Figure 3 for the heavy displacement and in Figure 4 for the light displacement. Appendix 4 contains the corrected data which were used in plotting the ship trial curves. Figure 5 shows the torque and thrust characteristics of the propeller as determined by open water tests in the basin. In view of the comparatively low propeller RPM and SHP no cavitation tests were made on this model.

It may be noted from Figures 3 and 4 that the SHP and RPM values for the ship are consistently lower than those for the model. At a speed of 17 knots in the heavy displacement condition the SHP for the ship is approximately 4 percent less and the RPM 1 percent less than the corresponding values predicted from the model test. At the same speed in the light condition the SHP is approximately 6 percent less and the RPM 1 percent less than that predicted from model test. The true slip and wake fraction are lower for the ship than for the model, but the difference is considered to be within the combined accuracies of the ship and model tests.

It is necessary to consider some of the assumptions made in computing the ship data from the model test results when seeking an explanation for the discrepancy between the ship trial results and the model predictions. It is the practice at the Model Basin to use Schoenherr's frictional resistance coefficients for both the model and ship with a roughness allowance coefficient added to the ship friction value. The roughness allowance coefficient now used is 0.0004 which is the figure adopted by the American Towing Tank Conference in 1947 pending the availability of further reliable full-scale trial data. On the assumption that the ship propulsive coefficient (PC) is the same as the model, the roughness allowance coefficient for the PENNSYLVANIA would be 0.00025. Since the ship PC is probably somewhat greater than that obtained from the model test because the RPM and therefore the slip is less for the ship and the propeller efficiency greater, the ship EHP is thus relatively greater. On this basis the roughness allowance obtained from EHP comparisons would be slightly greater than 0.00025, probably about 0.00030. These results indicate a smooth hull surface and therefore agree with the opinion expressed after a visual inspection of the paint surface on this vessel before undocking.

Although the paint surface was judged to be quite smooth and the roughness allowance substantiates this conclusion it should be noted that the roughness allowance is composed of what might be called "built-in-roughness" as well as the paint roughness. The built in roughness is a function of the structural design of the hull, the material condition of the shell plating and the shipbuilding procedures. Specifically it is due to the mill scale on the hull plates, the butt and seam rivets, laps or welds, condenser scoops, overboard discharges and other hull excresences. On the PENNSYLVANIA most of the mill scale should have been removed inasmuch as the hull was sandblasted prior to painting. Regarding ship construction methods it appears that the underwater surface of the PENNSYLVANIA is smoother than that of most naval vessels since there are fewer sea chests and they are fitted with doubler plates on the inside of the shell plating which is contrary to the average naval practice. The bilge strake and one other plating seam are the only ones lapped and riveted, all other seams and butts being flush welded.

SUMMARY

The trials of the PENNSYLVANIA were carefully conducted and the results appear to be above average for this type of trial. The shaft horsepower and RPM for the ship are less than predicted from model tests, however, the configuration of model and ship curves agree very well.

It appears that the roughness allowance coefficient of 0.0004 adopted for ships by the American Towing Tank Conference (ATTC) in 1947 may be excessive for vessels painted with commerci type paints, which evidently produce an underwater surface about as smooth as that of Navy type 15 RC paint. Full-scale trials of naval vessels painted with 15 RC indicated that ship values of thrust and SHP were generally less than predicted from model tests based on the 0.0004 roughness allowance coefficient. While some progress has been made in securing paint roughness data from carefully run trials of naval vessels, similar information for commercial-type vessels with commercial paints is very meager.

REFERENCES

(1) TelCon of 21 July 49 between Mr. H. F. Robinson, Bethlehem Steel Co., and Admiral C. O. Kell, DTMB.

(2) "Power and Flow Characteristics for the Bethlehem Steel Company 28,000-Ton-Deadweight Single-Screw Tanker as predicted from Tests with Model 4057" by M. S. Harper, DTMB Report No. 646 of April 1948.

(3) "Trial Analysis Methods," by A. S. Pitrie, Trans. Soc. Naval Arch. Marine Engineers, Vol. 40, 1932.

(4) "Report of official Trials SS PENNSYLVANIA Rockland, Maine August 1-4, 1949" by Bethlehem Steel Company, Quincy, Mass.

Figure 1 - Stern View of Model 4057
Representing SS PENNSYLVANIA

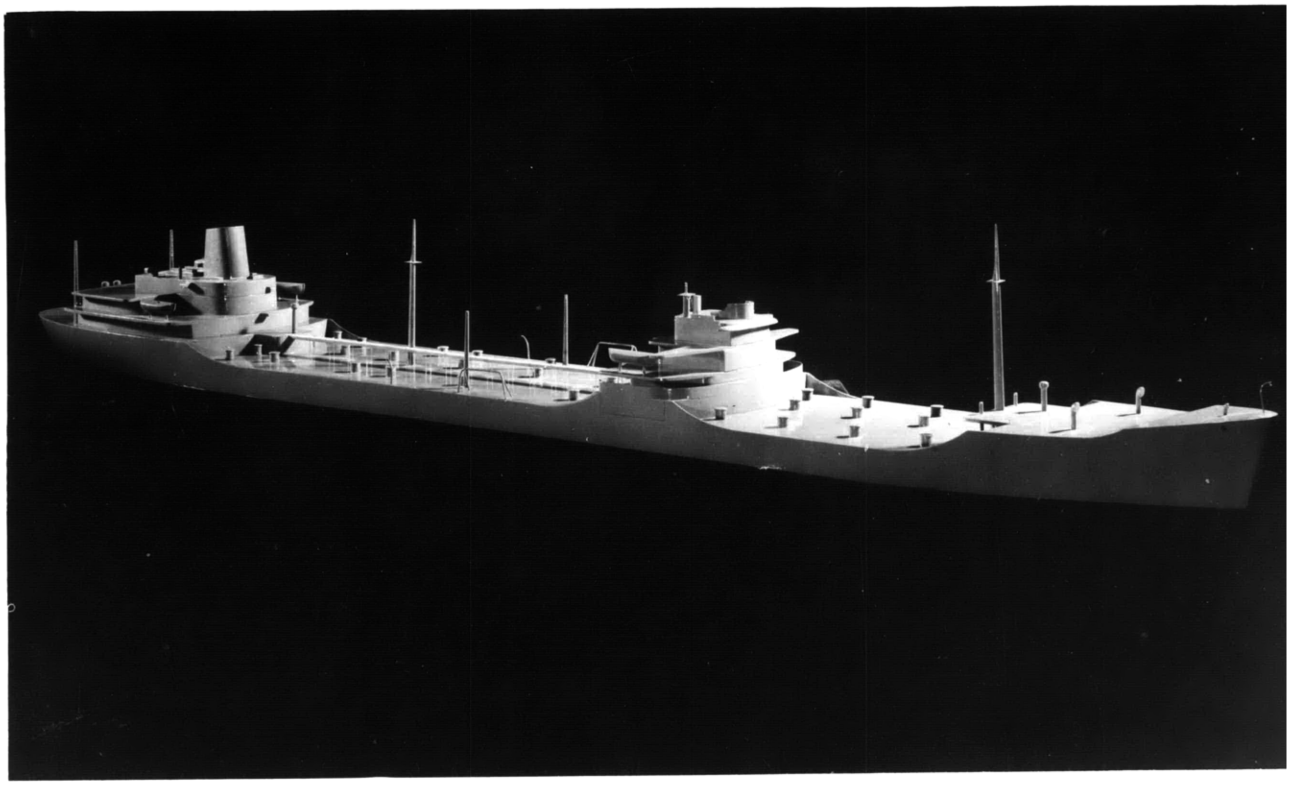

Figure 2 - Side View of Wind Tunnel Model No. 4197
Representing SS PENNSYLVANIA

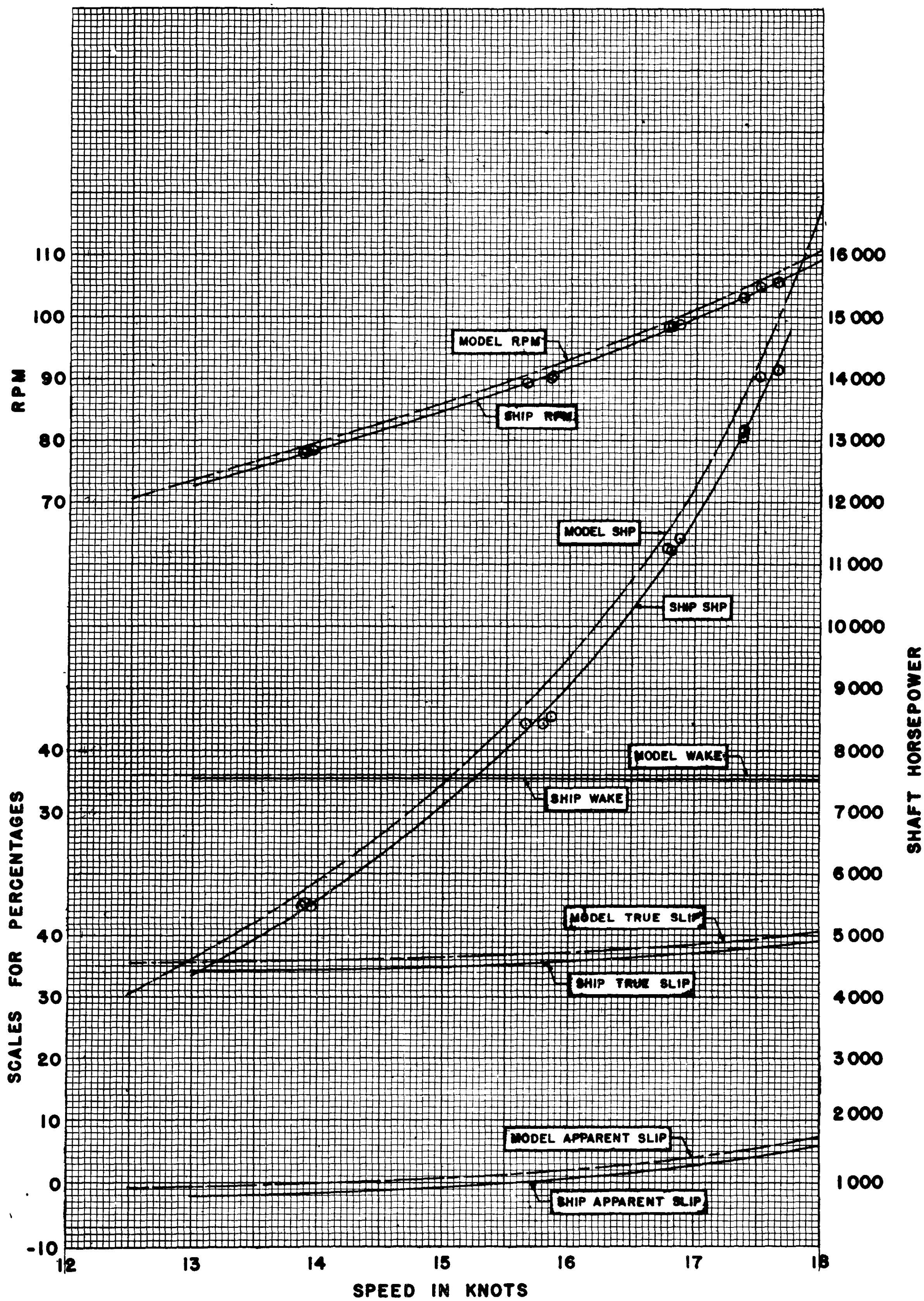

Figure 3 - Trial Results for SS PENNSYLVANIA on 2 August 1949 at a Displacement of 36289 Tons, Compared with Self-Propulsion Model Test No. 4

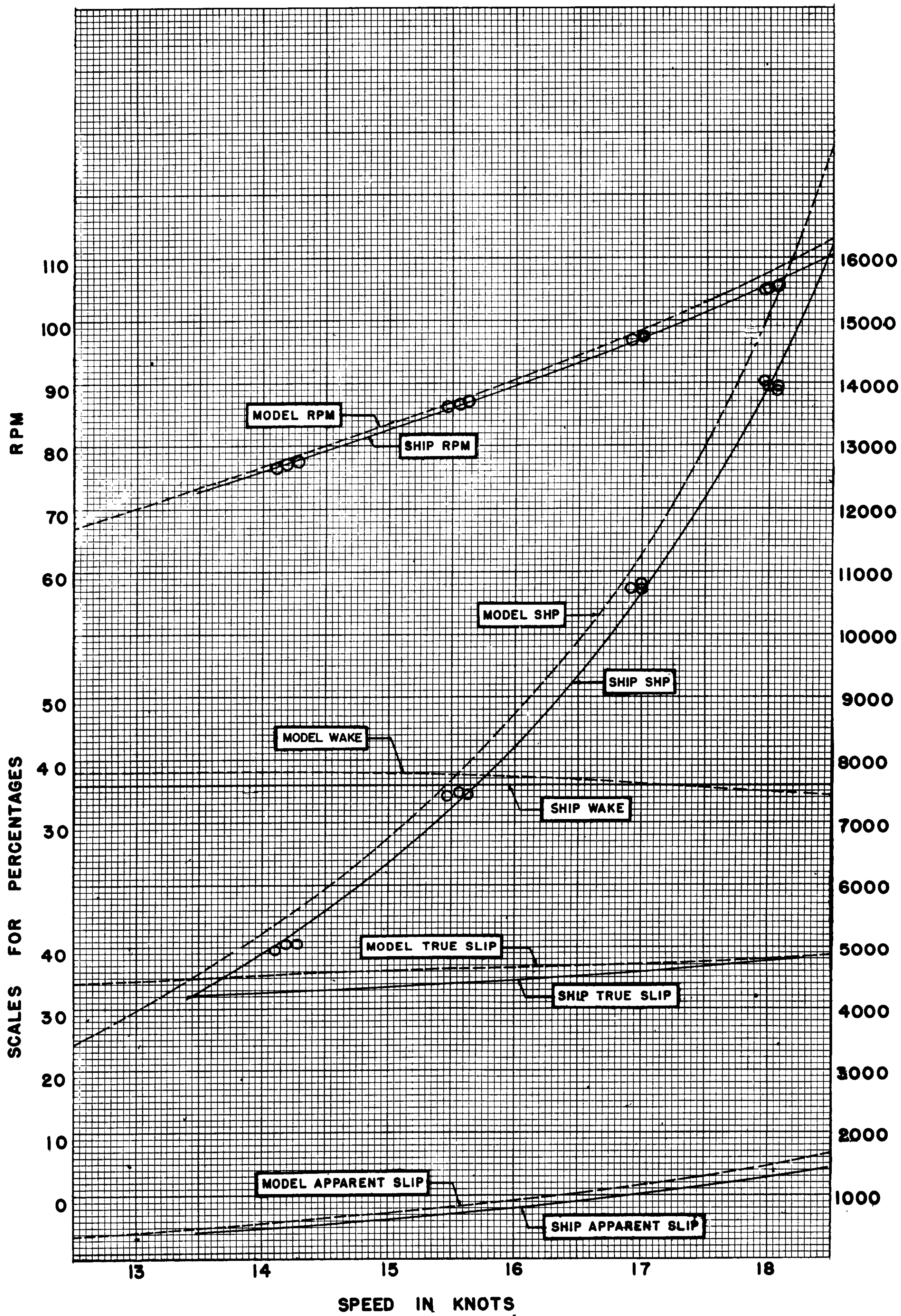

Figure 4 - Trial Results for SS PENNSYLVANIA on 3, 4 August 1949 at a Displacement of 25945 Tons, Compared with Self-Propulsion Model Test No. 10

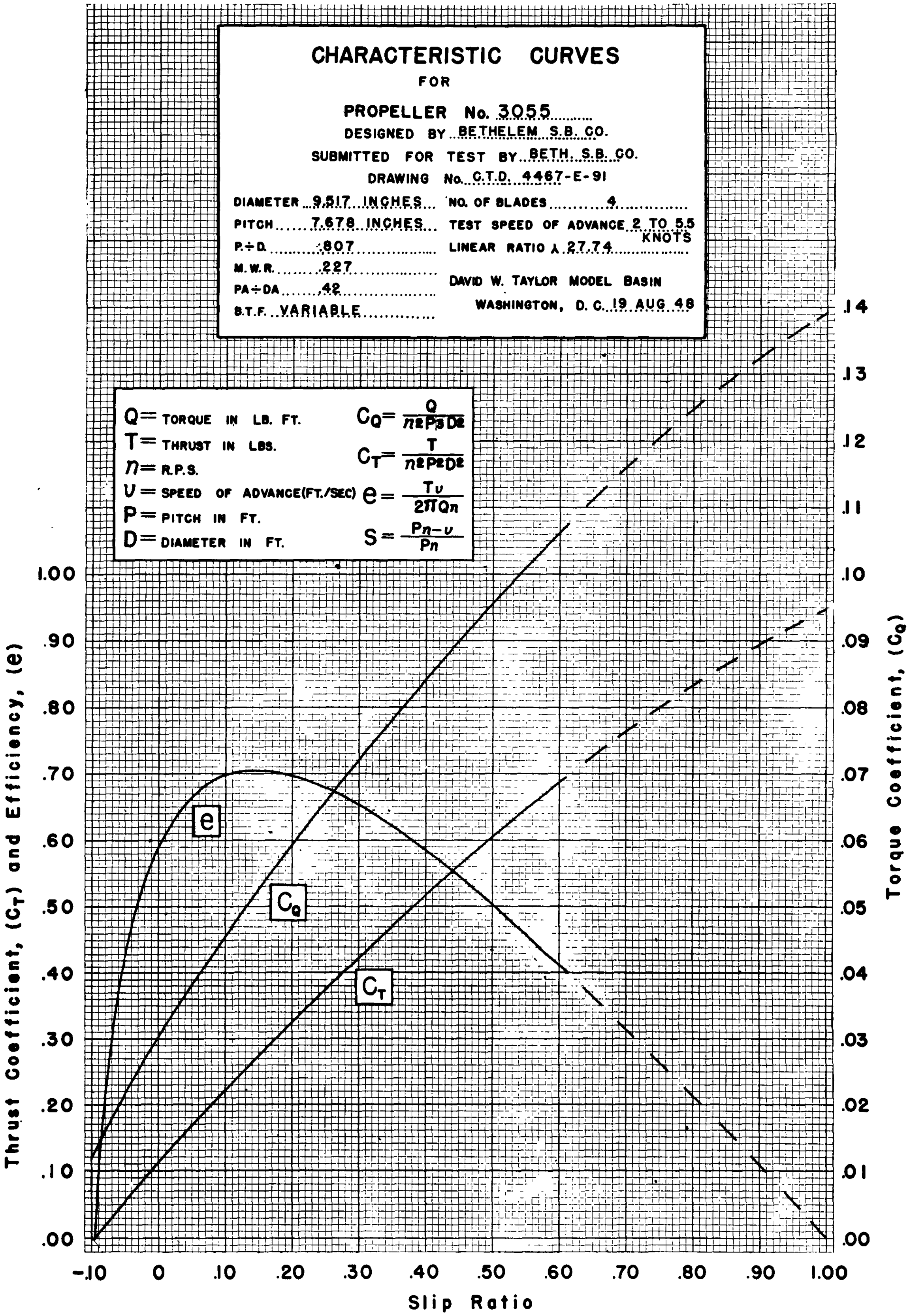

Figure 5 - Propeller Characteristic Curves Derived from Tests with Model Propeller No. 3055

APPENDIX 1

Full-Scale Trial Data - Observed Values

TABLE 2

Heavy Displacement (36,289 Tons) Standardization Data From Trial SS PENNSYLVANIA on 2 August 1949

Run Number and Direction	Observed Speed (V_o) (Knots)	Observed RPM (N_o)	Torsionmeter Reading	Relative Wind Direction	Apparent Wind Velocity (K
1N	17.92	105.7	76.65	001	14.9
2S	17.07	104.9	76.53	346	28.8
3N	17.92	105.7	76.64	007	15.0
4S	16.98	103.2	73.09	350	24.0
5N	17.61	103.2	72.90	000	15.5
6S	17.01	103.1	72.40	350	26.0
7N	16.89	98.3	65.56	010	15.0
8S	16.70	98.5	65.20	345	26.0
9N	16.64	98.9	66.08	012	14.0
10S	15.85	90.1	53.48	344	25.0
11N	15.20	89.3	53.95	030	14.0
12S	16.19	90.5	53.99	340	28.0
13N	13.12	78.1	40.48	045	15.0
14S	14.49	78.4	40.02	335	23.0
15N	13.00	77.9	40.27	020	17.0

TABLE 3

Light Displacement (25,945 Tons) Standardization Data From Trials SS PENNSYLVANIA on 3, 4 August 1949

Run Number and Direction	Observed Speed (V_o) (Knots)	Observed RPM (N_o)	Torsionmeter Reading	Relative Wind Direction	Apparent Wind Velocity (Knots)
1S	14.21	76.6	36.51	338	19.0
2N	13.72	77.1	37.01	025	17.0
3S	14.63	77.6	36.88	335	14.0
4N	14.67	86.2	48.72	020	19.0
5S	16.39	87.1	48.50	350	14.0
6N	14.46	86.7	48.98	005	20.0
7S	17.79	97.3	62.45	335	18.0
8N	16.04	96.9	63.01	005	18.0
9S	17.61	97.3	63.10	353	20.0
4 August 1949					
1N	17.67	105.5	75.53	325	11.0
2S	17.96	105.0	75.87	000	37.0
3N	17.88	105.4	75.15	315	5.0
4S	17.66	105.0	76.17	000	38.0

APPENDIX 2

METHOD OF REDUCTION OF SHAFT TORQUE DATA TO SHAFT HORSEPOWER

1. The shaft torque data was obtained by a Siemens-Ford A.C. torsionmeter. This torsionmeter contains two husk transformers placed 180 degrees apart to remove any error from bending moments in the shaft. These transformers which are connected in series indicate the shaft twist on one transformer in the indicato The null balance system is used in this torsionmeter. The section moduli of the shaft was obtained by taking an average of the various moduli obtained by the Bethlehem Steel Company on previous shaft calibrations.

2. The torsionmeter zeros were obtained by the so-called "drag shaft" method. The shafts were dragged ahead prior to and upon completion of trials each day. The average of the morning and evening readings are considered to be the zero reading for the trials conducted on that date. The variation in zero was less than one percent of the full-power torque. The following information was obtained from Reference 4:

<u>Zero Readings</u>

2 Aug 49 $\frac{(-1.2) + (+1.0)}{2} = -0.1$

3 Aug 49 $\frac{(-1.3) + (0.0)}{2} = -0.65$

4 Aug 49 $\frac{(-1.2) - (0.0)}{2} = -0.6$

<u>Transformer Ratio</u>

2 Aug 49 = .967
3 Aug 49 = .969
4 Aug 49 = .969

<u>Constant</u>

$$K_1 = 256.79 \times 10^7 \times \frac{L x R}{D^4 x G_p} = .593$$

where L = Clamping Distance of Meter = 32-1/32 inch
R = Radius of Transformer Poles = 15.16 inche
D = Diameter of Shaft = 20.503 inches
G_p = Torsional Modulus of Shaft = 11.9×10^6 lbs/in^2

$K_2 = K_1 \times$ Transformer Ratio

$K_2 = .593 \times .967 = .573$ 2 Aug 49
$.593 \times .969 = .575$ 3 and 4 Aug 49

$$SHP = \frac{CTR \times RPM}{K_2}$$

where CTR = corrected Torsionmeter Reading
= Torsionmeter Reading - Zero Readi[illegible]
RPM = Revolutions per Minute of Shaft
$K_2 = K_1 \times$ Transformer Ratio

APPENDIX 3

METHODS OF TRIAL ANALYSIS TO REDUCE DATA TO STANDARD CONDITIONS

1. The trial data were reduced by Eggert's power method as described by Pitrie in (3).

2. The analysis attempts to evaluate the effects of wind and current in order to reduce the data to standard model-basin conditions of zero current and zero air resistance. A description of the analysis as regards speed may be summarized as follows:

a. The wind direction coefficient, k, for the observed apparent wind direction was found from the wind resistance test of a 5-foot model of the SS PENNSYLVANIA.

b. The horsepower expended in overcoming the wind resistance is calculated from the formula

$$\Delta \text{EHP} = \frac{R_w \, A \, W_a^2 \, V_o \, k}{325.7}$$

where R_w is the specific resistance coefficient from a model test (0.00261 from SS PENNSYLVANIA wind tunnel model test)

- A is the above-water cross-sectional area of the ship, (4260 sq. ft. for the heavy displacement, 4980 sq. ft. for the light displacement),
- W_a is the relative wind velocity,
- V_o is the speed through the water (second mean of the observed speeds for a three-run group)
- k is the wind direction coefficient representing the ratio of increase in axial resistance for any angle of attack, based on the axial resistance for zero angle of attack, and $\frac{1}{325.7}$ is a factor to reduce resistance (pounds) multiplied by speed (knots) to EHP.

c. A curve of slope of EHP against speed is plotted. The increase in EHP per knot change in speed, $\frac{\Delta \text{EHP}}{\Delta V}$, is read from this curve at the group average speeds.

d. The Δ EHP from Step b is divided by the EHP per knot from Step c, which gives the increment of speed ΔV due to the wind effect.

e. The increments of speed are added (subtracted if k is negative) to the observed speeds V_G over the ground with no air resistance.

f. The speeds V_G, Step e, corrected for wind effect, are still influenced by the current existing over the trial course during the runs. It has been shown in more detailed papers on trial analysis that if the current varies uniformly, the second mean (weighted average) of the observed speeds in a three-run group at constant RPM is a close approximation to the true speed through the water. Since the RPM varies somewhat over a three-run group, the average RPM for the group is divided by the weighte average V_G to find the average RPM per knot.

g. The RPM for each run is in turn divided by the RPM per knot, Step f, to find the corrected speed through the water V_W.

h. The actual speed through the water, V_{AW}, is the corrected speed through the water, V_W, minus the speed correction ΔV due to the wind.

3. Values of torque coefficient, true slip, apparent slip and wake fraction are determined in the following manner:

a. The observed torque coefficient, C_{Qo}, is calculated from the formula

$$C_{Qo} = \frac{33000 \times 3600 \ SHP_o}{2 \pi P \ D^2 \ N_o^3 \ \partial}$$

where 33000 is a factor to convert SHP to pound feet per second,
3600 is a factor to convert RPM to RPS,
∂ is the ratio of density of the water in which the ship trials were conducted to the density of the water in which the model propeller open-water test was run.
P is the pitch of the propeller, in feet,
D is the diameter of the propeller, in feet,
N_o is the RPM of the propeller.

b. Enter the open-water characteristic curves for the model propeller and determine the true slip ratio s_o for the values of C_{Qo}, Step a.

c. The speed of advance for the propeller, V_a, is expressed by the formula

$$V_a = \frac{(1-S_o) \ PN_o}{101.33}$$

where S_o is the observed true slip from Step b.
P and N are as defined in Step a

$\frac{1}{101.33}$ is a constant to convert feet per minute to knots

d. The wake fraction w is determined from the formula

$$w = \frac{V_o - V_a}{V_o}$$

where V_o is the weighted average of the observed speeds,
V_a is the weighted average of the speeds of advance

e. The apparent slip $s_a = 1 - \frac{101.33\ V_w}{P\ N_o}$

where V_w is the corrected speed through water, P, N_o,

$\frac{1}{101.33}$ are the same as in Step 3c, above.

APPENDIX 4

Full-Scale Trial Data - Corrected to Zero Wind and Zero Current Condition

TABLE 5

Heavy Displacement (36289 tons) Standardization Data from Trials SS PENNSYLVANIA on 2 August 1949

Run Number and Direction	Corrected Speed Through Water (V_W)	Observed RPM (N_o)	Observed SHP (SHP_o)	Observed True Slip (s_t)	Wake Fraction (w)	Apparent Slip (s_a)
1N	17.65	105.7	14160			
2S	17.51	104.9	14030			
3N	17.64	105.7	14150			
	17.58	105.3	14090	.384	.351	.047
4S	17.38	103.2	13180			
5N	17.38	103.2	13140			
6S	17.37	103.1	13050			
	17.38	103.2	13130	.378	.351	.038
7N	16.78	98.3	11270			
8S	16.81	98.5	11220			
9N	16.87	98.9	11420			
	16.82	98.5	11280	.369	.349	.026
10S	15.79	90.1	8424			
11N	15.65	89.3	8425			
12S	15.86	90.5	8545			
	15.74	89.8	8455	.362	.357	.000
13N	13.90	78.1	5532			
14S	13.95	78.4	5489			
15N	13.87	77.9	5490			
	13.92	78.2	5500	.352	.356	- .016

TABLE 6

Light Displacement (25,945 tons) Standardization Data From Trials SS PENNSYLVANIA on 3, 4 August 1949

Run Number and Direction	Corrected Speed Through Water (V_W)	Observed RPM (N_o)	Observed SHP (SHP_o)	Observed True Slip (s_t)	Wake Fraction (w)	Apparent Slip (s_a)
3 August 1949						
1S	14.11	76.6	4952			
2N	14.19	77.1	5048			
3S	14.28	77.6	5062			
	14.19	77.1	5028	.322	.350	- .051
4N	15.47	86.2	7402			
5S	15.63	87.1	7445			
6N	15.56	86.7	7483			
	15.57	86.8	7444	.346	.358	- .024
7S	17.00	97.3	10680			
8N	16.92	96.9	10720			
9S	17.00	97.3	10790			
	16.96	97.1	10730	.365	.360	+ .003
4 August 1949						
1N	18.07	105.5	13970			
2S	17.98	105.0	13960			
3N	18.04	105.4	13880			
4S	17.96	105.0	14020			
	18.01	105.2	13940	.379	.360	+ .022