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PREDICTIONS OF POWERING PERFORMANCE INCLUDING TOWROPE PULL AND --ETC(U)

SEP 80 K J ANDERSON, W G DAY

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DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Maryland 20084

DTNSRDC/SPD-0957-01

PREDICTIONS OF POWERING PERFORMANCE INCLUDING TOWROPE PULL AND THE RESULTS OF PROPELLER DISK WAKE SURVEY FOR THE ARS-46 SALVAGE SHIP REPRESENTED BY MODEL 5391

K.J. Anderson and W.G. Day

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SHIP PERFORMANCE DEPARTMENT

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September 1980 DTNSRDC/SPD-0957-01

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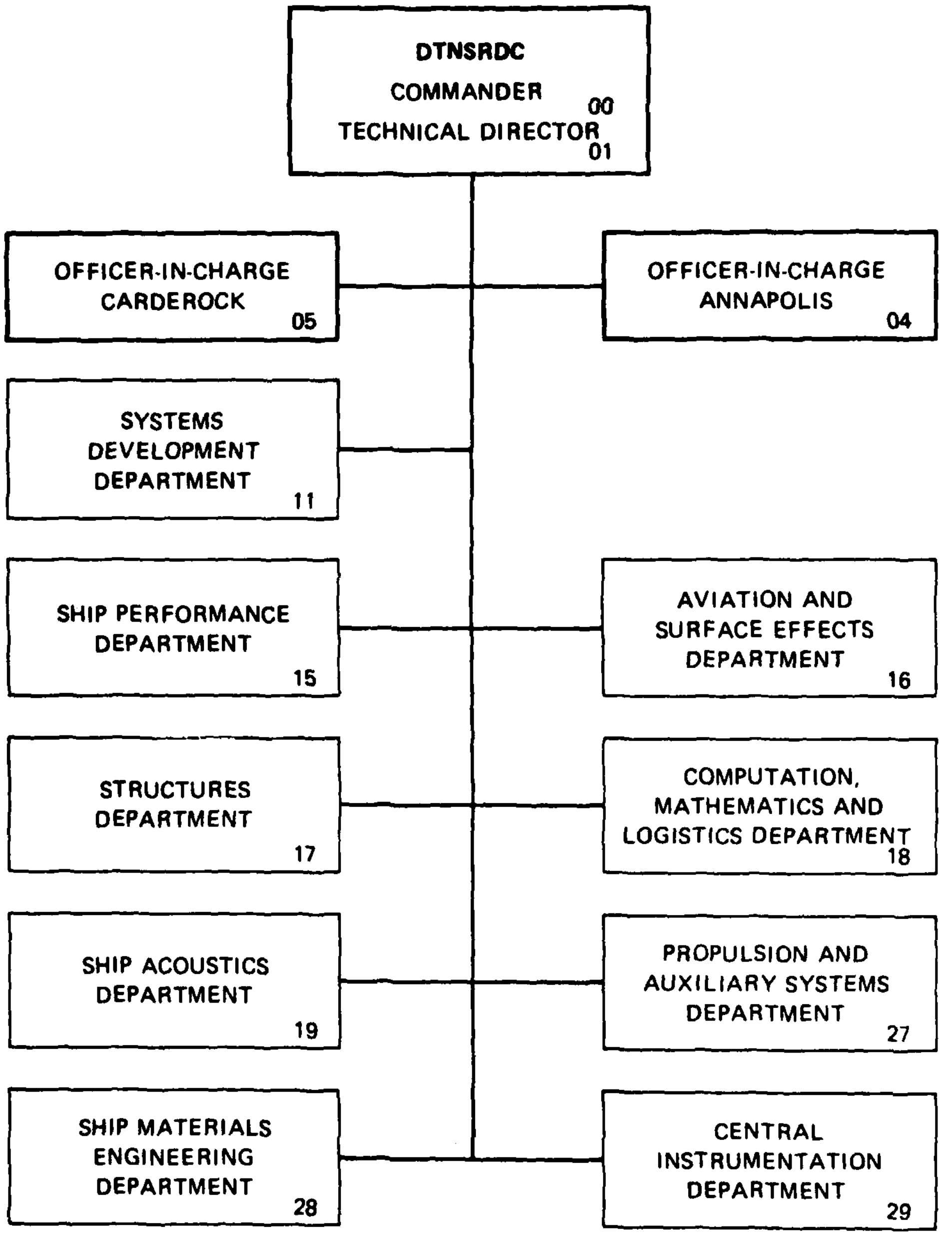
MAJOR DTNSRDC ORGANIZATIONAL COMPONENTS



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Towrope Pull
Wake Survey
Model Experiments

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Model experiments were conducted in a towing tank to determine the fully appended powering predictions for a preliminary design of a Salvage Ship (ARS-46) fitted with stock propellers. Powering predictions for the ship going astern and for the ship in bollard-pull and towrope-pull conditions are presented. The results of a wake survey experiment performed in the plane of the propeller disk are presented. The harmonic analysis of the circumferential distribution of the longitudinal and tangential velocities are also presented.

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NOTATION

The notation in this report is consistent with the International Towing Tank Conference Standard Symbols of 1976.* Any other symbols used in this report are defined on the following pages.

*The British Ship Research Association, Technical Memorandum Number 500, May 1976

NOTATION (CONTINUED)

CONVENTIONAL SYMBOL	SYMBOL APPEARING ON PLOTS	DEFINITION
A_N	COS COEF	The cosine coefficient of the $N^{\underline{th}}$ harmonic*
B_N	SIN COEF	The sine coefficient of the $N^{\underline{th}}$ harmonic*
C	C	Pressure reading at center hole of 5-hole pitot tube
D	---	Propeller diameter
J_V	J_V	Apparent advance coefficient $J_V = \frac{V}{nD}$ (dimensionless)
N	N	Harmonic number
n	---	Propeller revolutions
P	P	Pressure
r/R or x	Radius or RAD.	Distance (r) from the propeller axis expressed as a ratio of the propeller radius (R)
R_n	R_n	Reynolds number $V \cdot L/\nu$
R1, R2	R1, R2	Pressure reading at radial holes of 5-hole pitot tube
T1, T2	T1, T2	Pressure reading at tangential holes of 5-hole pitot tube
V	V	Actual model or ship velocity
$V_b(x,\theta)$	---	Resultant inflow velocity to blade for a given point
$\bar{V}_b(x)$	---	Mean resultant inflow velocity to blade for a given radius
$V_r(x,\theta)$	VR	Radial component of the fluid velocity for a given point (positive toward the shaft centerline)

(*see footnote on page x)

NOTATION (CONTINUED)

CONVENTIONAL SYMBOL	SYMBOL APPEARING ON PLOTS	DEFINITION
$\bar{V}_r(x)$	---	Mean radial velocity component for a given radius
$V_r(x,\theta)/V$	VR/V	Radial velocity component ratio for a given point
$\bar{V}_r(x)/V$	VRBAR	Mean radial velocity component ratio for a given radius
$V_t(x,\theta)$	VT	Tangential component of the fluid velocity for a given point (positive in a counterclockwise direction looking forward)
$\bar{V}_t(x)$	---	Mean tangential velocity component for a given radius
$V_t(x,\theta)/V$	VT/V	Tangential velocity component ratio for a given point
$\bar{V}_t(x)/V$	VTBAR	Mean tangential velocity component ratio for a given radius
$(\tilde{V}_t(x)/V)_N$	AMPLITUDE	Amplitude (B_N for single screw symmetric; C_N otherwise) of Nth harmonic of the tangential velocity component ratio for a given radius*
$V_x(x,\theta)$	VX	Longitudinal (normal to the plane of survey) component of the fluid velocity for a given point (positive in the astern direction)
$\bar{V}_x(x)$	---	Mean longitudinal velocity component for a given radius
$V_x(x,\theta)/V$	VX/V	Longitudinal velocity component ratio for a given point
$V_x(x)/V$	VXBAR	Mean longitudinal velocity component ratio for a given radius
$(\tilde{V}_x(x)/V)_N$	AMPLITUDE	Amplitude (A_N for single screw symmetric; C_N otherwise) of Nth harmonic of the longitudinal velocity component ratio for a given radius*

NOTATION (CONTINUED)

CONVENTIONAL SYMBOL	SYMBOL APPEARING ON PLOTS	DEFINITION
$1-w(x)$	1-WX	Volumetric mean velocity ratio from the hub to a given radius

$$1-w(r/R) = \left[\frac{2 \cdot \int_{r_{hub}/R}^{r/R} (\bar{V}_{x_c}(x)/V) \cdot x \cdot dx}{(r/R)^2 - (r_{hub}/R)^2} \right]$$

where $$\bar{V}_{x_c}(x)/V = \int_0^{2\pi} \left[\frac{V_{x_c}(x,\theta)}{2\pi V} \right] d\theta$$

and $$V_{x_c}(x,\theta)/V = (V_x(x,\theta)/V) - (V_t(x,\theta)/V) \tan(\beta(x,\theta))$$

CONVENTIONAL SYMBOL	SYMBOL APPEARING ON PLOTS	DEFINITION
$1-w_v(x)$	1-WVX	Volumetric mean velocity ratio from the hub to a given radius (without the tangential velocity correction)

$$1-w(r/R) = \left[\frac{2 \cdot \int_{r_{hub}/R}^{r/R} (\bar{V}_x(x)/V) \cdot x \cdot dx}{(r/R)^2 - (r_{hub}/R)^2} \right]$$

CONVENTIONAL SYMBOL	SYMBOL APPEARING ON PLOTS	DEFINITION
$\beta(x,\theta)$	---	Advance angle in degrees for a given point
$\bar{\beta}(x)$	BBAR	Mean advance angle in degrees for a given radius
$+\Delta\beta$	BPOS	Variation of the maximum advance angle from the mean for a given radius

NOTATION (CONTINUED)

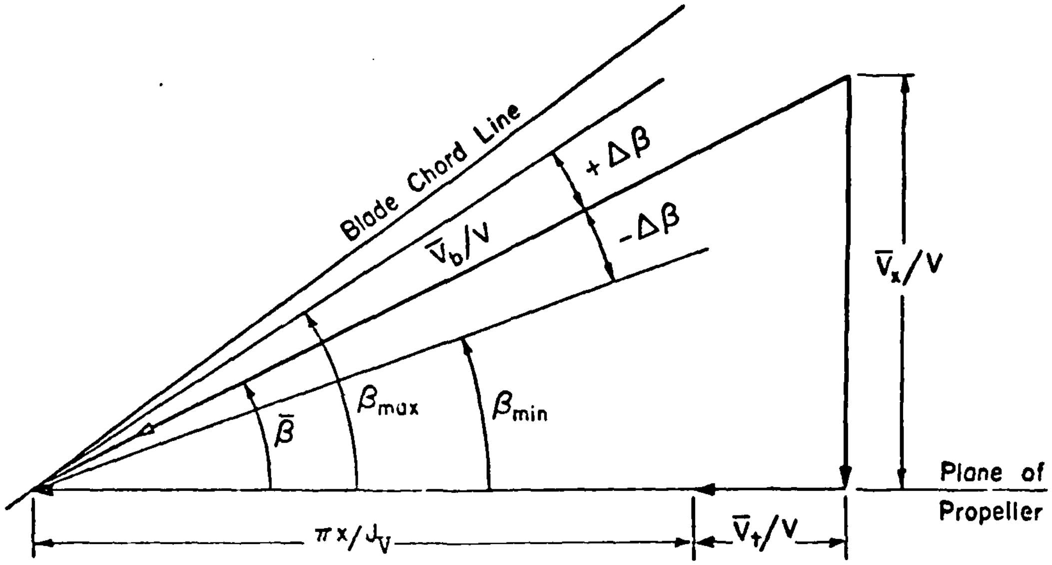
CONVENTIONAL SYMBOL	SYMBOL APPEARING ON PLOTS	DEFINITION
ϕ_N	PHASE ANGLE	Phase angle of Nth harmonic*

*The harmonic amplitudes of any circumferential velocity distribution $f(\theta)$ are the coefficients of the Fourier Series:

$$f(\theta) = A_o + \sum_{N=1}^{N} A_N \cos(N\theta) + \sum_{N=1}^{N} B_N \sin(N\theta)$$
$$= A_o + \sum_{N=1}^{N} C_N \sin(N\theta + \phi_N)$$

NOTATION (CONTINUED)

$-\Delta\beta$	BNEG	Variation of the minimum advance angle from the mean for a given radius
θ	Angle in degrees	Position angle (angular coordinate) in degrees



VELOCITY DIAGRAM OF BETA ANGLES

ENGLISH/SI EQUIVALENTS

ENGLISH	SI
1 inch	25.400 millimetres [0.0254 m (metres]
1 foot	0.3048 m (metres)
1 foot per second	0.3048 m/sec (metres per second)
1 knot	0.5144 m/sec (metres per second)
1 degree (angle)	0.01745 rad (radians)
1 inch Water (60^{o}F)	248.8 pa (pascals)

ABSTRACT

Model experiments were conducted in a towing tank to determine the fully appended power predictions for a preliminary design of a Salvage Ship (ARS-46) fitted with stock propellers. Powering predictions for the ship going astern and for the ship in bollard-pull and towrope-pull conditions are presented. The results of a wake survey experiment performed in the plane of the propeller disk are presented. The harmonic analysis of the circumferential distribution of the longitudinal and tangential velocities are also presented.

ADMINISTRATIVE INFORMATION

This project was performed at the David W. Taylor Naval Ship R&D Center (DTNSRDC) Bethesda, Maryland 20084. This investigation was authorized by the Naval Sea Systems Command (NAVSEA) in Work Request N65197-79-WR91584. The DTNSRDC Work Unit Numbers are 1524-698 and 1524-710.

INTRODUCTION

The Naval Sea Systems Command (NAVSEA) initiated a model experimental program at the David W. Taylor Naval Ship R&D Center (DTNSRDC) to aid in the evaluation of a preliminary design for a 240-foot (73.15 m) ARS-46 salvage ship. This report presents results from the following experiments:

1. Optimum Rudder Angle, Resistance and Free Route Propulsion
2. Ahead Bollard Pull and Towrope Pull
3. Astern Propulsion and Bollard Pull
4. Wake Survey in Free Route Ahead Condition

DESCRIPTION OF MODEL

Fiberglass Model 5391 represents a 240-foot (73.15 m) ARS-46 salvage ship constructed in accordance with NAVSEA molded lines Drawing 3213 SK.NO. 0006 dated 6 June 1979. A linear ratio of 15.357 was selected so that a 4-bladed stock propeller with a diameter of 7.72 inches (19.61 cm) could be used in the powering experiments. All experiments were performed using the model fitted with shafts, struts, bilge keels, skeg, rudders and with the bow thruster tunnel completely open. Turbulence was induced by a

0.025 inch (0.64 mm) trip wire located 9.378 inches (23.82 cm) aft of the leading edge of the bow. Since the trip-wire drag appeared to be insignificant, no correction was made to the total drag of the model. Additional ship and model data along with hull characteristics are given in Table 1. Abbreviated hull lines of the ARS-46 are shown in Figure 1. Open-water characteristic curves for DTNSRDC stock propellers 3228 and 3229 are shown in Figure 2.

DESCRIPTION OF EXPERIMENTS AND PRESENTATION OF RESULTS

All powering predictions reported herein are for the ship operating in smooth, deep, salt water with a temperature of 15 degrees Celsius. A correlation allowance (C_A) of 0.0005 and the 1957 ITTC Ship-Model Correlation Line were used for all frictional calculations as requested by the sponsor. All predictions are made for the ship at the design draft of 15.5 feet (4.72 m), trimmed to a level baseline and a displacement corresponding to 2862 tons (2908 metric tons). Propeller rotation was in the outboard direction.

Data for the optimum rudder experiment are presented graphically in Figure 3. Predictions of P_E, P_D, and allied data from the resistance and the free route propulsion experiments are tabulated on Tables 2 and 3 and are shown graphically in Figure 4.

Data for the ahead bollard pull condition are tabulated in Table 4 and presented graphically in Figure 5. Data for the ahead towrope pull condition at a ship speed of 6 knots are presented in Table 5 and are presented graphically in Figure 6.

The P_E, P_D, RPM and other data from the backing resistance and propulsion experiments are presented in Tables 6 and 7. These data are presented graphically in Figure 7. The speeds for the backing condition were limited to a maximum of 8 knots full-scale as requested by the sponsor. Data for the astern bollard pull condition are presented in Table 8 and graphically presented in Figure 8.

The accuracies normally expected of model experiments for surface ships conducted at DTNSRDC deep-water basin at model speeds above 2 knots (for this ship 8 knots, full scale) are $\pm$ 1.5 percent for effective power predictions and $\pm$ 2.5 percent for delivered power predictions.

A propeller disk wake survey was performed with the model fitted with appendages except for one rudder. The wake survey was conducted with the model ballasted to represent a full load draft of 15.5 feet (4.72 m) with zero initial trim, at a displacement of 2862 tons (2908 metric tons) full scale, and at a velocity representing a ship speed of 16.0 knots (8.23 m/s). The propeller plane in which the measurements of velocity were taken was 5.0 feet (1.52 m) aft of section 18.

A pitot tube rake, DTNSRDC No. 6, and 4 differential pressure gauges were used to measure the velocities in the plane of the propeller disk at five radial locations. Figure 9 shows the five 5-hole spherical pitot tubes mounted in a housing.

The full scale propeller disk was 9.9 feet (3.02 m) in diameter. The measurements were made at non-dimensional radii (r/R) of 0.332, 0.516, 0.715, 0.883, and 1.088.

To ensure the proper running trim throughout the experiments, the model was towed at the proper speed and displacement, allowed to trim to a steady running condition and locked in place at this trimmed condition.

The circumferential distribution of the longitudinal, tangential, and radial velocity component ratios are shown graphically for each pitot tube radius in Figures 10 through 14. The mean longitudinal (VXBAR), tangential (VTBAR), and radial (VRBAR) component ratios of the velocity component ratios and volumetric mean wake velocity ratio ($1-w_x$) are presented in Table 9. Except for the radial component (VRBAR), these quantities are shown graphically in Figure 15.

Calculated mean values of the advance angle (BBAR), and the maximum variations of advance angle, (BPOS) and (BNEG), are given in Figure 16 and Table 9. An advance coefficient, J , of 0.807, determined from the propulsion experiments, was used to calculate the advance angles. A diagram showing the relationship between the longitudinal and tangential velocity vectors, the advance coefficients and the advance angles is described in the notation section of this report.

Tables 10 through 13 present the harmonic analysis of the circumferential distributions of the longitudinal and tangential velocity component component ratios at the experimental radii.

The accuracy of the wake survey apparatus is estimated to be ± 1 percent on the longitudinal velocity component ratio (V_X/V) except in areas where steep velocity gradients occur. In these areas such as behind a shaft strut the accuracy is significantly less.

CONCLUSIONS

The data from the free route propulsion experiments show that when fitted with 9.9-foot prototypes of DTNSRDC stock propellers 3228 and 3229, the ARS-46 will attain a speed of about 16.1 knots using 5200 delivered horsepower (3877 kW) at 205 propeller revolutions per minute.

The ahead bollard pull experimental data show that at 5200 delivered horsepower (3877 kW) a bollard pull of about 108,000 pounds (480.kN) will be attained. For the 6-knot towrope pull experiment at the delivered power of 5200 horsepower a pull of about 88,500 pounds (394. kN) will be attained.

Data from the astern propulsion experiment show that the ARS-46 will attain a backing speed of about 8.0 knots using about 690 delivered horsepower (514.kW) at 103 propeller revolutions per minute. The data for the astern bollard pull condition show that at the delivered power of 5200 horsepower (3877 kW) a bollard pull of about 87,000 pounds (387.kN) will be attained.

The data from the wake survey experiment has been compared with data from the ATS-1 design, which is somewhat similar to ARS-46. This comparison showed that the results from this wake survey are reasonable.

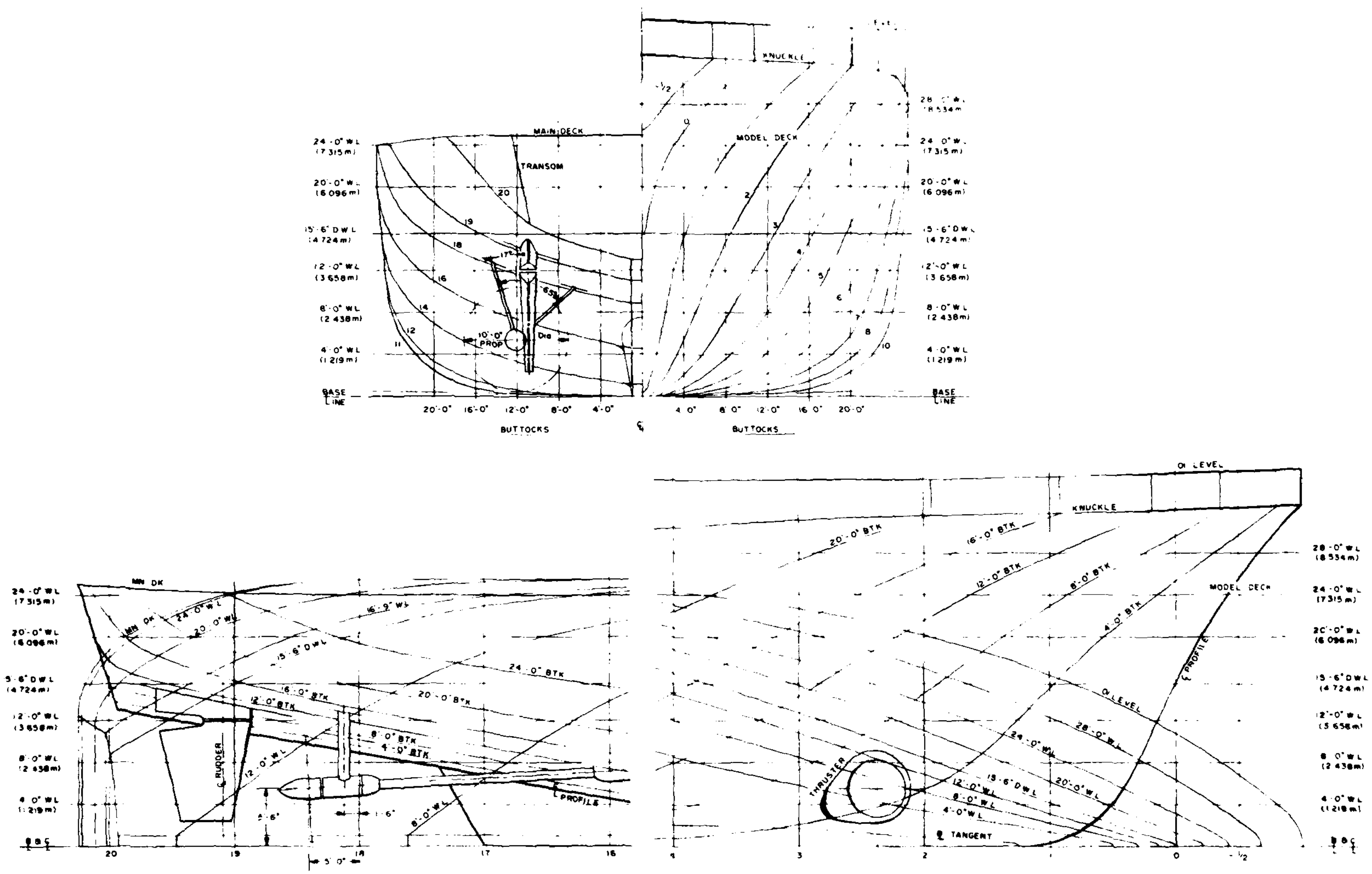


Figure 1 - SHIP LINES DRAWING OF MODEL 5391 REPRESENTING THE ARS 46 DESIGN

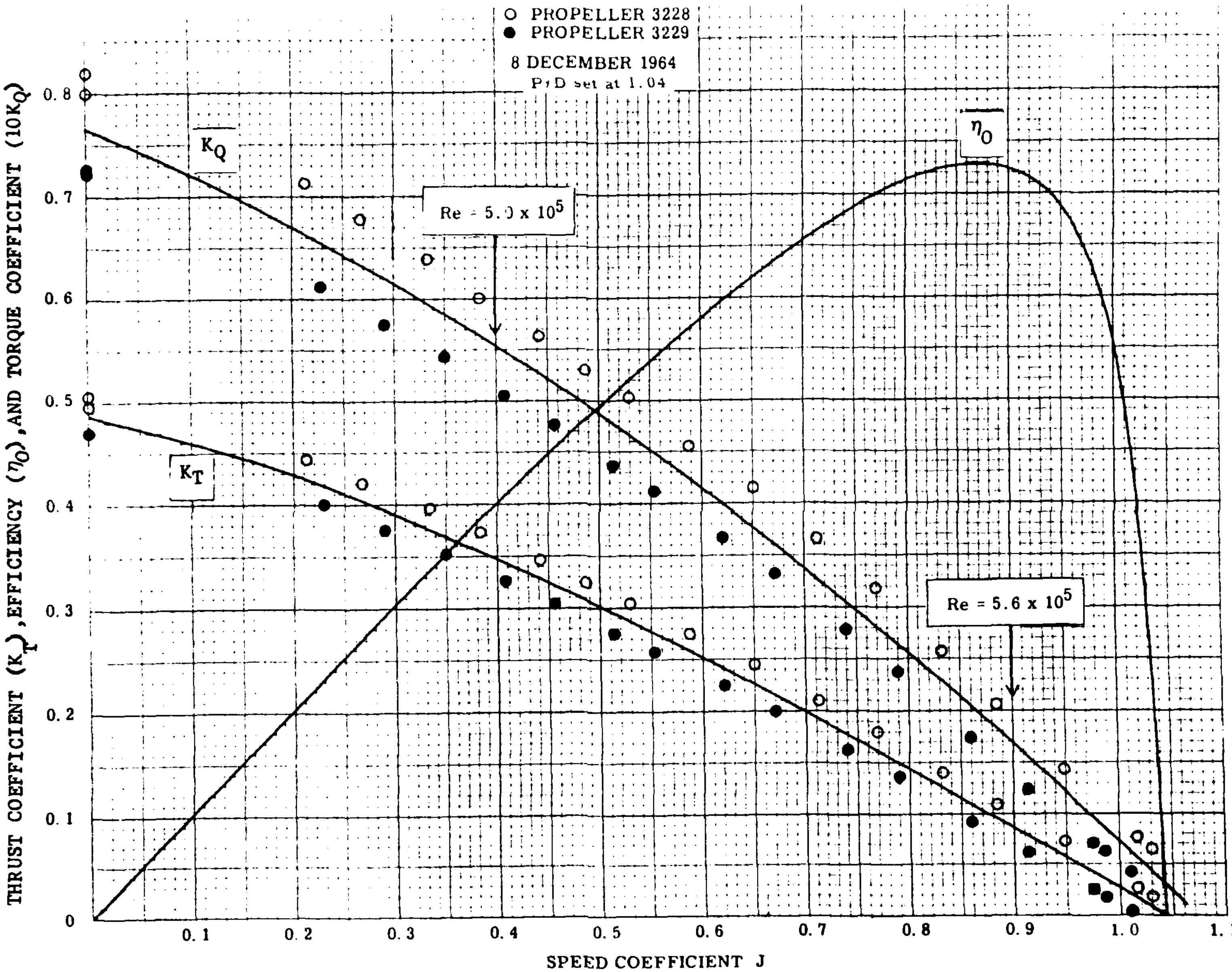


Figure 2 - OPEN WATER CURVES FOR PROPELLERS 3228 AND 3229

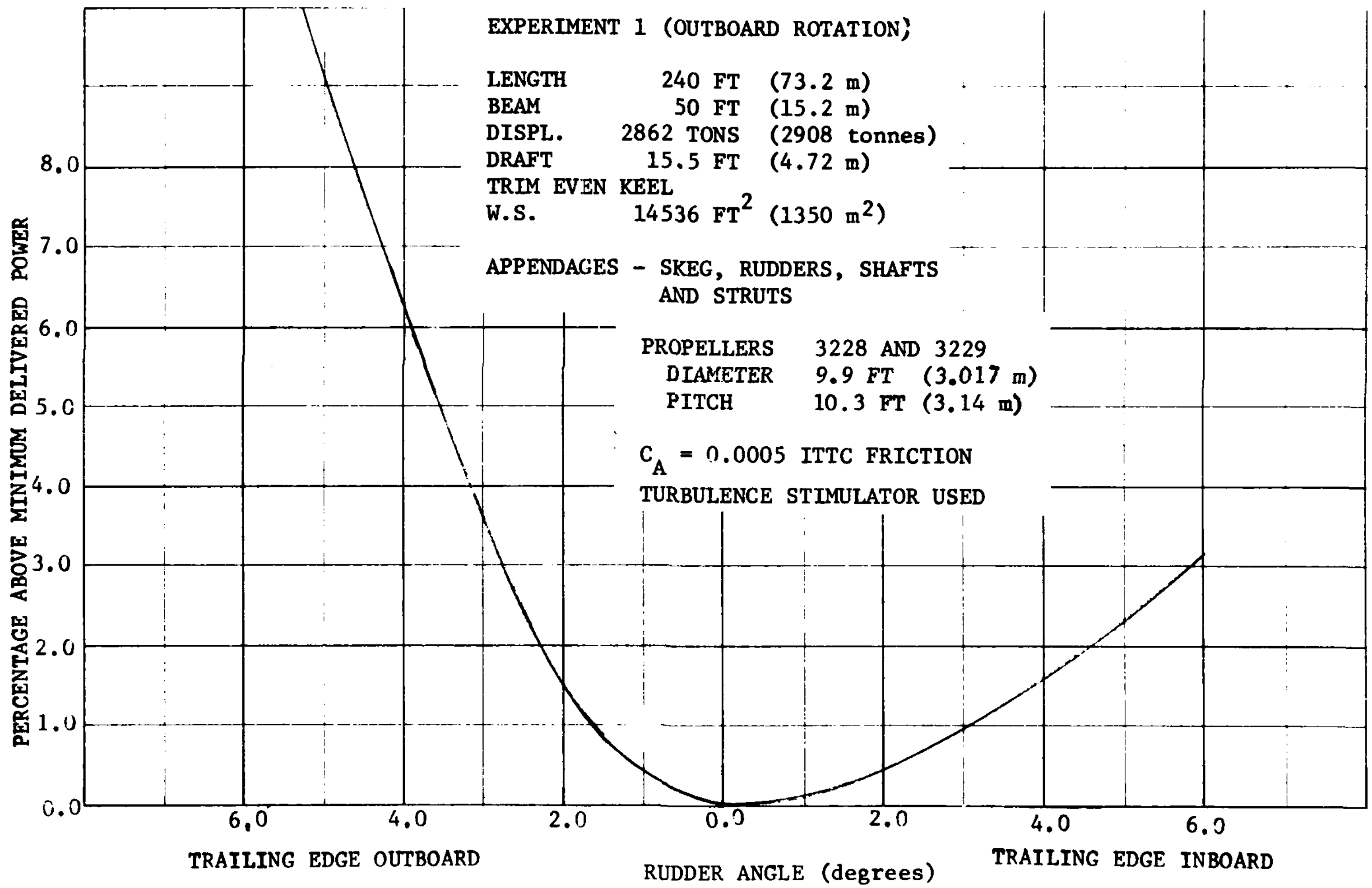


Figure 3 - OPTIMUM RUDDER ANGLE FOR ARS-46 REPRESENTED BY MODEL 5391

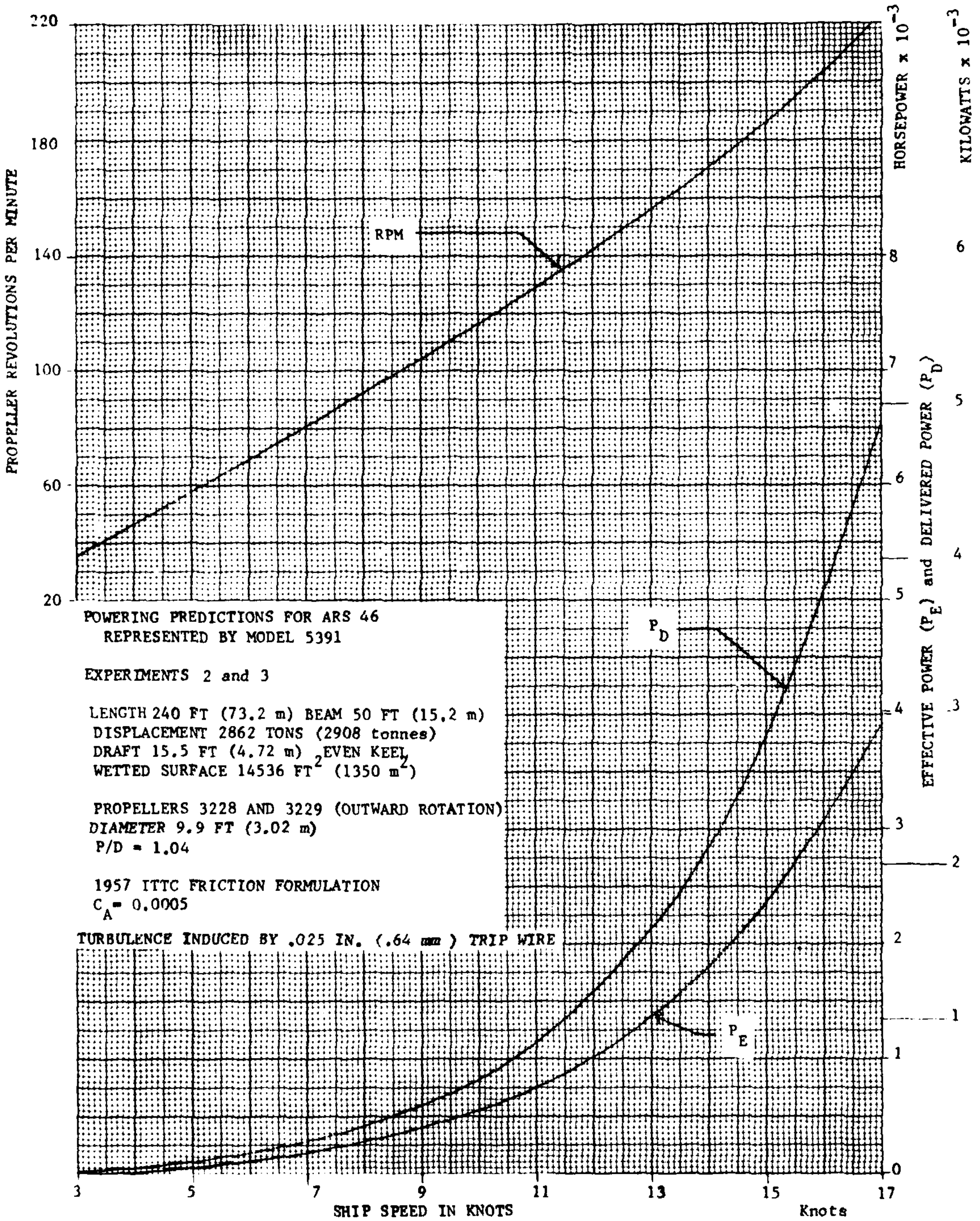


Figure 4 - POWERING PREDICTIONS FOR ARS-46 REPRESENTED BY MODEL 5391

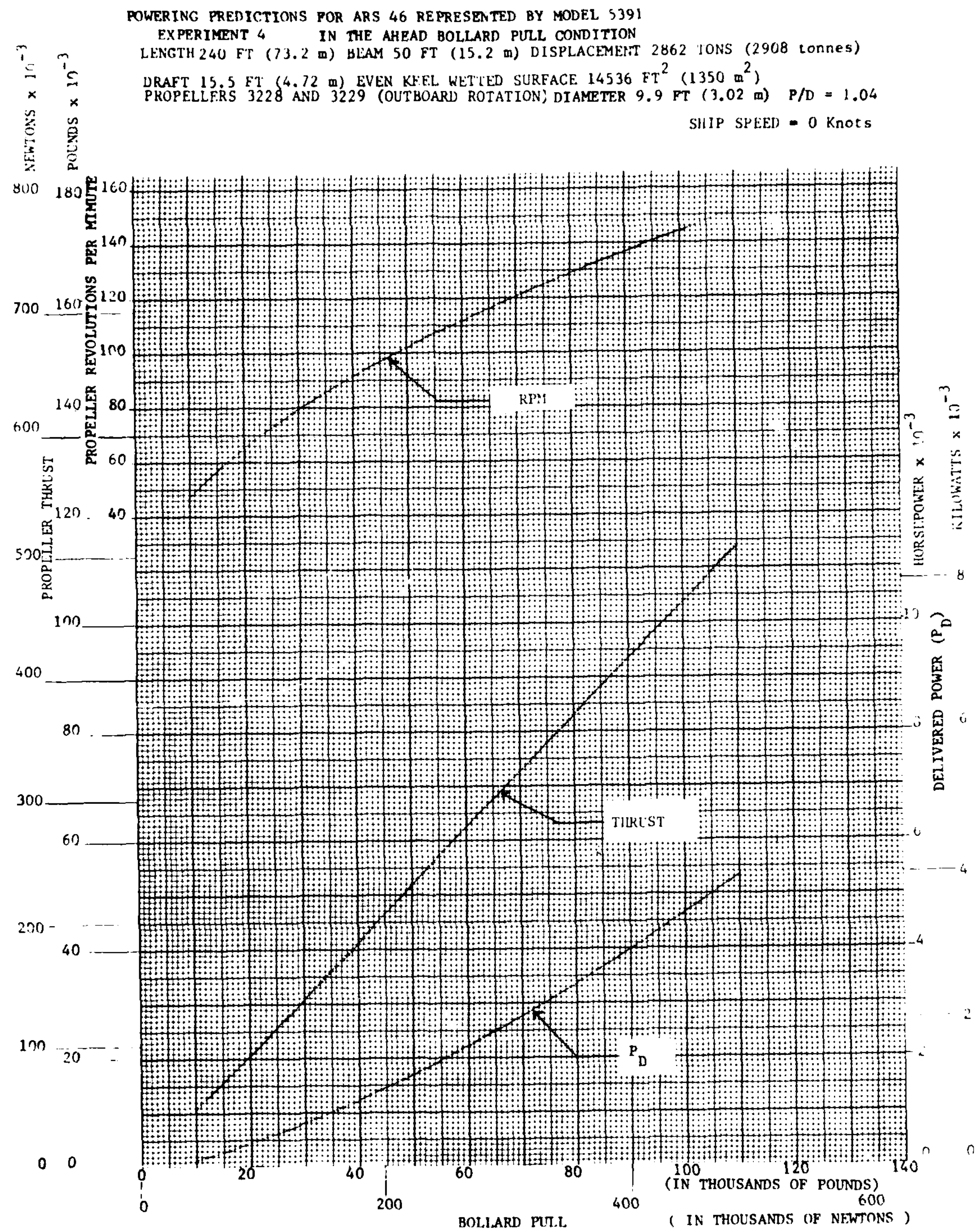


Figure 5 - POWERING PREDICTIONS FOR ARS-46 REPRESENTED BY MODEL 5391 IN THE AHEAD BOLLARD PULL CONDITION

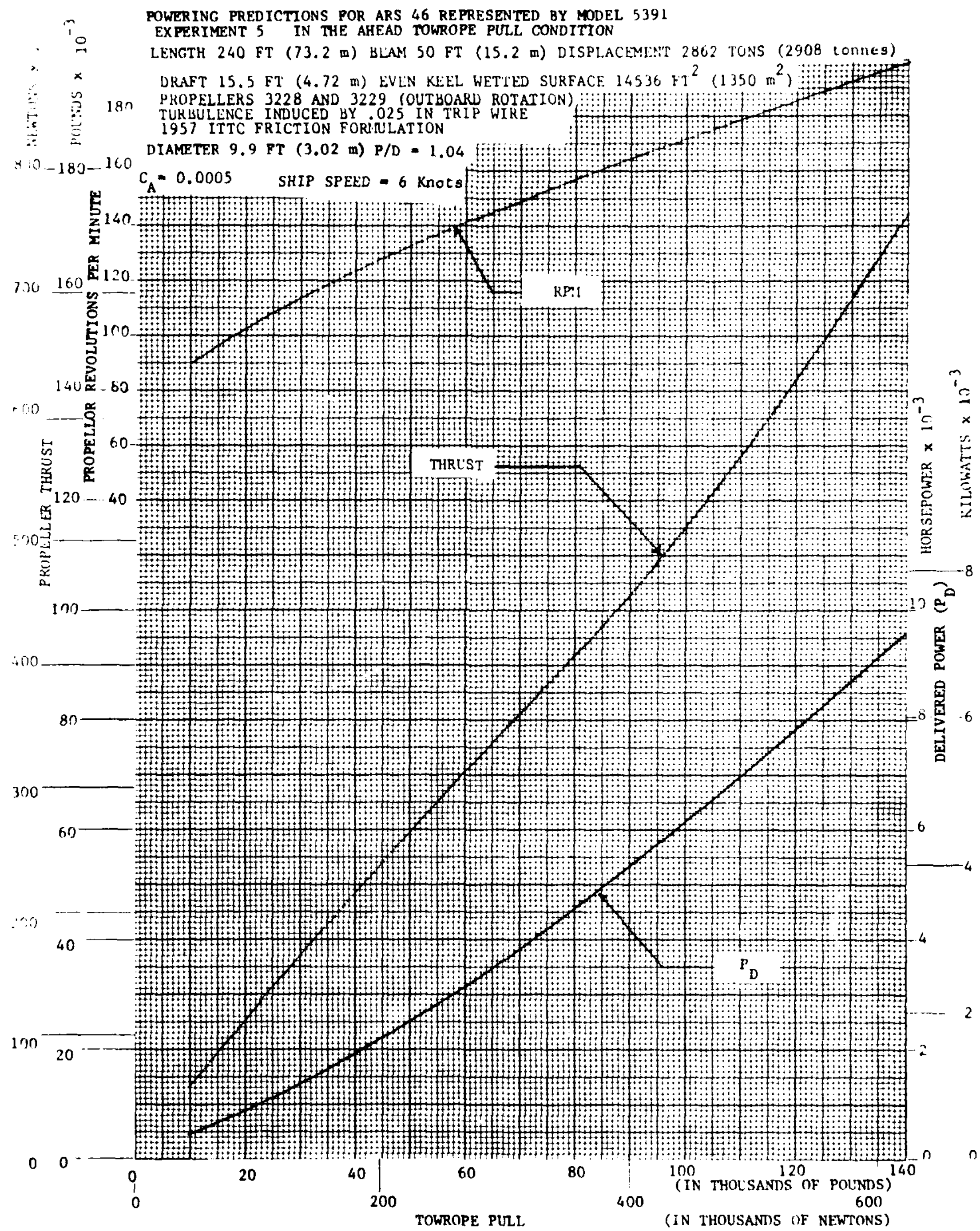


Figure 6 - POWERING PREDICTIONS FOR ARS-46 REPRESENTED BY MODEL 5391 IN THE AHEAD TOWROPE PULL CONDITION

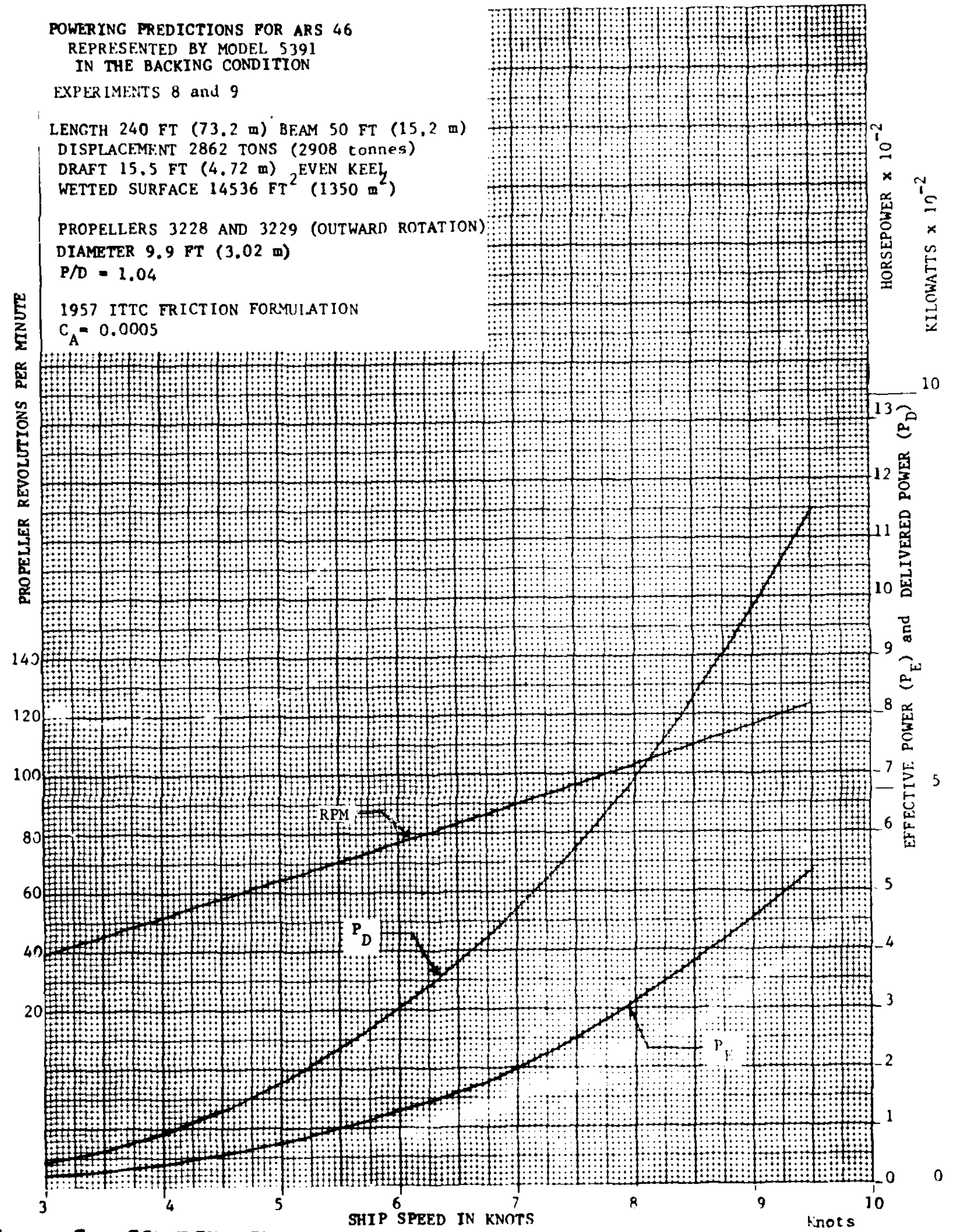


Figure 7 - POWERING PREDICTIONS FOR ARS-46 REPRESENTED BY MODEL 5391 IN THE BACKING CONDITION

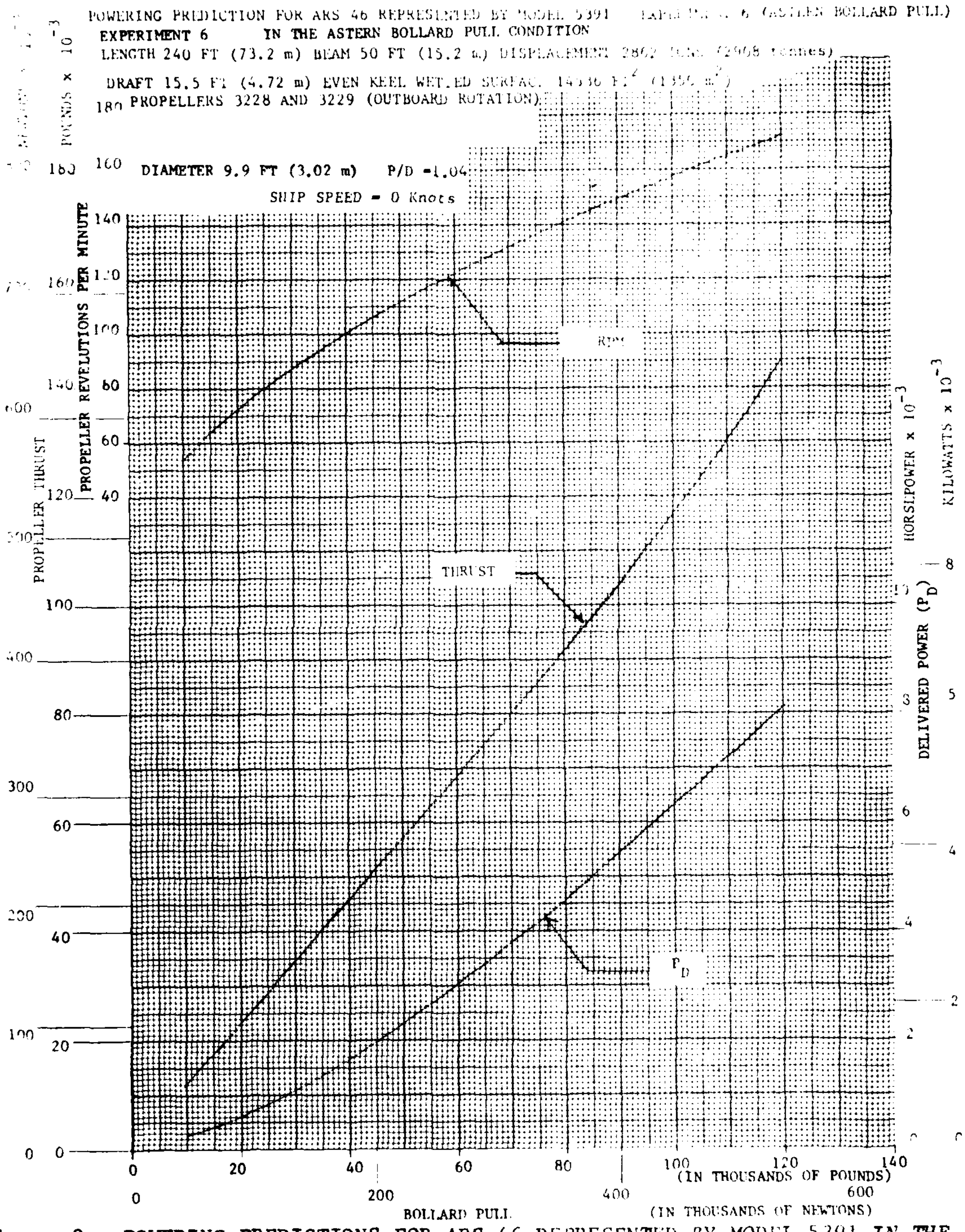


Figure 8 - POWERING PREDICTIONS FOR ARS-46 REPRESENTED BY MODEL 5391 IN THE ASTERN BOLLARD PULL CONDITION

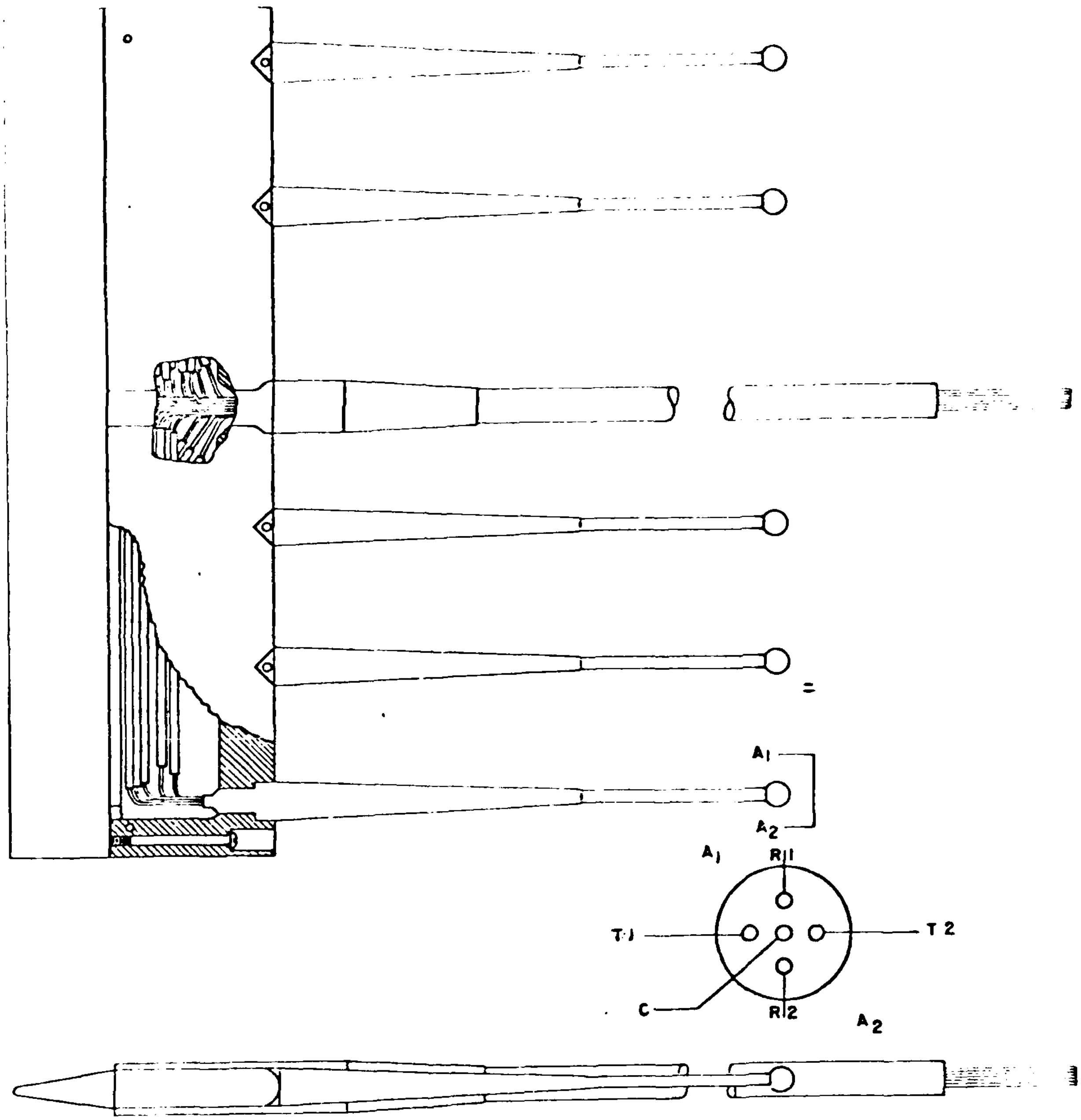


Figure 9 - PITOT TUBE ARRANGEMENT SHOWING SPHERICAL HEAD PITOT TUBES

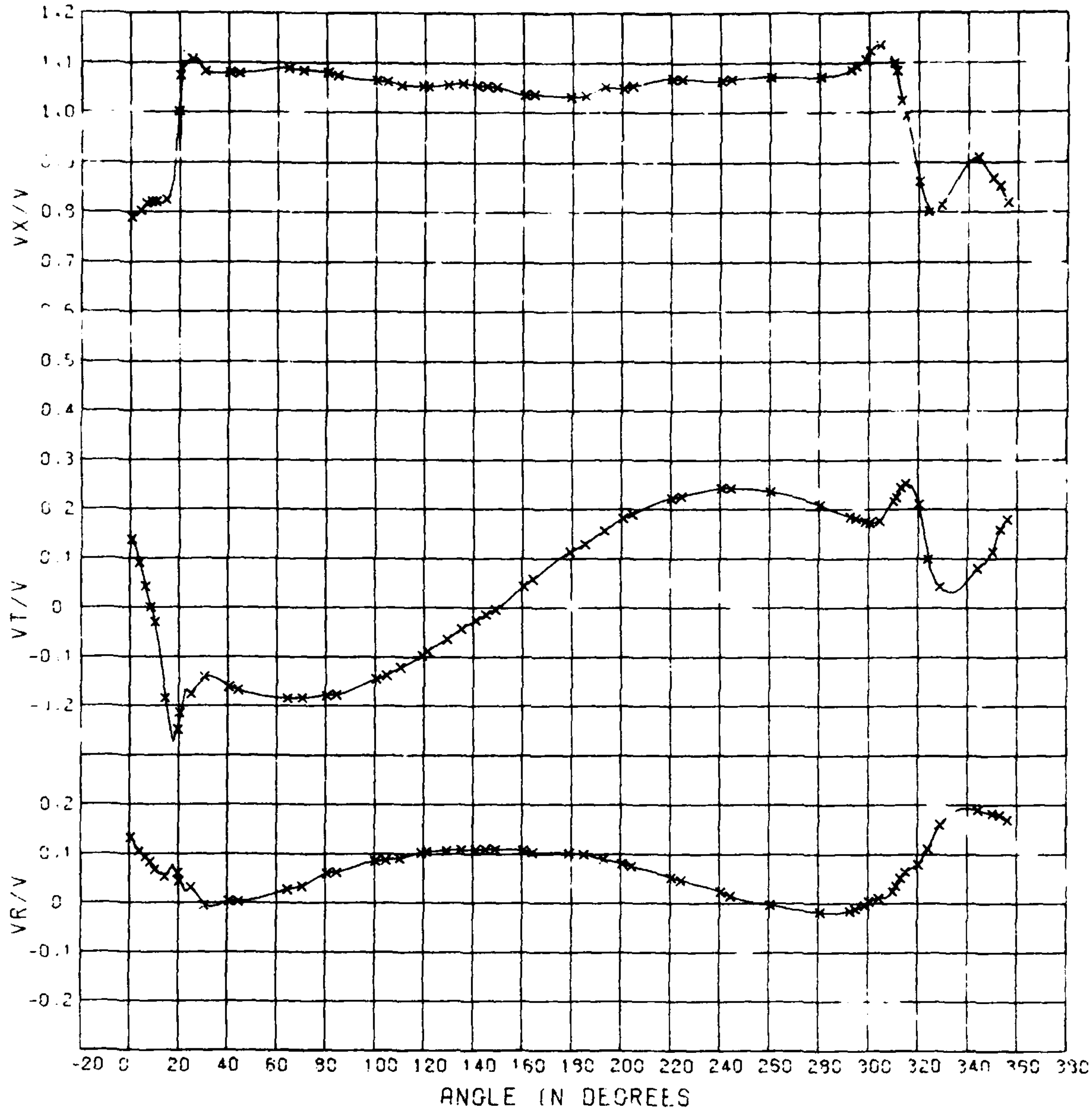


Figure 10 - CIRCUMFERENTIAL DISTRIBUTION OF THE LONGITUDINAL, TANGENTIAL AND RADIAL VELOCITY COMPONENT RATIOS - RADIUS RATIO = .332

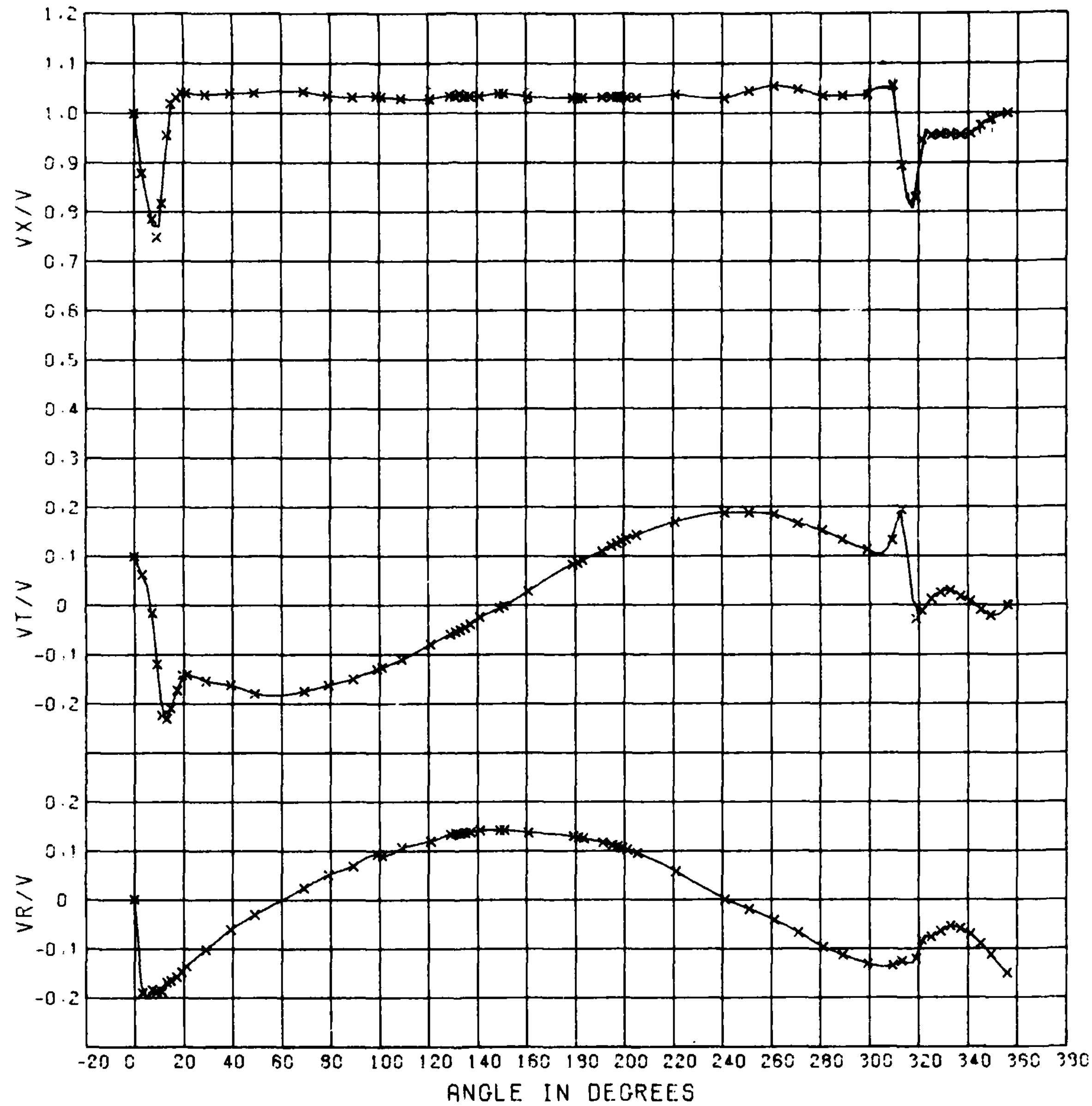


Figure 11 - CIRCUMFERENTIAL DISTRIBUTION OF THE LONGITUDINAL, TANGENTIAL AND RADIAL VELOCITY COMPONENT RATIOS - RADIUS RATIO = .516

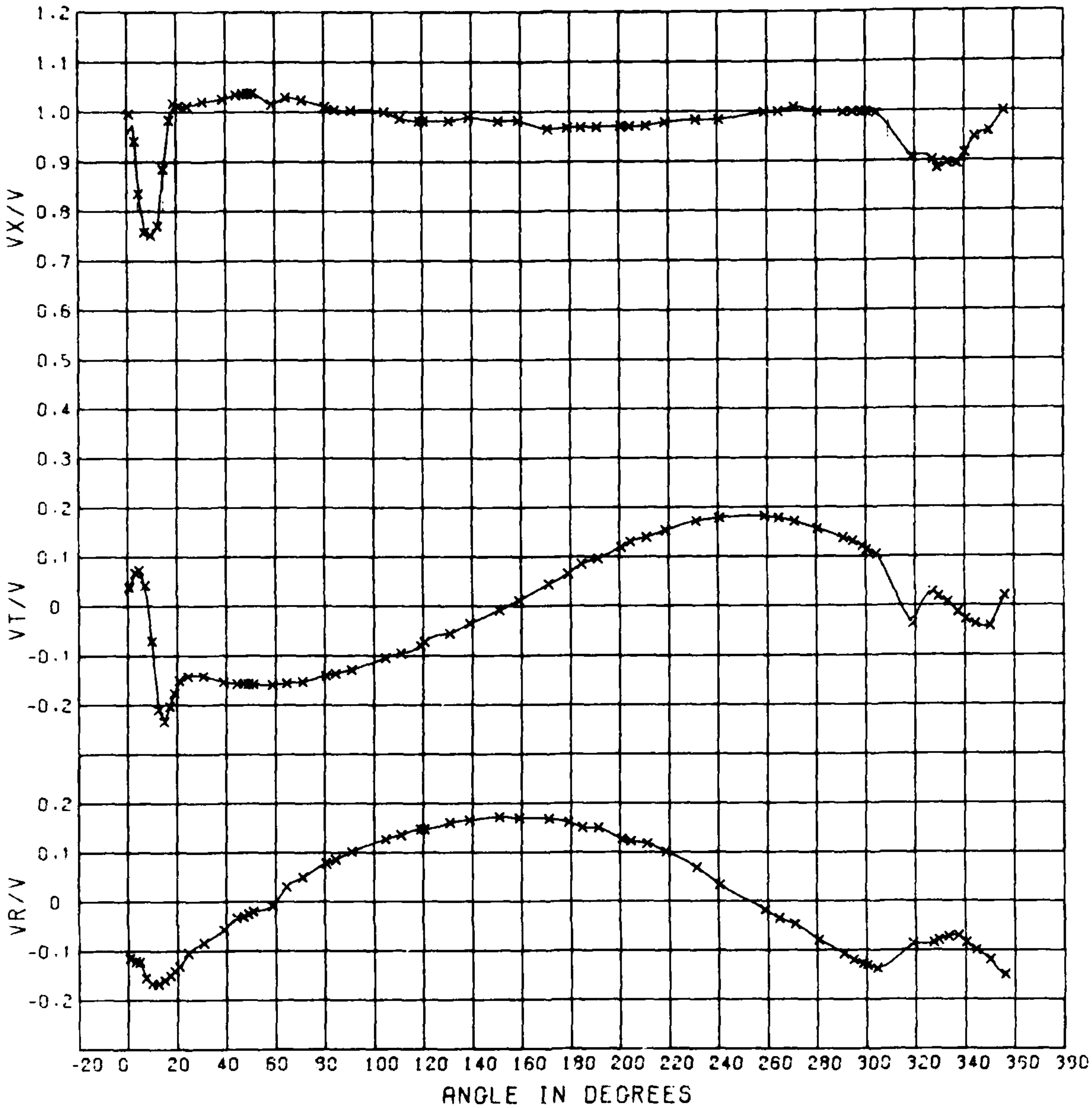


Figure 12 - CIRCUMFERENTIAL DISTRIBUTION OF THE LONGITUDINAL, TANGENTIAL AND RADIAL VELOCITY COMPONENT RATIOS - RADIUS RATIO = .715

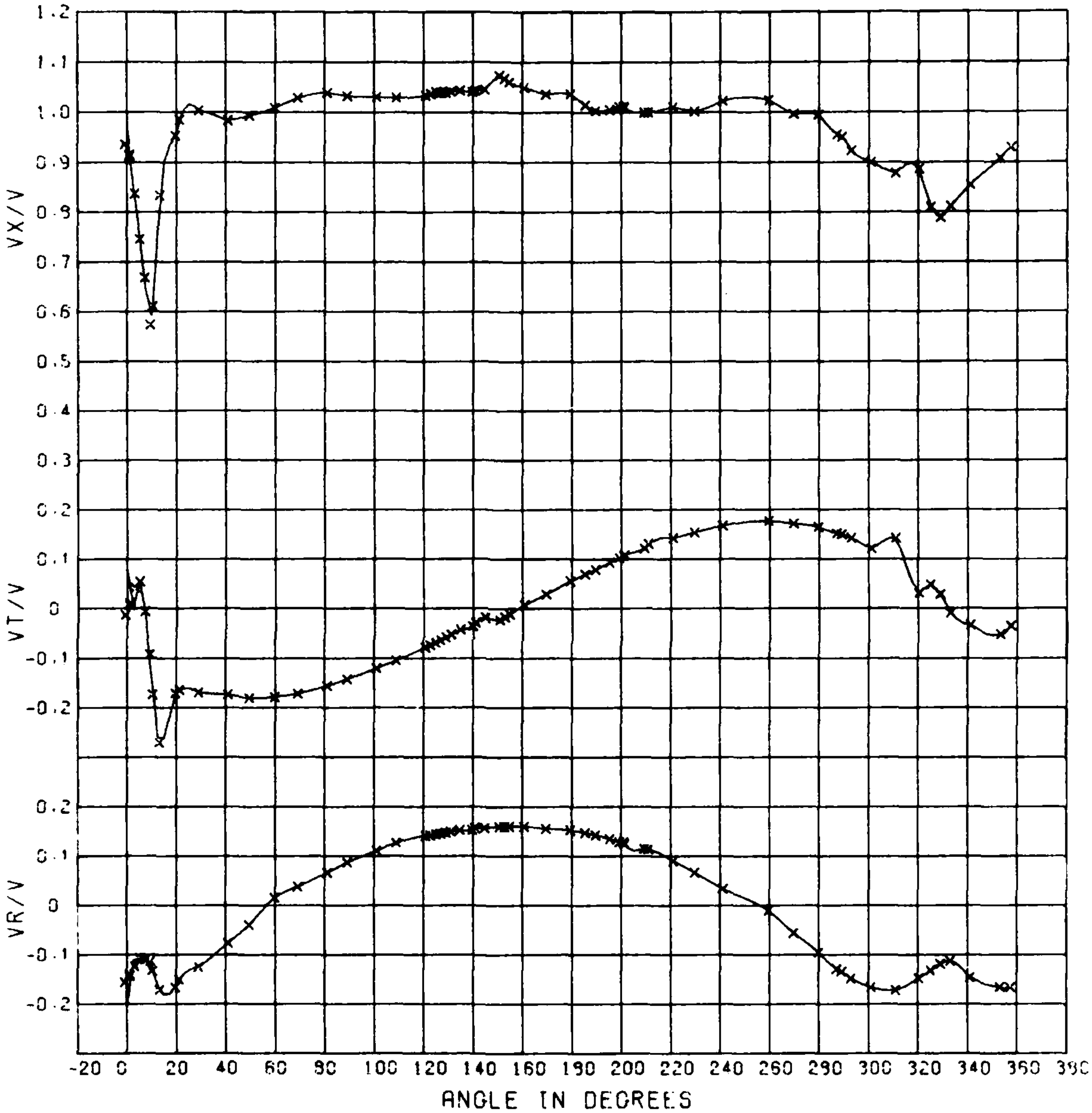


Figure 13 - CIRCUMFERENTIAL DISTRIBUTION OF THE LONGITUDINAL, TANGENTIAL AND RADIAL VELOCITY COMPONENT RATIOS - RADIUS RATIO = .883

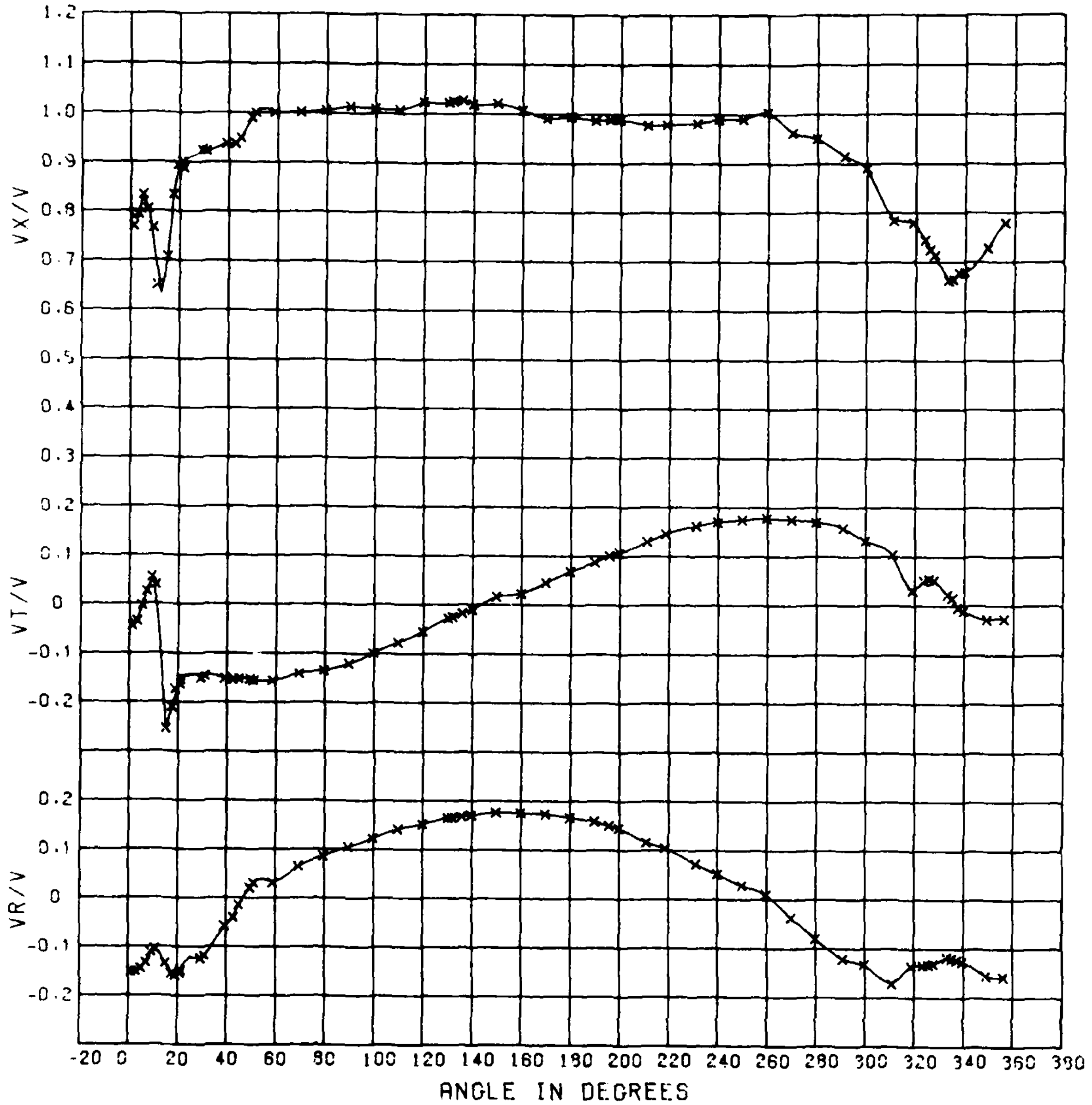


Figure 14 - CIRCUMFERENTIAL DISTRIBUTION OF THE LONGITUDINAL, TANGENTIAL AND RADIAL VELOCITY COMPONENT RATIOS - RADIUS RATIO = 1.088

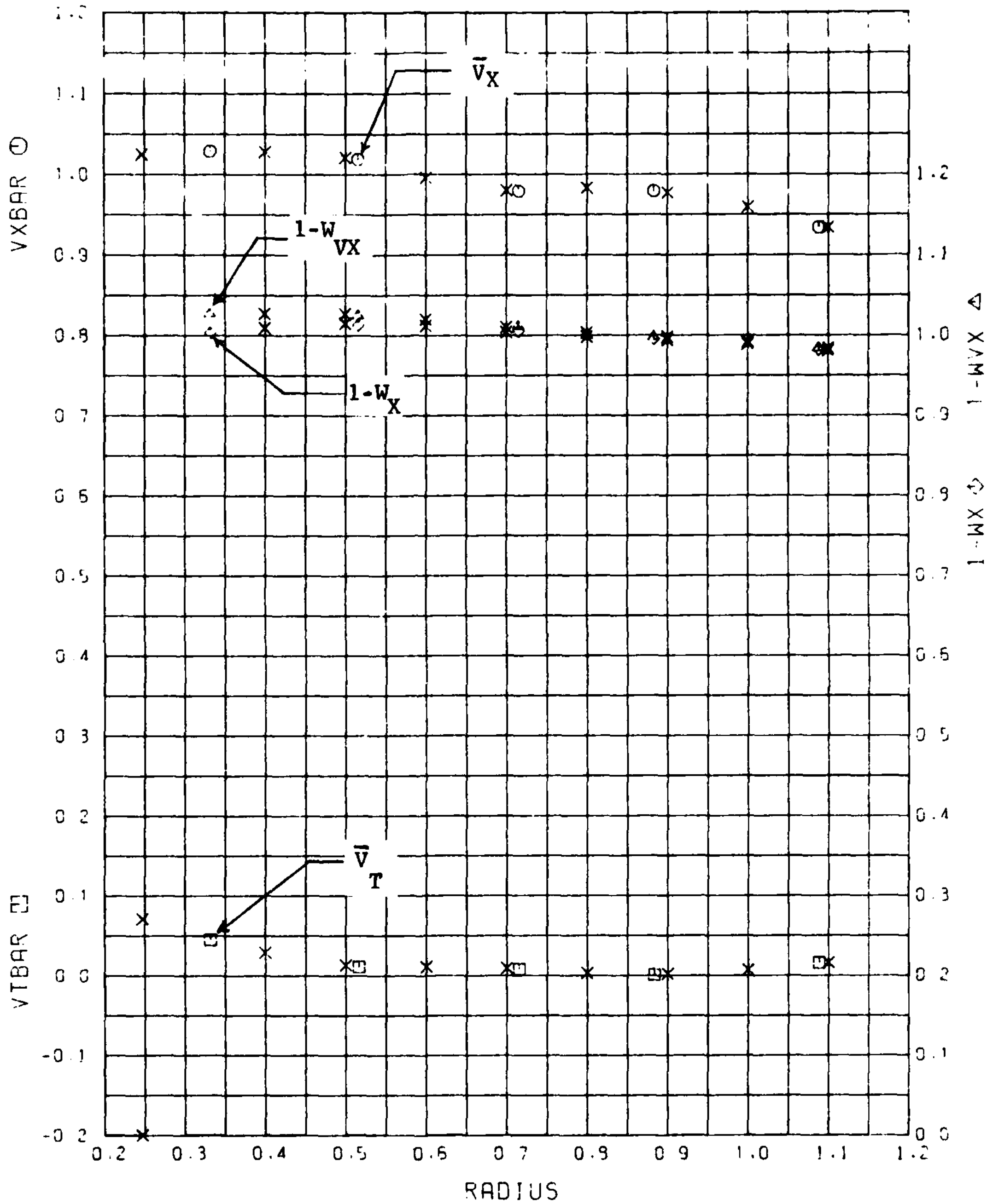


Figure 15 - RADIAL DISTRIBUTION OF THE MEAN VELOCITY COMPONENT RATIOS

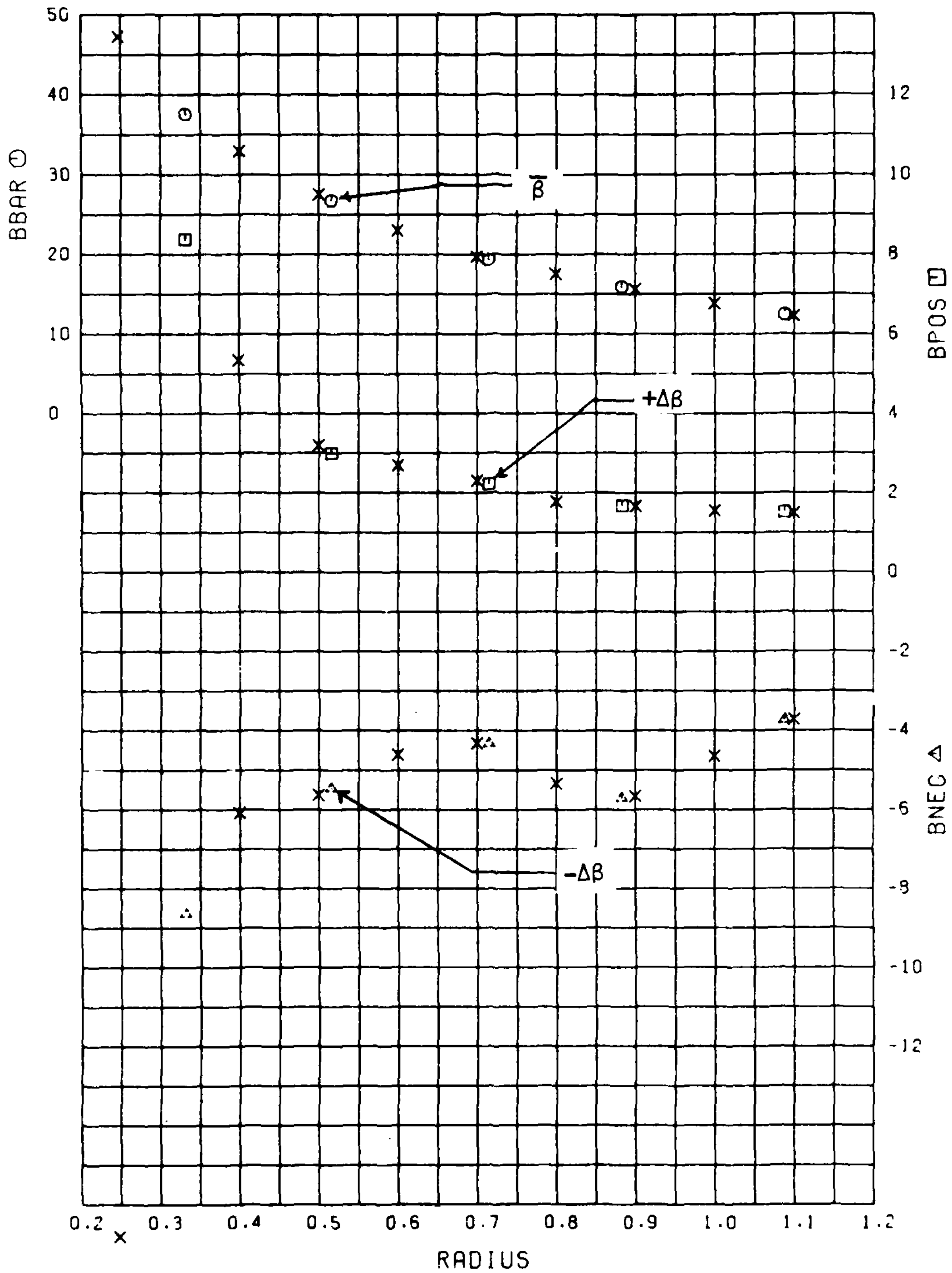


Figure 16 - RADIAL DISTRIBUTION OF THE MEAN ADVANCE ANGLE AND ADVANCE ANGLE VARIATIONS

Table 1

SHIP AND MODEL DATA FOR ARS 46 DESIGN, REPRESENTED BY MODEL 5391

Appendages: Bare Hull with Skeg and Tunnel

DIMENSIONS

	Ship English	Ship Metric	Model English	Model Metric
LENGTH (LWL)	240.0	73.15	15.63	4.76
LENGTH (LBP)	240.0	73.15	15.63	4.76
BEAM (B_X)	50.0	15.24	3.26	0.99
DRAFT (H)	15.5	4.72	1.01	0.31
DISPL. IN TONS	2862. S.W.	2908. S.W.	0.77 F.W.	0.78 F.W.
WETTED SURF. SQ. FT.(SQ.M)	13337.	1239.	56.55	5.25
DESIGN V IN KNOTS (m/s)	16.0	8.23 m/s	4.08	2.10 m/s

LCB/LWL = .510

LCB/LBP = .510

WL. ENTRANCE HALF ANGLE = 18°

λ = 15.357 $V/\sqrt{LWL}$ = 1.033

Ⓚ = 2.48 Ⓟ = 0.990

Lines: NAVSEA 240 ft Salvage Ship
Drawing No. 3213-0006
Date 6/11/79

LWL COEFFICIENTS

C_B	0.538		
C_P	0.592		
C_X	0.908	L_E/L	0.51
C_W	0.792		
C_{PF}	0.605	L_R/L	0.49
C_{PA}	0.606	L/B_X	4.80
C_{PE}	0.605	B_X/H	3.23
C_{PR}	0.606	$\Delta/(.01L)^3$	207.
C_{PV}	0.695	$S/\sqrt{\nabla L}$	2.61

LBP COEFFICIENTS

C_B	0.550	L/B_X	4.80
C_P	0.605	$\Delta/(.01L)^3$	207.03

Table 2

EFFECTIVE POWER PREDICTIONS FOR ARS 46
REPRESENTED BY MODEL 5391
FULLY APPENDED

(EXPERIMENT 2)

	SHIP	MODEL
LENGTH	240.00 FT (73.2 M)	15.63 FT (4.763 M)
WETTED SURFACE	14536.SQ FT (1350. SQ M)	61.64 SQ FT (5.73 SQ M)
DISPLACEMENT	2862.TONS (2908. TONNE)	.77 TONS (.78 TONNE)

LINEAR RATIO 15.357
ITTC FRICTION LINE
CORRELATION ALLOWANCE (CA) .00050

VS		PE		FRICTIONAL POWER		FN	V-L	1000CR
KNOTS	M/S	HP	KW	HP	KW			
3.00	1.54	13.7	10.2	8.9	6.6	.058	.194	1.410
3.50	1.80	21.5	16.1	13.8	10.3	.067	.226	1.420
4.00	2.06	32.0	23.8	20.3	15.2	.077	.258	1.435
4.50	2.31	45.4	33.9	28.6	21.3	.086	.290	1.460
5.00	2.57	62.3	46.5	38.8	28.9	.096	.323	1.490
5.50	2.83	83.3	62.1	51.0	38.1	.106	.355	1.535
6.00	3.09	109.1	81.3	65.6	48.9	.115	.387	1.591
6.50	3.34	140.4	104.7	82.7	61.7	.125	.420	1.660
7.00	3.60	178.0	132.7	102.5	76.4	.134	.452	1.740
7.50	3.86	222.2	165.7	125.1	93.3	.144	.484	1.820
8.00	4.12	271.9	202.7	150.8	112.5	.154	.516	1.870
8.50	4.37	328.1	244.6	179.7	134.0	.163	.549	1.910
9.00	4.63	390.9	291.5	212.1	158.1	.173	.581	1.940
9.50	4.89	462.7	345.0	248.0	184.9	.182	.613	1.980
10.00	5.14	546.1	407.2	287.7	214.5	.192	.645	2.043
10.50	5.40	643.9	480.2	331.4	247.1	.202	.678	2.135
11.00	5.66	757.9	565.2	379.1	282.7	.211	.710	2.250
11.50	5.92	887.6	661.9	431.3	321.6	.221	.742	2.373
12.00	6.17	1031.8	769.4	487.8	363.8	.230	.775	2.489
12.50	6.43	1188.9	886.5	549.1	409.5	.240	.807	2.590
13.00	6.69	1362.6	1016.1	615.2	458.8	.250	.839	2.690
13.50	6.94	1558.5	1162.2	686.3	511.8	.259	.871	2.803
14.00	7.20	1786.4	1332.1	762.6	568.7	.269	.904	2.950
14.50	7.46	2051.1	1529.5	844.3	629.6	.279	.936	3.130
15.00	7.72	2352.9	1754.5	931.5	694.6	.288	.968	3.330
15.50	7.97	2698.7	2012.4	1024.4	763.9	.298	1.001	3.555
16.00	8.23	3089.1	2303.5	1123.2	837.6	.307	1.033	3.795

Table 3

POWERING PREDICTIONS FOR ARS 46, REPRESENTED BY MODEL 5391
(EXPERIMENT 3)

DISPLACEMENT	2862 TONS	(2908 tonnes)
DRAFT	15.5 FT	(4.72 m)
WETTED SURFACE	$14536\ FT^2$	$(1350\ m^2)$
C_A	0.0005	

EVEN KEEL FULLY APPENDED PROPELLERS 3228 AND 3229

SHIP SPEED		EFFECTIVE POWER(PE)		DELIVERED POWER		REVOLUTIONS PER MINUTE
(KNOTS)	(M/SEC)	(HORSE-POWER)	(KILO-WATTS)	(HORSE-POWER)	(KILO-WATTS)	
3.0	1.54	15.	10.	20.	15.	34.9
4.0	2.06	30.	25.	50.	35.	46.6
5.0	2.57	60.	45.	95.	70.	58.2
6.0	3.09	110.	80.	165.	125.	69.9
7.0	3.60	180.	135.	270.	205.	81.5
8.0	4.12	270.	205.	415.	310.	93.2
9.0	4.63	390.	290.	595.	445.	104.8
10.0	5.14	545.	405.	835.	620.	117.1
11.0	5.66	760.	565.	1170.	870.	129.6
12.0	6.17	1030.	770.	1610.	1200.	143.0
13.0	6.69	1360.	1020.	2130.	1590.	155.9
14.0	7.20	1790.	1330.	2770.	2070.	169.2
15.0	7.72	2350.	1750.	3730.	2780.	185.2
16.0	8.23	3090.	2300.	5060.	3780.	203.7

SHIP SPEED (KNOTS)	EFFICIENCIES(ETA) ETAD	ETAO	ETAH	ETAR	THRUST DEDUCTION AND WAKE FACTORS 1-THDF	1-WFTT	1-WFTQ	ADVANCE COEF. ADVC
3.0	0.655	0.720	0.980	0.930	0.925	0.945	0.920	0.830
4.0	0.655	0.720	0.975	0.930	0.925	0.950	0.925	0.835
5.0	0.655	0.720	0.975	0.930	0.925	0.950	0.930	0.835
6.0	0.655	0.720	0.980	0.930	0.925	0.945	0.925	0.835
7.0	0.655	0.720	0.985	0.925	0.925	0.940	0.915	0.825
8.0	0.655	0.715	0.990	0.920	0.925	0.935	0.905	0.820
9.0	0.655	0.715	0.995	0.920	0.925	0.930	0.905	0.820
10.0	0.655	0.715	0.990	0.925	0.925	0.935	0.905	0.820
11.0	0.650	0.710	0.985	0.925	0.915	0.930	0.900	0.810
12.0	0.640	0.710	0.970	0.930	0.900	0.925	0.900	0.795
13.0	0.640	0.705	0.970	0.935	0.895	0.925	0.895	0.790
14.0	0.645	0.700	0.975	0.940	0.900	0.920	0.900	0.780
15.0	0.630	0.695	0.950	0.955	0.880	0.925	0.905	0.770
16.0	0.610	0.690	0.920	0.960	0.870	0.945	0.925	0.760

NOTE: ALL VALUES ARE ROUNDED

Table 4

POWERING PREDICTIONS FOR ARS 46, REPRESENTED BY MODEL 5391, IN THE AHEAD BOLLARD PULL CONDITION

(EXPERIMENT 4)

DISPLACEMENT	2862 TONS	(2908 tonnes)
DRAFT	15.5 FT	(4.72 m)
WETTED SURFACE	14536 FT^2	(1350 m^2)
C_A	0.0005	

EVEN KEEL FULLY APPENDED PROPELLERS 3228 AND 3229

BOLLARD PULL (lb force)	BOLLARD PULL (newtons)	PROPELLER THRUST (lb force)	PROPELLER THRUST (newtons)	DELIVERED POWER (h.p.)	DELIVERED POWER (kilowatts)	RPM
10000.	44480.	10480.	46610.	155.	115.	47.5
20000.	88965.	20880.	92880.	440.	330.	65.7
30000.	133445.	31245.	138985.	800.	595.	80.0
40000.	177930.	41560.	184870.	1220.	910.	92.0
50000.	222410.	51880.	230775.	1700.	1270.	103.0
60000.	266895.	62190.	276635.	2240.	1670.	113.0
70000.	311375.	72520.	322585.	2790.	2080.	121.9
80000.	355860.	82870.	368625.	3380.	2520.	130.0
90000.	400340.	93120.	414220.	4020.	2995.	137.5
100000.	444820.	103540.	460570.	4685.	3495.	145.0
110000.	489305.	113970.	506965.	5395.	4020.	151.6

Table 5

POWERING PREDICTIONS FOR ARS 46, REPRESENTED BY MODEL 5391, IN THE AHEAD TOWROPE PULL CONDITION

(EXPERIMENT 5)

DISPLACEMENT	2862 TONS	(2908 tonnes)	EVEN KEEL
DRAFT	15.5 FT	(4.72 m)	FULLY APPENDED
WETTED SURFACE	14536 FT^2	(1350 m^2)	PROPELLERS 3228 AND 3229
C_A	0.0005		SHIP SPEED= 6 KNOTS

TOWROPE PULL (lb force)	TOWROPE PULL (newtons)	PROPELLER THRUST (lb force)	PROPELLER THRUST (newtons)	DELIVERED POWER (h.p.)	DELIVERED POWER (kilowatts)	RPM
10000.	44480.	13440.	59785.	455.	340.	89.7
20000.	88965.	26070.	115965.	910.	680.	100.8
30000.	133445.	37990.	168990.	1380.	1030.	111.8
40000.	177930.	49160.	218675.	1930.	1440.	122.5
50000.	222410.	59970.	266760.	2500.	1865.	132.9
60000.	266895.	70800.	314935.	3150.	2350.	141.5
70000.	311375.	81380.	362000.	3860.	2880.	149.8
80000.	355860.	92000.	409235.	4600.	3430.	158.4
90000.	400340.	102800.	457280.	5330.	3975.	165.0
100000.	444820.	115500.	513770.	6120.	4565.	172.0
110000.	489305.	128500.	571595.	6920.	5160.	178.2
120000.	533785.	142650.	634540.	7770.	5795.	184.9
130000.	578270.	156620.	696680.	8645.	6445.	191.0
140000.	622750.	170590.	758820.	9545.	7120.	197.0

Table 6

EFFECTIVE POWERING PREDICTIONS FOR ARS 46, REPRESENTED BY MODEL 5391, IN THE BACKING CONDITION

(EXPERIMENT 7)

	SHIP	MODEL
LENGTH	240.00 FT (73.2 M)	15.63 FT (4.763 M)
WETTED SURFACE	14536.SQ FT (1350. SQ M)	61.64 SQ FT (5.73 SQ M)
DISPLACEMENT	2862.TONS (2908. TONNE)	.76 TONS (.78 TONNE)

LINEAR RATIO 15.357
ITTC FRICTION LINE
CORRELATION ALLOWANCE (CA) .00050

VS		PE		FRICTIONAL POWER		FN	V-L	1000CR
KNOTS	M/S	HP	KW	HP	KW			
2.00	1.03	6.8	5.0	2.8	2.1	.038	.129	3.961
2.50	1.29	12.1	9.0	5.2	3.9	.048	.161	3.464
3.00	1.54	18.4	13.7	8.9	6.6	.058	.194	2.782
3.50	1.80	25.8	19.2	13.8	10.3	.067	.226	2.200
4.00	2.06	39.3	29.3	20.4	15.2	.077	.258	2.335
4.50	2.31	54.5	40.6	28.6	21.3	.086	.290	2.246
5.00	2.57	74.6	55.7	38.8	28.9	.096	.323	2.269
5.50	2.83	99.3	74.0	51.0	38.1	.106	.355	2.292
6.00	3.09	128.9	96.1	65.6	48.9	.115	.387	2.314
6.50	3.34	160.2	119.4	82.7	61.7	.125	.420	2.229
7.00	3.60	199.1	148.5	102.5	76.4	.134	.452	2.228
7.50	3.86	246.8	184.1	125.1	93.3	.144	.484	2.281
8.00	4.12	308.8	230.2	150.8	112.5	.154	.516	2.439
8.50	4.37	374.2	279.0	179.8	134.0	.163	.549	2.503
9.00	4.63	448.8	334.7	212.1	158.2	.173	.581	2.567
9.50	4.89	536.6	400.1	248.0	185.0	.182	.613	2.661
10.00	5.14	630.6	470.3	287.8	214.6	.192	.645	2.711
10.50	5.40	735.8	548.7	331.4	247.1	.202	.678	2.762

Table 7

POWERING PREDICTIONS FOR ARS 46, REPRESENTED BY MODEL 5391, IN THE BACKING CONDITION

(EXPERIMENT 8)

DISPLACEMENT	2862 TONS	(2908 tonnes)	EVEN KEEL
DRAFT	15.5 FT	(4.72 m)	FULLY APPENDED
WETTED SURFACE	14536 FT^2	(1350 m^2)	PROPELLERS 3228
C_A	0.0005		AND 3229

SHIP SPEED		EFFECTIVE POWER(PE)		DELIVERED POWER		REVOLUTIONS PER MINUTE
(KNOTS)	(M/SEC)	(HORSE-POWER)	(KILO-WATTS)	(HORSE-POWER)	(KILO-WATTS)	
3.0	1.54	20.	15.	45.	30.	39.7
3.5	1.80	25.	20.	60.	45.	45.1
4.0	2.06	40.	30.	90.	70.	51.5
4.5	2.31	55.	40.	125.	95.	57.8
5.0	2.57	75.	55.	175.	130.	64.4
5.5	2.83	100.	75.	230.	175.	71.0
6.0	3.09	130.	95.	300.	225.	77.0
6.5	3.34	160.	120.	375.	280.	83.1
7.0	3.60	200.	150.	460.	340.	89.6
7.5	3.86	245.	185.	560.	420.	96.1
8.0	4.12	310.	230.	685.	510.	102.4
8.5	4.37	375.	280.	820.	610.	109.1
9.0	4.63	450.	335.	975.	730.	115.3
9.5	4.89	535.	400.	1150.	860.	123.2

SHIP SPEED (KNOTS)	EFFICIENCIES (ETA)				THRUST DEDUCTION AND WAKE FACTORS			ADVANCE COEF. [illegible]
	ETAD	ETAO	ETAH	ETAR	1-THDF	1-WFTT	1-WFTQ	
3.0	0.425	0.700	0.775	0.780	0.780	1.005	0.885	0.780
3.5	0.425	0.710	0.775	0.775	0.780	1.005	0.890	0.800
4.0	0.425	0.705	0.785	0.770	0.780	0.995	0.875	0.795
4.5	0.430	0.710	0.780	0.775	0.780	1.000	0.885	0.800
5.0	0.430	0.710	0.775	0.775	0.780	1.005	0.890	0.800
5.5	0.430	0.710	0.770	0.780	0.780	1.010	0.900	0.800
6.0	0.430	0.710	0.780	0.775	0.780	1.000	0.885	0.800
6.5	0.430	0.710	0.765	0.790	0.765	0.995	0.890	0.795
7.0	0.435	0.710	0.760	0.805	0.760	0.995	0.900	0.795
7.5	0.440	0.710	0.760	0.815	0.760	0.995	0.905	0.795
8.0	0.450	0.705	0.775	0.830	0.760	0.985	0.900	0.790
8.5	0.455	0.705	0.780	0.830	0.770	0.990	0.905	0.790
9.0	0.460	0.705	0.795	0.820	0.785	0.990	0.900	0.790
9.5	0.465	0.710	0.790	0.830	0.800	1.010	0.930	0.800

Table 8

POWERING PREDICTIONS FOR ARS 46, REPRESENTED BY MODEL 5391, IN THE ASTERN BOLLARD PULL CONDITION

(EXPERIMENT 6)

DISPLACEMENT	2862 TONS	(2908) tonnes)	EVEN KEEL
DRAFT	15.5 FT	(4.72 m)	FULLY APPENDED
WETTED SURFACE	14536 FT^2	(1350 m^2)	PROPELLERS 3228
C_A	0.0005		AND 3229

BOLLARD PULL (lb force)	BOLLARD PULL (newtons)	PROPELLER THRUST (lb force)	PROPELLER THRUST (newtons)	DELIVERED POWER (h.p.)	DELIVERED POWER (kilowatts)	RPM
10000.	44480.	11360.	50530.	245.	185.	52.5
20000.	88965.	22720.	101065.	620.	460.	72.9
30000.	133445.	34270.	152440.	1090.	815.	88.0
40000.	177930.	45690.	203240.	1640.	1225.	101.0
50000.	222410.	57150.	254215.	2280.	1700.	113.0
60000.	266895.	68610.	305190.	2960.	2210.	123.4
70000.	311375.	80375.	357525.	3705.	2765.	133.0
80000.	355860.	92160.	409950.	4510.	3365.	142.0
90000.	400340.	104290.	463905.	5350.	3990.	150.0
100000.	444820.	117325.	521890.	6240.	4655.	158.0
110000.	489305.	131120.	583250.	7170.	5350.	165.5
120000.	533785.	145630.	647795.	8130.	6065.	172.2

HARMONIC ANALYSIS FOR ARS REPRESENTED BY MODEL 5391 AUG 79
PROPELLER DIAMETER = 9.88 FEET JA = .807

RADIUS =	.332	.516	.715	.883	1.088	.247	.400	.500	.600	.700	.800	.900	1.000	1.100
VXBAR =	1.029	1.019	.979	.979	.934	1.025	1.028	1.021	.996	.980	.983	.977	.959	.934
VTBAR =	.045	.011	.008	.001	.016	.071	.029	.013	.011	.009	.003	.002	.007	.016
VRBAR =	.065	.003	.022	.006	.021	.119	.034	.006	.016	.022	.010	.006	.010	.021
1-WVX =	1.027	1.025	1.011	.998	.984	0.000	1.027	1.027	1.020	1.010	1.003	.998	.992	.984
1-WX =	1.003	1.013	1.005	.995	.982	0.000	1.009	1.015	1.012	1.004	.998	.994	.989	.981
BBAR =	37.57	26.76	19.32	15.89	12.38	44.79	32.95	27.52	23.01	19.72	17.51	15.58	13.82	12.25
BPOS =	8.38	2.99	2.22	1.68	1.51	13.45	5.34	3.19	2.69	2.30	1.77	1.66	1.55	1.49
THETA =	22.50	60.00	50.00	77.50	55.00	22.50	22.50	60.00	50.00	50.00	72.50	77.50	82.50	55.00
BNEG =	-8.64	-5.46	-4.33	-5.71	-3.75	-16.81	-6.09	-5.63	-4.61	-4.32	-5.34	-5.66	-4.65	-3.72
THETA =	0.00	315.00	7.50	10.00	12.50	357.50	2.50	315.00	7.50	7.50	10.00	10.00	10.00	12.50

VXBAR IS CIRCUMFERENTIAL MEAN LONGITUDINAL VELOCITY.
VTBAR IS CIRCUMFERENTIAL MEAN TANGENTIAL VELOCITY.
VRBAR IS CIRCUMFERENTIAL MEAN RADIAL VELOCITY.
1-WVX IS VOLUMETRIC MEAN WAKE VELOCITY WITHOUT TANGENTIAL CORRECTION.
1-WX IS VOLUMETRIC MEAN WAKE VELOCITY WITH TANGENTIAL CORRECTION.
BBAR IS MEAN ANGLE OF ADVANCE.
BPOS IS VARIATION BETWEEN THE MAXIMUM AND MEAN ADVANCE ANGLES (DELTA BETA PLUS).
BNEG IS VARIATION BETWEEN THE MINIMUM AND MEAN ADVANCE ANGLES (DELTA BETA MINUS).
THETA IS ANGLE IN DEGREES AT WHICH CORRESPONDING BPOS OR BNEG OCCURS.

Table 9 - Listing of the Mean Velocity Component Ratios, the Mean Advance Angles and other Derived Quantities at the Experimental and the Interpolated Radii

Table 10 - Harmonic Analyses of Longitudinal Velocity Component Ratios at the Experimental Radii

HARMONIC ANALYSIS FOR ARS REPRESENTED BY MODEL 5391 AUG 79
PROPELLER DIAMETER = 9.88 FEET JA = .807

HARMONIC ANALYSES OF LONGITUDINAL VELOCITY COMPONENT RATIOS (VX/V)

HARMONIC =	1	2	3	4	5	6	7	8
RADIUS = .332								
AMPLITUDE =	.0567	.0734	.0497	.0344	.0098	.0055	.0213	.0278
PHASE ANGLE =	282.7	293.5	302.5	311.0	343.7	188.6	185.7	201.6
RADIUS = .516								
AMPLITUDE =	.0307	.0302	.0209	.0054	.0055	.0115	.0170	.0201
PHASE ANGLE =	281.5	298.6	316.4	310.6	173.6	191.8	193.1	212.0
RADIUS = .715								
AMPLITUDE =	.0187	.0354	.0213	.0068	.0064	.0127	.0164	.0156
PHASE ANGLE =	318.9	297.6	308.0	273.5	175.4	185.3	176.9	182.7
RADIUS = .883								
AMPLITUDE =	.0849	.0437	.0245	.0080	.0066	.0118	.0138	.0183
PHASE ANGLE =	295.2	300.3	337.5	193.0	238.3	225.0	197.3	189.0
RADIUS = 1.088								
AMPLITUDE =	.1185	.0734	.0357	.0067	.0048	.0059	.0099	.0070
PHASE ANGLE =	293.3	299.6	330.0	333.7	124.9	106.3	138.5	144.7

Table 10 (continued)

HARMONIC ANALYSIS FOR ARS REPRESENTED BY MODEL 5391 AUG 79
PROPELLER DIAMETER = 9.88 FEET JA = .807

HARMONIC ANALYSES OF LONGITUDINAL VELOCITY COMPONENT RATIOS (VX/V)

HARMONIC =	9	10	11	12	13	14	15
RADIUS = .332							
AMPLITUDE =	.0273	.0184	.0081	.0017	.0081	.0092	.0086
PHASE ANGLE =	217.9	230.4	246.7	359.0	76.9	85.3	84.0
RADIUS = .516							
AMPLITUDE =	.0180	.0084	.0036	.0097	.0159	.0187	.0160
PHASE ANGLE =	232.1	243.2	153.2	128.0	142.9	158.9	176.3
RADIUS = .715							
AMPLITUDE =	.0166	.0126	.0110	.0105	.0127	.0118	.0097
PHASE ANGLE =	187.9	179.3	163.6	159.0	153.2	144.9	134.0
RADIUS = .883							
AMPLITUDE =	.0200	.0208	.0192	.0128	.0099	.0123	.0091
PHASE ANGLE =	176.7	173.5	182.7	169.2	155.1	132.2	111.6
RADIUS = 1.088							
AMPLITUDE =	.0062	.0076	.0121	.0102	.0055	.0052	.0039
PHASE ANGLE =	141.2	137.0	142.0	136.9	125.8	93.2	54.0

Table 11 - Harmonic Analyses of Longitudinal Velocity Component Ratios at the Interpolated Radii

HARMONIC ANALYSIS FOR ARS REPRESENTED BY MODEL 5391 AUG 79
PROPELLER DIAMETER = 9.88 FEET JA = .807

HARMONIC ANALYSES OF LONGITUDINAL VELOCITY COMPONENT RATIOS (VX/V)

HARMONIC =	1	2	3	4	5	6	7	8
RADIUS = .247								
AMPLITUDE =	.0726	.1090	.0734	.0573	.0216	.0015	.0249	.0330
PHASE ANGLE =	285.8	292.3	298.7	309.8	345.4	151.2	178.4	192.2
RADIUS = .400								
AMPLITUDE =	.0459	.0520	.0356	.0204	.0026	.0083	.0193	.0245
PHASE ANGLE =	280.8	294.9	306.9	312.2	334.2	191.7	190.3	207.8
RADIUS = .500								
AMPLITUDE =	.0326	.0321	.0222	.0068	.0048	.0112	.0172	.0206
PHASE ANGLE =	280.9	298.1	315.2	312.0	174.5	192.0	193.2	212.1
RADIUS = .600								
AMPLITUDE =	.0124	.0318	.0210	.0071	.0066	.0127	.0170	.0166
PHASE ANGLE =	305.1	297.5	306.5	295.7	166.8	182.6	181.5	196.9
RADIUS = .700								
AMPLITUDE =	.0163	.0349	.0213	.0070	.0065	.0129	.0165	.0156
PHASE ANGLE =	321.9	297.5	306.8	277.4	173.1	184.0	176.8	183.7
RADIUS = .800								
AMPLITUDE =	.0560	.0378	.0215	.0069	.0062	.0126	.0153	.0184
PHASE ANGLE =	298.5	299.4	327.9	211.4	221.9	213.0	192.1	188.3
RADIUS = .900								
AMPLITUDE =	.0897	.0454	.0253	.0078	.0064	.0113	.0134	.0179
PHASE ANGLE =	294.8	300.3	338.2	191.8	239.2	226.0	197.1	188.6
RADIUS = 1.000								
AMPLITUDE =	.1107	.0580	.0302	.0034	.0036	.0058	.0101	.0131
PHASE ANGLE =	293.7	300.2	336.9	205.4	222.1	215.7	181.6	180.9
RADIUS = 1.100								
AMPLITUDE =	.1185	.0734	.0357	.0067	.0048	.0059	.0099	.0070
PHASE ANGLE =	293.3	299.6	330.0	333.7	124.9	106.3	138.5	144.7

Table 11 (continued)

HARMONIC ANALYSIS FOR ARS REPRESENTED BY MODEL 5331 AUG 79
PROPELLER DIAMETER = 9.88 FEET JA = .807

HARMONIC ANALYSES OF LONGITUDINAL VELOCITY COMPONENT RATIOS (VX/V)

HARMONIC =	9	10	11	12	13	14	15
RADIUS = .247							
AMPLITUDE =	.0348	.0267	.0150	.0097	.0147	.0206	.0235
PHASE ANGLE =	205.8	219.7	249.0	312.2	21.4	32.3	43.9
RADIUS = .400							
AMPLITUDE =	.0231	.0137	.0040	.0044	.0105	.0119	.0092
PHASE ANGLE =	226.5	239.3	233.0	111.5	120.2	138.0	152.1
RADIUS = .500							
AMPLITUDE =	.0186	.0090	.0031	.0092	.0154	.0182	.0155
PHASE ANGLE =	232.4	244.5	159.2	126.4	141.3	157.9	175.6
RADIUS = .600							
AMPLITUDE =	.0158	.0083	.0066	.0095	.0145	.0148	.0121
PHASE ANGLE =	211.1	205.8	152.6	143.3	148.0	154.4	160.2
RADIUS = .700							
AMPLITUDE =	.0163	.0119	.0104	.0103	.0129	.0121	.0099
PHASE ANGLE =	190.2	181.1	161.9	157.4	152.7	146.3	137.3
RADIUS = .800							
AMPLITUDE =	.0200	.0190	.0168	.0122	.0114	.0129	.0099
PHASE ANGLE =	181.2	176.2	180.5	168.2	155.6	138.0	121.6
RADIUS = .900							
AMPLITUDE =	.0195	.0206	.0192	.0127	.0096	.0120	.0088
PHASE ANGLE =	175.8	172.8	182.2	168.6	154.6	130.9	109.5
RADIUS = 1.000							
AMPLITUDE =	.0142	.0159	.0165	.0116	.0073	.0090	.0064
PHASE ANGLE =	168.2	165.6	172.7	158.9	146.5	120.4	92.9
RADIUS = 1.100							
AMPLITUDE =	.0062	.0076	.0121	.0102	.0055	.0052	.0039
PHASE ANGLE =	141.2	137.0	142.0	136.9	125.8	93.2	54.0

Table 12 - Harmonic Analyses of Tangential Velocity Component Ratios at the Experimental Radii

HARMONIC ANALYSIS FOR ARS REPRESENTED BY MODEL 5391 AUG 79
PROPELLER DIAMETER = 9.88 FEET JA = .807

HARMONIC ANALYSES OF TANGENTIAL VELOCITY COMPONENT RATIOS (VT/V)

HARMONIC =	1	2	3	4	5	6	7	8
RADIUS = .332								
AMPLITUDE =	.2163	.0252	.0196	.0115	.0134	.0210	.0261	.0283
PHASE ANGLE =	196.0	137.8	150.0	140.1	111.6	96.8	101.9	112.0
RADIUS = .516								
AMPLITUDE =	.1800	.0101	.0100	.0076	.0075	.0106	.0121	.0126
PHASE ANGLE =	204.5	166.3	124.7	117.2	108.7	109.4	119.4	128.6
RADIUS = .715								
AMPLITUDE =	.1655	.0073	.0105	.0136	.0143	.0132	.0101	.0075
PHASE ANGLE =	205.7	267.4	85.9	92.7	113.9	121.4	128.3	107.7
RADIUS = .883								
AMPLITUDE =	.1754	.0225	.0046	.0031	.0076	.0100	.0119	.0130
PHASE ANGLE =	203.5	219.3	157.4	75.8	99.6	92.4	103.9	107.3
RADIUS = 1.088								
AMPLITUDE =	.1613	.0205	.0053	.0048	.0092	.0074	.0052	.0056
PHASE ANGLE =	204.7	215.8	79.4	80.2	99.3	100.0	101.0	73.6

Table 12 (continued)

HARMONIC ANALYSIS FOR ARS REPRESENTED BY MODEL 5391 AUG 79
PROPELLER DIAMETER = 9.88 FEET JA = .807

HARMONIC ANALYSES OF TANGENTIAL VELOCITY COMPONENT RATIOS (VT/V)

HARMONIC =	9	10	11	12	13	14	15
RADIUS = .332							
AMPLITUDE =	.0246	.0184	.0090	.0026	.0065	.0092	.0093
PHASE ANGLE =	119.3	131.2	126.2	72.5	15.5	17.5	25.9
RADIUS = .516							
AMPLITUDE =	.0091	.0062	.0060	.0094	.0132	.0142	.0133
PHASE ANGLE =	127.7	113.7	63.9	54.6	57.5	72.7	83.7
RADIUS = .715							
AMPLITUDE =	.0080	.0116	.0143	.0145	.0118	.0092	.0055
PHASE ANGLE =	72.7	63.4	69.2	74.1	79.1	78.6	57.6
RADIUS = .883							
AMPLITUDE =	.0098	.0099	.0090	.0104	.0117	.0104	.0091
PHASE ANGLE =	101.9	96.6	73.6	65.5	65.7	63.8	67.1
RADIUS = 1.088							
AMPLITUDE =	.0053	.0084	.0082	.0032	.0064	.0045	.0046
PHASE ANGLE =	60.3	51.3	44.9	43.0	35.7	35.4	359.8

Table 13 - Harmonic Analyses of Tangential Velocity Component Ratios at the Interpolated Radii

HARMONIC ANALYSIS FOR ARS REPRESENTED BY MODEL 5391 AUG 79
PROPELLER DIAMETER = 9.68 FEET JA = .807

HARMONIC ANALYSES OF TANGENTIAL VELOCITY COMPONENT RATIOS (VT/V)

HARMONIC =	1	2	3	4	5	6	7	8
RADIUS = .247								
AMPLITUDE =	.2429	.0342	.0267	.0157	.0202	.0298	.0369	.0398
PHASE ANGLE =	191.1	132.0	153.9	140.9	113.3	95.1	97.9	106.1
RADIUS = .400								
AMPLITUDE =	.1998	.0189	.0150	.0092	.0099	.0157	.0194	.0210
PHASE ANGLE =	199.7	144.6	144.3	135.7	109.9	99.7	106.8	117.9
RADIUS = .500								
AMPLITUDE =	.1822	.0111	.0104	.0076	.0075	.0110	.0128	.0135
PHASE ANGLE =	204.0	162.0	128.3	120.4	108.6	107.7	117.4	127.4
RADIUS = .600								
AMPLITUDE =	.1704	.0027	.0109	.0124	.0124	.0127	.0108	.0087
PHASE ANGLE =	205.5	225.5	97.0	99.9	113.8	120.4	127.9	121.1
RADIUS = .700								
AMPLITUDE =	.1656	.0066	.0108	.0138	.0144	.0133	.0101	.0074
PHASE ANGLE =	205.7	270.7	86.1	93.4	114.1	121.9	129.1	109.1
RADIUS = .800								
AMPLITUDE =	.1729	.0162	.0056	.0069	.0099	.0111	.0116	.0117
PHASE ANGLE =	204.2	227.1	120.7	88.2	107.5	104.6	111.9	108.8
RADIUS = .900								
AMPLITUDE =	.1753	.0234	.0046	.0026	.0073	.0098	.0117	.0130
PHASE ANGLE =	203.4	218.5	161.1	71.7	98.2	90.7	102.8	106.7
RADIUS = 1.000								
AMPLITUDE =	.1709	.0246	.0034	.0023	.0073	.0086	.0095	.0104
PHASE ANGLE =	203.6	216.0	146.8	63.2	94.9	88.3	99.0	99.7
RADIUS = 1.100								
AMPLITUDE =	.1613	.0205	.0053	.0048	.0092	.0074	.0052	.0056
PHASE ANGLE =	204.7	215.8	79.4	80.2	99.3	100.0	101.0	72.6

Table 13 (continued)

HARMONIC ANALYSIS FOR ARS REPRESENTED BY MODEL 5391 AUG 79
PROPELLER DIAMETER = 9.88 FEET JA = .807

HARMONIC ANALYSES OF TANGENTIAL VELOCITY COMPONENT RATIOS (VT/V)

HARMONIC =	9	10	11	12	13	14	15
RADIUS = .247							
AMPLITUDE =	.0360	.0278	.0155	.0033	.0069	.0137	.0154
PHASE ANGLE =	114.2	128.8	134.3	174.4	307.3	328.8	338.3
RADIUS = .400							
AMPLITUDE =	.0175	.0126	.0059	.0054	.0095	.0109	.0106
PHASE ANGLE =	123.9	131.3	107.4	53.7	40.9	51.0	62.4
RADIUS = .500							
AMPLITUDE =	.0100	.0067	.0057	.0089	.0128	.0140	.0132
PHASE ANGLE =	128.1	118.7	67.4	53.7	55.9	71.1	82.4
RADIUS = .600							
AMPLITUDE =	.0072	.0088	.0114	.0127	.0122	.0113	.0082
PHASE ANGLE =	93.8	71.7	66.5	68.9	70.9	77.4	74.5
RADIUS = .700							
AMPLITUDE =	.0079	.0114	.0142	.0145	.0118	.0094	.0056
PHASE ANGLE =	73.2	63.1	68.0	73.9	78.8	79.0	59.2
RADIUS = .800							
AMPLITUDE =	.0093	.0104	.0111	.0122	.0122	.0105	.0084
PHASE ANGLE =	94.7	86.3	72.9	70.8	72.0	69.8	67.4
RADIUS = .900							
AMPLITUDE =	.0097	.0098	.0086	.0101	.0114	.0102	.0090
PHASE ANGLE =	102.2	97.0	73.0	64.2	64.4	62.6	66.3
RADIUS = 1.000							
AMPLITUDE =	.0078	.0084	.0075	.0087	.0092	.0080	.0067
PHASE ANGLE =	95.2	85.8	62.1	54.1	54.2	54.2	52.5
RADIUS = 1.100							
AMPLITUDE =	.0053	.0084	.0082	.0062	.0064	.0045	.0046
PHASE ANGLE =	60.3	51.3	44.9	43.0	35.7	35.4	359.8

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