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Surface Pressure Measurements on the KCS Model (SRI M. S. No. 631) in the SRI 400m Towing Tank

Report of Ship Performance Division

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Research on Systematic Experiments for Evaluating Ship Performance in Seaway

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1. Introduction

The present report describes the surface pressure measurements around a ship model of the 3,600TEU Korea Research Institute of Ships and Ocean Engineering (KRISO) container ship (KCS) for the International Workshop on CFD in Ship Hydrodynamics, Gothenburg 2000. The Ship Research Institute (SRI) was asked to provide validation data on this ship to the workshop. The purpose of this investigation is to obtain reliable experimental data on the surface pressure on a modern and practical hull form ship with a bulbous bow, transom stern and stern bulb.

The information on geometrical shape and the experimental conditions of the KCS [1] was provided by KRISO. The ship model was manufactured at the SRI model workshop based on the lines drawn by KRISO and a Japanese company, and made by a different manufacturing method and materials.

The measurements were performed at the SRI 400m towing tank. The propeller model, SRI M. P. No.460, was offered from KRISO to use for self-propulsion tests, hull surface pressure and local velocity field measurements. The surface pressure measurements were conducted on the hull surface near stern from the square station, S.S. 3 to S.S. 1/2. The measurements were performed not only under the propeller working condition but also under the without propeller condition.

The measurement results obtained through the present careful experiments are expected to provide valuable information for the entire CFD and EFD community.

2. Experimental Setup

2.1 Ship Model

The principal particulars and the geometrical hull form shape of the ship model, SRI M. S. No. 631 are given in **Table 1** and **Fig. 1**, respectively. The ship model was manufactured to the same size as that used at KRISO, and was made of a combination of paraffin and wood.

The lines of this ship model were slightly modified and drawn by SRI and a Japanese company based on the lines given by KRISO with a scale ratio of 31.5994, so as to be able to manufacture the model at the SRI model workshop. A noticeable difference in the lines between SRI and KRISO could be observed mainly around the bulbous bow and flat stern hull above the propeller.

Unfortunately the ship model made at SRI shrank non-uniformly by about 5mm in the longitudinal direction, especially around the aft body. The deformation in other directions was within 1mm and occurred primarily during the first measurement at the SRI 400m towing tank.

In spite of slight modification of the lines and deformation of the ship model, reasonable correlation on the local velocity field measurements at the propeller plane was found between the SRI and KRISO data [2].

The square station described in this report is defined as the length between the fore and the aft perpendiculars divided by ten, and the aft and the fore perpendiculars are denoted as S.S. 0 and 10, respectively. The maximum sectional area of this ship is located at S.S. 4 3/4, not at the midship, that is, S.S. 5.

Studs with trapezoidal heads for turbulence stimulation were placed at S.S. 9 1/2 and the middle of the bow bulb with 10mm intervals to make the flow around the hull fully turbulent. The height and front width of studs were 1.5mm. The rudder shape was simplified as shown in **Fig. 1** but not used in the pressure measurement.

The present model was used for resistance tests [3], self-propulsion tests [3], wave profile measurements [4], local velocity field measurements [2], and surface pressure measurements. For the surface pressure measurements, 161 pressure taps were provided on the hull mainly from S.S. 3 to 1/4 on the port side of the model.

2.2 Propeller Model

The principal particulars and the geometrical shape of the propeller model, SRI M. P. No. 460 (KRISO KP505) are given in **Table 2** and **Fig. 2**, respectively. This model was manufactured by KRISO and sent to SRI for rental use. The curves of propeller open water characteristics measured at SRI [5] are shown in **Table 3** and **Fig. 3**. The measured thrust K_T and torque K_Q at SRI are larger than those measured at KRISO at the same advance ratio J. The propeller model was equipped at x/L=0.4825, that is, 0.0175L (127.3mm) upstream from A.P.

2.3 Experimental Apparatus

The measurements were performed at the SRI 400m towing tank with dimensions of 400m in length, 18m in breath and 8m in depth. The maximum speed of the towing carriage is currently around 12m/s. The adjustment of the draft of the ship model was made in the trimming tank through glass windows.

For the surface pressure measurements on the stern hull, 144 pressure taps were employed. The diameters of the pressure tap head and the hole are 6mm and 1mm, respectively. A drawing of the surface pressure measurement system is shown in **Fig. 5**. The calibration of the pressure transducer was carried at the SRI 400m towing tank before and after the respective measurements. The present calibration was carried out by simply changing the vertical position of pressure transducers from –40 to 40mm.

Pressure taps were connected to six semi-conductor type pressure transducers (Toyoda PD104W, capacity; 3,000mmAq) by vinyl tubes through six scanning valves (W0602/1P-24T). Other two pressure transducers were employed to measure the pressure at the bottom of the ship model and static pressure at a reference Pitot tube. The pressure signals were amplified 2,000 times by eight measuring amplifiers (Toyoda AA3004). The cut-off frequency of the low pass filters (Kyowa LFV-21A) was set to 10Hz. The filtered signals were monitored by a multi-pen recorder (Graphtec MC 6625) and the un-filtered pressure signals were recorded by an analogue data recorder (Kyowa RTP-650B) at a tape speed of 1.2cm/s and over a frequency range of DC to 625Hz.

The data acquisition of mean pressure was made by a personal computer (HP Vectra) through an A/D signal board (National Instrument, ±10Volt, 16bits) where the sampling rate and period were 20Hz and 7 seconds, respectively. The measured signal was simply averaged and normalized by the ship speed to the ground U.

In order to correct for the effect of variation in the rail height and tank water level during the present measurements, a reference Pitot tube was utilized.

3. Experimental Procedure and Conditions

The measurements of wave profile and local velocity field on the KCS model were carried out at the KRISO towing tank under fixed conditions [1]. The trim and sinkage of the ship model were not allowed at the given draft by using two clamping devices. This method could not be adapted to the measurement at the SRI 400m towing tank due to a leakage of tank water.

In order to conduct the present measurements under similar experimental conditions to the KRISO measurements on resistance, self-propulsion, wave profile, local velocity field, the initial trim and the weight arrangement were sought by a trial and error method to realize zero trim and sinkage of the ship model in a free running condition. This condition of the ship model was called the even keel condition. The carriage speed relative to the ground was kept at 2.196m/s corresponding to Fr=0.2600 under the even keel condition.

Eight sets of measurements were possible by changing the scanning valves during one carriage run and the measured data at 48 points could be obtained at each run. The surface pressure measurements at 144 points were accomplished by three carriage runs. Three repeat tests were made for each condition.

All of the measurements were performed without a rudder. Under the resistance test condition without a propeller, total resistance coefficient C_{TM} and residuary resistance coefficient C_R were estimated to be 0.003519 and 0.0006888, respectively. Reynolds number Re was 1.406×10^7 at 15.1°C. The density of tank water ρ was assumed to be $101.88 kg*s^2/m^4$ in this report.

The propeller revolution rate of the propeller model was set to 9.5rps with an even keel and self-propulsion condition at the "ship point" ", that is , the ship self-propulsion condition. The thrust K_T and torque K_Q coefficients were 0.1703 and 0.02880, respectively. The thrust loading coefficient C_{Th} and advance coefficient J were estimated 0.5074 and 0.728 from the propeller open water characteristics curves measured by SRI as shown in **Fig.3**. Reynolds number Re was 1.406×10^7 at 15.1°C and the same as that under the without propeller condition.

4. Results of Surface Pressure Measurement

4.1 Measured Quantities

In the present measurement, each static pressure on the stern hull, the speed of the ship model relative to the tank water, the resistance, the dipping at both perpendiculars and the heel were measured. Additionally thrust and torque were measured under the self-propulsion condition. The heel was measured by an inclinometer.

In the presentation of the measurements, a Cartesian coordinate system was adopted and the x–, y–, z– axis are in the direction of aftship, starboard side of the hull, upper desk, respectively. The origin was defined to be at the intersection of the water plane at load water line and the midship S.S. 5.

4.2 Measurements without the Propeller

Measurements on the hull surface pressure were carried out to compare with CFD computation. The surface pressure measurements on the port side of the hull under the even keel condition without the propeller are shown in **Fig. 6**. The contour curves were generated by interpolating the pressure data obtained at discrete measuring points. The interval of pressure contour curves is 0.025. Near the bottom of the ship model, the surface pressure was relatively low, while the pressure recovery for the water lines near free surface was larger than these near the bottom of the hull. The pressure measurement results were seriously affected by inaccurate arrangement of pressure taps and deformation of the hull shape.

4.3 Measurement with the Working Propeller

Measurements of surface pressure on the stern hull with the operating propeller model at the even keel condition were carried out only on the port side except at a few points on the starboard side of the hull. The contour curves generated from the measured results are shown in **Fig. 7**. The difference of pressure contour map between under the without propeller and under the propeller working condition was small in the area upstream from S.S. 1 1/2, while the pressure recovery area downstream from S.S. 1 under the latter condition was remarkably less due to the propeller suction effects, comparing with the former condition. The influence of the working propeller was observed in the area downstream from S.S. 7/8, about 2.5 diameters upstream from the propeller disk, except the water lines near free surface.

5. Concluding Remarks

This report describes the measurements of surface pressure around a modern and practical 3,600TEU KRISO container ship (KCS) model. The ship model was manufactured at the SRI model workshop by using the lines offered by KRISO but used a different manufacturing method and materials.

The surface pressure measurements on the KCS model without the propeller and with the working propeller under the even keel condition were obtained. It is expected that the data will be useful for validating CFD computations.

Repeat tests were performed to carry out uncertainty analysis and the results will be published in near future.

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Nomenclatures

A_M Midship Section Area [m^2]

A_0 Propeller Disk Area [m^2], $=(\pi Dp^2)/4$

a_E Expanded Area Ratio [-]

B Breadth of Ship [m]

C_B Block Coefficient [-]

C_F Frictional Resistance Coefficient [-], $=R_F/(1/2\rho U^2 S_W)$

C_M Midship Section Coefficient [-], $=A_M/BT$

C_P Pressure Coefficient [-], $=(P-P_O)/(1/2\rho U^2)$

C_P Prismatic Coefficient [-], $=\nabla/(A_M L_{PP})$

C_R Residuary Resistance Coefficient [-], $=R_R/(1/2\rho U^2 S_W)$

C_{Th} Thrust Loading Coefficient [-], $=T/(1/2\rho U^2 A_0)$

C_{TM} Total Resistance Coefficient [-], $=R_{TM}/(1/2\rho U^2 S_W)$

D Depth of Ship [m]

D_p Propeller Diameter [m]

d Draft of Ship [m]; T

F_h, F_{h8} Function to determine Horizontal components of Flow Angle for Each Five-Hole System [-]

F_v, F_{v8} Function to determine Vertical components of Flow Angle for Each Five-Hole System [-]

F_r Froude Number Based on Length between Perpendiculars, L; F_n, $=U/(gL)^{1/2}$

G_h, G_{h8} Function to determine Horizontal component of Inflow Velocity [-]

G_v, G_{v8} Function to determine Vertical component of Inflow Velocity [-]

g Acceleration of Gravity [m/s^2]

$H_T, H_B, H_C, H_P, H_S, H_{T1}, H_{P1}, H_{S1}$

Head at Each Pressure Hole, T, B, C, P, S, T_1, P_1 and S_1 of Eight-Hole Spherical Type Pitot Tube [Aq]

I Propeller Immersion [m]

J Advance Coefficient [-], $= V_A / n_P D$

K_Q Torque Coefficient [-], $=Q/\rho n_P{}^2 D^5$

K_T Thrust Coefficient [-], $=T/\rho n_P{}^2 D^4$

L Length between Perpendiculars [m]; L_{PP}

L_{PP} Length between Perpendiculars [m]; L

L_{WL} Length at Load Water Line [m]

l_{CB} Center of Buoyancy from Midship [% L_{PP}, Backward +]

N Number of Individual Readings [-]

n_P Propeller Revolution Rate [1/s, Hz]

P Pressure [kg/ m^2]

P_O	Reference Pressure at Infinity [kg/ m²]
p	Pitch Ratio [-]
R_e	Reynolds' Number Based on Length between Perpendiculars [-]
R_F	Frictional Resistance [kg]
R_R	Residuary Resistance [kg]
R_T	Total Resistance [kg]
S_R	Wetted Surface Area of Rudder [m^2]
S_W	Wetted Surface Area of Naked Hull without Rudder [m^2]
T	Draft of Ship [m]; d
T_W	Temperature of Tank Water [°C]
U	Speed of Ship Model [m/s]
u,v,w	Local Mean-Velocities in (x,y.z) directions
V_A	Propeller Advance Speed [m/s]; =$(1-w_T)U$
V_e	Speed of Ship Model to the Ground [m/s]
V_h	Horizontal Component of Inflow Velocity to Pitot Tube [m/s]
V_v	Vertical Component of Inflow Velocity to Pitot Tube [m/s]
w_T	Axial Wake Fraction determined by Propeller Thrust [-]
x	Coordinate for Longitudinal Direction of Ship [m]
x_B	Propeller Boss Ratio [-]
y	Coordinate for Transverse Direction of Ship [m]
Z	Number of Blade [-]
z	Coordinate for Vertical Direction of Ship [m]
β_h	Flow Angle between Horizontal Component of Inflow and X-Axis [deg]
β_v	Flow Angle between Vertical Component of Inflow and X-Axis [deg]
η_o	Propeller Efficiency [-]; =$(JK_T)/(2\pi K_Q)$
Θ_R	Rake Angle [deg]
Θ_S	Skew Angle [deg]
θ	Sensitivity Coefficient
ν	Coefficient of Kinematic Viscosity [m^2/s]
ρ	Density of Water [$kg*s^2/m^4$]
∇	Displacement Volume of Ship Model [m^3]

Table 1 Principal Particulars of Tested Ship

Ship Model Name			KRISO Container Ship
SRI M. S. No.			631
KRISO M. S. No.		m	KS621
Length between Perpendiculars	L_{PP}	m	7.2786
Length of Load Water Line	L_{WL}	m	7.3568
Breadth (Moulded)	B	m	1.0190
Depth (Moulded)	D	m	0.5696
Draft (Moulded)	d	m	0.3418
Wetted Surface Area w/o Rudder*	S_W	m^2	9.4984
Rudder Surface Area	S_R	m^2	0.0741
Displacement w/o Rudder*	∇	m^3	1.6497
Center of Buoyancy from Midship (Backward, +) *	l_{CB}	% L_{PP}	1.48
Blockage Coefficient*	C_B	—	0.6508
Midship Coefficient*	C_M	—	0.9849
Prismatic Coefficient*	C_P	—	0.6608

* These values were calculated by a Japanese Company

Table 2 Principal Particulars of Tested Propeller

Propeller Name			KCS Propeller
SRI M. P. No.			460 & 465
KRISO M. P. No.			KP505
Diameter	D_P	m	0.2500
Boss Ratio	x_B	—	0.1800
Pitch Ratio at 0.7R	p	—	0.9967
Expanded Blade Area Ratio	a_E	—	0.800
Rake Angle	Θ_R	deg	0.000
Skew Angle	Θ_S	deg	32.0
Number of Blade	Z	—	5
Direction of Rotation			Right
Blade Section			NACA66 Thickness +a=0.8 Camber

Table 3 Propeller Open Test Results in SRI Towing Tank

J	Kt	10Kq	Eta0
0.000	0.518	0.725	0.000
0.100	0.482	0.677	0.113
0.150	0.458	0.646	0.169
0.200	0.435	0.622	0.223
0.250	0.412	0.589	0.278
0.300	0.387	0.557	0.332
0.350	0.361	0.531	0.379
0.400	0.336	0.497	0.431
0.450	0.310	0.466	0.477
0.500	0.285	0.437	0.519
0.550	0.259	0.405	0.561
0.600	0.235	0.376	0.597
0.650	0.209	0.343	0.631
0.700	0.185	0.311	0.665
0.750	0.161	0.278	0.691
0.800	0.137	0.247	0.705
0.850	0.111	0.215	0.697
0.900	0.083	0.181	0.654
0.950	0.053	0.140	0.575
1.000	0.022	0.096	0.373
1.050	-0.012	0.046	-0.437

Table 4 (a) Position of Pressure Taps and Measured Pressure Coefficients
- without Propeller -

[Port Side]

S.S.	W.L.	X[mm]	Y[mm]	Z[mm]	Cp[-]
5	0.00	-0.5	0.0	-341.8	-0.025
5	0.00	0.3	-251.9	-342.6	-0.044
5	9.00	-1.5	-509.3	-58.1	0.018
3	0.00	1453.4	-0.5	-341.5	-0.068
3	0.00	1453.4	-63.0	-341.3	-0.051
3	0.00	1454.2	-127.7	-341.5	-0.071
3	0.00	1454.0	-188.6	-341.6	-0.098
3	1.00	1454.8	-342.0	-311.0	-0.087
3	2.00	1454.1	-402.2	-278.9	-0.089
3	3.00	1454.9	-443.2	-246.3	-0.113
3	4.00	1454.7	-469.4	-217.2	-0.096
3	5.00	1453.9	-490.2	-184.6	-0.130
3	6.00	1453.5	-503.1	-152.9	-0.148
3	7.00	1452.9	-509.3	-120.0	-0.132
3	8.00	1453.7	-509.2	-89.5	-0.089
3	9.00	1453.7	-509.5	-56.4	-0.124
3	10.00	1453.7	-509.3	-25.3	-0.097
2 1/2	0.00	1817.4	-1.0	-340.4	-0.055
2 1/2	0.00	1817.1	-62.8	-340.8	-0.067
2 1/2	0.00	1817.4	-126.5	-341.1	-0.083
2 1/2	1.00	1817.8	-258.7	-310.3	-0.093
2 1/2	2.00	1817.7	-316.1	-279.4	-0.102
2 1/2	3.00	1817.7	-364.4	-247.3	-0.103
2 1/2	4.00	1818.3	-405.9	-214.9	-0.108
2 1/2	5.00	1818.3	-442.6	-183.0	-0.121
2 1/2	6.00	1817.4	-473.5	-150.9	-0.125
2 1/2	7.00	1817.4	-494.2	-120.5	-0.126
2 1/2	8.00	1816.9	-506.5	-89.3	-0.141
2 1/2	9.00	1816.9	-509.1	-55.9	-0.117
2 1/2	10.00	1817.6	-509.2	-25.2	-0.106
2	0.00	2181.9	-0.4	-340.8	-0.076
2	0.00	2181.9	-63.4	-341.2	-0.090
2	1.00	2181.9	-185.8	-310.0	-0.133
2	2.00	2181.1	-227.2	-279.0	-0.137
2	3.00	2182.8	-263.4	-247.0	-0.097
2	4.00	2181.4	-302.0	-215.1	-0.106
2	5.00	2182.6	-345.2	-183.4	-0.111
2	6.00	2181.7	-396.6	-151.9	-0.122
2	7.00	2181.7	-446.9	-120.5	-0.112
2	8.00	2180.9	-484.0	-89.8	-0.139
2	9.00	2180.2	-504.9	-56.8	-0.080
2	10.00	2181.1	-509.1	-24.7	-0.103
1 1/2	0.00	2544.2	-0.3	-340.9	-0.062
1 1/2	1.00	2545.4	-120.3	-310.0	-0.109
1 1/2	2.00	2546.1	-147.3	-279.6	-0.105

S.S.	W.L.	X[mm]	Y[mm]	Z[mm]	Cp[-]
1 1/2	3.00	2545.3	-168.9	-247.4	-0.066
1 1/2	4.00	2546.4	-191.2	-215.7	-0.078
1 1/2	5.00	2545.5	-219.5	-184.1	-0.062
1 1/2	6.00	2545.5	-258.2	-152.9	-0.063
1 1/2	7.00	2545.5	-319.6	-120.3	-0.050
1 1/2	8.00	2544.5	-402.0	-89.1	-0.047
1 1/2	9.00	2544.4	-471.5	-57.4	-0.062
1 1/2	10.00	2544.8	-499.8	-25.5	-0.013
1 1/4	0.00	2726.6	-0.2	-341.4	-0.033
1 1/4	1.00	2726.6	-94.4	-310.7	-0.121
1 1/4	2.00	2726.1	-115.7	-280.0	-0.105
1 1/4	3.00	2724.6	-129.3	-247.3	-0.069
1 1/4	4.00	2725.9	-141.6	-215.1	-0.043
1 1/4	5.00	2726.9	-158.1	-183.3	-0.027
1 1/4	6.00	2726.9	-184.5	-152.2	-0.032
1 1/4	7.00	2726.9	-232.7	-120.4	-0.033
1 1/4	8.00	2726.2	-321.0	-88.9	-0.006
1 1/4	9.00	2726.6	-422.4	-57.4	0.005
1 1/4	10.00	2725.6	-484.2	-26.0	0.009
1	0.00	2907.4	-0.3	-341.7	0.004
1	1.00	2907.9	-72.4	-310.7	-0.077
1	2.00	2908.5	-87.8	-278.9	-0.057
1	3.00	2907.2	-94.0	-247.1	-0.014
1	4.00	2908.4	-96.7	-215.7	0.004
1	5.00	2907.4	-102.6	-183.9	0.007
1	6.00	2908.1	-116.1	-151.8	0.021
1	7.00	2908.3	-144.3	-120.9	0.020
1	8.00	2908.4	-217.4	-89.1	0.020
1	9.00	2908.1	-349.7	-57.4	0.031
1	10.00	2907.8	-452.0	-26.0	0.037
7/8	0.00	2998.8	-0.5	-341.3	-0.019
7/8	1.00	2999.4	-62.2	-309.6	-0.046
7/8	2.00	2998.5	-74.5	-280.2	-0.002
7/8	3.00	2997.1	-78.8	-245.4	0.005
7/8	4.00	2998.7	-78.7	-215.9	0.006
7/8	5.00	2997.8	-80.4	-184.4	0.012
7/8	6.00	2997.8	-87.0	-152.6	0.020
7/8	7.00	2998.7	-105.1	-121.7	0.038
7/8	8.00	2999.5	-164.1	-88.8	0.043
7/8	9.00	2998.9	-305.6	-57.0	0.045
7/8	10.00	2999.2	-425.0	-26.4	0.042
3/4	0.00	3090.2	-1.7	-340.9	-0.010
3/4	1.00	3090.2	-51.6	-309.8	-0.028
3/4	2.00	3088.3	-63.7	-277.6	0.015
3/4	3.00	3090.6	-65.2	-246.8	0.038
3/4	4.00	3089.9	-62.2	-215.8	0.024
3/4	5.00	3090.0	-59.3	-184.4	0.039

Table 4 (a) Position of Pressure Taps and Measured Pressure Coefficients - without Propeller -

S.S.	W.L.	X[mm]	Y[mm]	Z[mm]	Cp[-]
3/4	6.00	3088.8	-60.1	-152.2	0.050
3/4	7.00	3090.0	-69.6	-120.5	0.059
3/4	8.00	3090.5	-110.1	-88.9	0.050
3/4	9.00	3089.8	-246.5	-57.2	0.052
3/4	10.00	3090.1	-394.0	-25.5	0.054
5/8	0.00	3180.3	-1.6	-340.6	-0.022
5/8	1.00	3180.3	-39.3	-310.5	0.000
5/8	2.00	3179.7	-52.7	-278.7	0.038
5/8	3.00	3179.3	-53.4	-244.6	0.078
5/8	4.00	3180.4	-46.6	-213.6	0.082
5/8	5.00	3180.4	-39.6	-182.6	0.083
5/8	6.00	3179.9	-35.3	-151.0	0.096
5/8	7.00	3179.9	-37.6	-119.7	0.106
5/8	8.00	3180.9	-61.1	-88.9	0.101
5/8	9.00	3180.9	-162.4	-57.1	0.101
5/8	10.00	3181.5	-351.2	-25.3	0.077
1/2	1.00	3272.1	-25.5	-310.0	0.050
1/2	2.00	3271.9	-41.5	-277.6	0.069
1/2	3.00	3271.6	-43.2	-245.9	0.101
1/2	4.00	3270.8	-34.0	-212.6	0.113
1/2	5.00	3270.8	-23.4	-181.7	0.129
1/2	6.00	3270.8	-16.6	-148.9	0.128
1/2	7.00	3271.8	-15.4	-117.9	0.137
1/2	8.00	3271.8	-26.3	-87.6	0.153
1/2	9.00	3272.3	-88.2	-56.2	0.137
1/2	9.65	3271.2	-222.3	-35.3	0.122
1/2	10.00	3271.2	-300.1	-24.9	0.087
1/4	9.39	3453.5	-0.3	-43.3	0.212
1/4	9.67	3451.9	-32.1	-38.8	0.186
1/4	9.84	3451.9	-78.9	-31.9	0.160
1/4	10.00	3453.5	-130.5	-24.4	0.138
P.D.	9.85	3506.3	-1.2	-32.3	0.188
P.D.	9.91	3506.9	-30.2	-28.6	0.187
P.D.	10.08	3506.9	-77.9	-23.8	0.170
A.P.	10.48	3633.4	-31.9	-10.1	0.170
A1	10.87	3729.0	0.9	0.5	0.171
A1	10.92	3728.1	-31.8	3.0	0.173

[Starboard Side]

S.S.	W.L.	X[mm]	Y[mm]	Z[mm]	Cp[-]
1 1/2	1.00	2545.1	120.7	-310.4	-0.115
1 1/2	4.00	2544.6	192.9	-214.8	-0.073
1 1/2	7.00	2543.3	318.7	-121.4	-0.052
1 1/4	1.00	2725.0	94.7	-310.4	-0.083
1 1/4	4.00	2726.0	141.2	-217.1	-0.045
1 1/4	7.00	2726.6	233.4	-120.2	-0.010
1	1.00	2907.3	73.5	-309.6	-0.060
1	4.00	2908.7	97.3	-215.5	-0.015
1	7.00	2907.4	144.4	-120.9	0.025
7/8	1.00	2998.5	62.8	-309.8	-0.051
7/8	4.00	2999.9	79.2	-214.6	0.002
7/8	7.00	2997.9	105.9	-121.0	0.022
3/4	2.00	3090.2	64.0	-277.4	0.019
3/4	3.00	3090.2	66.2	-245.7	0.041
3/4	4.00	3089.9	62.9	-213.8	0.042
3/4	5.00	3089.7	59.6	-182.5	0.043
3/4	6.00	3090.4	60.7	-151.2	0.045
3/4	7.00	3088.8	70.5	-120.6	0.057
3/4	8.00	3089.2	111.7	-88.4	0.052
5/8	1.00	3180.4	40.1	-310.1	-0.007
5/8	4.00	3180.4	47.6	-213.8	0.085
5/8	7.00	3181.1	37.6	-120.3	0.100
1/2	1.00	3271.0	26.9	-309.7	0.034
1/2	4.00	3271.5	35.4	-213.0	0.117
1/2	7.00	3271.3	15.1	-119.9	0.153
1/4	9.67	3451.1	32.2	-38.9	0.184
1/4	9.84	3450.7	80.0	-32.1	0.173
1/4	10.00	3451.9	130.9	-23.9	0.144
P.D.	9.91	3505.8	34.3	-28.4	0.198
P.D.	10.08	3505.8	81.7	-23.5	0.170
A.P.	10.48	3633.0	31.8	-10.2	0.172
A1	10.92	3728.5	33.2	3.2	0.172

Table 4 (b) Position of Pressure Taps and Measured Pressure Coefficients - with Working Propeller -

[Port Side]

S.S.	W.L.	X[mm]	Y[mm]	Z[mm]	Cp[-]
5	0.00	-0.5	0.0	-341.8	-0.022
5	0.00	0.3	-251.9	-342.6	-0.044
5	9.00	-1.5	-509.3	-58.1	0.014
3	0.00	1453.4	-0.5	-341.5	-0.068
3	0.00	1453.4	-63.0	-341.3	-0.051
3	0.00	1454.2	-127.7	-341.5	-0.071
3	0.00	1454.0	-188.6	-341.6	-0.103
3	1.00	1454.8	-342.0	-311.0	-0.093
3	2.00	1454.1	-402.2	-278.9	-0.090
3	3.00	1454.9	-443.2	-246.3	-0.112
3	4.00	1454.7	-469.4	-217.2	-0.098
3	5.00	1453.9	-490.2	-184.6	-0.133
3	6.00	1453.5	-503.1	-152.9	-0.153
3	7.00	1452.9	-509.3	-120.0	-0.138
3	8.00	1453.7	-509.2	-89.5	-0.091
3	9.00	1453.7	-509.5	-56.4	-0.124
3	10.00	1453.7	-509.3	-25.3	-0.099
2 1/2	0.00	1817.4	-1.0	-340.4	-0.059
2 1/2	0.00	1817.1	-62.8	-340.8	-0.067
2 1/2	0.00	1817.4	-126.5	-341.1	-0.082
2 1/2	1.00	1817.8	-258.7	-310.3	-0.089
2 1/2	2.00	1817.7	-316.1	-279.4	-0.101
2 1/2	3.00	1817.7	-364.4	-247.3	-0.103
2 1/2	4.00	1818.3	-405.9	-214.9	-0.107
2 1/2	5.00	1818.3	-442.6	-183.0	-0.121
2 1/2	6.00	1817.4	-473.5	-150.9	-0.131
2 1/2	7.00	1817.4	-494.2	-120.5	-0.125
2 1/2	8.00	1816.9	-506.5	-89.3	-0.134
2 1/2	9.00	1816.9	-509.1	-55.9	-0.119
2 1/2	10.00	1817.6	-509.2	-25.2	-0.112
2	0.00	2181.9	-0.4	-340.8	-0.080
2	0.00	2181.9	-63.4	-341.2	-0.098
2	1.00	2181.9	-185.8	-310.0	-0.138
2	2.00	2181.1	-227.2	-279.0	-0.137
2	3.00	2182.8	-263.4	-247.0	-0.101
2	4.00	2181.4	-302.0	-215.1	-0.110
2	5.00	2182.6	-345.2	-183.4	-0.119
2	6.00	2181.7	-396.6	-151.9	-0.132
2	7.00	2181.7	-446.9	-120.5	-0.115
2	8.00	2180.9	-484.0	-89.8	-0.141
2	9.00	2180.2	-504.9	-56.8	-0.084
2	10.00	2181.1	-509.1	-24.7	-0.109
1 1/2	0.00	2544.2	-0.3	-340.9	-0.069
1 1/2	1.00	2545.4	-120.3	-310.0	-0.120
1 1/2	2.00	2546.1	-147.3	-279.6	-0.113

S.S.	W.L.	X[mm]	Y[mm]	Z[mm]	Cp[-]
1 1/2	3.00	2545.3	-168.9	-247.4	-0.073
1 1/2	4.00	2546.4	-191.2	-215.7	-0.087
1 1/2	5.00	2545.5	-219.5	-184.1	-0.067
1 1/2	6.00	2545.5	-258.2	-152.9	-0.070
1 1/2	7.00	2545.5	-319.6	-120.3	-0.059
1 1/2	8.00	2544.5	-402.0	-89.1	-0.055
1 1/2	9.00	2544.4	-471.5	-57.4	-0.067
1 1/2	10.00	2544.8	-499.8	-25.5	-0.022
1 1/4	0.00	2726.6	-0.2	-341.4	-0.042
1 1/4	0.00	2726.6	-422.4	-57.4	-0.004
1 1/4	1.00	2726.6	-94.4	-310.7	-0.135
1 1/4	2.00	2726.1	-115.7	-280.0	-0.121
1 1/4	3.00	2724.6	-129.3	-247.3	-0.080
1 1/4	4.00	2725.9	-141.6	-215.1	-0.052
1 1/4	5.00	2726.9	-158.1	-183.3	-0.039
1 1/4	6.00	2726.9	-184.5	-152.2	-0.042
1 1/4	7.00	2726.9	-232.7	-120.4	-0.044
1 1/4	8.00	2726.2	-321.0	-88.9	-0.020
1 1/4	10.00	2725.6	-484.2	-26.0	0.001
1	0.00	2907.4	-0.3	-341.7	-0.010
1	1.00	2907.9	-72.4	-310.7	-0.096
1	2.00	2908.5	-87.8	-278.9	-0.078
1	3.00	2907.2	-94.0	-247.1	-0.032
1	4.00	2908.4	-96.7	-215.7	-0.012
1	5.00	2907.4	-102.6	-183.9	-0.009
1	6.00	2908.1	-116.1	-151.8	0.005
1	7.00	2908.3	-144.3	-120.9	0.004
1	8.00	2908.4	-217.4	-89.1	0.006
1	9.00	2908.1	-349.7	-57.4	0.017
1	10.00	2907.8	-452.0	-26.0	0.028
7/8	0.00	2998.8	-0.5	-341.3	-0.032
7/8	1.00	2999.4	-62.2	-309.6	-0.066
7/8	2.00	2998.5	-74.5	-280.2	-0.021
7/8	3.00	2997.1	-78.8	-245.4	-0.018
7/8	4.00	2998.7	-78.7	-215.9	-0.019
7/8	5.00	2997.8	-80.4	-184.4	-0.010
7/8	6.00	2997.8	-87.0	-152.6	-0.001
7/8	7.00	2998.7	-105.1	-121.7	0.020
7/8	8.00	2999.5	-164.1	-88.8	0.026
7/8	9.00	2998.9	-305.6	-57.0	0.029
7/8	10.00	2999.2	-425.0	-26.4	0.028
3/4	0.00	3090.2	-1.7	-340.9	-0.031
3/4	1.00	3090.2	-51.6	-309.8	-0.053
3/4	2.00	3088.3	-63.7	-277.6	-0.011
3/4	3.00	3090.6	-65.2	-246.8	0.013
3/4	4.00	3089.9	-62.2	-215.8	-0.008
3/4	5.00	3090.0	-59.3	-184.4	0.010

Table 4 (b) Position of Pressure Taps and Measured Pressure Coefficients
- with Working Propeller -

S.S.	W.L.	X[mm]	Y[mm]	Z[mm]	Cp[-]
3/4	6.00	3088.8	-60.1	-152.2	0.025
3/4	7.00	3090.0	-69.6	-120.5	0.035
3/4	8.00	3090.5	-110.1	-88.9	0.028
3/4	9.00	3089.8	-246.5	-57.2	0.035
3/4	10.00	3090.1	-394.0	-25.5	0.039
5/8	0.00	3180.3	-1.6	-340.6	-0.054
5/8	1.00	3180.3	-39.3	-310.5	-0.033
5/8	2.00	3179.7	-52.7	-278.7	0.003
5/8	3.00	3179.3	-53.4	-244.6	0.047
5/8	4.00	3180.4	-46.6	-213.6	0.050
5/8	5.00	3180.4	-39.6	-182.6	0.050
5/8	6.00	3179.9	-35.3	-151.0	0.066
5/8	7.00	3179.9	-37.6	-119.7	0.076
5/8	8.00	3180.9	-61.1	-88.9	0.071
5/8	9.00	3180.9	-162.4	-57.1	0.079
5/8	10.00	3181.5	-351.2	-25.3	0.063
1/2	1.00	3272.1	-25.5	-310.0	0.005
1/2	2.00	3271.9	-41.5	-277.6	0.018
1/2	3.00	3271.6	-43.2	-245.9	0.058
1/2	4.00	3270.8	-34.0	-212.6	0.070
1/2	5.00	3270.8	-23.4	-181.7	0.093
1/2	6.00	3270.8	-16.6	-148.9	0.090
1/2	7.00	3271.8	-15.4	-117.9	0.103
1/2	8.00	3271.8	-26.3	-87.6	0.126
1/2	9.00	3272.3	-88.2	-56.2	0.105
1/2	9.65	3271.2	-222.3	-35.3	0.100
1/2	10.00	3271.2	-300.1	-24.9	0.070
1/4	9.39	3453.5	-0.3	-43.3	0.191
1/4	9.67	3451.9	-32.1	-38.8	0.165
1/4	9.84	3451.9	-78.9	-31.9	0.137
1/4	10.00	3453.5	-130.5	-24.4	0.121
P. D.	9.85	3506.3	-1.2	-32.3	0.204
P. D.	9.91	3506.9	-30.2	-28.6	0.196
P. D.	10.08	3506.9	-77.9	-23.8	0.177
A.P.	10.48	3633.4	-31.9	-10.1	0.203
A1	10.87	3729.0	0.9	0.5	0.195
A1	10.92	3728.1	-31.8	3.0	0.197

[Starboard Side]

S.S.	W.L.	X[mm]	Y[mm]	Z[mm]	Cp[-]
1 1/2	1.00	2545.1	120.7	-310.4	-0.129
1 1/2	4.00	2544.6	192.9	-214.8	-0.080
1 1/2	7.00	2543.3	318.7	-121.4	-0.060
1 1/4	1.00	2725.0	94.7	-310.4	-0.093
1 1/4	4.00	2726.0	141.2	-217.1	-0.061
1 1/4	7.00	2726.6	233.4	-120.2	-0.026
1	1.00	2907.3	73.5	-309.6	-0.076
1	4.00	2908.7	97.3	-215.5	-0.031
1	7.00	2907.4	144.4	-120.9	0.013
7/8	1.00	2998.5	62.8	-309.8	-0.071
7/8	4.00	2999.9	79.2	-214.6	-0.024
7/8	7.00	2997.9	105.9	-121.0	-0.003
3/4	2.00	3090.2	64.0	-277.4	-0.007
3/4	3.00	3090.2	66.2	-245.7	0.016
3/4	4.00	3089.9	62.9	-213.8	0.016
3/4	5.00	3089.7	59.6	-182.5	0.012
3/4	6.00	3090.4	60.7	-151.2	0.015
3/4	7.00	3088.8	70.5	-120.6	0.030
3/4	8.00	3089.2	111.7	-88.4	0.026
5/8	1.00	3180.4	40.1	-310.1	-0.042
5/8	4.00	3180.4	47.6	-213.8	0.053
5/8	7.00	3181.1	37.6	-120.3	0.070
1/2	1.00	3271.0	26.9	-309.7	-0.017
1/2	4.00	3271.5	35.4	-213.0	0.074
1/2	7.00	3271.3	15.1	-119.9	0.116
1/4	9.67	3451.1	32.2	-38.9	0.159
1/4	9.84	3450.7	80.0	-32.1	0.154
1/4	10.00	3451.9	130.9	-23.9	0.127
P. D.	9.91	3505.8	34.3	-28.4	0.214
P. D.	10.08	3505.8	81.7	-23.5	0.178
A.P.	10.48	3633.0	31.8	-10.2	0.209
A1	10.92	3728.5	33.2	3.2	0.201

SRI M. S. No. 631

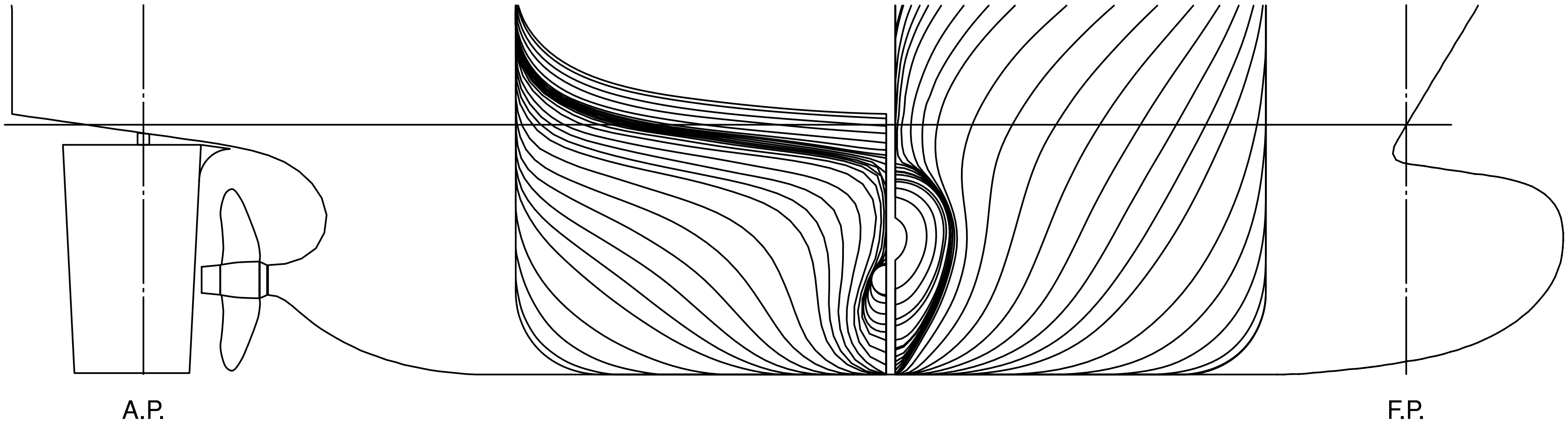

Fig. 1 Body Plan and Side Profile of Ship Model, SRI M. S. No. 631

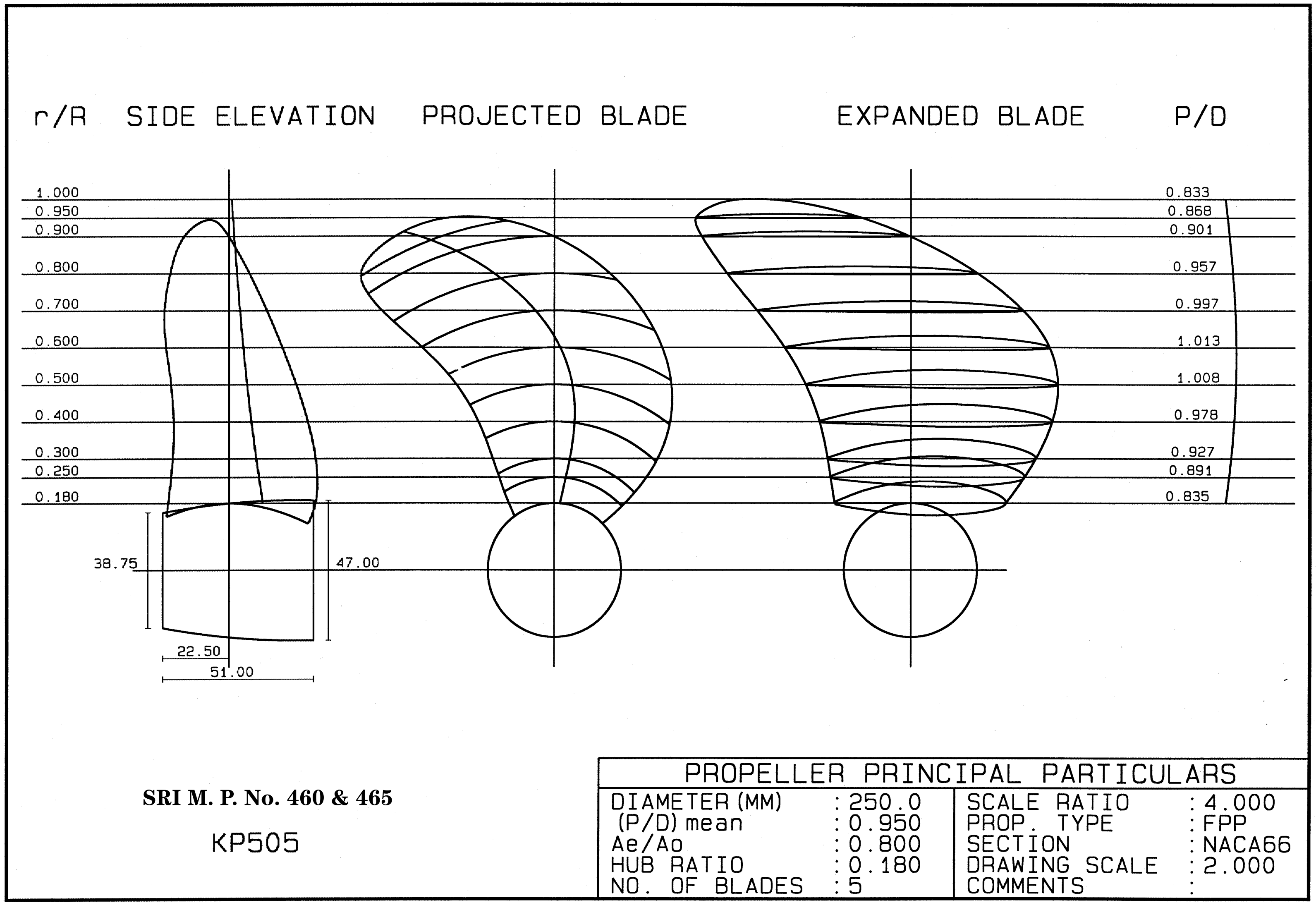

Fig. 2 Geometrical Shape Model of Propeller, SRI M. P. No. 460 & 465

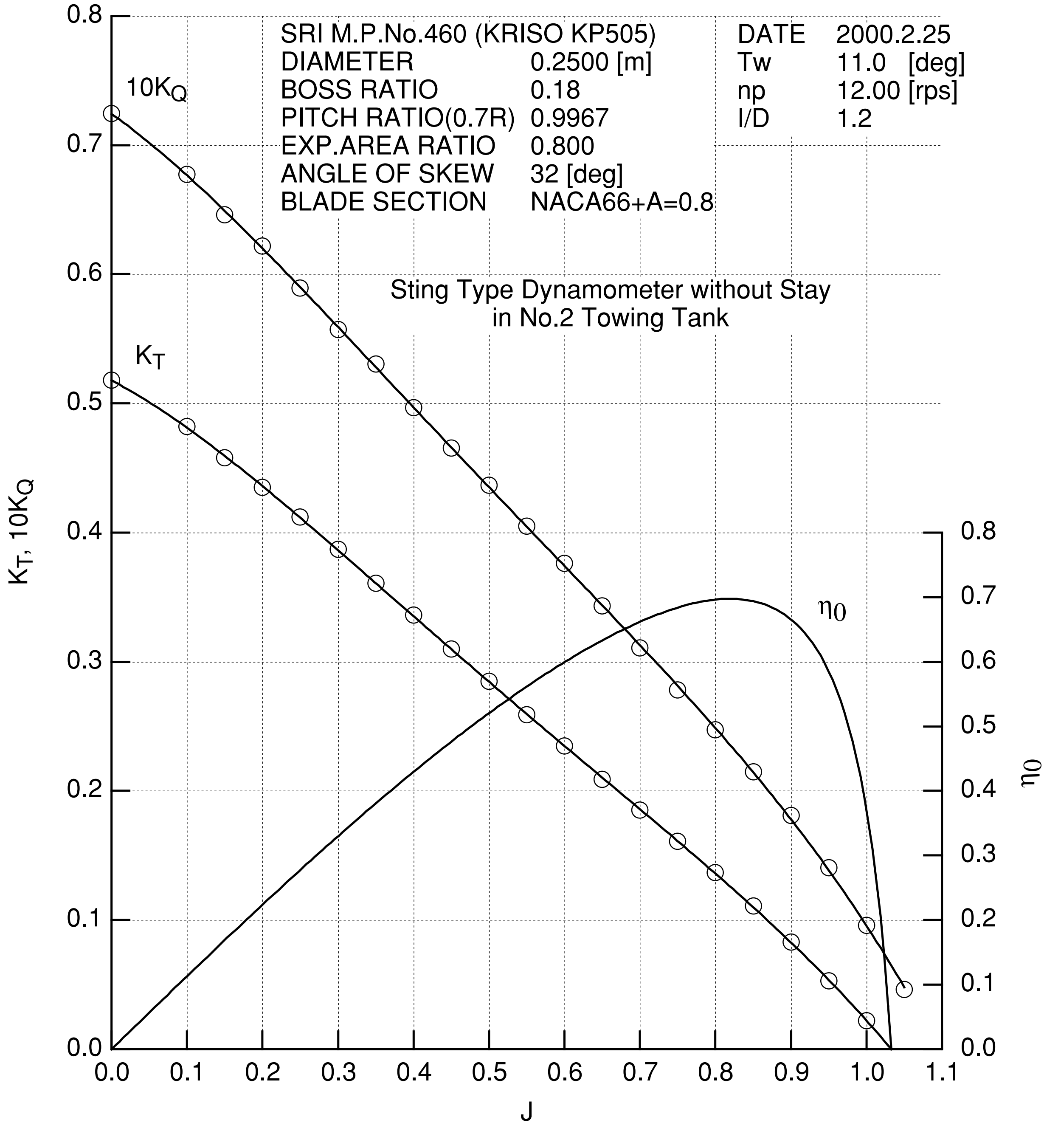

Fig. 3 Propeller Open Characteristics of Tested Propeller Model

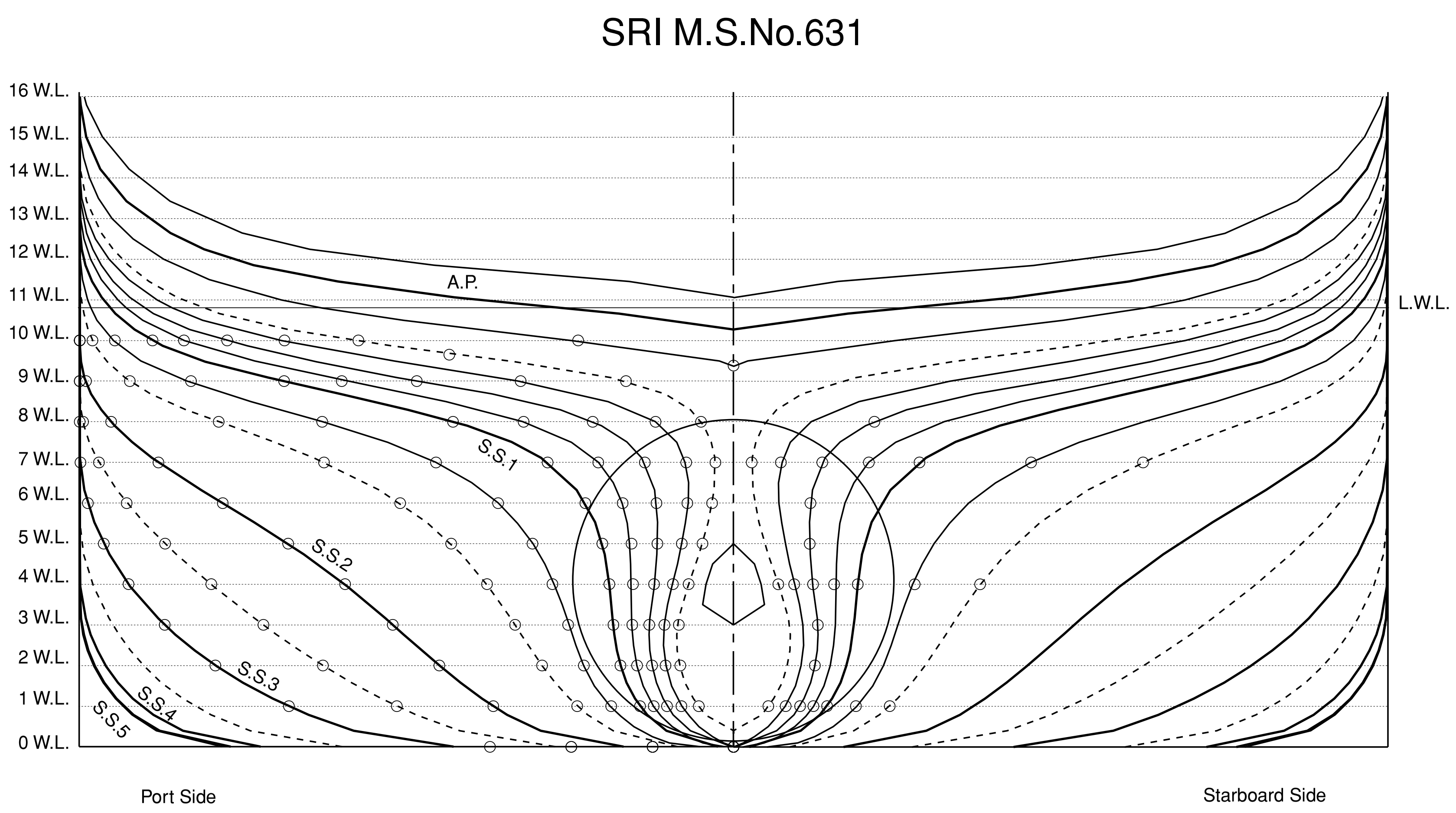

Fig. 4 Arrangement of Pressure Taps

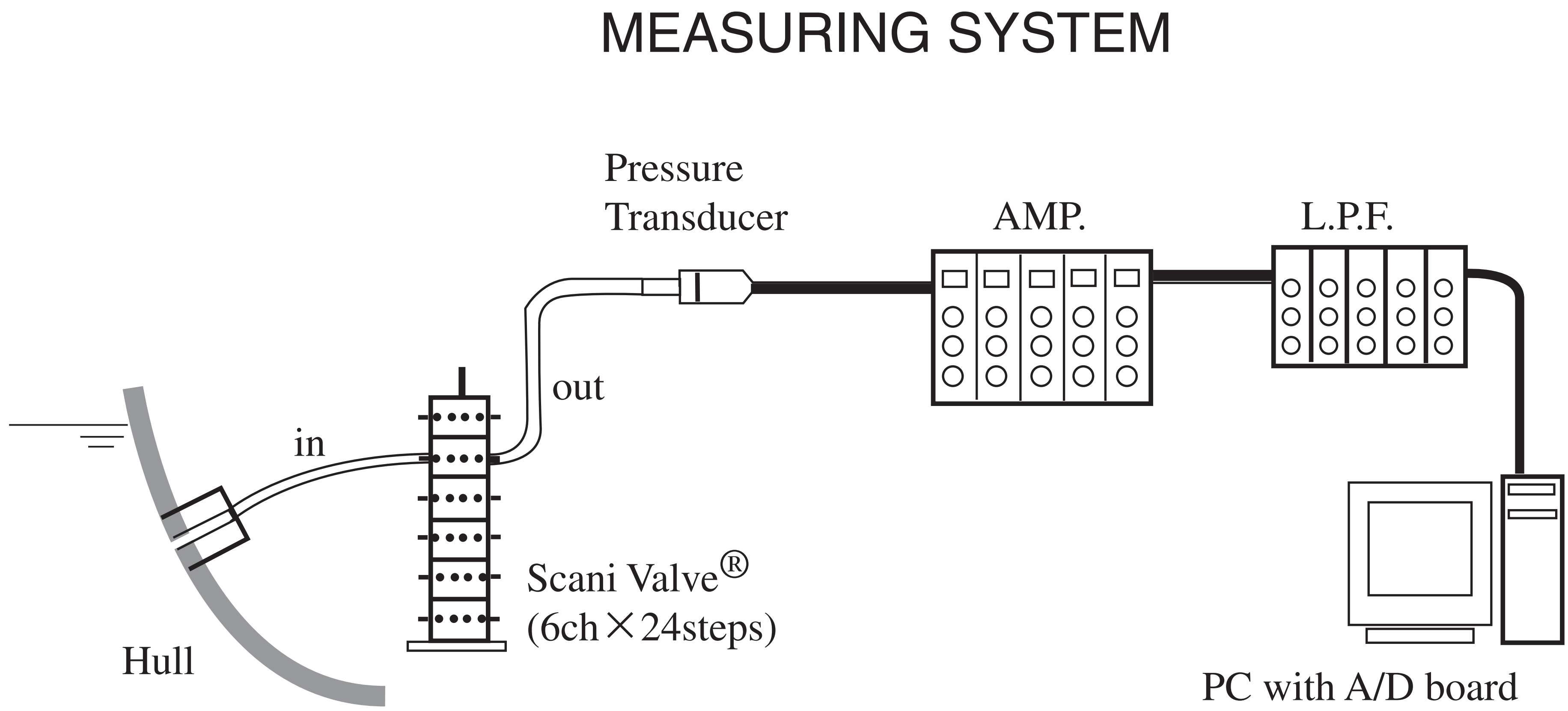

Fig. 5 Arrangement of Measuring System for Surface Pressure

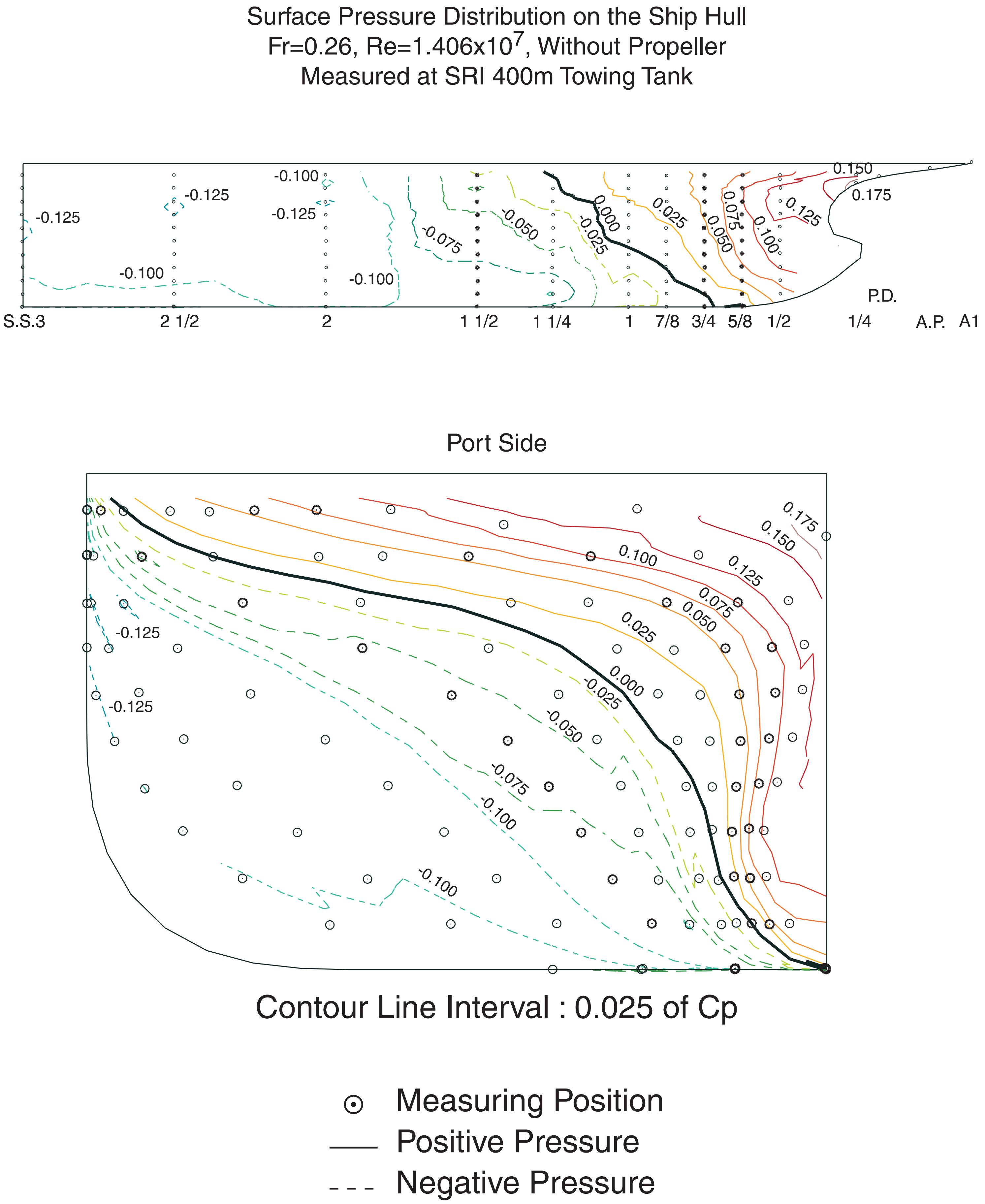

Fig. 6 Measure Results of Surface Pressure on the Hull under the without Propeller Condition

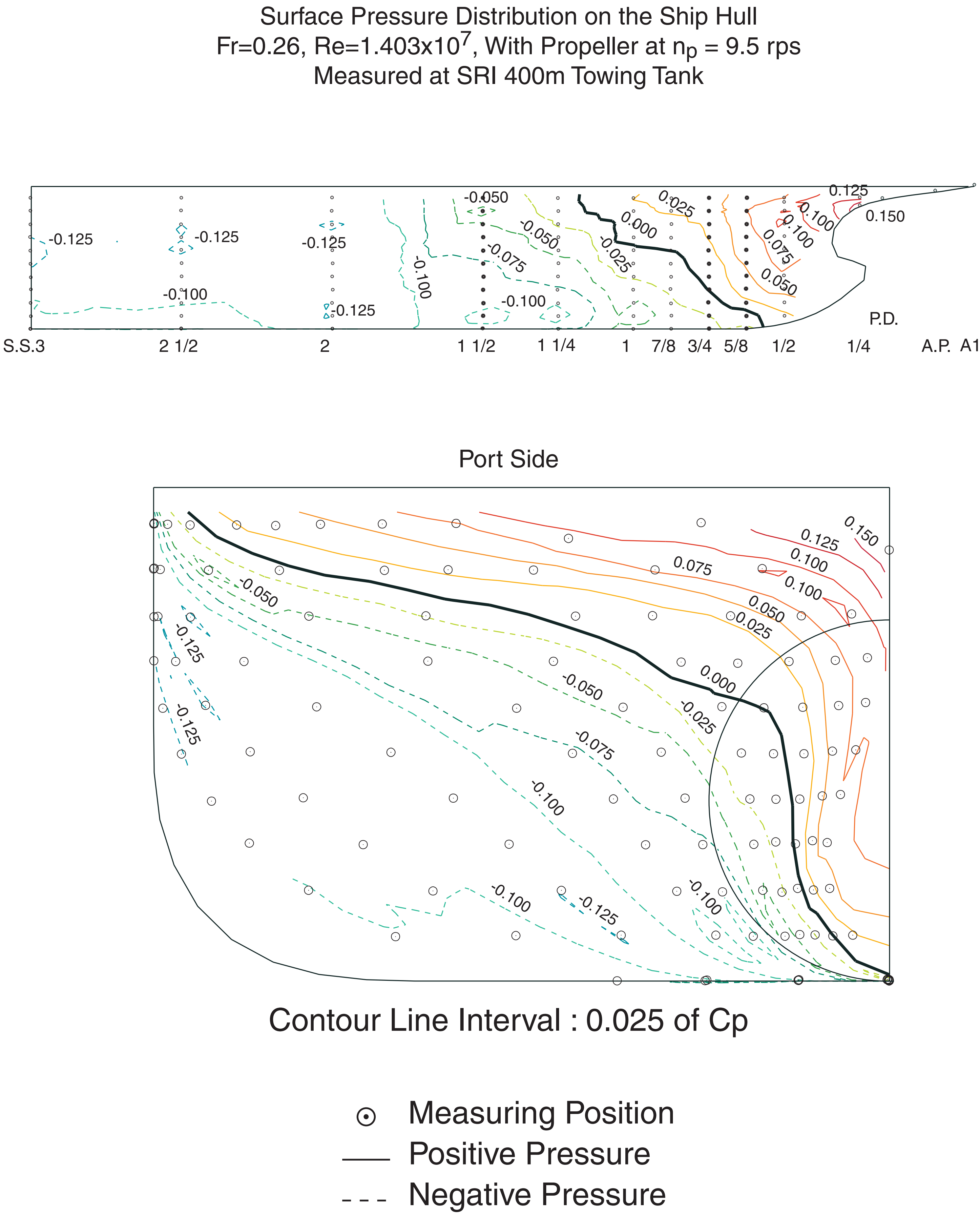

Fig. 7 Measure Results of Surface Pressure on the Hull under the Working Propeller Condition