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Research and Development Report

USS KINKAID (DD 965) Hull Fouling Standardization Trials

by
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CARDEROCKDIV/SHD-1371-01 USS KINKAID (DD 965) Hull Fouling Standardization Trials.

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Two Standardization Trials were conducted on the USS KINKAID (DD 965) in September 1991 to evaluate the effectiveness of the five year paint system currently on the ship. The trials were conducted on an instrumented tracking range off the California coast at LaJolla. Minimal marine growth was found and an average 0.9% shaft power differential between fouled and clean hull trial data supports the supposition that KINKAID's paint system is very effective. The highest measured shaft power common to both trials was 77,620 hp. The combined effect of the hull cleaning and the displacement differential was a 0.2 kn speed increase between the two trial conditions at this shaft power.

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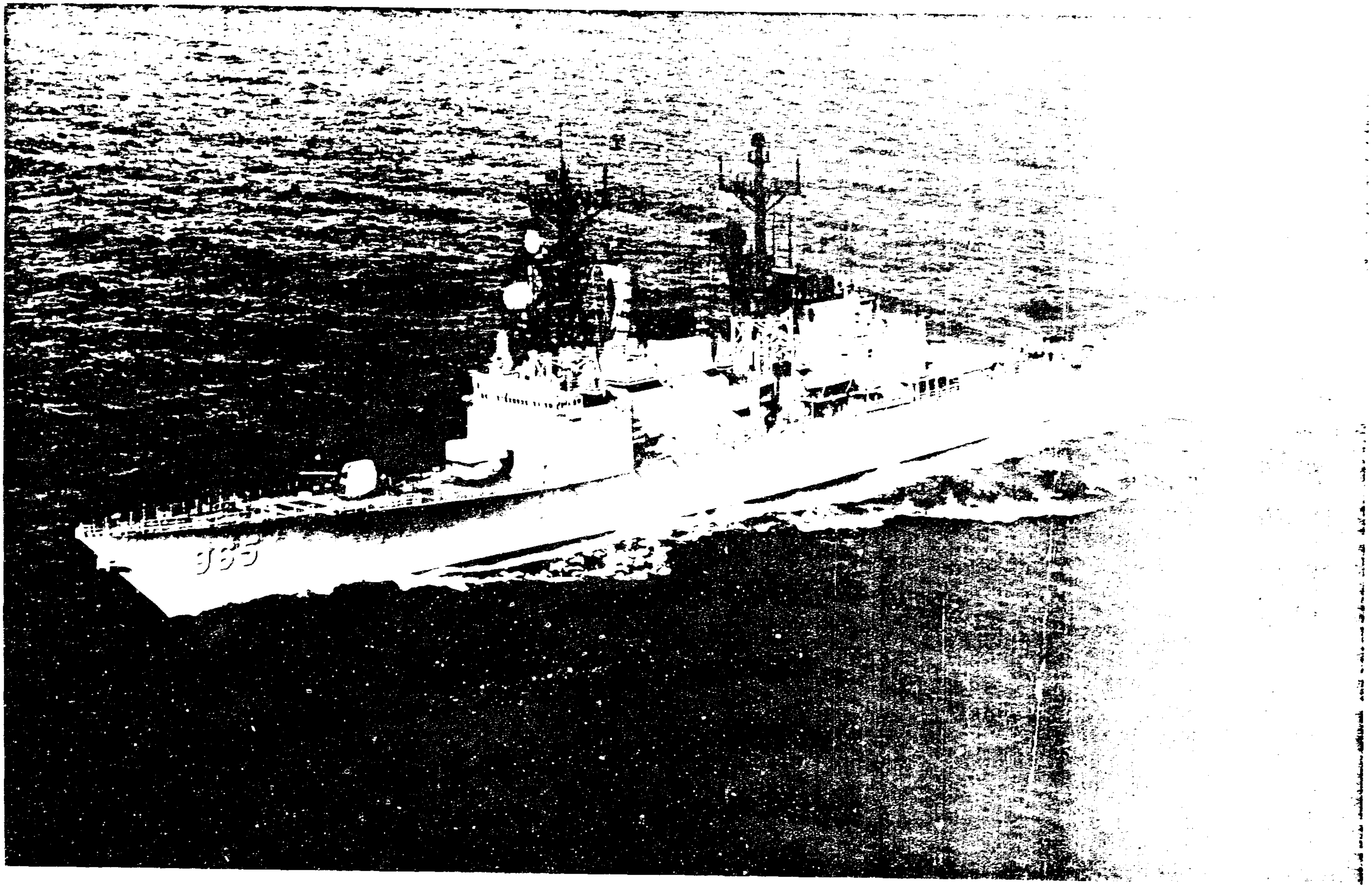

USS KINKAID (DD 965)

U.S. CUSTOMARY/METRIC UNITS

1 foot (ft)	=	0.3048 meters (m)
1 inch (in)	=	25.40 millimeters (mm)
1 knot (kn)	=	0.5144 meters per second (m/s)
1 pound-force (lbf)	=	4.448 Newtons (N)
1 pound-force-foot (lbf-ft)	=	1.35582 Newton-meters (Nm)
1 long ton (2,240 lb)	=	1.016 metric tons or 1,016 kilograms
1 horsepower (hp)	=	0.746 kilowatts (kW)
1 nautical mile (1nmi)	=	1.852 kilometers (km)
1 degree Fahrenheit (°F)	=	(°F-32)*0.5556 (°C)
1 pound-force/inch^2 (psig)	=	6894.8 pascals (Pa)

ABSTRACT

Two Standardization Trials were conducted on the USS KINKAID (DD 965) in September 1991 to evaluate the effectiveness of the five year paint system currently on the ship. The trials were conducted on an instrumented tracking range off the California coast at La Jolla. Minimal marine growth was found and an average 0.9% shaft power differential between fouled and clean hull trial data supports the supposition that KINKAID 's paint system is very effective. The highest measured shaft power common to both trials was 77,620 hp. The combined effect of the hull cleaning and the displacement differential was a 0.2 kn speed increase between the two trial conditions at this shaft power.

ADMINISTRATIVE INFORMATION

The work described herein was performed by the Carderock Division, Naval Surface Warfare Center (CDNSWC), Code 1523. This project was accomplished under CDNSWC Work Unit 1-2759-947-13. The source of funding was the Office of Naval Research, Code 12E.

INTRODUCTION

The USS KINKAID (DD 965) is the third destroyer of the USS SPRUANCE (DD 963) Class. KINKAID is powered by four LM2500 gas turbine engines capable of providing a total of 80,000 shaft horsepower to the ship's two controllable pitch (CP) propellers.

The KINKAID is one of the destroyers participating in the Navy five-year paint program. This paint scheme utilizes an anti-fouling copper ablative paint. In order to determine the effectiveness of the paint system in minimizing marine growth on ship hulls, Standardization Trials are conducted. By measuring the differences in the speed/power characteristics of a clean versus fouled hull, and documenting the hull conditions with a British Maritime Technology (BMT) hull roughness analyzer, investigators can determine the effectiveness of the paint system. Another benefit realized is an understanding of marine growth rates in different geographic locations.

The trials were conducted off the California coast at La Jolla. Two trials were conducted. The first Standardization Trial was conducted with a fouled hull and clean propellers. The KINKAID was last cleaned on March 9, 1990. The second Standardization Trial was conducted with a clean hull and clean propellers. The results of the trials are considered good and the ship's electro-magnetic (EM) speed log compared well with the range speed.

TRIAL CONDITIONS

KINKAID's paint system is designed such that the ship requires a painting or touch-up of the underwater hull and appendages with a BRA 540 anti-fouling copper ablative paint every five years. Anti-corrosion paint is applied under the anti-fouling paint. This anti-corrosion paint is supposed to be effective for ten years.

Prior to the first Standardization Trial, divers determined that the hull was covered with a light slime from the waterline to a point approximately 15 ft toward the keel. From this point to the keel the paint scheme proved to be effective and little to no slime was evident. Calcareous growth (tube worms and barnacles) was in evidence on the hull where keel blocks were in place during paint application. The propeller shafts were painted with the same paint scheme as the hull. This paint was also intact. Divers conducted a photographic survey and a BMT hull roughness survey. The propellers were then polished in preparation for the first trial.

After conducting the first Standardization Trial on 25 September 1991 at the La Jolla tracking range, the divers cleaned the hull and reinspected the propellers on 26 September 1991. The propellers did not require further polishing. BMT hull roughness measurements were taken and the hull photo documented. The second or clean hull Standardization Trial was then conducted at the same trial site on 27 September 1991. A more detailed description of the cleaning and the BMT hull roughness survey will be published in a future report by CDNSWC, Code 2841.

Principal ship and propeller characteristics are shown in Table 1. Both trials were conducted in almost ideal environmental conditions. The sea state was 1 and true wind speed varied 3.3 to 16.7 kn for the fouled hull Standardization Trial and 1.7 to 14.4 kn for the clean hull Standardization Trial. Further details of the trial conditions can be found in Table 2.

TRIAL INSTRUMENTATION AND PROCEDURES

Installation of the trial instrumentation occurred during the period 19 to 24 September 1991 at the Naval Station in San Diego, California. Temporary trial torsionmeters and shaft speed counters were installed in the Sewage Plant #2 room on the 6th deck. Data output from this location were routed to the Central Control Station (CCS) located on the second deck and relayed to the Electronic Warfare Equipment (EW) room on the 03 level. Additional ship signals were obtained in the CCS and also routed to the EW room. These signals include EM log speed, rudder angles, wind direction, wind speed, and hydraulic oil power module (HOPM) oil pressures and temperatures.

CDNSWC also installed a Motorola Falcon 484 pulse radar tracking system and a commercial Global Positioning System (GPS) to provide positional information and enable the calculation of ship speed. The Falcon 484 required the installation of a radar tracking range. The range consisted of transponders located at two surveyed shore stations and a receiver/transmitter (R/T) located on the ship's aft mast approximately 110 ft above the main deck. The Falcon continually determined and updated the ship's position in X and Y coordinates and the time between position readings. Using this information, a CDNSWC computer calculated the ship's speed over the ground using the position component that is parallel to the baseline delineated by the two surveyed stations.

The Global Positioning System (GPS) utilized satellite ranging to determine ship's position. The satellites are used as reference points for triangulating the position of the ship. GPS required the availability of at least three satellites in a geometric configuration such that the Precision Dilution of Position (PDOP), a multiplicative factor that modifies ranging error, is minimized. GPS was operated in the Autonomous mode. In this mode, a single GPS receiver onboard the ship ranged the satellites to calculate position by determining the distance from the ship to the satellites. A limiting factor in operating a commercial GPS receiver in Autonomous mode is Selective Availability (S/A). S/A is an operating mode used by the Department of Defense (DoD) to degrade the accuracy of the satellite system. Only when S/A is off can the calculated position be used to determine speed over the ground to the specified accuracy. GPS continually determined and updated the ship's position in latitude and longitude and the time between position readings. This information is converted by a CDNSWC computer into X and Y coordinates. The ship's speed over the ground is calculated in the same manner as the Falcon 484 system. The calculated GPS and Falcon 484 speeds are considered range speeds.

All of the data were monitored and recorded on a Hewlett-Packard Series 9000, Model 300 computer. An instrumentation block diagram is shown in Figure 1 and a list of measurement uncertainties can be found in Table 3.

The Standardization Trials were conducted in accordance with Chapter 094 of the Naval Ship's Technical Manual. Data were obtained for speeds corresponding to 70 r/min up to full power (168 r/min). Two to three runs, alternating in direction and of three minute duration, were made at each speed. An average was applied to take into account the effects of current. For a three pass spot, the odd direction run was doubled and the four spots were then averaged.

Both trials were conducted with the propulsion system in the Manual Control Mode. The propeller pitch was adjusted to an "up against the stops" propeller pitch condition which is 110% of design. CDNSWC monitored the hydraulic oil pressure readings at the Hydraulic Oil Power Module (HOPM). The "up against the stops" or 110% propeller pitch condition is defined as the point where the hydraulic oil pressure spikes as pressure is increased. At this point, the ship was asked to back the pitch off the stops to the point right before the pressure spike. The shaft r/mins and torques were then balanced and steady state run data was taken along a base course parallel to the baseline formed by the two shore stations. The water current averaged 0.2 kn and very little current gradient was observed.

Prior to and after each of the Standardization Trials, draft readings were taken at the pier. The displacements for the fouled and clean hull Standardization trials were 8820 LT and 8580 LT, respectively. Drag shaft tests were conducted on the morning of each of the Standardization Trials so that the residual torque in the propeller shaft could be accounted for.

PRESENTATION AND DISCUSSION OF TRIAL RESULTS

Data obtained during these trials are considered good and representative of the KINKAID in the trial conditions tested. Both trials were conducted at a nominal propeller pitch of 110%.

The fouled hull Standardization Trial was conducted at a displacement of 8820 LT. The KINKAID reached a maximum ship speed of 31.65 kn as measured by GPS. Other ship measurements at this speed were:

Average shaft r/min	=	165.5 r/min
Total shaft torque	=	2,463,700 lbf-ft
Total shaft power	=	77,620 hp

After the ship was cleaned, the clean hull Standardization Trial was conducted. The displacement was 8580 LT. The maximum ship speed as derived by the GPS was 32.0 kn. This was achieved at the following ship conditions:

Average shaft r/min	=	167.8 r/min
Total shaft torque	=	2,493,900 lbf-ft
Total shaft power	=	79,690 hp

From the trials data, it is apparent that a shaft power imbalance exists in several runs. In these instances, it is suspected that the propeller pitches were not the same. This would account for the power imbalance.

The difference in displacement between the two Standardization Trials was 240 LT or 2.7%. Over the speed range, KINKAID required an average 2.8% less shaft torque and 3.6% less shaft power to achieve a given speed after the hull was cleaned. These values do not differentiate between the changes in powering characteristics caused by the difference in displacement and the hull cleaning. In order to isolate the effect of hull cleaning on shaft power, it was necessary to eliminate the effect due to the displacement differential. The following procedure was utilized:

$$(1)\quad \frac{\text{Total SHP}_{\text{fouled hull}} - \text{Total SHP}_{\text{clean hull}}}{\text{Total SHP}_{\text{fouled hull}}} = \text{Total Shaft Power Difference}$$

$$(2)\quad \frac{\dfrac{\text{Total SHP}}{\text{Displacement}_{\text{fouled hull}}} - \dfrac{\text{Total SHP}}{\text{Displacement}_{\text{clean hull}}}}{\dfrac{\text{Total SHP}}{\text{Displacement}_{\text{fouled hull}}}} = \text{Change in Shaft Power due to Hull Cleaning}$$

$$(3)\quad \text{Equation (1)} - \text{Equation (2)} = \text{Change in Shaft Power due to Displacement Differential}$$

When the shaft power was normalized using the SHP/ton procedure outlined above, an average 0.9% difference in shaft power was realized after the hull was cleaned. An average 2.7% difference in shaft power resulted due to the displacement differential. As noted in the trials condition section of this report, negligible marine growth was evident on the hull which suggests that the paint system was very effective. The small average 0.9% shaft power differential between the two sets of trials data, gives credence to this supposition.

Comparison of speed/power measurements indicate that 2.1% less shaft torque and 3.5% less shaft power were required to attain 31.65 kn after the hull was cleaned. It should be noted that these values include the effects of the hull cleaning and displacement differential variables but do not quantify the individual variable's effect on shaft power.

At the shaft power common to both trials of 77,620 hp, an increase of 0.2 kn was realized with a clean hull. This value not only reflects the results of the hull cleaning, but includes the effects of displacement differential. These trial results are tabulated in Tables 4, 5, 6 and 7 and are graphically displayed in Fig. 2.

As mentioned previously, ship speed was derived by three separate means. The Falcon 484 pulse radar tracking system and the GPS speeds never varied by more than 0.20 kn. The majority of the speed comparisons were within hundredths of a knot. The Falcon tracking system was inoperative during part of the clean hull Standardization Trial. This was due to transmissions by other ships on the tracking system's frequencies. The Falcon 484 assumed these transmissions were legitimate responses from the shore transponders. Hence, the data obtained was spurious. Therefore, in order for a meaningful trial comparison to be made, GPS range speeds are used for Fig. 2. A comparison of the Falcon and GPS range speeds can be found in Fig. 3. The third speed measurement comes from the ship's EM speed log. Figure 4 is a comparison of GPS range speed and EM log speed and indicates that the ship's EM log is in calibration over most of the speed range and is approximately 0.4 kn low at the top speed.

CONCLUSIONS

The results of the two Standardization Trials on KINKAID are considered to be good and the data applicable to the ship in the conditions tested. The following conclusions can be drawn from these trials:

1. The paint system is very effective. The 0.9% shaft power differential between the fouled and clean hull trials data indicated minimal marine growth approximately one and a half years after the latest paint application. The diver inspection and hull survey verified this fact.

2. The effect of cleaning the hull resulted in KINKAID requiring an average of 0.9% less shaft power to attain a given speed.

3. When comparing fouled and clean hull speed/power data at the highest measured speed common to both trials, the ship required 2.1% less shaft torque and 3.5% less shaft power to reach this maximum speed of 31.65 kn. These values represent the combined effect of the hull cleaning and the displacement differential.

4. The highest measured shaft power common to both trials was 77,620 hp. The combined effect of the hull cleaning and the displacement differential was a 0.2 kn speed increase between the two trial conditions at this shaft power.

RECOMMENDATIONS

Difficulties in utilizing the Motorola Falcon 484 to develop ship speed were encountered in the San Diego/La Jolla operations area. Even though all KINKAID's communications and radar operations in the Falcon's operating frequencies were curtailed, the Falcon became inoperable due to outside sources of frequency interference. Three other ships were operating the SPS 67 radar. This put the trials in jeopardy since the Falcon tracking system accepted these transmissions as legitimate responses from the shore transponders. The tracking data were intermittently available and dependent on the other ships operations. In the past, operational interference was caused by multiple users of the Falcon. In this situation, increased transmissions by other ships caused the problem. The use of the Falcon 484 pulse radar tracking system in the San Diego/La Jolla area has become undesirable. The Falcon 484 system is still adequate as a secondary system. GPS, operating in the autonomous mode, proved to be more reliable for tracking in the San Diego/La Jolla area and should be used as the primary means of tracking test vehicles for the purposes of developing speed and maneuvering characteristics. However, the accuracy of the commercial GPS receiver is limited by DoD's deliberate degradation of positional information via S/A. To eliminate this operating constraint, it is recommended that a military P-code GPS unit, which is unaffected by S/A, be utilized.

ACKNOWLEDGMENTS

The authors would like to thank the officers and crew of the USS KINKAID for their interest, flexibility, and support provided during the trials period. The cooperation provided by CDR MacKinnon and the ship's engineering department was vital to the success of these trials and is greatly appreciated.

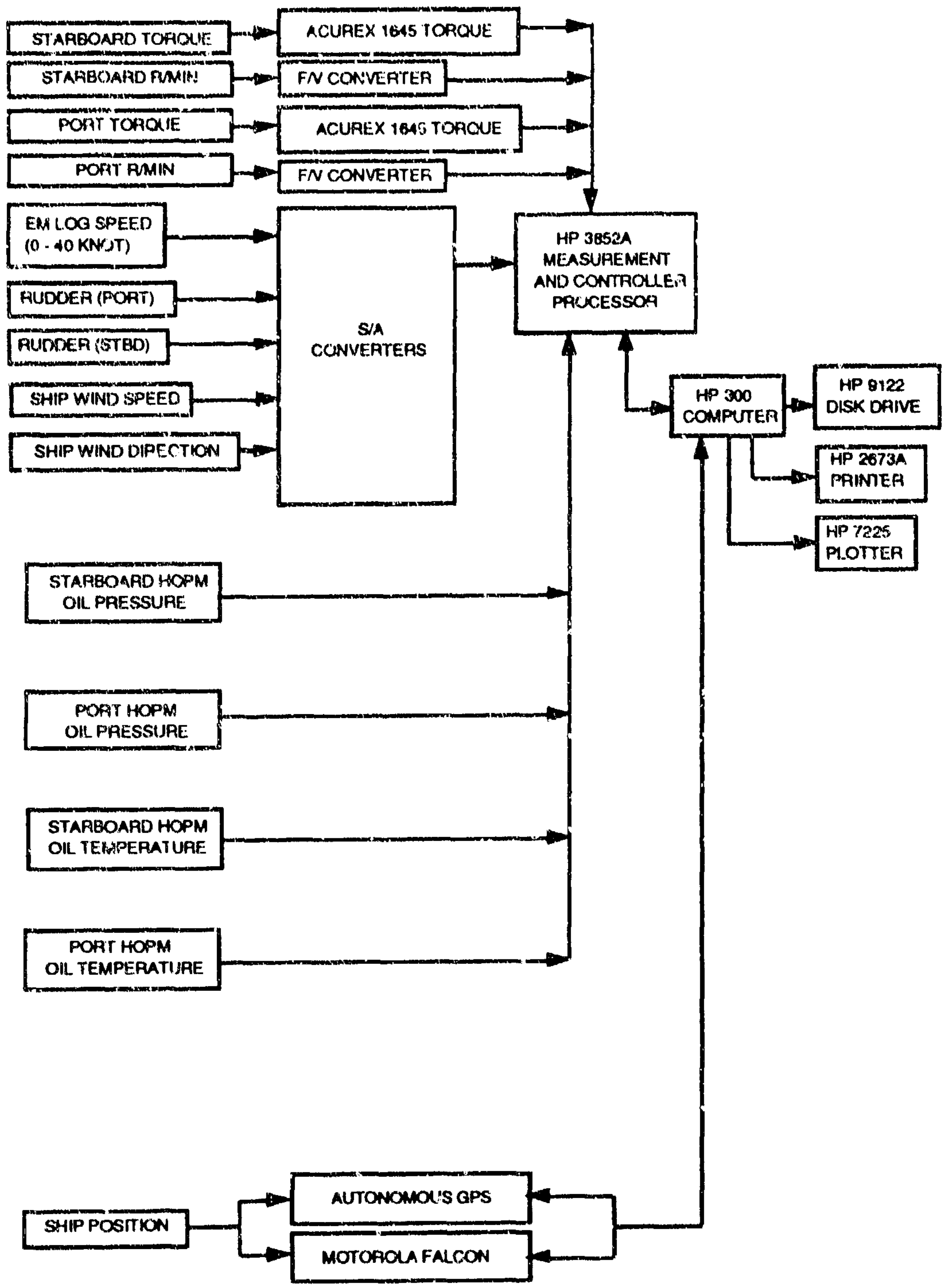

Fig. 1. USS KINKAID (DD 965) trials instrumentation diagram.

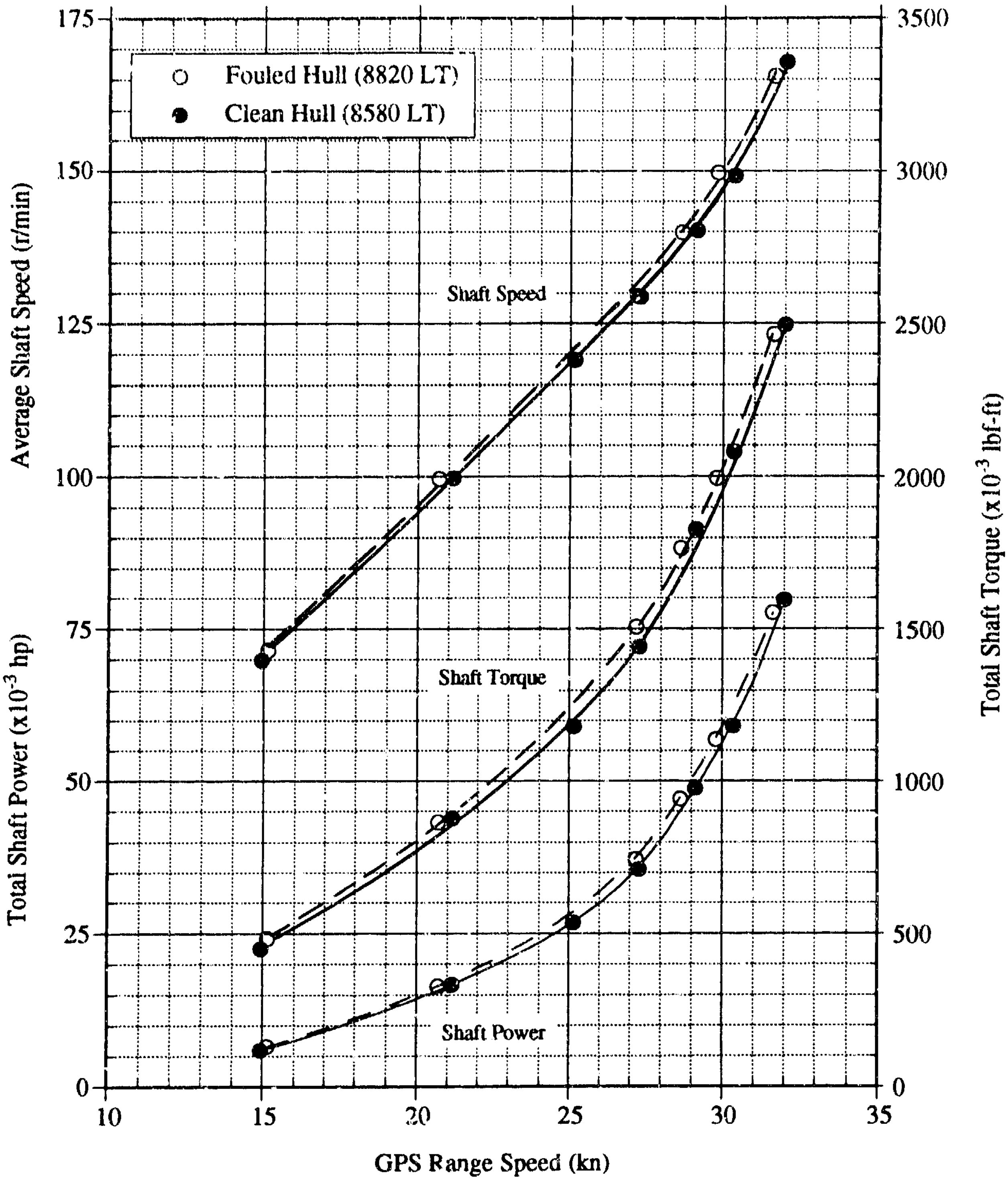

Fig. 2. USS KINKAID (DD 965) Standardization Trial results.

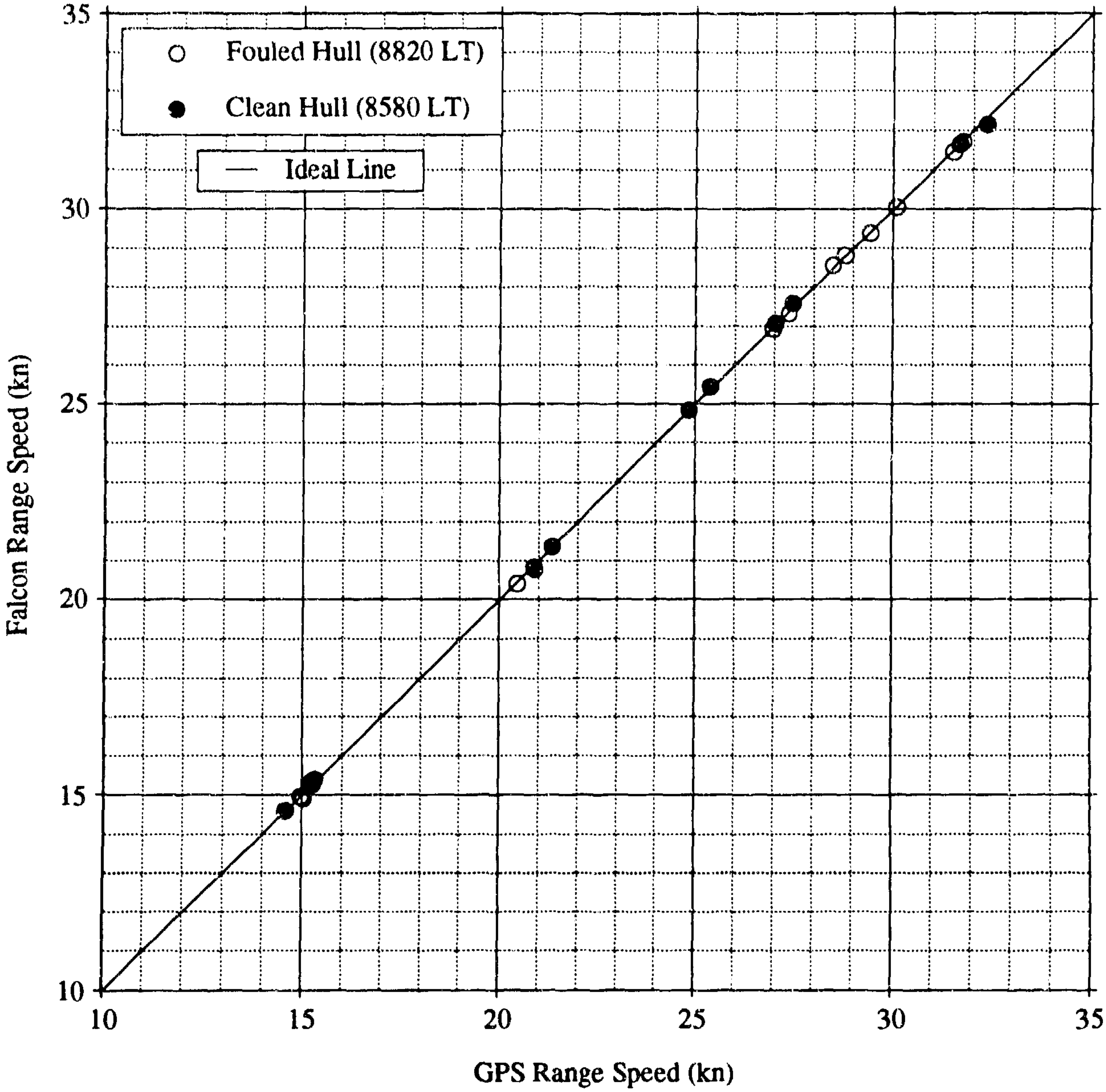

Fig. 3. USS KINKAID (DD 965) Motorola Falcon 484 range speed versus Global Positioning System (GPS) range speed.

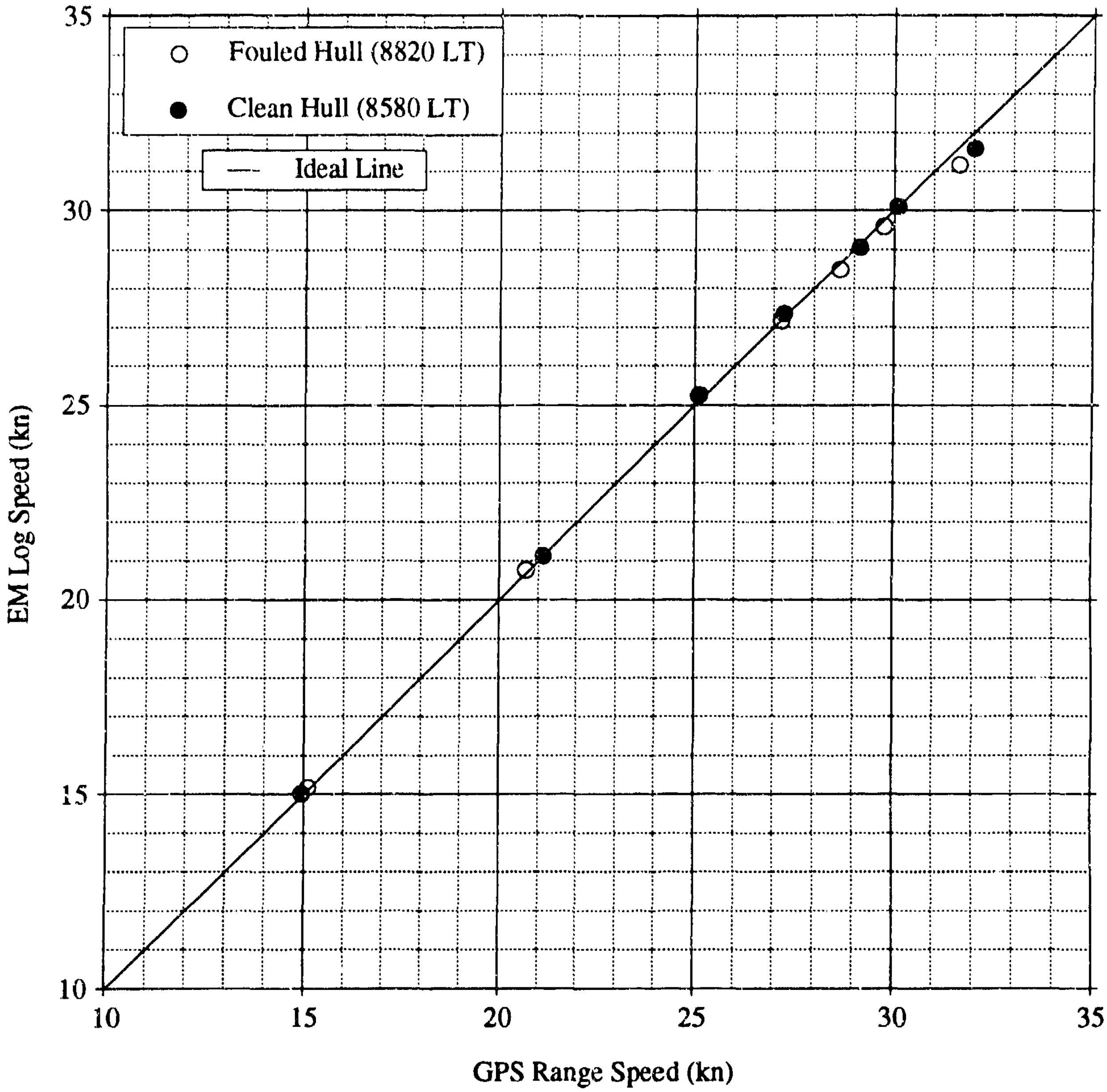

Fig. 4. USS KINKAID (DD 965) EM log speed versus Global Positioning System (GPS) range speed.

Table 1. USS KINKAID (DD 965) principal ship and propeller characteristics.

Ship Characteristics	
Length overall (LOA)	563.1 ft
Length between perpendiculars (LBP)	528.8 ft
Beam, maximum at DWL	55.1 ft
Number of rudders	2
Projected rudder area (per rudder)	162.6 ft^2
Propeller Characteristics	
Number of propellers	2
Serial number (port)	10838
Serial number (starboard)	10837
Type of propeller	CP
Number of blades	5
Propeller diameter	17.0 ft
Propeller pitch at 0.7 radius	26.2 ft
Pitch ratio at 0.7 radius	1.54
Expanded area	165.70 ft^2
Disc area	226.98 ft^2
Projected area	134.1 ft^2
Material	Ni-AL-Bz
Manufacturer	Bird-Johnson Co.
Bird-Johnson drawing number	115651002

Table 2. USS KINKAID (DD 965) trial conditions.

Fouled Hull Standardization Trial

Trial date	25 September 1991
Displacement	8820 LT
Ship trim	0.04 ft up by the bow
Sea state	1
Air temperature	69°F
Water temperature	71°F
Water specific gravity	1.026
True wind speed (varied)	3.3 kn to 16.7 kn
True wind direction (varied)	ranges from 254 deg thru 125 deg
Days out of dock	565 days

Clean Hull Standardization Trial

Trial date	27 September 1991
Displacement	8580 LT
Ship trim	0.42 ft up by the bow
Sea state	1
Air temperature	72°F
Water temperature	70°F
Water specific gravity	1.026
True wind speed (varied)	1.7 kn to 14.4 kn
True wind direction (varied)	ranges from 278 deg thru 031 deg
Days out of dock	567 days

Table 3. USS KINKAID (DD 965) measurement uncertainties.

Measurement	Source	Calibration Source	Units	Resolution [1]	Bias Limit [3]	Precision Limit	Uncertainty
Shaft Speed (Port) Shaft Speed (Stbd)	Infrared Light Sensor	Electronic Oscillator	r/min	0.1	± 0.4	± 2.2 ± 1.8	± 2.3 ± 1.8
Shaft Torque (Port) Shaft Torque (Stbd)	Deflection Sensor	Deflection Calibration Stand	lbf-ft	0.01% FS [2]	± 1,742	± 23,433 ± 13,971	± 23,507 ± 14,079
Shaft Power (Port) Shaft Power (Stbd)	Mathematical Calculation	- -	hp	-	± 108.7	± 920.1 ± 612.5	± 962.5 ± 622.1
Rudder Angle (Port) Rudder Angle (Stbd)	Synchro Transmitter	Rudder Quadrant	deg	0.1	± 0.5	± 0.9 ± 1.8	± 1.1 ± 1.9
Hydraulic Oil Pres. (Port) Hydraulic Oil Pres. (Stbd)	Pressure Transducer	Pressure Calibration Stand	psig	0.1	± 2.5	± 28.0 ± 39.6	± 28.1 ± 39.7
Hydraulic Oil Temp. (Port) Hydraulic Oil Temp. (Stbd)	Strap-on Temperature Sensor	- -	°F	0.1	± 5.0	0.2 0.2	± 5.0 ± 5.0
Ship Wind Direction	Anemometer	Ship	deg	0.1	± 5.0	± 6.5	± 6.5
Ship Wind Speed	Anemometer	Ship	kn	0.1	± 0.5	± 1.1	± 1.2
Steady EM Log Speed	Synchro Transmitter	Standardization Trials	kn	0.1	± 0.4	± 0.6	± 0.7
Steady Ship Speed	Falcon 484 Pulse Radar	Surveyed Baseline	kn	0.01	± 0.1	± 0.8	± 0.8
Steady Ship Speed	Autonomous GPS	-	kn	0.01	± 0.1	± 0.2	± 0.2

1. Resolution - least detectable change in measurement
2. FS - Full Scale
3. Bias Limit - Based on "Uncertainty Analysis of Standardization Trials on a U.S. Navy Fleet Oiler. Erik H. Johnson

Table 4. USS KINKAID (DD 965) fouled hull Standardization Trial results.

Run No.	Falcon Range Speed (kn)	GPS Range Speed (kn)	EM Log Speed (kn)	Shaft Speed (r/min)			Shaft Torque (1000 lbf-ft)			Shaft Power (hp)			True Wind Speed (kn)	True Wind Dir. (deg)
				Stbd	Port	Average	Stbd	Port	Total	Stbd	Port	Total		
1000N	15.00	15.00	15.2	71.7	71.8	71.8	253.4	238.7	492.1	3460	3260	6720	11.2	274
1010S	15.35	15.25	15.2	70.5	72.2	71.4	232.3	244.7	477.0	3120	3360	6480	7.6	299
1020N	14.90	15.00	15.2	70.5	72.2	71.4	241.1	248.4	489.5	3240	3420	6660	13.1	254
Average	15.15	15.15	15.2			71.5			483.9			6590		
1060S	20.85	20.90	20.7	98.7	100.4	99.6	426.4	428.5	854.9	8010	8190	16200	4.1	64
1070N	20.40	20.45	20.9	98.7	100.5	99.6	433.1	442.0	875.1	8140	8460	16600	4.9	328
Average	20.65	20.70	20.8			99.6			865.0			16400		
1120N	26.90	27.00	27.2	129.1	130.0	129.6	762.0	750.3	1512.3	18730	18570	37300	16.4	279
1130S	27.30	27.40	27.1	129.0	130.0	129.5	751.6	749.9	1501.5	18450	18560	37010	5.9	125
Average	27.10	27.20	27.2			129.5			1506.9			37160		
1150N	28.55	28.50	28.6	139.3	140.9	140.1	890.9	880.9	1771.8	23630	23630	47260	16.7	288
1160S	28.80	28.80	28.4	139.3	140.6	140.0	880.4	879.3	1759.7	23350	23540	46890	4.6	310
Average	28.70	28.65	28.5			140.0			1765.8			47080		
1180S	30.05	30.10	29.6	149.4	149.8	149.6	1032.5	1007.4	2039.9	29370	28730	58100	3.3	358
1190N	29.40	29.50	29.6	149.5	149.9	149.7	1003.3	943.8	1947.1	28560	26940	55500	6.9	317
Average	29.75	29.80	29.6			149.7			1993.5			56800		
1220N	31.45	31.50	31.3	164.9	166.0	165.5	1271.1	1195.9	2467.0	39910	37800	77710	6.4	302
1230S	31.70	31.75	31.0	165.1	165.9	165.5	1270.8	1189.6	2460.4	39950	37580	77530	5.7	83
Average	31.60	31.65	31.2			165.5			2463.7			77620		

Table 5. USS KINKAID (DD 965) clean hull Standardization Trial results.

Run No.	Falcon Range Speed (kn)	GPS Range Speed (kn)	EM Log Speed (kn)	Shaft Speed (r/min) Stbd	Shaft Speed (r/min) Port	Shaft Speed (r/min) Average	Shaft Torque (1000 lbf-ft) Stbd	Shaft Torque (1000 lbf-ft) Port	Shaft Torque (1000 lbf-ft) Total	Shaft Power (hp) Stbd	Shaft Power (hp) Port	Shaft Power (hp) Total	True Wind Speed (kn)	True Wind Dir. (deg)
2000S	15.40	15.30	15.0	69.1	70.5	69.8	222.5	223.1	445.6	2930	3000	5930	11.0	314
2010N	14.60	14.60	15.0	69.1	70.5	69.8	230.6	223.9	454.5	3030	3010	6040	6.1	314
2020S	15.30	15.25	15.0	69.1	70.5	69.8	224.3	221.1	445.4	2950	2970	5920	11.1	316
Average	15.00	14.95	15.0			69.8			450.0			5980		
2060S	21.35	21.35	21.1	99.2	100.2	99.7	430.7	444.1	874.8	8140	8470	16610	13.9	284
2070N	20.80	20.90	21.2	99.1	100.3	99.7	432.6	444.6	877.2	8160	8490	16650	3.3	287
Average	21.10	21.15	21.1			99.7			876.0			16630		
2091S	25.45	25.40	25.2	118.3	119.6	119.0	582.0	593.4	1175.4	13110	13510	26620	11.4	278
2100N	24.85	24.85	25.3	118.4	119.7	119.1	584.3	601.3	1185.6	13170	13700	26870	3.3	280
Average	25.15	25.15	25.3			119.0			1180.5			26750		
2120N	27.05	27.05	27.5	128.9	129.7	129.3	714.6	729.7	1444.3	17540	18020	35560	4.1	342
2130S	27.60	27.50	27.3	128.9	129.8	129.4	705.8	731.4	1437.2	17320	18080	35400	14.2	296
Average	27.35	27.30	27.4			129.3			1440.8			35480		
2150S	-	29.40	29.1	139.8	140.6	140.2	936.2	902.3	1838.5	24920	24160	49080	14.4	285
2160N	-	28.95	29.1	139.9	140.5	140.2	929.6	894.5	1824.1	24760	23930	48690	1.7	31
2170S	-	29.35	29.0	139.8	140.6	140.2	924.8	894.2	1819.0	24620	23940	48560	12.6	286
Average	-	29.15	29.1			140.2			1826.4			48760		
2180S	-	30.35	30.0	148.0	149.8	148.9	1045.4	1036.7	2082.1	29460	29570	59030	13.2	295
2190N	-	30.30	30.2	149.1	149.7	149.4	1061.1	1015.8	2076.9	30120	28950	59070	3.1	0
Average	-	30.35	30.1			149.2			2079.5			59050		
2220S	32.15	32.35	31.5	167.0	168.0	167.5	1246.1	1245.3	2491.4	39620	39830	79450	13.5	288
2230N	31.65	31.65	31.6	168.3	168.0	168.2	1276.0	1220.4	2496.4	40890	39040	79930	2.0	3
Average	31.90	32.00	31.6			167.8			2493.9			79690		

Table 6. USS KINKAID (DD 965) comparison of shaft torque results.

GPS Range Speed (kn)	Total Shaft Torque Clean Hull [1] (lbf-ft)	Total Shaft Torque Fouled Hull (lbf-ft)	Total Shaft Torque Difference (%)
15.15	473,000	483,900	2.3%
20.70	836,000	865,000	3.4%
27.20	1,463,000	1,506,900	2.9%
28.65	1,701,000	1,765,800	3.7%
29.80	1,940,000	1,993,500	2.7%
31.65	2,412,000	2,463,700	2.1%
Average			2.8%

1. Interpolated values from Standardization curves (Figure 2.)

Table 7. USS KINKAID (DD 965) comparison of shaft power results.

GPS Range Speed (kn)	Total Shaft Power Clean Hull [1] (hp)	Total Shaft Power Fouled Hull (hp)	Total Shaft Power Difference (%)	Total SHP/ton Clean Hull [2] (shp/ton)	Total SHP/ton Fouled Hull [3] (shp/ton)	Hull Cleaning Effect on Shaft Power [4] (%)	Displacement Effect on Shaft Power [5] (%)
15.15	6,400	6,590	2.9%	0.7459	0.7472	0.2%	2.7%
20.70	15,900	16,400	3.0%	1.8531	1.8594	0.3%	2.7%
27.20	35,600	37,160	4.2%	4.1492	4.2132	1.5%	2.7%
28.65	45,200	47,080	4.0%	5.2681	5.3379	1.3%	2.7%
29.80	54,700	56,800	3.7%	6.3753	6.4399	1.0%	2.7%
31.65	74,900	77,620	3.5%	8.7296	8.8005	0.8%	2.7%
Average			3.6%			0.9%	2.7%

1. Interpolated values from Standardization curves (Figure 2.)
2. Displacement at clean hull condition = 8580 LT
3. Displacement at fouled hull condition = 8820 LT
4. Hull Cleaning Effect on Shaft Power = [(shp/ton (fouled hull) - shp/ton (clean hull)]/[shp/ton (fouled hull)]
5. Displacement Effect on Shaft Power = (Total Shaft Power Difference - Hull Cleaning Effect on Shaft Power)

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