An update on SES design techniques and their application to repowering the USCG WSES and the USN SES-200

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RÉSUMÉ

La garde côtière et la marine militaire des États-Unis exploitent actuellement des appareils à effet de sol (surface effect ships, SES). La première possède trois WSES basés à Key West et exploités dans le détroit de Floride. Quant à la marine militaire, son SES-200 exploité par le Surface Effect Ship Support Office (SESSO) basé à Patuxent River dans le Maryland, revient d'Europe où il a participé à des manoeuvres opérationnelles dans le cadre du programme d'essais en collaboration avec les forces de l'OTAN. Tant les WSES que le SES-200 ont largement démontré les hautes performances et l'excellente tenue de mer qui caractérisent généralement les aéroglisseurs marins.

Toutefois, les missions devant être confiées à ces navires exigent des vitesses supérieures à celles qui les caractérisent présentement, et plus proches de celles du LCAC, engin de débarquement actuellement mis en service par l'U.S. Navy. Donc, pour atteindre ces vitesses, tant les WSES que le SES-200 devront être équipés de moteurs beaucoup plus puissants leur permettant d'élargir les rôles qui pourront leur être attribués.

Grâce à des techniques améliorées de conception et de prévision des performances, fruit d'un nombre incalculable d'expérimentations en bassin de carènes, il est maintenant possible de calculer avec précision les puissances motrices qui devront être mises en oeuvre en fonction des résistances, et de déterminer le relèvement des vitesses et des aptitudes fonctionnelles qui pourra être obtenu par tranche de puissance installée accrue. Diverses configurations des WSES et SES-200 sont présentées, équipées de différents ensembles de propulsion et groupes auxiliaires.

AN UPDATE OF SES DESIGN TECHNIQUES AND THEIR APPLICATION TO REPOWERING THE USCG WSES AND THE USN SES-200

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ABSTRACT

The U.S. Coast Guard and the U.S. Navy are presently operating surface effect ships (SESs). The Coast Guard has three WSES craft stationed in Key West that operate in the Florida Straits. The Navy's SES-200 stationed at the Surface Effect Ship Support Office (SESSO) in Patuxent River, Maryland, has recently returned from operational deployment in Europe as part of a NATO cooperative trials program. The WSES and the SES-200 offer operational evidence of the benefits of high speed and excellent seakeeping that are characteristics of air cushion supported vehicles.

Future mission scenarios may require speed capabilities greater than those of the WSES and the SES-200 and nearer to the speed capability of the presently operational U.S. Navy LCAC. For the WSES and the SES-200 to achieve these speeds and explore future mission capabilities, higher power levels must be installed in the existing craft.

Improvements in performance predictions and design techniques resulting from a myriad of towing tank experiments allow accurate calculations of resistance and powering for the WSES and the SES-200 that show the changes in speed and operating envelope for increased installed power levels. Various feasible engine, gearbox, propulsor, and auxiliary equipment options are presented for possible installation in the WSES and the SES-200.

INTRODUCTION

The surface effect ship (SES) effort in the U.S. Navy has oscillated during the past 20 years from design of experimental development craft to the detail design of an ocean-going combatant, and is again undergoing towing tank experiments and individual ship design studies. The transition from a developmental craft to an operational SES combatant has been a difficult process. Full-scale operational craft (the BH-110, the U.S. Coast Guard WSES, and the U.S. Navy

SES-200 - a reconfigured BH-110) are providing further investigation of combatant performance and mission capabilities for existing and future U.S. Navy SES mission requirements. The significant progress made over the past few years in SES performance and design has ensured the continued use of SES craft beyond the BH-110, the WSES, and the SES-200.

SES BACKGROUND AND UPDATE

A significant number of SESs have been constructed in the United States since the early 1960's. The XR-1, XR-3, XR-5, and the SES-100A and SES-100B were developmental craft (Figs. 1-5). These craft were of aluminum construction, with numerous seal configurations, and high and low cushion length-to-beam ratios. The various propulsion systems included conventional outboard motors, gas turbine engines, fully submerged propellers, waterjet propulsion, and semi-submerged supercavitating propellers.

Fig. 1. XR-1

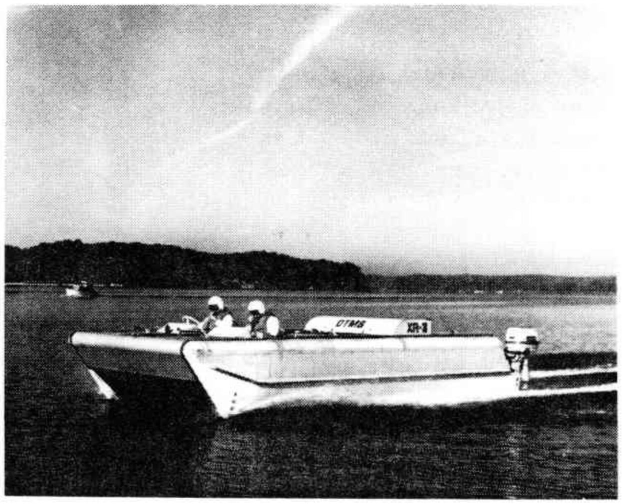


Fig. 2. XR-3

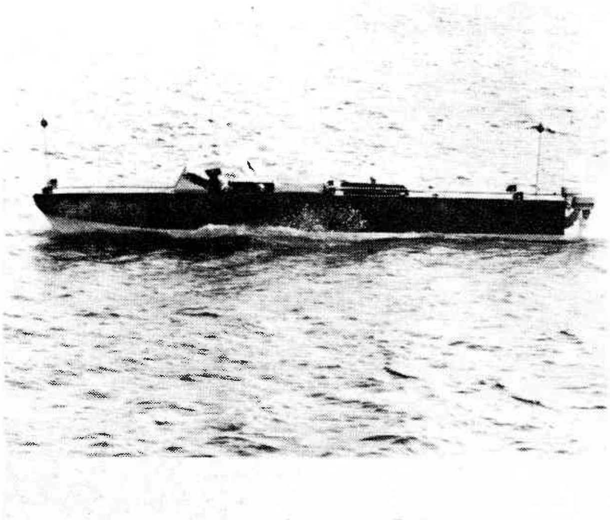


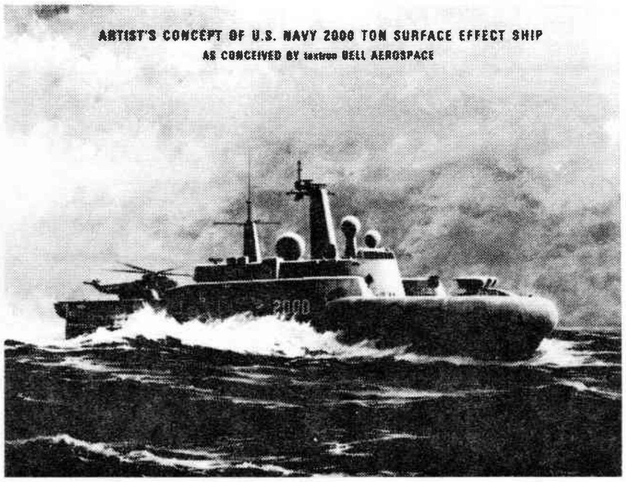
Fig. 3. XR-5

WORKING TODAY TO BUILD THE SHIP OF TOMORROW

Fig. 4. SES-100A

Low length-to-beam technology and waterjet propulsion were used in the 2000-ton SES (2KSES) and the 3000-ton SES (3KSES) combatant designs (Figs. 6-7). The 2KSES and the 3KSES, both 80-knot ocean-going combatants, were in the detail design process when the SES program was cancelled in 1980. Since then numerous towing tank model tests have been performed to better determine

Fig. 5. SES-100B



ARTIST'S CONCEPT OF U.S. NAVY 2000 TON SURFACE EFFECT SHIP
AS CONCEIVED BY textron BELL AEROSPACE

Fig. 6. 2KSES

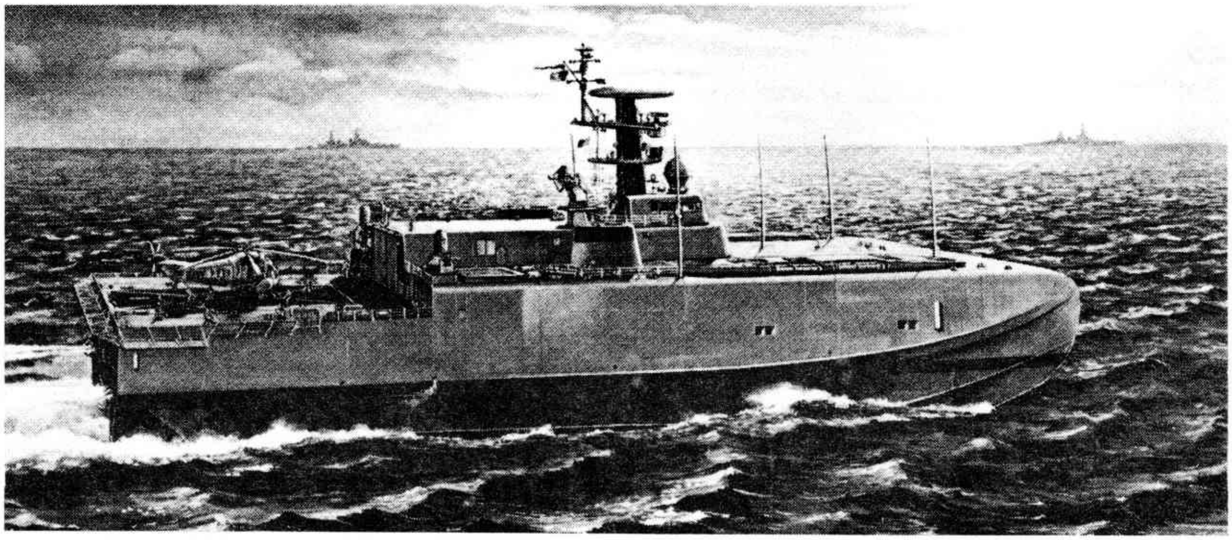


Fig. 7. 3KSES

the resistance and stability of various cushion sidewall configurations, with low to high cushion length-to-beam ratios and varying cushion densities, and different seal types. Thin and thick sidewalls have been tested with bag and finger seals, planing seals, and transversely stiffened membrane seals.

The SES craft MSH, SWCM, and PXM (Figs. 8-10) were the first real efforts since the 3KSES to design operational SES combatants. The myriad of design,

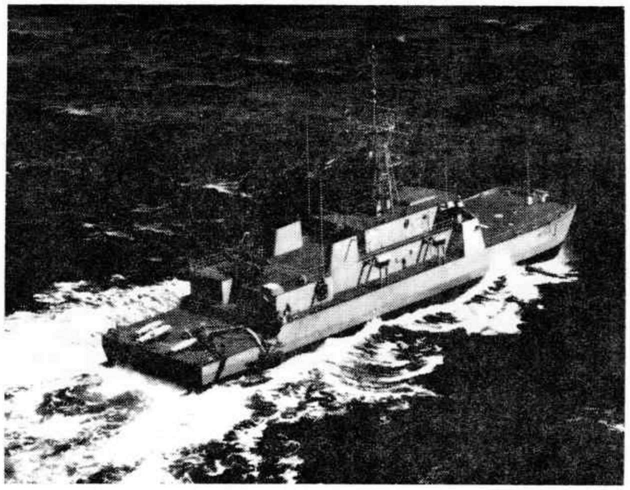


Fig. 8. MSH

Fig. 9. SWCM

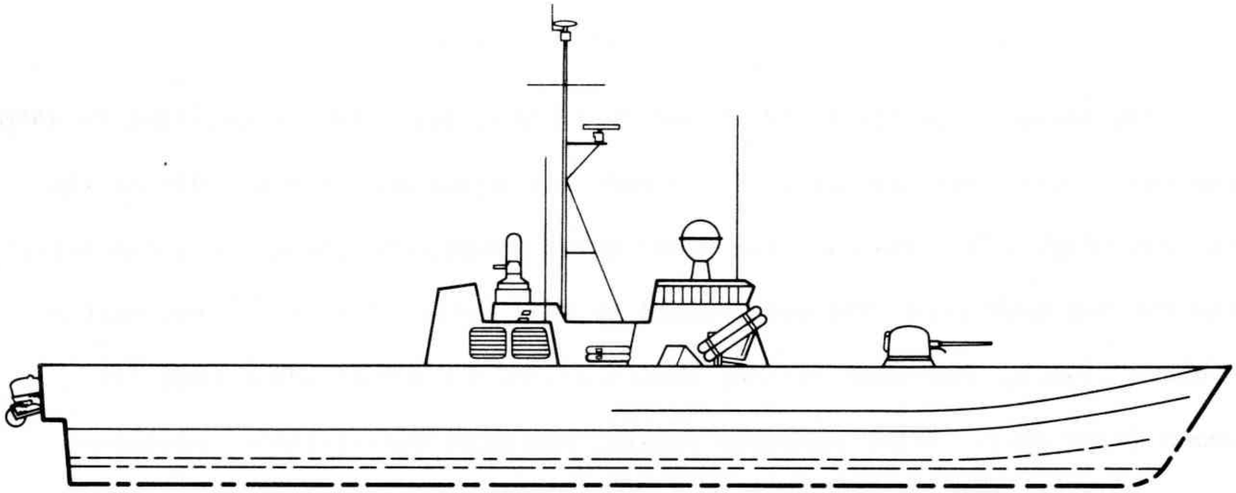


Fig. 10. PXM

development, and model test data of the last 20 years has yet to transition the SES from a research and development platform to an operational Navy ship. The only existing operational U.S. surface effect ships are the result of the design and construction of the BH-110 by Bell Halter in New Orleans, Louisiana, in 1978 (Fig. 11).

Fig. 11. BH-110

The Dorado, the first U.S. Coast Guard SES, was a BH-110 modified in 1980 for Coast Guard and Navy use. The Dorado was again modified in 1982 to the SES-200 (Fig. 12). The existing Coast Guard WSESs, the Shearwater, the Petrel, and the Sea Hawk (Fig. 13) constructed by Bell Halter (later Textron Marine Systems, Inc.), underwent various modifications to better adapt them for Coast Guard duty. After numerous trials, and with considerable commitment and dedication of the Coast Guard detachment in Key West and engineers in Washington, the WSESs are now successfully operating in the Florida Straits[1]. Performance goals are being met, and craft economy and reliability are better than those of some other existing Coast Guard craft. The SES-200 has been used both as an SES demonstration vessel and as a test platform. While speed and power have been of interest, the greater concern has been with operating the SES-200 in an ocean environment with the qualification and determination of acceptable habitability conditions.

Fig. 12. SES-200

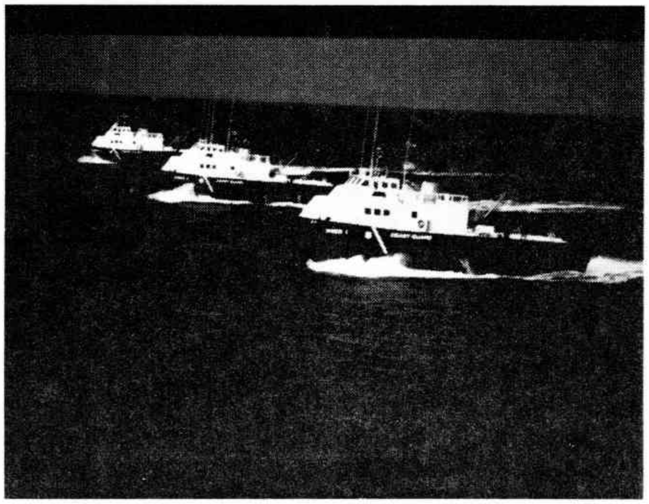


Fig. 13. WSES

The SES-200 NATO trials program conducted from December 1985 through August 1986 provided opportunity for NATO nations to test and observe the SES-200 in sea conditions characteristic of each country's operational waters and to simulate operational scenarios for future SES craft. A data exchange program guaranteed each participating NATO member an in-depth data package on the SES-200.

Future plans for the WSES include their continued operation in the Florida Straits. The future of the SES-200 is unclear, but the craft has already undergone an extended tour and special weapons testing. Also, repowering the SES-200 to investigate varied propulsion systems and arrangements for use in future surface effect ships is a possibility.

The WSES and the SES-200 are the only successful operational surface effect ships in the United States. With their capabilities already having been demonstrated, these craft can make a major contribution to the future use of SES in both services. The WSES and the SES-200 offer existing designs for consideration in the continuing SWCM and PXM acquisition programs. Earlier SWCM and PXM design requirements were for higher speeds, long ranges, and multimission capabilities. These capabilities in an existing craft design to satisfy the PXM and SWCM speed and range requirements reinforces the suitability of the WSES and the SES-200. The use of an existing ship or craft design will reduce the costs and the risks associated with advanced naval platforms and unqualified machinery equipment.

SES PERFORMANCE PREDICTION AND SHIP DESIGN ANALYSIS

Developmental surface effect ships were designed during the 1960's. Speed and powering predictions were based on the data from model towing tank experiments using semi-empirical methods.

During the 1970's, experimental towing tank data were organized and used to improve a parametric performance prediction computer program. The analytical program was developed at the David Taylor Research Center (DTRC) and used some parameters based on model data to predict the speed, power, and range for SES designs. The resistance of the ship consisted of aerodynamic drag, wavemaking drag, friction drag, residual or seal drag, and rough water drag (in waves). Aerodynamic drag was based on frontal area, and wavemaking drag was calculated by the method of Neuman and Poole [2]. Friction drag was based on a friction coefficient; wetted area predictions were improved with underwater photographs of SES models in the DTRC towing tank. Residual drag (believed to be mostly seal drag) was based on the difference between total model drag in calm water and the calculated resistance components. Rough water drag was determined in a similar manner from towing tank tests performed in scaled seas. The computer program was strictly oriented to the calculation of SES resistance, powering, range, and group weights for full-scale craft.

The 1980's brought about an integration of SES performance data with improved ship design techniques [3-6]. Resistance and powering became no more important than ship structures, combat systems, arrangements, and machinery layouts.

The CONFORM program [7] generated SES designs that were scrutinized by the Naval Sea Systems Command (NAVSEA) to determine if all aspects of the designs were compatible with Navy ship design practices. These studies resulted in design calculations for use in the areas of ship weight groups (SWBS) to three digits and required volumes for all ship spaces [8,9]. The CONFORM effort determined the need for more detailed studies into propulsion and structural design calculations.

The MSH and SWCM (Figs. 8 and 9) design efforts provided the opportunity for comparison of the latest prediction techniques with proposed SES design configurations and with actual scale model towing tank data. Agreement between the MSH model test data and predictions was obtained after significant modifications to account for the relatively low cushion pressure and low Froude number operation of the design. The revised procedure was used in the calculation of SWCM characteristics. Satisfactory agreement was obtained for the SWCM calm water model test data; however, modifications were necessary to obtain agreement with rough water model resistance data. The final resistance and powering calculations for the MSH and SWCM designs were acceptable. Full-load displacement and structural weight calculations for both designs were not examined in the same detail as were the resistance calculations. Structural weights from the SWCM program have been helpful in the calculation of existing and future SES designs.

Also during the 1980's, the PXM (Fig. 10) feasibility design involved many NAVSEA personnel and contractors with the details of SES design. Lift and propulsion machinery, general arrangements, manning, reliability, and other ship design areas were all examined at the feasibility level of design. A large number of SES configurations were studied with (1) various engine makes and sizes, (2) different hull materials, and (3) both waterjet and propeller configurations. The PXM study revealed the limited availability of gas turbines and diesels that were rated by and acceptable to the U.S. Navy, and the suitability of aluminum and steel in the construction of advanced naval vehicles.

The recent French NES-200 and German SES-700 towing tank tests at DTRC have provided scale model results for designs presently under consideration for construction by France and West Germany, respectively. The choice of prismatic coefficients for SES hullform description in the performance prediction program has simplified the comparison of experimental data with predicted resistance values for the NES-200 and the SES-700 towing tank tests. These tests have also demonstrated the importance of propulsor tests in determining the final craft running configurations.

The towing tank tests of a scale model landing craft (LCX) provided the opportunity to compare prediction results with model results for a highly loaded SES. The predictions compare favorably with model data.

The towing tank tests of the MSH, SWCM, NES-200, SES-700, and LCX models have provided substantial resistance data. The performance prediction computer program has been updated to obtain good correlation between model test results and computer predictions. The prediction method, which essentially is analytical, is based on geometric and wave drag considerations. The method predicts what is considered to be an achievable minimum value of resistance for an SES hull configuration. The method is acceptable for low and high length-to-beam cushion ratios, for thick or thin sidewalls, for various inner and outer sidewall deadrise angles, and for different chine and spray rail locations, with flow above or below the chine.

BH-110, WSES AND SES-200 ANALYSIS

The operational success of the Coast Guard's WSES, and the Navy's SES-200 has led to an increased desirability to characterize these craft. The capability to analytically describe these craft successfully will allow the examination of craft modifications for use in future SES designs.

Model test data and multi-phased design histories exist for most Navy ships and craft; however, there are no model test data nor design histories within the

Navy for the BH-110, or the WSES. Scale model tests of the SES-200 were conducted at DTRC during the past summer. General information is available from varied sources [1,10] to quantify the performance characteristics and design of the WSES and the SES-200.

To calculate the resistance and powering of the WSES and the SES-200 requires knowledge of the sidewall geometry, craft weight, cushion dimensions, and appendage characteristics. The primary inputs for calculating craft performance in general include craft weight, overall length, overall beam, cushion length, cushion beam, cushion pressure, keel flat width, inner and outer sidewall deadrise angle, chine height, and appendage geometry.

The results of the performance calculations for the WSES and the SES-200 in Figs. 14 and 15 show drag at higher design speeds for each craft's design weight and for increased displacements. Thrust available is also noted for several power levels. The increase in full-load displacement (FLD) due to the installation of increased horsepower in the WSES and the SES-200 can be

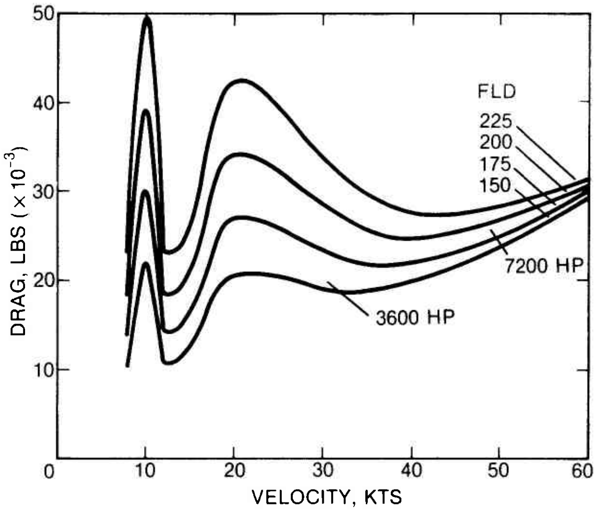


Fig. 14. WSES speed/power

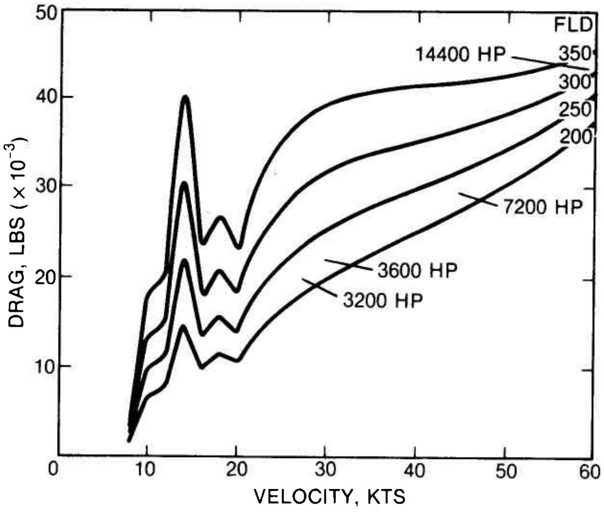


Fig. 15. SES-200 speed/power

investigated using the ship design option of the performance prediction computer program. This option determines the resulting full-load displacement for each propulsion system installed to achieve higher velocity.

The ship design program option uses the previously discussed resistance calculation, a constant velocity or a constant power calculation to determine ship range, a three-digit SWBS weight group calculation, and an ASSET [9] volume calculation. A total of 50 ship performance and design inputs are necessary to determine ship full-load displacement, including a variety of parameters from the number of crew members and mission duration to the hull material, engine type (diesel or gas turbine), and number of lift fans.

To obtain a starting point in determining the effect of installed horsepower on the full-load displacement of the WSES and the SES-200, a baseline weight estimate is calculated for the existing WSES and the SES-200 configurations. The results of the ship design computer calculations show a full-load displacement of 155 long tons for the WSES and 210 long tons for the SES-200. The SWBS groups (300, 400, 500, and 600) calculated for the WSES are assumed to be the same for the SES-200; the weight variations in craft FLD are because of the difference in structural weights due to the different craft lengths, and the different lift systems and fuel loads. Examination of the SWBS three-digit weight values shows a difference between the actual and predicted values. This difference is possibly due to the weight algorithms used in the design of combatants. Nevertheless, the FLD calculated for both craft is representative of the actual operational displacement at which the given speeds are obtainable at the installed power levels. The establishment of baseline performance and weight calculations provides verification of the performance and design techniques for use in estimating ship displacements at higher installed power levels.

INCREASED INSTALLED POWER LEVELS

The capability of an SES to "catch up" to a high-speed contact or to reposition itself in a convoy protection screen is becoming a highly desirable ship characteristic. Design studies for the SWCM, the PXM, and other SESs may indicate that heavier craft are required for the increased speeds with corresponding increases in installed power. The repowering of the WSES and the SES-200, however, would provide the experience of high-speed operation without involving a specific design and construction of a new prototype craft.

The ship design option of the performance computer program is used to calculate the propulsion and lift powers required and to determine new full-load displacements for the WSES and the SES-200 for speeds of 40, 50, and 60 knots using the original payload and fuel load. The full-load displacements for the WSES baseline configuration (at 30 knots) and at speeds of 40, 50, and 60 knots are presented for diesel designs in Table 1 and for gas turbine designs in Table 2.

Table 1. WSES SWBS (Diesel)

SPEED (KTS)	30	40	50	60
SWBS				
100	57.72	57.72	57.72	57.72
200	30.74	41.01	56.00	75.34
300	4.58	4.58	4.58	4.58
400	2.90	2.90	2.90	2.90
500	12.65	12.65	12.65	12.65
600	7.46	7.46	7.46	7.46
700	0.00	0.00	0.00	0.00
LIGHTSHIP	116.05	126.32	141.31	160.65
MARGIN	7.62	8.35	7.36	10.02
LIGHTSHIP W/MARGIN	123.67	134.67	150.67	170.67
VARIABLE LOAD	31.33	31.33	31.33	31.33
FULL LOAD DISPLACEMENT	155.00	166.00	182.00	202.00

Table 2. WSES SWBS (Gas Turbine)

SPEED (KTS)	30	40	50	60
SWBS				
100	57.72	57.72	57.72	57.72
200	25.33	34.44	48.61	66.03
300	4.58	4.58	4.58	4.58
400	2.90	2.90	2.90	2.90
500	12.65	12.65	12.65	12.65
600	7.46	7.46	7.46	7.46
700	0.00	0.00	0.00	0.00
LIGHTSHIP	110.64	119.75	133.92	151.34
MARGIN	6.55	7.44	8.22	9.85
LIGHTSHIP W/MARGIN	117.19	127.19	142.19	161.19
VARIABLE LOAD	37.81	38.81	39.81	40.81
FULL LOAD DISPLACEMENT	155.00	166.00	182.00	202.00

The full-load displacements for the SES-200 baseline configuration (at 28 knots) and at speeds of 40, 50, and 60 knots are presented in Tables 3 and 4 for the diesel and gas turbine designs, respectively. Although the main propulsion power plants for the repowering of the WSES and the SES-200 include both diesels and gas turbines, only diesels are considered for the lift system.

Table 3. SES-200 SWBS (Diesel)

SPEED (KTS)	28	40	50	60
SWBS				
100	77.53	77.53	77.53	77.53
200	34.48	54.67	77.25	104.93
300	4.58	4.58	4.58	4.58
400	2.90	2.90	2.90	2.90
500	12.65	12.65	12.65	12.65
600	7.46	7.46	7.46	7.46
700	0.00	0.00	0.00	0.00
LIGHTSHIP	139.60	159.79	182.37	210.05
MARGIN	8.47	10.28	11.70	13.02
LIGHTSHIP W/MARGIN	148.07	170.07	194.07	223.07
VARIABLE LOAD	61.93	61.93	61.93	61.93
FULL LOAD DISPLACEMENT	210.00	232.00	256.00	285.00

Table 4. SES-200 SWBS (Gas Turbine)

SPEED (KTS)	28	40	50	60
SWBS				
100	77.53			
200	29.34	47.82	69.51	98.87
300	4.58			
400	2.90			
500	12.65			
600	7.46			
700	0.00			
LIGHTSHIP	134.46	152.94	174.63	203.99
MARGIN	7.93	8.92	10.31	12.37
LIGHTSHIP W/MARGIN	142.39	161.86	184.94	216.36
VARIABLE LOAD	67.61	70.14	71.06	68.64
FULL LOAD DISPLACEMENT	210.00	232.00	256.00	285.00

Consideration must be given to the lift system if the WSES and the SES-200 are to achieve higher speeds. The calculated lift flow requirements for the WSES and the SES-200 are presented in Figs. 16 and 17; these lift flow requirements are based on the amount of flow required for minimum total power, and are the same order of magnitude as the full-scale lift flows reported in Refs. 1 and 10. Actual flow requirements can be as much as one-half the calculated value without dramatically increasing the craft resistance and propulsion power. Consequently, a 40-, 50-, or 60-knot design of the WSES or the SES-200 could be accomplished with no appreciable change in the existing lift system.

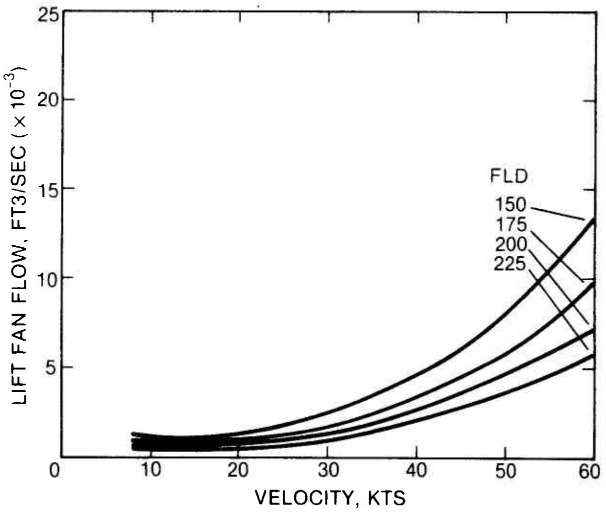


Fig. 16. WSES lift flow

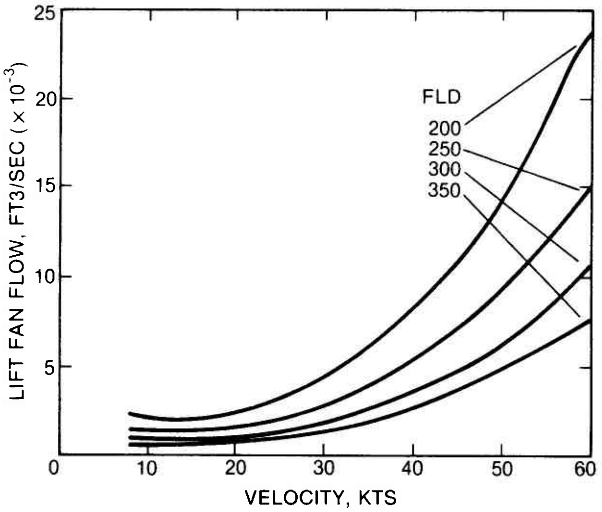


Fig. 17. SES-200 lift flow

The full-load displacements in Tables 1 through 4 are based on lift power required to achieve lift flow in Figs. 16 and 17 and propulsion power required to produce the thrust equal to the resistance in Figs. 14 and 15. The increase in FLD with speed (Tables 1 through 4) for the WSES and the SES-200 is due to the required increase in propulsion and lift system power to achieve the higher speeds; no structural weight increase with speed is assumed. The FLD obtained for the WSES and SES-200 diesel configurations in Tables 1 and 3 are used for the gas turbine configurations in Tables 2 and 4. The gas turbine propulsion fuel load is increased or decreased with a decrease or increase in propulsion weight. The full-load displacements for both craft are superimposed on Figs. 14 and 15 and presented in Figs. 18 and 19.

Increasing the propulsion power using the existing lift system in each craft may not result in the same speed gains shown in Figs. 18 and 19. It is estimated that the predicted 40 knots (Figs. 18 and 19) would be achieved; however, the predicted 50 knots (Figs. 18 and 19) would actually be less by about 5 knots.

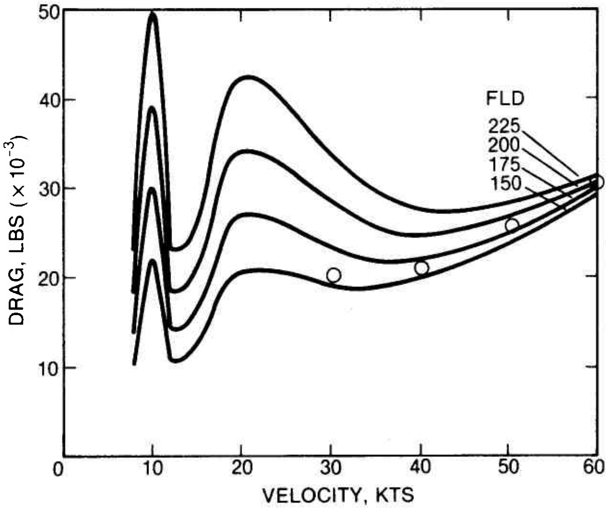


Fig. 18. WSES full-load displacement

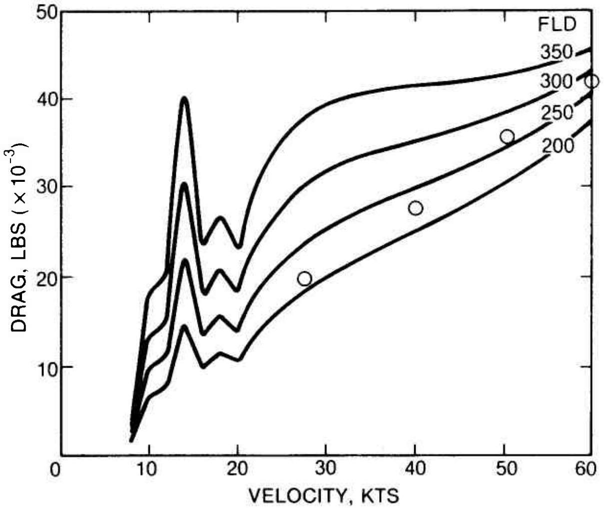


Fig. 19. SES-200 full-load displacement

LIFT AND PROPULSION MACHINERY

The three-digit SWBS 200 Groups for the WSES diesel and gas turbine configurations are presented in Tables 5 and 6 for speeds of 30, 40, 50, and 60 knots. The SES-200 diesel and gas turbine configurations are presented in Tables 7 and 8 for 28, 40, 50, and 60 knots. The weight differences between the diesel and gas turbine SWBS 200 Groups are the lighter gas turbines (SWBS 234), the heavier gas turbine reduction gears (SWBS 241), and the heavier intakes and uptakes (SWBS 251, 259).

The lift systems for the WSES and the SES-200 include the lift diesel engines and the lift fans, which rotate at the same speed as the diesel engines. The WSES uses two lift engine/fan combinations; the SES-200 has four lift engine/fan combinations. The lift systems do not use reduction gearboxes. The lift systems are shown in Fig. 20 for the WSES and in Fig. 21 for the SES-200.

Table 5. SWBS 200 for diesel WSES

SPEED (KTS)	30	40	50	60
SWBS				
233	13.25	17.19	22.39	28.36
234				
241	2.25	3.98	7.52	13.59
242	0.18	0.27	0.42	0.64
243	0.29	0.38	0.55	0.78
244	0.12	0.16	0.23	0.33
245	0.21	0.25	0.39	0.48
248	3.61	6.28	9.54	12.87
251	0.74	1.13	1.77	2.64
252	0.51	0.64	0.81	0.98
256	1.33	1.66	2.08	2.55
259	0.35	0.54	0.84	1.26
261	0.26	0.39	0.61	0.92
262	0.71	0.83	1.01	1.26
264	0.07	0.10	0.16	0.25
298	6.38	6.45	6.57	6.74
299	0.48	0.73	1.14	1.70
200	30.74	41.01	56.00	75.34

Table 6. SWBS 200 for gas turbine WSES

SPEED (KTS)	30	40	50	60
SWBS				
233	3.93	5.47	7.23	9.07
234	2.27	2.78	3.49	4.27
241	2.70	4.84	9.55	16.25
242	0.18	0.27	0.42	0.63
243	0.29	0.38	0.55	0.76
244	0.12	0.16	0.23	0.32
245	0.21	0.25	0.34	0.47
248	3.61	6.28	9.54	12.56
251	1.51	1.93	2.65	3.65
252	0.51	0.64	0.81	0.98
256	1.33	1.66	2.08	2.53
259	0.78	1.26	2.22	3.74
261	0.26	0.39	0.61	0.90
262	0.71	0.83	1.01	1.25
264	0.07	0.10	0.16	0.24
298	6.38	6.45	6.57	6.73
299	0.48	0.73	1.14	1.68
200	25.33	34.44	48.61	66.03

Table 7. SWBS 200 for diesel SES-200

SPEED (KTS)	28	40	50	60
SWBS				
233	14.90	22.60	29.84	37.59
234				
241	2.13	6.04	12.12	21.72
242	0.17	0.36	0.58	0.85
243	0.27	0.50	0.74	1.03
244	0.11	0.21	0.32	0.44
245	0.21	0.37	0.54	0.74
248	5.58	10.26	15.19	20.29
251	0.73	1.50	2.41	3.56
252	0.60	0.85	1.08	1.31
256	1.55	2.21	2.79	3.40
259	0.35	0.72	1.15	1.70
261	0.25	0.52	0.84	1.24
262	0.71	0.93	1.19	1.53
264	0.07	0.14	0.22	0.33
298	6.38	6.52	6.69	6.91
299	0.47	0.96	1.55	2.30
200	34.48	54.67	77.25	104.93

Table 8. SWBS 200 for gas turbine SES-200

SPEED (KTS)	28	40	50	60
SWBS				
233	6.06	8.92	11.75	14.80
234	2.16	3.18	4.08	5.00
241	2.52	7.78	15.22	28.21
242	0.17	0.36	0.58	0.85
243	0.27	0.50	0.74	1.03
244	0.11	0.21	0.32	0.44
245	0.21	0.37	0.54	0.73
248	5.58	10.26	15.19	20.26
251	1.49	2.34	3.41	4.85
252	0.60	0.85	1.08	1.31
256	1.55	2.21	2.79	3.40
259	0.73	1.77	3.33	5.70
261	0.25	0.52	0.84	1.23
262	0.71	0.93	1.19	1.53
264	0.07	0.14	0.22	0.33
298	6.38	6.52	6.69	6.91
299	0.47	0.96	1.55	2.29
200	29.34	47.82	69.51	98.87

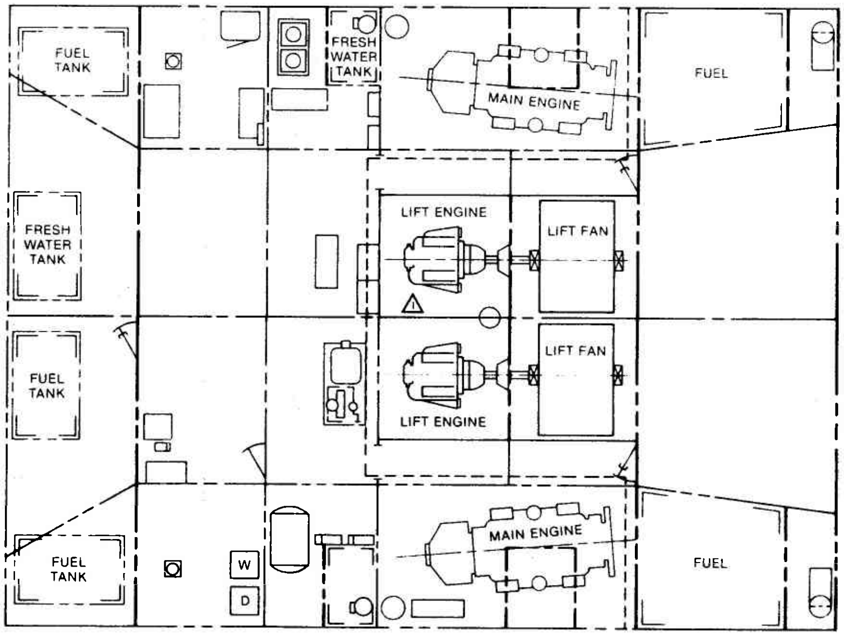


Fig. 20. WSES lift system

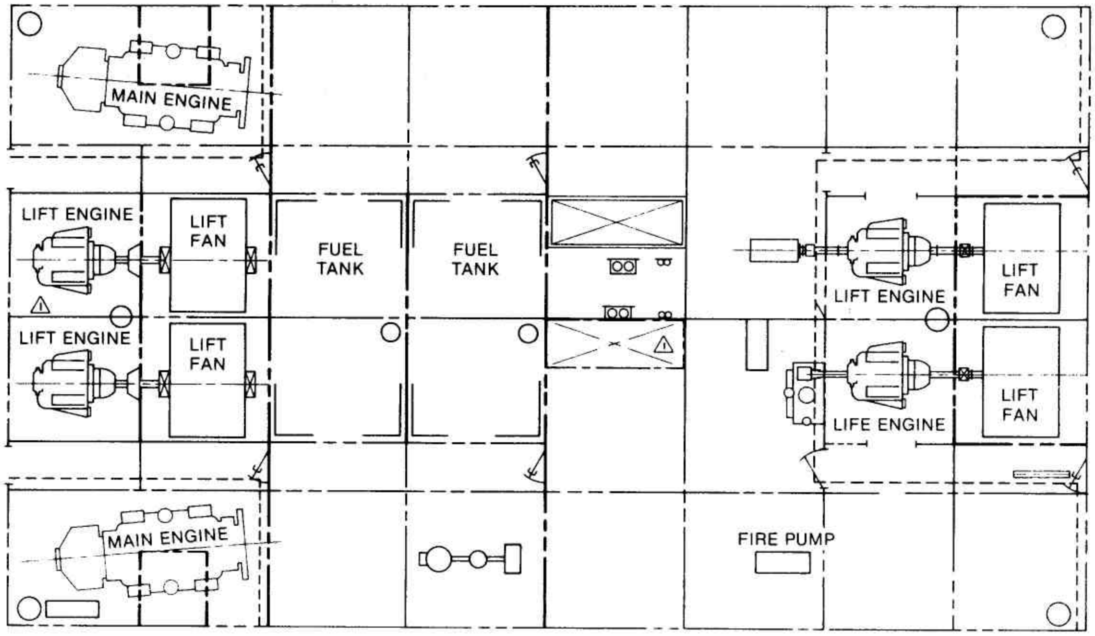


Fig. 21. SES-200 lift system

The diesel propulsion system for both the WSES and the SES-200 consists of two diesel engines and the associated reversing-reduction gearboxes, shafting, and fixed-pitch propellers. The gas turbine propulsion system includes two gas turbines, each with reduction gearbox, reversing gearbox, shafting, and a fixed-pitch propeller. Typical diesel and gas turbine propulsion machinery arrangements are shown in Figs. 22 and 23, respectively. The diesel arrangement shown is similar to the original configuration of each craft.

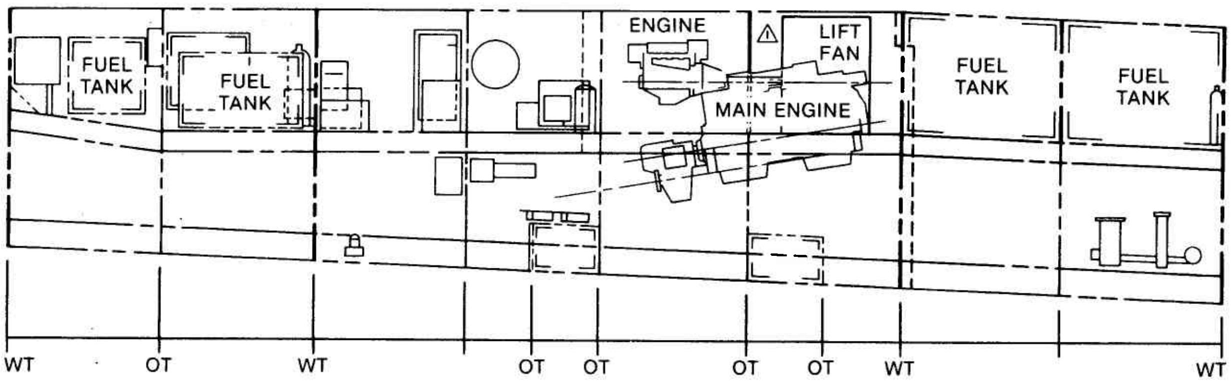


Fig. 22. Diesel propulsion system

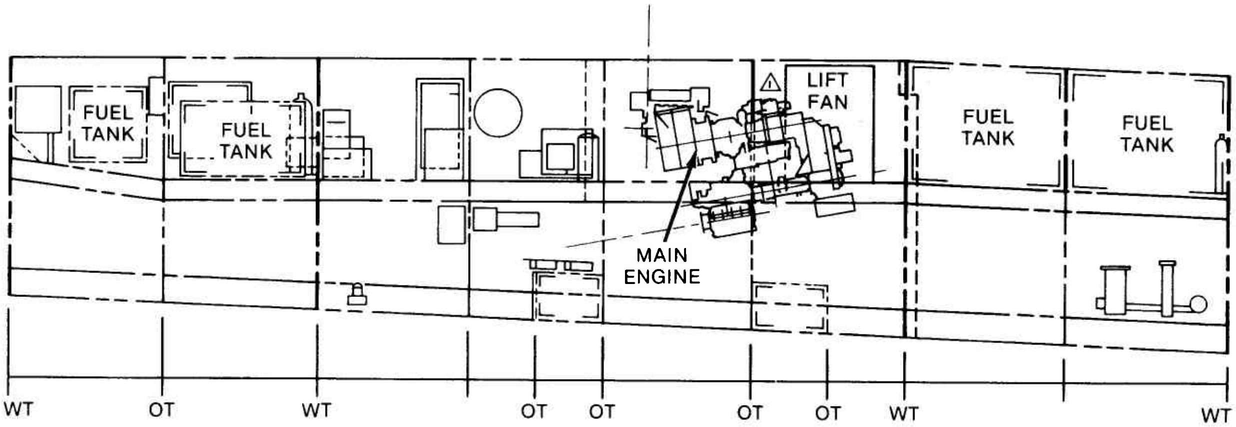


Fig. 23. Gas turbine propulsion system

The maximum installed diesel propulsion power is dependent on the physical size of the diesel engine. The gas turbine installation being considered for the WSES and the SES-200 uses a gas turbine whose output shaft at the compressor inlet drives through a C-type reduction gearbox then passes through a reversing gearbox to the propeller shaft. The diesel configuration has one diesel per shaft; whereas, the gas turbine installation can use one or two engines per shaft.

Total propulsion horsepower levels required to achieve speeds of 30 to 60 knots range from the presently installed level of 3,600 to 14,000 horsepower. A variety of power plants are available in this horsepower range. Marine diesels exist at many horsepower levels within a 1600- and 8000-horsepower range. Reversing reduction gearboxes are available for these diesels. Various gas turbines are also available, which can be used singularly or in pairs. Reduction gearboxes have been designed and constructed for some turbine engines, but are less available than those for the diesel engines. While the gas turbines are compact, the space allotted for them must include the inlet filtration, demisters, and uptakes. The SES-200 has more space than the WSES to accommodate the gas turbine intake and exhaust modules, although the WSES stacks are suitable for either diesel or gas turbines.

Increased propulsion horsepower requires larger propulsors and larger propeller shafts. Of the various propulsors, the fixed-pitch (fully submerged) propeller requires the least amount of modification and is the least expensive. Other options include a controllable pitch propeller (CRP), fully or partially submerged, or a waterjet. The use of the CRP or the waterjet would eliminate the reversing gearbox needed with a fixed-pitch propeller. With the controllable pitch propeller, the shaft angle is increased due to the increased size of the hub control mechanism that is required. The waterjet controls are simple, but the waterjet is large and heavy compared to the fixed-pitch propeller and the CRP. Installation of a waterjet in the WSES or the SES-200, however, would require modification and reconstruction of the sidehulls.

NEAR-TERM PLANS

The propulsion machinery selected for installation in the WSES and the SES-200 should be based on near-term and far-term applications of the SES. One WSES and the SES-200 should be repowered to permit investigation of performance at higher speeds and increased displacements. The power plant chosen to upgrade the installed power should equal the power required to achieve speeds on the order of 60 knots. The use of diesels in this horsepower range is unacceptable because of their physical size. Gas turbines in the WSES and the SES-200 would be a viable solution to installing the maximum power in the limited space available. Using multiple engines per shaft would permit the operation of a single engine per shaft at the lower speeds, which is characteristic of U.S. Navy gas turbine operated frigates and destroyers. The multiple engine per shaft configuration would be similar to that used in large U.S. Navy ships but would achieve the high speed that is characteristic of SESs. The fixed-pitch propeller should be considered for the initial retrofit, since its capabilities may prove acceptable in the lower speed ranges.

The SES-200 platform should be retrofitted with four gas turbines, two per shaft. This configuration permits the opportunity for engineering development in the areas of (1) gas turbine operation in an SES, (2) the operation of one or two turbines per shaft as is characteristic of U.S. Navy frigates and destroyers and (3) experimentation with fixed-pitch propeller operation to determine the suitability of the fixed-pitch propeller for speeds above and below 40 knots. The use of a CODOG arrangement (combined diesel or gas turbine) on the SES-200, using small diesels, would allow the comparison of low-speed operation with the diesels and with the gas turbines; however it is uncertain that the SES-200 could accommodate such an installation.

In the interest of a more effective USCG patrol boat, the WSES should be retrofitted with two small diesels and two gas turbines in CODOG arrangements designed for quiet high-speed interception and efficient low-speed operation during time on station. The repowering of these ships makes possible the investigation of operating SES craft at the higher speeds and displacements that will be characteristic of possible future Navy and Coast Guard SES designs.

FAR-TERM PLANS

The calculation of resistance, powering, and full-load displacement provides credible numbers for the characterization of present U.S. SES designs. While the WSES and the SES-200 are successful operational craft, a more detailed effort should be conducted in the definition and integration of candidate propulsion systems for future surface effect ships. The candidate propulsors (fixed-pitch propeller, controllable pitch propeller, semi-submerged controllable pitch propeller, and waterjet) must be evaluated with their prime movers to determine acceptable performance characteristics, noise levels, safety of operation, ship controllability, maintenance, and reliability. Simulations based on propulsion model tests should be conducted to provide a clear definition of the benefits and suitability of the candidate propulsors at different speeds for future surface effect ship designs.

SUMMARY

Over the past few years a variety of surface effect ships have been designed and many towing tank investigations have been conducted. The model tests have provided a significant amount of data that have been used to refine the calculation of SES resistance. Surface effect ship designs have become highly detailed to assure the accuracy of the calculated weight and performance of the craft.

The construction and development of the BH-110, WSES, and SES-200 have provided the U.S. Coast Guard and the U.S. Navy with a successful operational surface effect ship group. The international exposure of the capabilities of these craft has resulted in renewed efforts to design and construct surface effect ships for coastal and open-ocean military missions. The operational WSES and SES-200 are considered suitable for some of these missions in existing and modified configurations.

Installation of higher horsepower engines and candidate propulsion systems in the WSES and the SES-200 should provide operational information for the design and development of future surface effect ships.

ACKNOWLEDGMENTS

The author extends appreciation to Phillip Viars, Charles Heber, Fred Wilson, and Richard Wares (formerly of DTRC) for their dedicated efforts toward the development of SES technology and to TEXTRON Marine Systems, Inc. for their construction of and commitment to the BH-110 surface effect ship.

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THE AUTHOR

Robert Church is an aerospace engineer in the New Vehicles Division, of the Aviation Department, at the David Taylor Research Center, Bethesda, Maryland. He received his B.S. degree in aerospace engineering from the Pennsylvania State University in 1963 and an M.S. degree in ocean engineering from the University of Miami in 1968. Mr. Church has worked with advanced naval vehicles since 1972. He has been involved with the SRN5 Arctic ACV and the AALC JEFF(A) and JEFF(B) and was a member of the LCAC evaluation team. His work with SES began in 1982, and he has participated in the CONFORM design studies and the PBM, MSH, SWCM, PXM, LCX, ITSL, and SFS SES design efforts. He has published reports on tilt rotor performance, Arctic ACV maneuvering and control, ACV resistance and powering, and the JEFF(A) and JEFF(B) test and trials program. Mr. Church is a member of the U.S. Hovercraft Society and the American Society of Naval Engineers.

Discussion on presentation by Robert Church

Q How do you account for the model test results and scaling them to full size ships?

A Initially when the testing was done there wasn't any real effort to match the model data , everything was aimed at big ships. When we ran into trouble with some of the data that we got, my attitude was to say we have to match some of the model data. If we understand this we have a broad feeling of how we can scale it. That is essentially Froude scaled with the friction coefficients for the Reynolds number on the wetted surface.

The only thing we do look at in as far as the model data goes, the friction coefficients are in the program, is Larry Doctor's method of wave drag calculation. His methods have provision for the depth of the tank. That is the only correlation we will put in. Because some of the models that we have used have been so long compared to the water depth that you do get a difference. Doctor's procedure gives us an insight to this and helps us in the correlation of model data with the program.

Q How do you scale residual drag?

A We have gone to a number of ways of scaling residual drag (if you want, call it seal drag) The most common approach is to Froude scale it. We have found that it works. That is a good approach, if you Froude scale the residual drag. There are some people that say seal drag is zero. This program does not take that approach and it does Froude scale it to a large extent.

Q Were your predictions verified in full scale?

A Yes. When we did the program and we predicted full scale shifts we didn't have anything to compare it with. At the time I was working with the JEFF(A) and JEFF(B). We did a number of tests at David Taylor with model ACV's and also with the JEFF(A) and 1/6th scale JEFF(B) models. We used Doctor's wave drag to look as some of the full scale results and it worked out very well. Those results are documented, of course nobody can have them, but they are documented.

Again when we got all these model results we were looking at full scale shifts with the idea of trying to correlate the model data: Because that was the only thing we really had, we didn't have any full scale data. But now that the SES-200 and the WSES is available, this seemed an appropriate way to apply the program and all the results and all the work we've done at David Taylor. So this is reasonable correlation.

Of course we are not allowed to present actual comparisons. About five years ago I hoped to give a paper on the JEFF(A) and JEFF(B) correlation. I was not able to do so. I would like to thank the Navy for giving me this opportunity for presenting some of the work we've done at David Taylor.