SURFACE EFFECT SHIP (SES) DEVELOPMENTS IN THE USA

by

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INTRODUCTION

A surface effect ship (SES) is an air-supported craft, or hovercraft, that has catamaran-like, rigid sidehulls in which the air between the hulls is contained by flexible bow and stern seals. This volume of trapped air is pressurized to modest levels to provide a lift force on the entire hull. The sidehulls are partially raised out of the water, considerably reducing drag and permitting the underwater propellers, or waterjets, at the aft end of the sidehulls to drive the craft at higher speeds. The sidehulls also provide hydrodynamic forces for stability and maneuvering so that the SES handles much like a conventional planing boat. The cushion system isolates the main hull from the surface to make high-speed operation over waves both efficient and comfortable. Figure 1 compares the SES configuration to other high-speed marine craft.

SES technology in the U.S. has, to date, been dominated by U.S. Navy-sponsored developments pointed toward military requirements. Bell Aerospace Textron, Division of Textron Inc., has played a major role in this development.

Bell Aerospace has been a leader in advanced vehicle development since the company was founded in 1935 at Buffalo, New York. A pioneering aviation and aerospace organization, Bell entered the air cushion vehicle (ACV) and surface effect ship (SES) fields in 1958. In 1969, the Bell New Orleans Operation was established to concentrate on the design and construction of these vessels. With over 20 years experience, Bell has established a dominant position in all areas of ACV and SES technology.

The original interest in SES in the mid-1960s arose from the potential for very high speed performance. Projections of multi-thousand ton ships crossing the oceans at 100 knot speeds were made, and aroused considerable interest in both the U.S. Navy and the U.S. Maritime Administration (MARAD). A joint project office was formed, and in the late 1960s contracted with Bell and Aerojet General for the construction of two 100-ton class test craft. Bell's craft, the SES-100B, was the more successful craft and achieved all

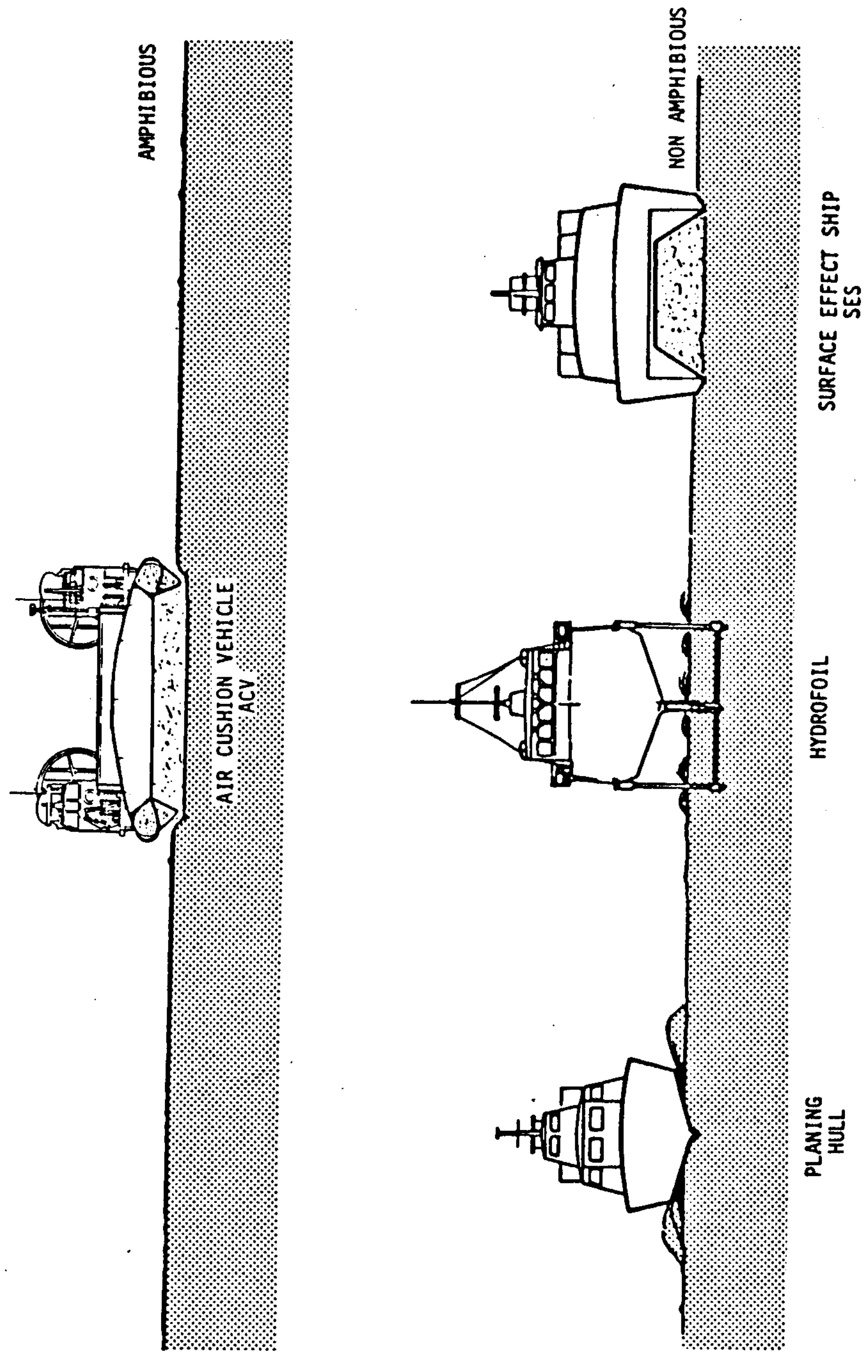


Figure 1 HIGH-SPEED MARINE CRAFT

program objectives, including a maximum speed of 91.9 knots, a missile launch at 65 knots, and rough water operation at 50-60 knots. The SES-100B still holds the world record for the fastest warship.

The SES-100B proved the technical feasibility of high-speed SES, but the mission requirements and cost effectiveness were questioned, and in the mid-1970s, Bell sought a better compromise between performance and cost. A joint venture with Halter Marine, Inc, of New Orleans was formed in 1977 so that their vast experience in conventional shipbuilding, and in particular high-speed aluminum craft, could be blended with Bell's SES technology. Halter Marine, Inc, the world's largest builder of offshore supply boats, has over 20 years experience and operates a number of shipyards in Louisiana and Mississippi. Halter has produced over 1,000 vessels for worldwide use and dominates the American workboat and marine equipment industry.

The joint design team concluded that, by giving up very high speed performance, both first cost and operating costs could be drastically reduced. The two companies initially agre to a limited joint venture, and provided funding for the construction of a 1.J-foot vessel to demonstrate the new design philosophy. This successful partnership is now incorporated as Bell Halter Inc, and is based in eastern New Orleans.

BELL HALTER SES PROGRAMS

This section presents a status report on the continuing development of the Bell Halter SES program.

A. Bell Halter 110 Program

The Bell Halter 110-foot demonstration SES (BH 110, Mk I) was constructed at Halter Marine's Chalmette, Louisiana, shipyard. The demonstration program, begun in early 1979 in the New Orleans coastal waters, was conducted for representatives of the offshore industry, ferryboat operations, and various visitors from foreign countries. During the early months of 1980, the U.S. Coast Guard (USCG), in conjunction with the U.S. Navy and Urban Mass Transportation Administration, evaluated the craft in a one-month test program conducted off the shore of Norfolk, Virginia. Maneuvering tests showed the SES can be handled in all conditions and it performed well in restricted areas. It also performed satisfactorily in towing tests with an 82-foot USCG WPB (patrol craft), both on and off cushion. During long-range missions off the northeastern U.S. coast, the BH 110 provided excellent seakeeping capability at all headings. It performed better than the conventional planing hull patrol boats.

The SES was operated in sea state 2 at speeds of 29 knots and in sea state 4 at 26 knots with significant vertical acceleration peaks of 0.5g. The SES towed the 82-foot USCG WPB at speeds of 11 knots. The maximum measured calm water speed of the SES was 33 knots at a displacement of 121 long tons and a fuel consumption of 6.9 gallons per nautical mile, yielding a top speed maximum range of 672 nautical miles. Turning performance and directional control were maintained during simulated combinations of propulsion and lift engine impairment.

Comparative smooth water performance (figure 2) shows the nondimensional speed/power results for the SES and 82-foot WPB, compared with similar type results for 10 other craft. Other craft range in size and type from a 25-foot surf rescue boat with a hybrid stepped hull and hydrofoil to a 165-foot patrol gunboat with a displacement hull. The format is a transportation efficiency coefficient versus speed coefficient (volume Froude number: F_Δ) computed from displacement, speed, and power factors. The several lines in figure 2 labeled for different hull types, and that together form an approximate diagonal on the figure, represent an indication of current state-of-the-art performance. The SES, especially when normally loaded (no. 1), is clearly in advance of the state of the art in this comparison. The LCVP(K) (no. 10) is included here because it was a prototype surface effect vessel (circa 1963) that had thin sidewalls, an articulated hinged flat bow seal to contain air ducted beneath the hull, and was termed an air-lubricated hull. The other craft presented in figure 2 are generally open-water patrol craft with top speeds comparable with that of the SES.

The conclusions of this program were summarized in the report as follows:

"The test results indicate the Bell Halter 110-foot SES is an effective and able marine vehicle that warrants consideration for varied future military and civilian applications."[1]

B. The RODOLF

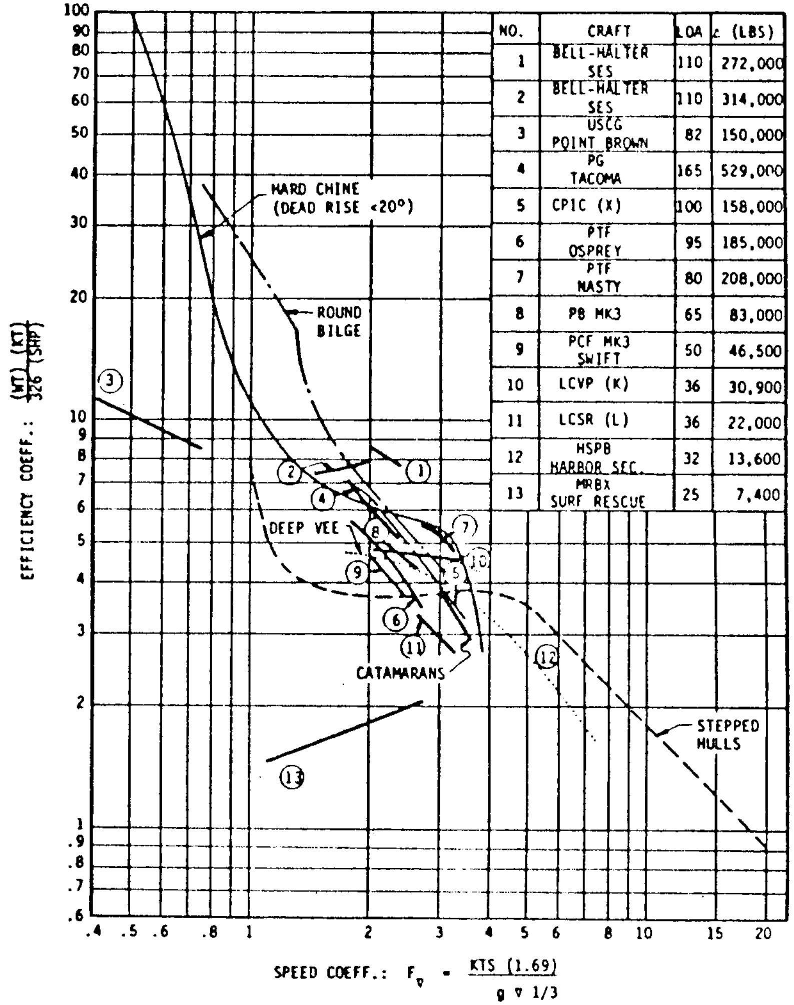
In 1978, the U.S. Army Corps of Engineers awarded a contract to Bell Halter to build an SES to perform hydrographic survey work on the Columbia River in Oregon and along the Pacific northwest coastline. The craft (see figure 3), delivered in late 1979, carries a payload of 750 pounds (together with crew, survey team, and 40 hours of fuel) at 25 mph. A speed of 35 mph is achieved in transit to and from the survey site. The **RODOLF** is 48 feet in length, 24 feet in beam, and drafts 4 feet on cushion (for more detailed specifications, see table I).

Since entering service, the vessel has been operating at an average rate of 6 to 7 hours per day. The wide cabin offers more space than a conventional boat and the widely spaced propellers provide increased maneuverability. It is more fuel efficient than the 65-foot aluminum craft the Corps of Engineers still operates, because the **RODOLF** surveys at 40 to 50 percent faster speed, yet consumes approximately the same amount of fuel per hour. Since fuel and personnel represent the major operating costs and are approximately the same on a per hour basis, the SES has proven to be much more cost effective than conventional vessels used for similar work.

C. Bell Halter 110 Mk II Program

In production since early 1980, the Mk II is basically the same design as the Mk I, with some added detail improvements and simplifications. The first two boats of this production program, the **SPEED COMMAND** and **SWIFT COMMAND**, are

[1]P.K. Spangler, Test and Evaluation of the Bell Halter 110-Foot Surface Effect Ship Demonstration Craft (NAVSEADET Norfolk Report No. 6660-60, February 1981).



NO.	CRAFT	LOA	Δ (LBS)
1	BELL-HALTER SES	110	272,000
2	BELL-HALTER SES	110	314,000
3	USCG POINT BROWN	82	150,000
4	PG TACOMA	165	529,000
5	CPIC (X)	100	158,000
6	PTF OSPREY	95	185,000
7	PTF NASTY	80	208,000
8	PB MK3	65	83,000
9	PCF MK3 SWIFT	50	46,500
10	LCVP (K)	36	30,900
11	LCSR (L)	36	22,000
12	HSPB HARBOR SEC.	32	13,600
13	MRBX SURF RESCUE	25	7,400

Figure 2 COMPARATIVE SMOOTH WATER PERFORMANCE

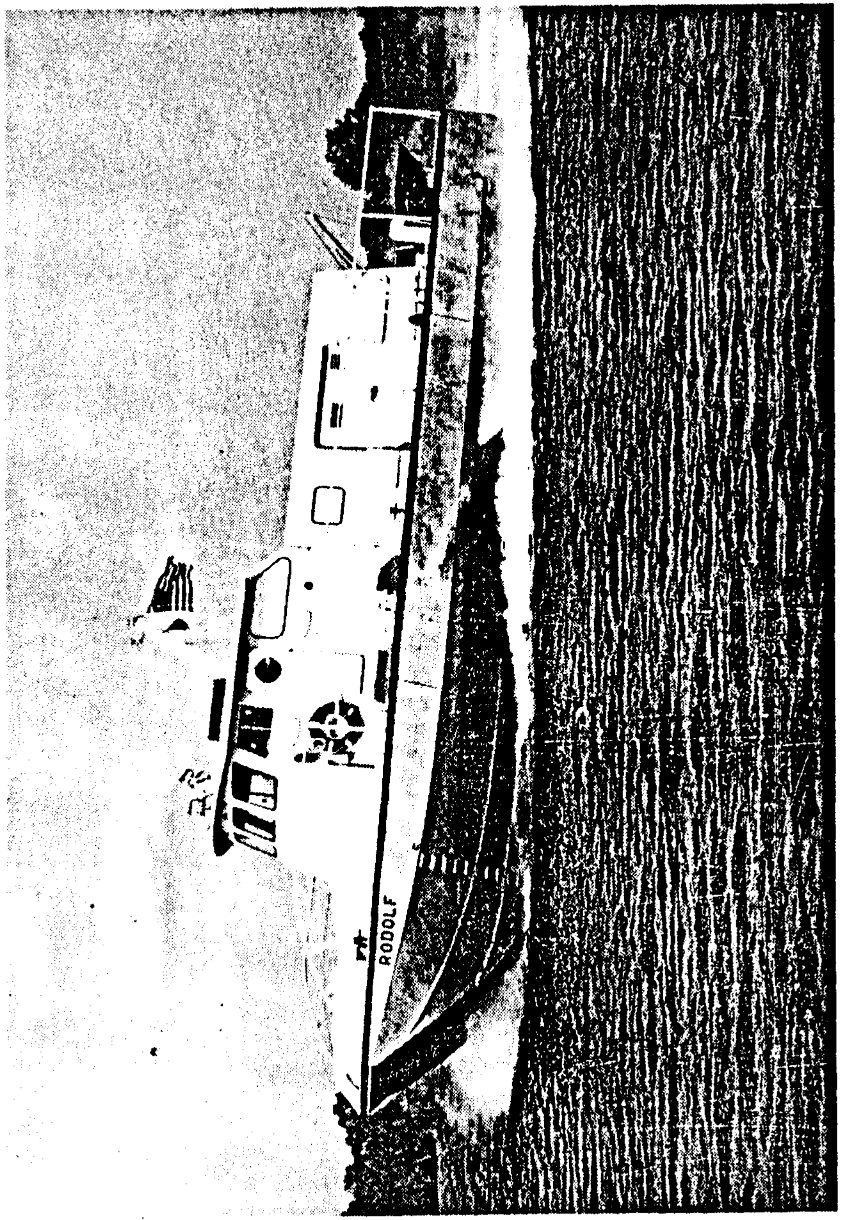


Figure 3 CORPS OF ENGINEERS HYDROGRAPHIC SURVEY BOAT

TABLE I

PRINCIPAL CHARACTERISTICS CORPS OF ENGINEERS HYDROGRAPHIC SURVEY BOAT

● DIMENSIONS	
Length	48 ft
Beam	24 ft
Hull Depth Molded	8 ft, 4 in.
Draft (Off Cushion)	5 ft, 10 in.
Draft (On Cushion)	4 ft
● LEADING PARTICULARS	
Light Ship Displacement	41,600 lb
Full Load Displacement	54,150 lb
Fuel	1,400 gal
● MACHINERY	
Main Engine (2) Detroit Diesel 8V-92N at	350 shp ea
Propellers (2) Four-Bladed Stainless Steel	24-in-dia

in the service of Command Marine, Inc., of Lafayette, Louisiana. The unique combination of stability and maneuverability of the craft at the Gulf of Mexico oil rigs has made them capable of successfully interfacing with the variety of personnel transfer methods employed in virtually all wind and sea conditions encountered. They routinely operate 14-16 hours a day, 6-7 days a week in almost all weather conditions. They have replaced both helicopters and conventional vessels for much of the support service to PEMEX oil rigs in the Bay of Campeche.

D. U.S. Coast Guard Operations

In September 1980, the U.S. Navy purchased the BH 110 to be used in a joint U.S. Navy/U.S. Coast Guard program. As a result of the successful engineering trials noted earlier, the U.S. Coast Guard conducted an operational evaluation of the BH 110 Mk I, commissioned as the **DORADO** WSES-1, in late 1981. In the 75 days subsequent to commissioning, the **DORADO** was underway in the Gulf of Mexico 43 days, with no major engineering or equipment failure, and saw operations involving 11 search and rescue cases, more than 30 boardings for the enforcement of laws and treaties, including the Texas Fisheries closure, research and development testing, aids to navigation outage response, and marine environmental protection rapid deployment capability with the National Strike Force and the Louisiana Offshore Oil Port (LOOP). The **DORADO** was operated by a crew from a U.S. Coast Guard 82-foot patrol boat after only a few hours of familiarization training. The low ship motions, both at high speed and at loiter, combined with generous interior space, resulted in high crew morale, and performance of tasks at sea that were normally possible only at dockside. Vessel maintenance consumed less than 17 percent of the total hours commissioned.

It was found that the spaciousness of the 39.5-foot-beam vessel provided for a quality of life at sea and in port superior to present vessels of comparable size. The same beam provided an extremely stable platform for search and rescue, enforcement of laws and treaties, and helicopter operations or resupply, allowing for greater vessel safety and mission efficiency.

It was concluded that **DORADO** was an exceptional asset. In the law enforcement mode, **DORADO** could prosecute an aircraft sighting report in 2 or 3 hours, compared to half a day, and make contact as opposed to generally losing it. **DORADO** responded to a burning pleasure craft offshore, arriving on scene before a helicopter. During the National Strike Force exercise at the LOOP facility, **DORADO** towed the fast delivery sled in excess of 20 knots, providing extraordinary response to a simulated offshore spill, as well as a stable platform for on-scene command and control.

After the extensive technical and operational evaluation described above, the U.S. Coast Guard chose the Bell Halter 110-foot SES to modernize its surface fleet. In June 1982, the Coast Guard awarded Bell Halter a contract for the purchase of three 110-foot SESs. In November 1982, the Coast Guard took delivery of the first two of the new class of cutters, which are being used principally for drug interdiction. These new cutters of the **Seabird** Class are designated **SEA HAWK** (WSES-2) and **SHEARWATER** (WSES-3). The **SEA HAWK** and **SHEARWATER** are used to stop, search, and detain illegal drug runners in the lower Gulf of Mexico and the Caribbean. In February 1983, the crew of the **SEA HAWK** seized almost 3.5 million dollars worth of marijuana. Using the high-speed patrol ship, the crew seized the drugs after stopping and boarding a 41-foot sailboat 300 miles southwest of Key West, Florida. The third SES cutter, designated the **PETREL** (WSES-4), was delivered to the USCG in June 1983. The **SEA HAWK** and **SHEARWATER** are shown in figure 4.

E. U.S. Navy SES-200 Program

Following the Coast Guard operational evaluation of the BH 110, Bell Halter added a 50-foot hull extension to the boat for the Navy. This decision was based on the fact that engineering analyses and model tests showed that a higher length-to-beam ratio vessel could offer increased useful load at the cost of a small loss in maximum speed. Just as the 727/DC9 type airplanes have been stretched, the first BH 110 was cut in half and a plug inserted to increase the overall length to 160 feet (see figure 5). The Navy then designated the craft the SES-200. The SES-200, the world's largest surface effect ship, was delivered to the Navy on September 24, 1982.

Prior to delivery of the SES-200 to the Navy, Bell Halter carried out a series of photographic missions with the 160-foot craft using a chase helicopter. During these operations, the helicopter cautiously made progressively closer approaches to the SES, while the latter was operating at 30 knots in 4- to 5-foot seas. Although no landings were permissible on the Navy vessel, the chief helicopter pilot stated that the smooth airflow over the aft deck of the SES and the limited motions of the wide hull would make the SES an ideal flight deck for helicopter operations. Although the deck is not structurally designed for a helicopter platform at this time, the rotor clearance and deck area would permit operation of the largest helicopters in Navy inventory.

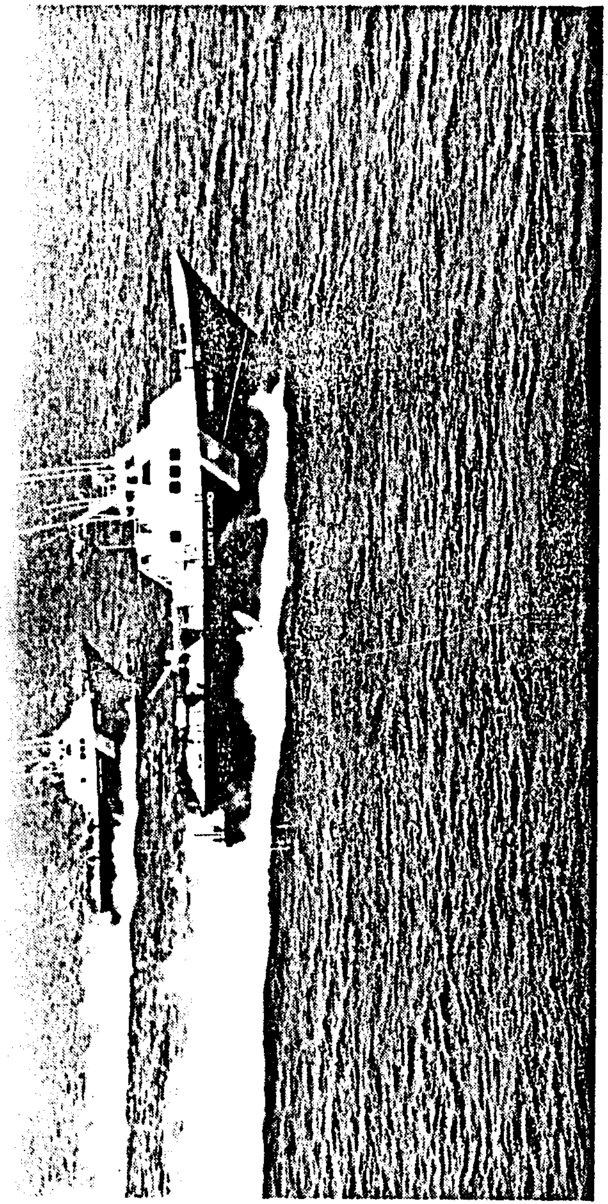


Figure 4 USCG SEA HAWK AND SHEARWATER

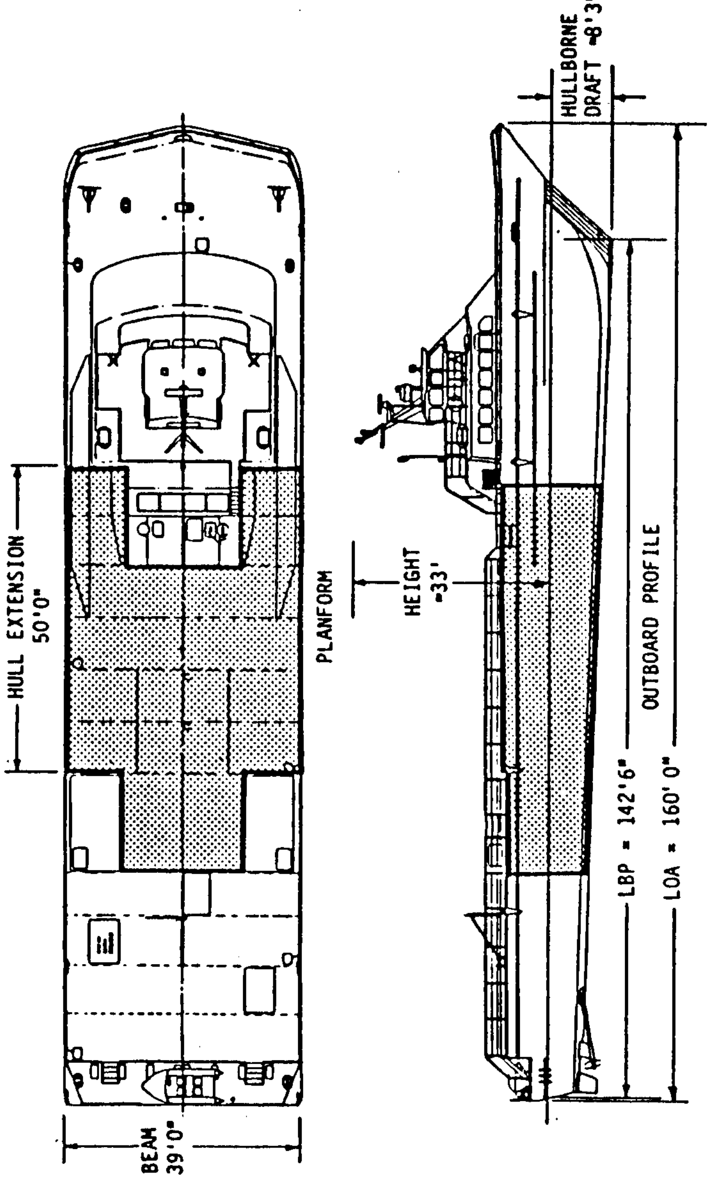


Figure 5 SES-200 HULL EXTENSION

On September 28, 1982, the SES-200 completed a record-breaking transit from New Orleans, Louisiana, to Patuxent River, Maryland. The transit, which began on September 25, 1982, was a 1,550-nautical mile, nonstop, nonrefueling voyage in which the SES-200 averaged 23.4 knots. The SES-200 Officer-in-Charge stated: "I really enjoyed the transit and we had no major problems . . . the SES-200 performed in an outstanding manner."

The SES-200 will be undergoing additional modifications while at the U.S. Navy Surface Effect Ship Test Facility in Patuxent River, Maryland. A digital ride-control system will be installed, along with a significant test and evaluation data acquisition system. The purpose of this effort is to undertake a comprehensive technical evaluation, in conjunction with the U.S. Coast Guard research and development efforts, of the engineering and operational characteristics of the high length-to-beam SES-200.

(1) High Length-to-Beam (L/B) SES

The cushion L/B ratio is a fundamental design parameter that must be selected in accordance with the operational requirements for the vessel. Low L/B designs result in higher drag at the so-called hump condition, but offer low drag at high speeds. Conversely, high L/B designs effectively eliminate the drag peak at hump, but result in increased drag at high speeds.

Other characteristics also result from the choice of L/B ratio. Lateral stability considerations impose practical limits to the cushion height for a given beam. Therefore, it will be evident that a high L/B craft will have a lower cushion height and, hence, lower wave clearance capability than an equivalent displacement low L/B vessel. Stated another way, for a given required sea state capability, a high L/B SES must be larger than a low L/B design. Because of the laws of Froude scaling, however, the hump speed of an SES increases with size; so large, high L/B designs are able to cruise at relatively high speeds in an efficient, subhump condition. Therefore, it can be reasoned that small, high-speed craft should be low L/B, and that high L/B becomes more attractive with increasing size or with reduced maximum speed requirements.

A key part of the overall U.S. Navy program to develop a high L/B ratio SES is the test and operation of such craft. As stated previously, Bell Halter modified the BH 110 by adding a 50-foot structural plug amidships, resulting in a high L/B craft. The SES-200 will have demonstrated all of the basic technology and many of the operational features of larger high L/B craft, similar to the SES-1,000 described below. The SES-200 was placed in operation in 1982 and is being used by the Navy as a test craft for verifying range-speed-payload performance and to evaluate candidate weapons systems for future Navy SESs.

Figure 6 shows the drag versus speed relationship for the BH 110 and the SES-200 for representative displacements of each craft. The useful load for the SES-200 is about 60 percent greater than that of the BH 110, using the same propulsion machinery.

At speeds less than 28 knots, the drag of the higher L/B craft is less than that of the low L/B, despite the significantly greater displacement.

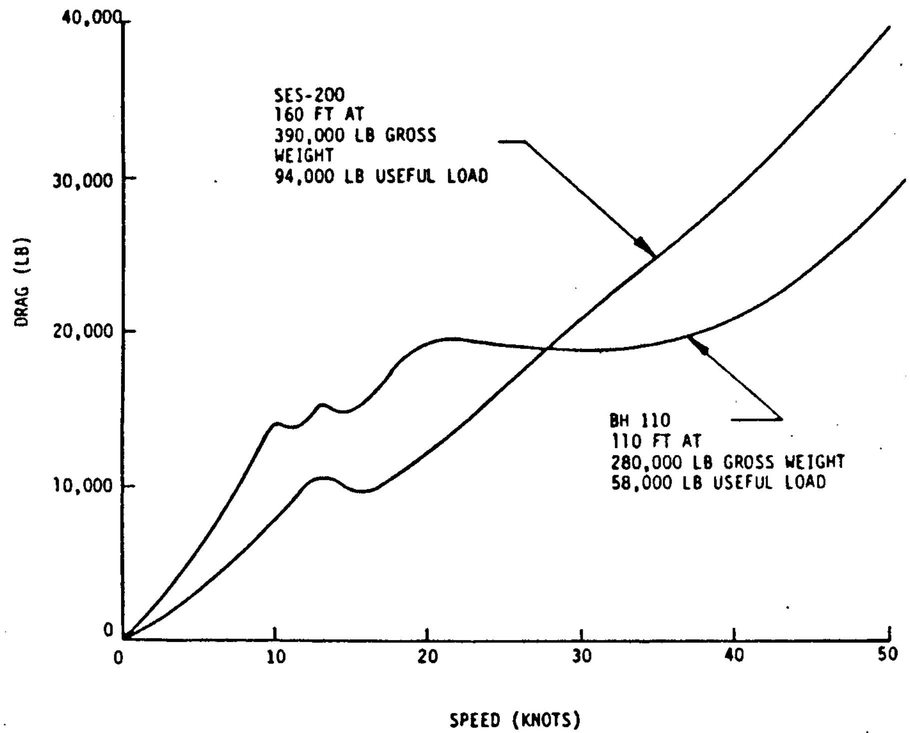


Figure 6 DRAG VERSUS SPEED FOR VARIOUS SES VESSELS (SS 2, TYPICAL DISPLACEMENTS)

With its large deck area and below-decks volume, and with the excellent motion and stability characteristics offered by the SES hullform, such vessels are ideally suited as weapons platforms. It is because of these features, together with the attractive performance capabilities of these craft, that the SES-200 can be equipped with various weapons systems elements and used as a test craft for evaluating that equipment.

While the performance of the standard BH 110 is significantly greater than comparably sized conventional planing craft, still higher speeds (40- to 45-knot range) may be required for some Navy missions. Since the hullform of the BH 110 is configured for speeds in excess of 60 knots, achieving 40 knots is primarily a matter of installing higher power diesels and selecting a different propeller.

Adding power to the BH 110 requires that the 1,600-hp Detroit Diesel 16V-149TI engine and fixed-pitch propellers be replaced with a 2,500-hp diesel engine and controllable-pitch propellers.

F. U.S. Navy SES Program

Through its BH 110 program, Bell Halter has evolved a sound, practical SES hullform that draws on two decades of technology development to provide a moderately high-speed, fleet-compatible surface effect ship of balanced design for the U.S. Navy. A 1,000- to 1,800-ton SES low-risk design (using a proven hullform, conventional marine systems, demonstrated seal designs, and standard machinery), while not replacing any of the larger Navy ships, could be an adjunct to the fleet at the lower end of the payload/range spectrum, that is, the low end of the high/low mix.

One typical 1,000-ton design based on the Bell Halter large displacement sidehull hullform is shown in figure 7. It uses diesel engines for both lift and propulsion power, with twin, controllable-pitch propellers. Ample deck-space at the second deck level and on the main deck and the 01 level is available for accommodating all personnel and mission equipment.

Machinery systems are located in the sidehulls and on the second deck. Fuel is located in the lower sidehulls, in tanks spaced for good center-of-gravity control. All sonar equipment, housed below the helicopter landing pad, is arranged for deployment through the transom. A permanent helicopter hangar, just aft of amidships, is equipped for performing routine maintenance and servicing.

The combat suite includes a forward-located 76-mm deck gun and a close-in weapon system (CIWS) positioned on the 02 level. An MK 92 fire control system is provided for controlling these weapons.

The ship complement is 100, with accommodations for 10 additional personnel available.

Although this 1,000-ton SES (table II) is designed with a speed capability of 40 knots using diesel engines only, higher speeds can be provided with a combined diesel and gas turbine (CODAG) or combined diesel or gas turbine (CODOG) arrangement. Combining diesels and gas turbines offers distinct

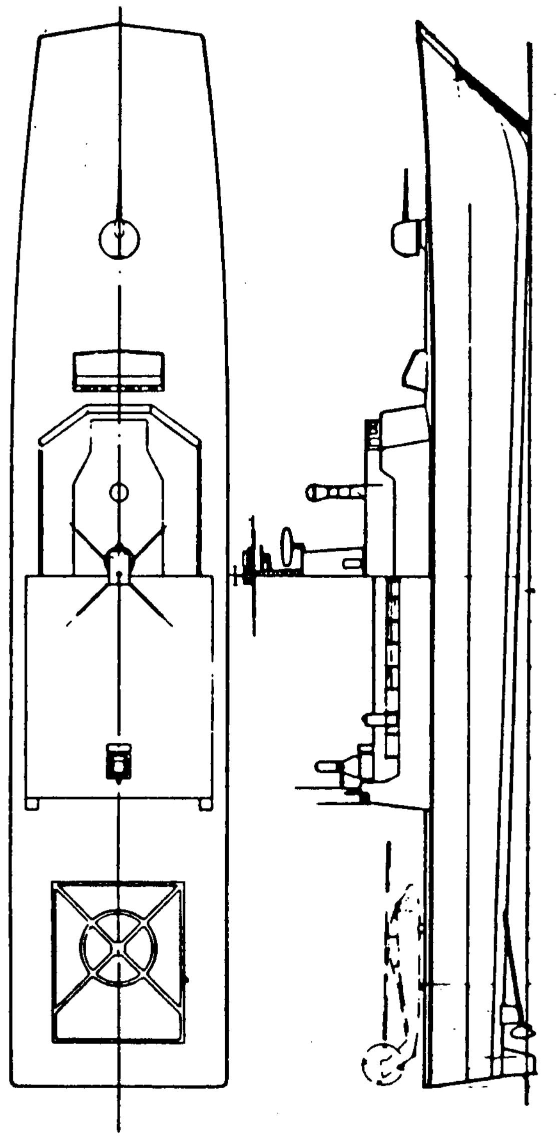


Figure 7 1,000-TON SES DESIGN

performance advantages for a somewhat higher first cost and support costs. The two major performance advantages are improved dash speed in excess of 50 knots and more efficient low-speed and medium-speed operations. In addition, the noise signature should be more favorable with turbines.

TABLE II

BELL HALTER 1,000-TON SES DESIGN PRINCIPAL CHARACTERISTICS

Length Overall	276 feet
Beam Overall	58 feet
Normal Displacement	1,000 long tons
Max Speed:	
Calm Water	40 knots
Sea State 3	38 knots
Range:	
At 40 knots	2,500 nmi
At 20 knots	4,400 nmi
At 15 knots	5,500 nmi
Payload Weight	150 long tons
Propulsion Power Continuous Rating (Max Power Rating, 8,400 hp Each)	(2) 7,000-hp Diesels
Lift Power Continuous Rating	(2) 2,200-hp Diesels

The decision to go to a CODAG or CODOG arrangement must depend on the ultimate mission requirements to be established by the Navy. However, diesels and gas turbines, with the proper ranges of power, are available for either the CODAG or CODOG design.

The 1,000-ton class SES low-risk design uses proven hullforms, conventional marine systems, and demonstrated subsystems. It would require no new manning skills or training and should be compatible with the existing fleet operations. Although its payload, weapons system, and range capability are less than the FFG-7 (**Oliver Hazard Perry** Class Guided Missile Frigate) (see table III), its capabilities are close enough to that ship to suggest that it could be used for some of the less demanding missions presently requiring the

FFG-7, hence, allowing the deployment of the larger, more expensive ships to the more critical mission requirements.

TABLE III

CAPABILITIES OF SEVERAL COMBATANT CRAFT

SHIP	DISPLACEMENT (L. TONS)	OVERALL LENGTH (FT)	MAX SPEED (KT)	COMBAT PAYLOAD
1,000-Ton SES Design	1,000	276	40	2 LAMPS Helicopters 8 Harpoons 1 76-MM Gun 1 CIWS Towed Sonar
FFG-7	3,605	445	29	2 LAMPS Helicopters 40 Harpoons 1 76-MM Gun 2 Triple Torpedo Tubes Hull Mounted Sonar
WMEC	1,780	270	19	1 LAMPS Helicopter ? Harpoons 1 76-MM Gun 1 MK 36 RBOC Towed Sonar

Figure 8 compares the range and speed characteristics of the SES with estimates for the FFG-7, and the WMEC (270-ft **Bear** Class Medium Endurance Cutters). Figure 9 shows the relative planforms of each craft. When comparing the WMEC and the SES, there is a direct equivalence at a speed capability of up to 19 knots; the SES could effectively carry out all of the WMEC missions. However, with its speed capability of up to 40 knots, the SES-1,000 will provide additional capability, particularly in the prosecution of intercept missions. The SES offers about 20 percent less range than the FFG, but it will still have a transatlantic capability, combined with dash speeds of 40 knots. As a complementary ship to the FFG, it will be available at a significantly lower acquisition and operating cost, while providing good seakeeping characteristics, large usable volume and deck area, and open ocean capability.

An analysis of the efficiency of the 1,000-ton SES and the FFG shows that allowing for the different allocation of the useful load to fuel and weapon suite, the efficiency in terms of payload ton miles per ton of fuel is the same.

The design of a conventional displacement hull, such as that of FFG-7, will require high length-to-beam ratios approaching 10, in order to achieve low hull resistance and a good efficiency. When smaller conventional ships

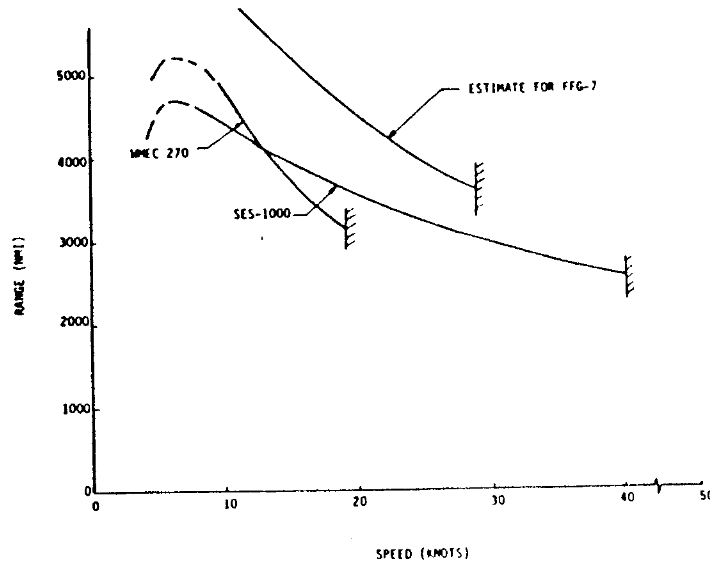


Figure 8 SPEED/RANGE COMPARISON BETWEEN THE 1,000-TON SES AND OTHER SHIPS

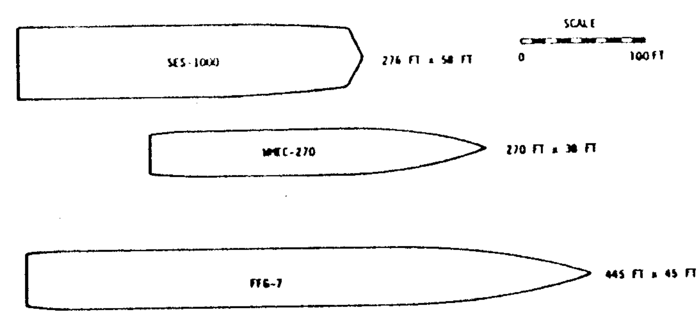


Figure 9 SHIP SIZE COMPARISON

such as the WMEC 270 are designed, a high length-to-beam ratio would result in an unacceptable ship beam and inadequate roll stability with the installation of the heavy military equipment. As a result, the naval architect has no choice but to select a lower length-to-beam ratio and accept a reduced hull efficiency.

On the other hand, the SES hull, with the same overall length as the WMEC and an even greater beam and roll stability, can achieve the efficiency of the larger conventional ship.

Preliminary design studies have also focused upon an SES combatant of approximately 1,500 tons displacement. The weapons suite includes a 76-mm rapid fire gun forward, a helicopter landing pad and maintenance hangar aft, and an array of vertical launch missiles amidships. The missile compartment is particularly compact, because the missile exhaust is directed into the cushion, thus avoiding the weight and space required for ducting hot gases back through the weather deck. The principal characteristics of this vessel are shown in table IV, and its general arrangement is shown in figure 10.

TABLE IV

PRINCIPAL CHARACTERISTICS OF 1,500-TON COMBATANT

Length Overall	327 feet
Beam	62.5 feet
Cushion Length	291 feet
Cushion Beam	52.3 feet
Displacement	1,500 long tons
Light Ship	782 long tons
Weapons Load	198 long tons
Fuel	520 long tons

A number of power options are available, including CODOG, CODAG, and all turbine machinery packages. Table V summarizes some typical engines available and the corresponding ship performance with each. Range at maximum speed will be in excess of 2,000 nautical miles, while range of the CODOG or CODAG versions on diesel power only will be 4,000 to 6,000 nautical miles, depending upon cruise speed.

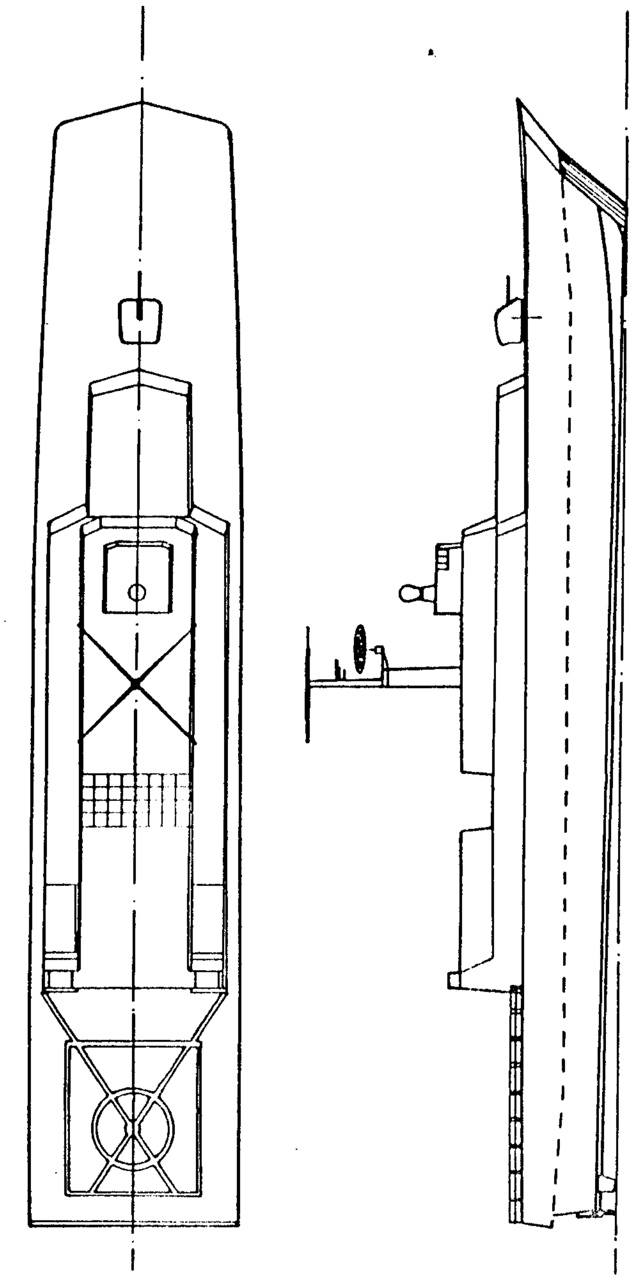


Figure 10 1,500-TON SES COMBATANT

TABLE V

1,500-TON COMBATANT POWER OPTIONS

MACHINERY ARRANGEMENT	ENGINES	POWER PER PROP CRUISE/DASH (SHP)	MAX SPEED IN SS 3 (KNOTS)
CODOG	SACM 195 V20/LM2500	5,400/25,000	58
CODAG	SACM 240 V16/Allison 570	8,400/15,400	46
All Turbine	(2) Allison 570	7,000/14,000	44
	GE LM2500	25,000	58

The key to good cruising efficiency over the entire speed range is the propeller system, which has been the subject of intensive study for the past several years. The propeller is a partially submerged supercavitating, controllable-pitch unit, designed by Bell using recently developed computer programs. It is 14.5 feet in diameter and operates at 50 percent submergence at high speed, on cushion, and 100 percent submergence at low speed off cushion. The blades feature modest degrees of rake and skew and have been thoroughly analyzed for structural strength and fatigue life.

It can be stated with confidence that the surface effect ships described above are low-risk and straightforward designs. They draw on proven design features and require no research or technology developments. Furthermore, they would provide performance capabilities superior to that of ships of equivalent class by offering high-speed and fuel-efficient operations with conventional marine systems. Their ride and motion characteristics would represent significant improvements with respect to conventional hulls. The SES is a balanced design, which is fully fleet-compatible in terms of ship speed/range capability, crew requirements, and support requirements.

G. The Minesweeper Hunter (MSH) and the Patrol Boat, Multi-Mission (PBM)

Bell Aerospace Textron has recently received two U.S. Navy awards for the application of the SES design to a minesweeper hunter (MSH) and a patrol boat, multi-mission (PBM).

As a minesweeper, the SES design, combines the advantages of an air cushion vehicle design, where the area of hull contact is minimized, with the endurance and control characteristics of a conventional craft. The air cushion under the vessel will make the MSH much less susceptible to underwater shock from mine explosions. The air cushion also reduces the underwater acoustic and pressure signatures of the vessel, making it less likely that

today's sophisticated mines will be triggered before they can be detected and neutralized by the systems carried aboard the MSH. This concept offers a dramatically new improvement, reducing the risk and cost of minesweeping.

The PBM is a new class of high-performance patrol boat, capable of carrying a variety of modular combat systems and will be designed to operate out of the well deck of existing amphibious assault ships.

H. Future Developments

The present Bell Halter design and development programs include military and commercial applications for SESs with maximum speeds from 30 to 50 knots.

One of the basic design decisions for SESs is the selection of the length-to-beam ratio. As discussed, there has been a tendency to see this as two ends of a spectrum with the designer's choice being simply low length-to-beam (about 2:1) or high length-to-beam (about 6:1).

However, the recent Bell Halter research, which has included analytical studies and tow tank tests, indicates that there may be no such clear demarcation, that the selection of the length-to-beam ratio may be anywhere between 2:1 to 7:1, and that for certain applications, some intermediate value of L/B may be optimum. In effect, length-to-beam becomes just another design parameter with a continuous range for selection by the designer.

An example of a design tradeoff with respect to the variation of length-to-beam is the recent design work that Bell Halter has carried out on an oceangoing, air-capable patrol boat, which could be applied to U.S. Coast Guard patrol boat and medium endurance cutter missions. The original design was a 130-foot SES with a cushion length-to-beam of 2.8, capable of almost 50 knots maximum speed in sea state 0, and 40 knots in sea state 4, with 11,000 hp total installed. With a typical patrol boat weapons suite, including the stowage of a LAMPS II helicopter, the fuel was sufficient for a range of 740 nautical miles in calm seas. Further design analysis varying the length of the craft from 130 to 160 feet (in effect increasing the length-to-beam ratio for the constant beam of 49 feet) showed that there would be some reduction in maximum speed. However, stretching an SES increases the lifting area of the cushion and, if it was assumed that the military payload would remain constant and all the additional useful load lifting capability of the SES used to increase the fuel capacity, then there was a very significant increase in the range capability. This is shown in figure 11. The selection of an overall length of 154 feet resulted in a reduction in the maximum speed capability to 44 knots in calm water, but an increase in the range in calm water to 1,500 nautical miles at maximum speed. In all of the mission analysis studies carried out to date, the significance of this increased range has far outweighed the loss in maximum speed.

Obviously, additional range could be obtained for this design with a further increase of length, and design studies are continuing to determine the tradeoff in performance. The requirement for open ocean performance for this patrol boat dictated the selection of a cushion clearance at the bow greater than that of the Bell Halter 110. For the selected clearance height of 9 feet, it was then necessary to design a boat with an overall beam of 49 feet

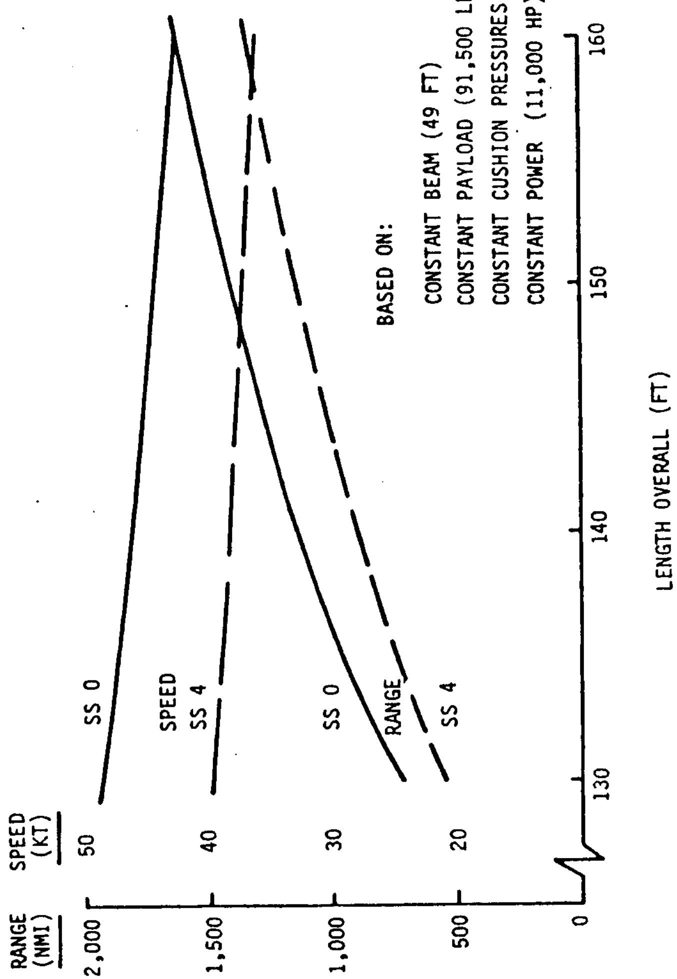


Figure 11 EFFECT OF CRAFT LENGTH ON PERFORMANCE MEASURES

in order to provide adequate roll stability. Therefore, it is considered that for the particular mission under consideration, a further increase in the length of the ship with this beam could result in too large and too expensive a hull.

The U.S Coast Guard operations with the BH 110 showed considerable potential for offshore patrol boat applications. The maximum range for the BH 110 in the Coast Guard patrol boat configuration with additional fuel tanks is 1,600 nautical miles at the maximum speed of 30 to 34 knots and 2,900 nautical miles at the economical cruising speed of 10 knots. While this is adequate for coastal patrol boat operations, it is necessary for the BH 110 to refuel from a medium endurance cutter for prolonged ocean cruises. Based on the developments with the U.S. Navy SES-200 design, a 160-foot patrol boat configuration has been developed (figure 12). This SES, with a length-to-beam ratio of 4.5, will have a maximum speed of only 2 knots less than the BH 110 with the same installed power, but a range of 3,000 miles at maximum speed and up to 10,500 miles at an economical cruise speed of 10 knots (assuming that all the additional useful load is allocated to fuel).

It must be emphasized that the range figures quoted are the maximum that could be achieved, and that in the final configuration selection some reduction in the maximum range may be accepted, in order to allocate some proportion of the increased useful load to the weapon suite.

In summary, it appears that with the selection of the appropriate length-to-beam ratio, the application of SESs to patrol boat missions can be optimized for the specific requirements of each mission and will allow the optimum selection of speed, maneuverability, and range.

SUMMARY

The Bell Halter SES program that started in 1977 has now achieved successful military and commercial applications of the BH 48-foot and BH 110 boats. The predicted efficiency of the large displacement sidehull Bell Halter SES above the state of the art of existing high-speed craft has been validated.

Future applications will consider other larger SESs and a wider range of hull length-to-beam ratios to provide optimum vessels for worldwide applications. Development could include an oceangoing SES of 1,000 to 1,500 tons displacement for both combatant and logistic Navy roles. SES designs at Bell Halter extend to conceptual arrangements of ships having displacements up to 15,000 tons and larger. There are no apparent technological reasons why very large surface effect ships could not be constructed, using multiple installations of 50,000 hp gas turbine engines. However, Bell Halter believes that development should proceed in modest steps, using an evolutionary approach based on successful hardware, such as the BH 110 and SES-200. Future development, so desirable for both national defense and commercial applications, will depend heavily upon success at each step. Bell Halter has demonstrated that a rational, conservative approach to design can offer the many advantages of the SES hullform, without the cost and controversy that occur when high-risk development encounters technical obstacles.

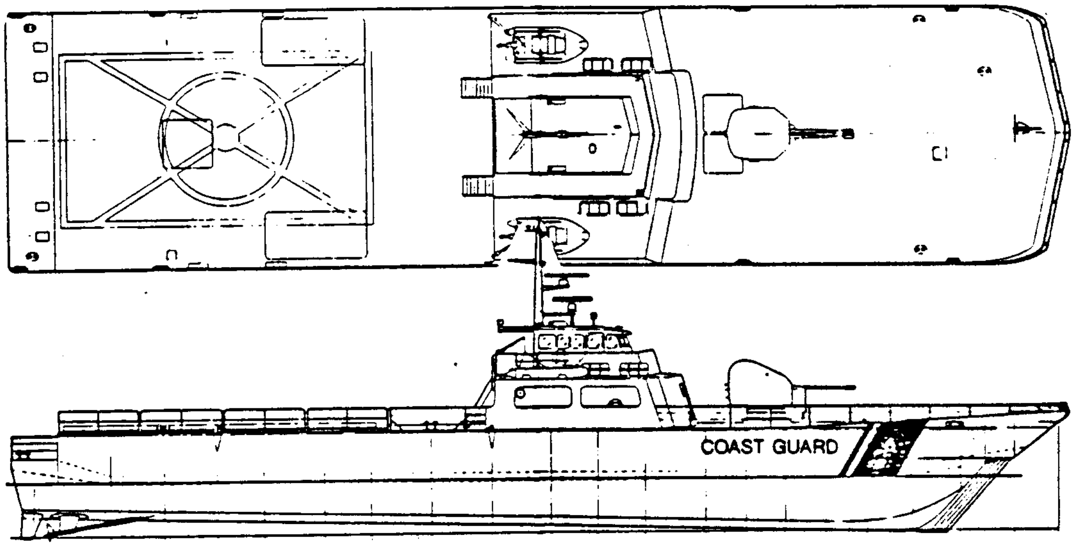


Figure 12 BH 110/160 SURFACE EFFECT PATROL CRAFT PROFILE