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The Atlantic Center for the Innovative Design and Control of Small Ships: Surface Effect Ship (SES) Test Program

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Abstract

The Office of Naval Research (ONR) established the National Naval Responsibility (NNR) for Naval Engineering program in order to maintain and strengthen the United States expertise in Naval Architecture and Marine Engineering disciplines. The primary mission of the NNR program is to ensure the presence of a strong Naval Architecture and Marine Engineering discipline in the United States for future generations of innovative ship design. The Atlantic Center for the Innovative Design and Control of Small Ships (ACCeSS) is a consortium of researchers from academia and industry that was established in order to support this ONR initiative. The academic members of ACCeSS include faculty and students from within the departments of Naval Architecture, Marine Engineering, Ocean Engineering and Systems Engineering of the U.S. Naval Academy, Stevens Institute of Technology, Webb Institute and University College of London.

In endeavoring to support the ONR NNR, the ACCeSS team has incorporated several students – both undergraduate and graduate – within all of its technical activities. This paper provides an overview of the efforts and projects undertaken by the ACCeSS members, and then discusses in some depth one of the technical projects performed by an undergraduate student at the U.S. Naval Academy with support from a faculty member as well as an engineer from a consulting company. The project is a physical hydrodynamic model test program for surface effect ship design and analysis. The project has served to engage students, faculty and industry professionals within and outside of the U.S. Naval Academy in an exciting, technically challenging, multidisciplinary effort that has application to the military and commercial industry.

Introduction

The Atlantic Center for the Innovative Design and Control of Small Ships (ACCeSS) is a consortium of several academic and industry partners. The academic partners include Stevens Institute of Technology, U.S. Naval Academy (USNA), University College of London and Webb Institute. The industry members include AMSEC LLC Group, Lockheed Martin Marine Systems, and VT Shipbuilding.

The ACCeSS consortium was formed as part of the Office of Naval Research (ONR) National Naval Responsibility for Naval Engineering (NNR-NE) program. ONR's NNR-NE program came into being after several years of study[1] of the status of and trends in naval engineering education and naval engineering industry activities. ONR's ultimate intent is to ensure continuing availability of expertise in naval engineering fields to support and carry out future ONR naval engineering science and technology development programs.

The ONR NNR-NE program presently supports six different consortia and cooperative research centers throughout the country, each concentrating on different aspects of naval engineering research and design. ACCeSS' focus, as the name implies, is on high speed, small vessel research, design and operations primarily in the littoral zone. To this end, the ACCeSS members are engaged in a variety of activities including the development of innovative design tools and control systems for small high speed vessels. And perhaps more notably, these ACCeSS activities have engaged undergraduate and graduate students into every aspect of their research and development efforts. The activities have also involved a tremendous amount of cooperation and collaboration between team members, an example of such cooperation is illustrated through the highlighted SES test program focus project discussed later.

A Brief Overview of Selected ACCeSS Research Activities

The academic and industry members of ACCeSS possess a wealth of naval engineering and systems engineering research, design and experimentation experience. In order to benefit from and make use of that knowledge and experience, several projects have been initiated and are presently in progress at the time of writing this paper. One such project involves the development of an extensive database of high-speed vessel experimental model tank test data and analyses. This database is being designed, populated, tested and used in coordination with an innovative design tool also developed by ACCeSS team members. The development of this database and design tool is being lead by the Stevens Institute team members; the database and design tool will soon be "beta-tested" by UCL Masters program students, at which time the students will employ it into their capstone design process.

Other projects currently underway include the development of Control and Automation systems for marine collision and obstacle avoidance. Two students and a faculty member from within the Systems Engineering major at the U.S. Naval Academy have been involved with the development of control and automation systems for surface vessels. Research into advanced and enhanced target sensing systems is also part of the study. Graduate students and faculty from Stevens Institute have been coordinating with the USNA team, applying systems management tools to improve and optimize the architecture system of controls aboard a high-speed littoral vessel. Also being investigated by the two systems engineering groups is operator assistance with general vessel maneuvers and control in order to improve safety and performance during high-risk operations.

A separate but related project on vision-based wave sensing is being lead by a first-class (senior) midshipman in the ocean engineering program at USNA along with two faculty members – one from the Systems Engineering Department and one form the Naval Architecture and Ocean Engineering Department. Vision-based water wave sensing is a technique that has many applications, including the potential incorporation into a pro-active ride control system for high-speed marine vessels. This project researches creating a vision-based wave sensing approach that will be able to determine pertinent wave characteristics, such as slope, height, and frequency.

The main motivation behind this project is to create a ride control system for a vessel which will proactively adjust for the waves the vessel encounters. By enabling the vessel to adjust for waves it has not yet encountered, the vessel's seakeeping characteristics may be significantly improved, allowing it to reach higher speeds. Seakeeping is a major concern for high-speed vessels; therefore factors such as pitch, heave and accelerations need to be limited for habitability as well as structural integrity reasons. In past research and applications, ride control systems have been mainly reactive—meaning the vessel must first move in an undesirable way before the systems responds—but now a vision-based system may allow preemptive actions to be taken before the vessel reaches the wave. Recent laboratory model tests investigating a reactive ride control system show the impressive heave, pitch and acceleration reductions; these improvements may be further enhanced incorporating a proactive wave-sensing system.

After an extensive literature review on vision-based wave sensing was conducted, it was revealed that many unsuccessful attempts to sense waves in a laboratory setting using stereo vision have been documented. However, several concepts contained in the literature such as three dimensional imaging prove to be useful background information. A novel laboratory tank-testing methodology was employed in an attempt to sense and measure the water surface using stereo imagery, despite the limited success of previous attempts found in the literature using somewhat more elaborate methodologies. A series of laboratory tests were performed at Davidson Laboratory, and the analysis of preliminary laboratory tests of the system developed by the ACCeSS team has revealed unprecedented accuracy and clarity with water wave imaging. The results of this project to date already show promise for future developments and continued research in a vision-based wave sensing system. It reveals that a vision-based wave prediction system has potential for active vessel ride control.

The Surface Effect Ship (SES) Test Program

A research and development program investigating Surface Effect Ship hull design application to high-speed littoral operations is also presently underway as part of the ACCeSS efforts. Students and faculty from USNA are leading this effort in cooperation with students and faculty from Stevens Institute. The focus of this program is to develop an experimental SES model test program, with the anticipation that a physical, model-scale test bed will be used to investigate design modifications that will ultimately improve SES performance and make the platform more viable for high-speed military operations. While many laboratory facilities performed SES tests in the 1960s, 1970s and 1980s, very little SES model testing has been performed since then, and currently no other domestic experimental facilities have active SES model test programs.

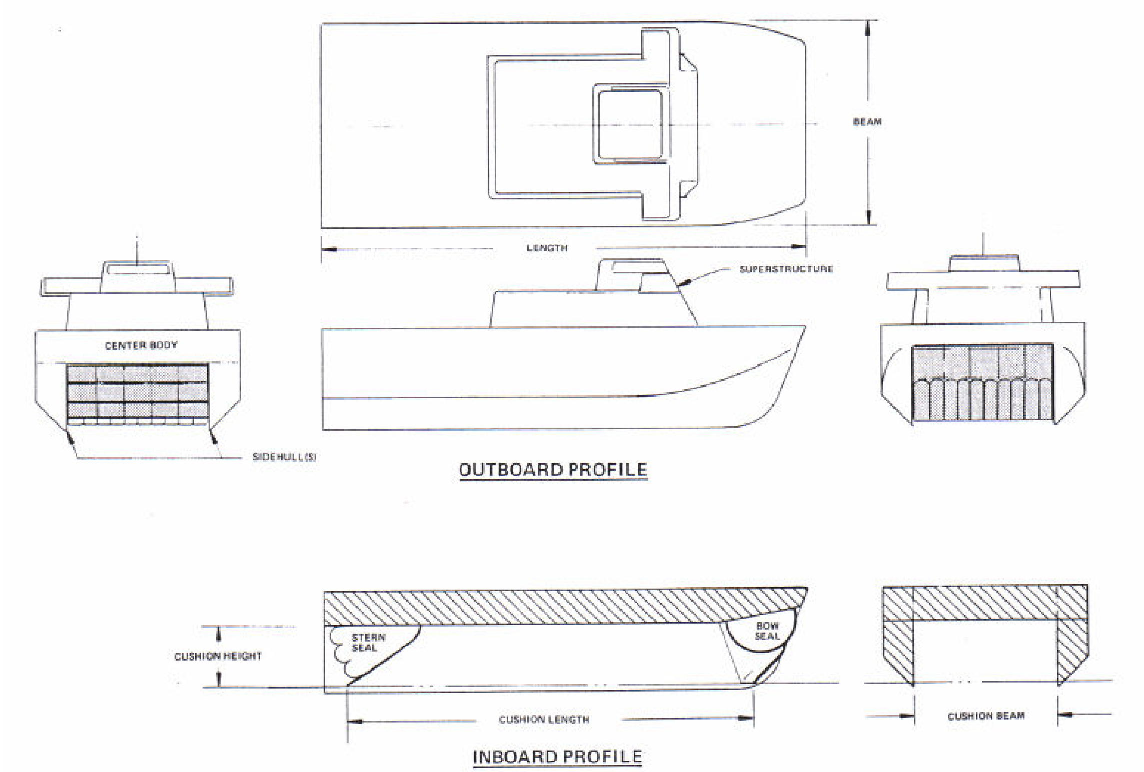

Figure 1: A Generic Surface Effect Ship (SES), from Butler, 1985[2]

Surface Effect Ship (SES) Design Project Background

Advanced marine designs such as hydrofoils, SWATHs, planing craft, and air-cushioned craft have demonstrated the Navy's continual desire to increase military seaborne operational speed. In the 1970's, Admiral Zumwalt encouraged the pursuit of a "100-knot Navy" as Chief of Naval Operations. He saw vast potential in one particular hybrid hull form—the surface effect ship. And now, nearly thirty years later, the SES is still widely considered one of the most promising solutions to our lingering quest for a high-speed warship.

The surface effect ship, conceived by Mr. Ford Allen in 1960, incorporates characteristics of twin-hull displacement vessels and air cushioned craft. Most SES's have a catamaran-type hull under which a pressurized cushion of air is kept. (See Figure 1.) This is made possible by a combination of rigid side hulls and flexible structures at the fore and aft ends of the ship, which are called "seals" or "skirts[3]." Using a high-capacity lift system, air is forced into the void and an air cushion is formed. On-cushion, up to 100% of the vessel's weight is supported by the cushion pressure, greatly reducing the underwater volume and corresponding wetted surface. This ground effect produced over the surface of the water significantly reduces the frictional and wave-making components of resistance for the vessel. For displacement vessels, there is a certain speed, above which a considerable amount of power is required to overcome wave-making resistance[4]. This steep speed/power curve rise is eliminated by the SES concept, which reduces the wave-making component through cushion lift. Although this adds an additional propulsive cost, the overall efficiency at these high speeds is greatly improved. The SES speed/power curve is not nearly as steep as an equivalent displacement hull form, most notably at speeds above 50 knots. Because the SES is essentially a catamaran, waterborne propulsion can be utilized, which provides much higher efficiencies than air propulsion systems at speeds up to about 120 knots.

But with great speed, come significant motions. High-speed vessels are not generally limited by their propulsion but by the vertical accelerations and vibrations at such speeds. These motions create a "human factor," a constraint due to the effects of onboard personnel. Aspirations for high-speed vessels can not be entertained without addressing the human factors—a ship that can sail at 80 knots endurance is useless if half the crew is unable to function. And, in the U.S. Navy, where the ship is only as good as its sailors, the human factor is indeed a dominating force. The SES, with its cushion of high-pressure air, provides reduced motions. And with the current technology, a sea-sensing ride control system, which varies the pressure at various points in the cushion to adapt to the upcoming sea state, is not out of reach.

Yet for the Navy, the SES has remained outside the realm of feasibility. To date, the Navy has been unsuccessful in its many attempts to add the SES to its arsenal. In fact, in the first 25 years of SES technology, over 460 SES's were developed and operational worldwide.[2] Eighteen years later the Navy has yet to capitalize on the valuable technology by commissioning even one SES warship. Several prototypes have been built and successfully tested. In fact, the 3K SES, a 3000-ton frigate derived from the successful 92-knot prototype SES-100A, was only three weeks away from the initiation of hull construction before the program was terminated in December of 1979.[5] Since then the Navy has shied away from the concept, relying on the "tried and true" hull forms—primarily conventional monohulls.

But the mission of the Navy has shifted drastically over the past decade, and is now in a position where the speed of an SES could prove increasingly effective. For the Navy, the SES could provide a sound and promising hull form, adding mission flexibility with its speed, stability, cargo-carrying capability, maximum flight deck area, and sustainability. The SES is currently one of the top three hull forms in the running for the Littoral Combat Ship (LCS) contract. Original concepts for the LCS began in the Office of Naval Research near the turn of the century, outlining a small, fast, maneuverable, and relatively inexpensive member of the DD(X) family of ships. The goal is to develop a small, agile vessel capable of a wide variety of littoral missions including countermine, anti-submarine, surface, and even strike warfare. The required speed and agility of such a vessel are essential elements, vital to its mission criteria. It must have the capability to operate at low speeds for littoral operations as well as the endurance for long open-ocean transits with a given battle group. Ultimately, the LCS must have the maximum sprinting speed necessary to evade/intercept small boat or submarine threats, conduct rapid insertion/extraction missions, and perform interdiction operations.

The SES is well suited for these and other military operations. Due to its relatively rectangular centerbody structure (a block coefficient of 0.7-1.0), the volumetric efficiency of the SES is much higher than that of a monohull of the same displacement, nearly 30% higher in some studies—therefore the displacement is approximately 70% of a monohull with an equivalent cargo-carrying capability.[2] The low draft of the SES allows operations in shallow littoral waters and makes the vessel virtually immune to the threat of mines, torpedoes and other types of underwater shock. With a relatively wide beam, the SES is highly suited for military payloads, and can easily be reconfigured according to mission criteria. Propulsion and cushion pressurizing equipment can be arranged for port and starboard redundancy, providing even greater survivability. And, paramount to its high-speed requirements, the SES is one of few hull-forms in the world with the potential to actually sustain high-speed operations without ignoring the human factors.

Under the NNR-NE initiative, since undergraduate and graduate students were given the opportunity to conduct research on advanced marine vehicles, ranging from the practical to the radical, the SES platform was chosen for its mission flexibility and potential for advancements such as ride control systems and hybrid hull modifications (such as t-foils on the side hulls to minimize lift requirements).

The SES Model Tests

The first step in conducting testing of an SES was to procure a suitable model. After extensive searching for available models from various sources, a set of lines corresponding to a generic high length-to-beam ratio (L/B) SES hull were provided by a local engineering consulting firm. From these lines, the USNA Model Shop constructed the model, using advanced composites to reduce the structural weight without sacrificing rigidity. The final product was a model with a length of 7.8 ft (2.4 m), resulting in a 1/64 nominal scale SES, whose principal characteristics are shown in Table 1.

Table 1: SES Model Particulars

	Model	**Full-Scale**
L_{OA}	94.5 in	504 ft
L_{PP}	89.4 in	477 ft
B	24.4 in	130 ft
L/B	3.67	3.67
T, hullborne	3.6 in	19.2 ft
Δ at DWL	74.3 lb	8700 LT
A_C (Cushion Area)	11.5 ft^2	47,000 ft^2

With the raw model built, the next step was to outfit the model for hullborne (off-cushion) as well as on-cushion tests. Figures 2 and 3 show the model prior to outfitting and after outfitting, respectively. Determination of the desired cushion pressure and flow rate for skirt construction was performed as well, with the skirt design and construction being performed by Brian Forstell of CDI Marine Company. (Note: the total weight supported by the cushion is assumed to be 80%.) Tests were performed in Davidson Laboratory's tank 3, since USNA's Hydromechanics Laboratory was not operational due to flooding damages endured in September 2003.

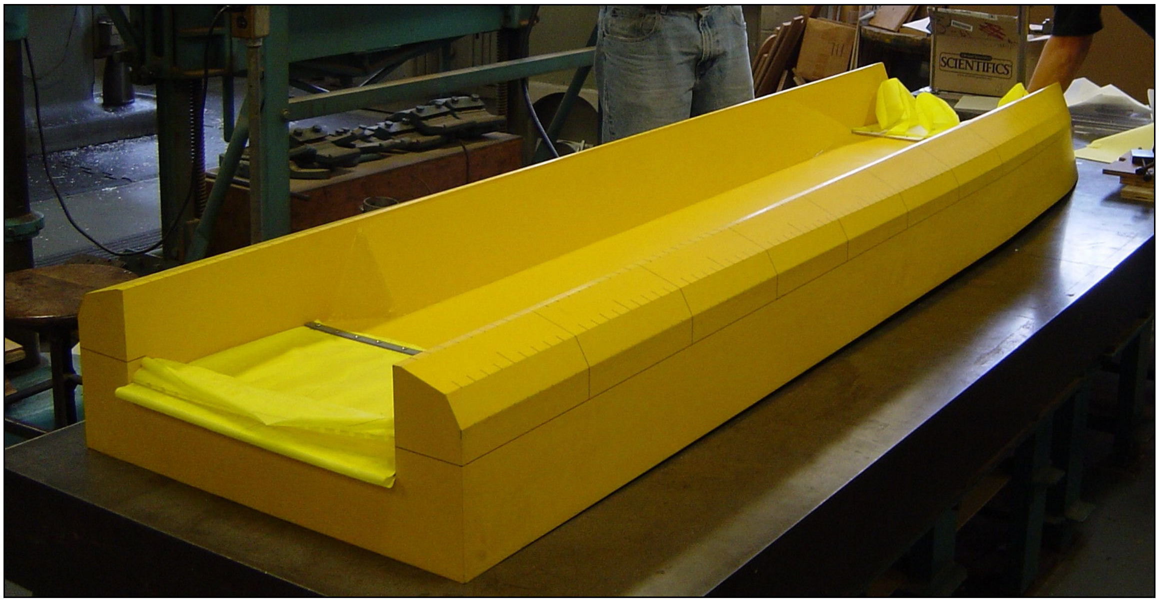

Figure 2: SES Model, prior to outfitting

Figure 3: SES Model, underway cushion-borne in Davidson Laboratory Tank 3

SES Model Test Results

A test matrix was developed using accepted SES scaling methods (see Lavis[8]). A total of two displacements and three LCGs were tested hullborne. One displacement and two LCGs were tested in the on-cushion condition. Calm-water tests as well as tests in sea states 4, 5, and 6 were conducted. The model was free to heave and pitch, but was constrained in all other degrees of freedom. Model speed, resistance (drag), heave, pitch, accelerations at two different locations, as well as cushion pressures at three separate locations were all measured and recorded. The hullborne speeds tested ranged up to a corresponding 50 knots full-scale. On-cushion tests included a range of speeds corresponding to a maximum of 100 knots full-scale.

While data analysis is presently on-going for the SES model results, the tests were clearly successful in developing an SES model-scale experimental test-bed. Preliminary analysis of the hullborne results correlate extremely well with existing published data for high L/B SES craft. A sample plot of the hullborne resistance in high sea states is shown in Figure 4.

Since baseline results have successfully been obtained for the vessel's "bare-hull" performance, the ACCeSS SES model test program now has the potential to investigate additional system enhancements such as those mentioned previously to improve SES performance, and perhaps make the SES platform more attractive for high-speed littoral military operations.

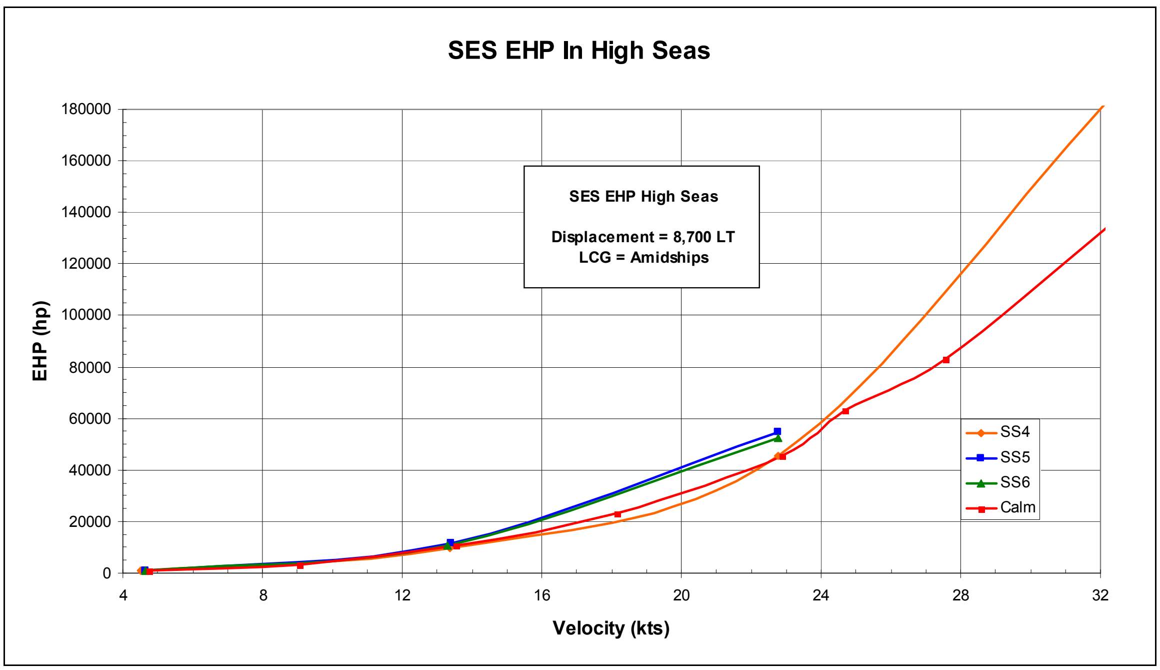

Figure 4: Sample SES Model Test Results, hull-borne tests performed at Davidson Laboratory

Conclusions

The ACCeSS projects described here have proven to be an attractive vehicle for increased student involvement in research related to naval engineering. It is anticipated that the SES program discussed here, as well as the other projects mentioned, will continue to attract students to naval engineering research, by engaging them in interesting and exciting research that is likely to impact their future careers. It is also apparent that the extensive cooperation and collaboration between the ACCeSS members experienced to date will continue as these research programs that have been initiated continue to develop through time.

Acknowledgements

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