

LIFTING BODY TECHNOLOGY FOR TRANSFORMATIONAL SHIP DESIGNS

Todd J. Peltzer, P.E.
Director of Programs
todd@navships.com
Navatek, Ltd.

SYNOPSIS

The current emphasis on the littorals, and the consequent focus on the use of unmanned surface vehicles, presents the naval architect with a dilemma: how to achieve low-speed seakeeping simultaneously with high-speed efficiency and seakeeping in the same hull form. Neither conventional hull forms (monohull or multi-hull) nor current advanced hull forms (such as SWATH and hydrofoil) are able to achieve these objectives in a single design. Hybrid ship designs employing lifting body technology offer potential solutions to this dilemma. This paper describes the transformational lifting body technology developed by Navatek, and focuses on several current applications.

INTRODUCTION

Due to emerging anti-access and asymmetric threats in the littoral zone, the U.S. Navy is seeking designs for a range of fast, stable, and inexpensive ships and craft to conduct a variety of increasingly important focused missions in the littoral. These missions include: intelligence, surveillance and reconnaissance (ISR); homeland defense/maritime intercept, including prosecution of other small boats; and Special Operation Forces support. It is difficult for conventional ships to meet the desired package of requirements necessary to accomplish many of these missions. Desired capabilities include:

- The agility to conduct extended operations at zero/loiter speeds; transit economically at 30+ knots; but also achieve high speed sprints of approximately 50 knots.
- Stability at zero speed and superior seakeeping to sea state 4.
- Improved range compared to existing ships and craft.
- The ability to carry, launch and retrieve efficiently and safely in rough seas a variety of small manned/unmanned aerial, surface, and underwater vehicles; ideally, the craft would be helicopter capable.

SEAKEEPING REQUIREMENTS

Good performance in a seaway is a pre-requisite for speed. The specific characteristics needed to achieve this performance are: low slamming, low added resistance in waves, and low accelerations. Without good seakeeping at both high and low speed, the performance of a small warship intended to deploy independently in all weather, keep station with much larger vessels and launch and recover a variety of air, surface and subsurface vehicles would be marginal. Current small warships of about 1,000 tons displacement start to experience

slamming at sea state 4 when operating in head seas; smaller ships will experience slamming at even lower sea states. Consequently all current small fast combatants are severely limited by their seakeeping characteristics. Speed loss due to high added resistance in waves, in part a consequence of poor seakeeping, degrades the ship's mission effectiveness. Conversely, good seakeeping characteristics yielding low motions and accelerations will lead to improved operational utility and increased crew effectiveness.

LIFTING BODY TECHNOLOGY

All good ship designs are the result of a number of compromises. Neither conventional hull forms nor existing advanced marine vehicles simultaneously provide: 1) good low-speed motions; and 2) high-speed efficiency combined with good motions. Among advanced marine vehicle types, small waterplane area twin hull (SWATH) ships provide excellent motions across their speed range, especially at low and zero speed, but they are inefficient at high speed. Hydrofoils are very efficient at high speed and have excellent motions while foil borne, but they typically operate within a very narrow speed band, and they have very poor motions characteristics while hull borne.

Navatek's approach to solving this naval architect's dilemma has been to develop hybrid solutions using its patented lifting body technology.

The following definitions are useful in our discussion of this technology:

Lifting bodies. Lifting bodies are underwater appendages with cambered foil cross sections that generate dynamic lift at speed. They are characterized by substantial volume, large planform areas, and low lift coefficients. Figure 1 shows two examples of Navatek-designed lifting bodies with struts.

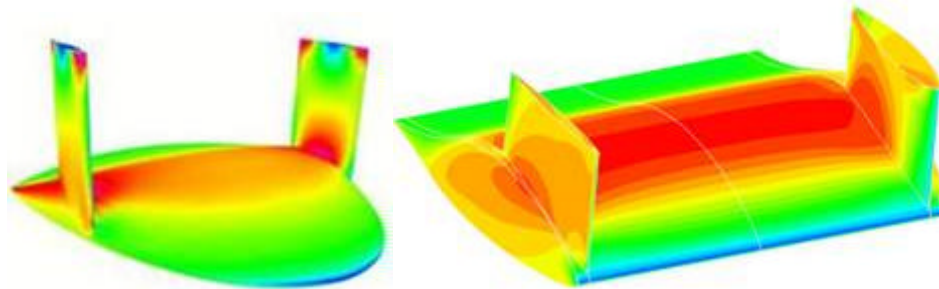


Figure 1 Two Examples of Patented Navatek Lifting Bodies

Hybrid lifting body ships. These are ship designs that combine a conventional parent hull form (monohull or multi-hull) with underwater displacement lifting bodies. Figure 2 (following page) shows examples of two different hybrid lifting body ships.

The potential benefits offered by lifting bodies as part of a hybrid ship include:

- Higher speed
- Higher payload
- Better seakeeping

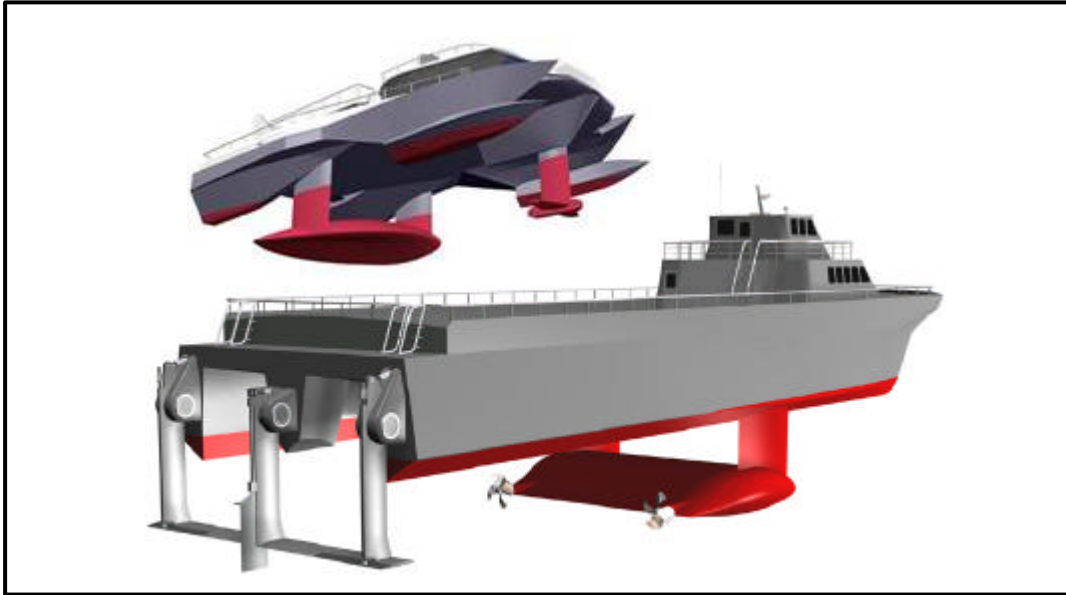


Figure 2 Hybrid Lifting Body Ships: *MIDFOIL* (top) and *HYSWAC* (bottom)

Higher Speed. By transferring displacement volume from the parent hull to the lifting body (or bodies), the wetted surface area of the parent hull is reduced, thus reducing its friction drag. The lifting body itself is designed to be a hydrodynamically efficient shape, with a high lift-to-drag ratio. A key characteristic of lifting bodies is the fact that because of their relatively short length, they operate at a high Froude number ($F_n = V/\sqrt{gL}$) and thus show very little wave drag. Figure 3, which shows a plot of wave making resistance vs. Froude number, graphically illustrates this phenomenon. Lifting bodies may also lend themselves to the application of certain drag reduction technologies such as polymer or micro bubble ejection. An additional consequence of reduced drag is that it results in better fuel efficiency, translating to longer range, increased mission duration, and lower operating costs.

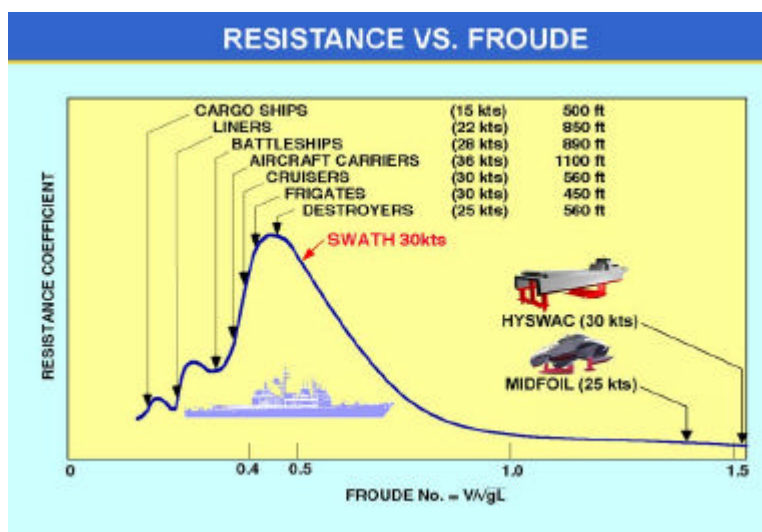


Figure 3 Wave Resistance vs. Froude Number

Higher payload. For a given parent hull, lifting bodies provide added displacement and useable volume. An existing hull design will gain displacement compared to the original, and the volume in the lifting body can be used for fuel

or propulsion equipment. An integrated design, in which the ratio of displacement in the parent hull to that in the lifting bodies is a design variable, can result in a smaller, shorter parent hull. This in turn will reduce the powering requirements and could also potentially result in a smaller structural weight fraction. The consequence of these effects is a larger payload fraction, which in turn translates to enhanced mission capabilities, extended range, or some combination of both.

Better seakeeping. A parallel consequence of transferring displacement volume from the parent hull to the lifting body is reduced waterplane area, which directly results in reduced wave excitation. This in turn leads to reduced motions across the speed spectrum. At zero and low speeds, the passive damping characteristics of lifting bodies, due to their large added mass and viscous damping mechanisms, result in significantly reduced motions. Test data from *MIDFOIL* trials, for example, shows heave accelerations on the order of 0.05 g (rms) in sea state 4 at zero speed. At higher speeds, the potential for incorporating control surfaces into the lifting bodies gives the possibility of adding dynamic control, resulting in even further improvements in seakeeping.

DESIGN AND PREDICTIVE TOOLS

Navatek uses a portfolio of design and predictive tools in its lifting body research and development program, including:

- State-of-the-art computational tools (CFD programs)
- Small-scale model tests
- Large-scale model tests/prototyping

Computational tools. The use of state-of-the-art computational fluid dynamics computer programs is at the heart of our lifting body research. Some of the tools at our disposal include:

- USAERO (AMI)—A commercially available coupled potential flow/boundary layer time-domain simulation program.
- CFX (AEA Technology)—A commercially available Reynolds-Averaged Navier-Stokes (RANS) code for fully viscous flow solutions.
- LAMP (SAIC)—A time-domain simulation system for ship motion, wave loads, and structural responses.
- AEGIR (Anteon-Engineering Technology Center)—A potential flow, Rankine boundary element method for solving linear and non-linear wave flows in the time-domain.

Small-scale model tests. Recognizing the inherent limitations of computational methods, we also employ limited small-scale model testing in towing tanks and recirculating water tunnel facilities. Given the lack of extensive correlation data between model scale and full scale for hybrid lifting body ships, our approach to model testing has generally been to use it as a means to validate our computer tools. Prior to conducting a model test, we use the CFD programs to predict the model scale results; comparison with the data from the test runs then gives us confidence that our predictions at full scale will be valid as well.

Large-scale model tests/prototyping. A distinguishing feature of our research and development program is our extensive use of large-scale models and prototypes. Figure 4 shows *MIDFOIL* configured to gather drag data on a large-scale test body shape. We consider it essential to the success of these ship designs to demonstrate them at a scale at which their features and benefits can be directly experienced by potential customers. Experimental data obtained from these larger scale vessels also provides further validation of our computational tools.



Figure 4 *MIDFOIL* as Experimental Test Platform

Recent testing has included the twin-lifting body configuration shown in Figure 5. The lifting bodies were instrumented to measure hydrodynamic pressures over both upper and lower surfaces, and the main struts were instrumented to measure lift and drag. Data reduction and analysis were ongoing at the time of this writing, but preliminary results showed excellent correlation with CFD predictions. Additionally, the performance of the boat in terms of ride quality and controllability proved to be outstanding.



Figure 5 Lifting Body Testing on 7.5 LT Test Craft in Chesapeake Bay

HULL FORM SELECTION AND INTEGRATION

Careful parent hull form selection, for an integrated hybrid ship design, is essential if the full benefit of lifting body technology is to be realized. Stated another way, the parent hull's characteristics must complement those of the lifting bodies to maximize the benefits.

Ideally, the parent hull form would be able to take best advantage of the reduced immersion provided by the transfer of buoyancy to the lifting bodies, discussed earlier. As one illustration of this principle, Figure 6 shows simplified midships sections for typical round bilge and deep-V hull designs at two different waterlines. For both hull types, as the immersion is reduced the wetted surface area decreases. In the round bilge case, as the waterline shifts from WL_1 to WL_2 , the effective beam remains essentially constant. In the deep-V case, shifting from WL_1 to WL_2 produces a significant change in the effective beam, resulting in an increase in the effective length-to-beam ratio, further improving its resistance characteristics.

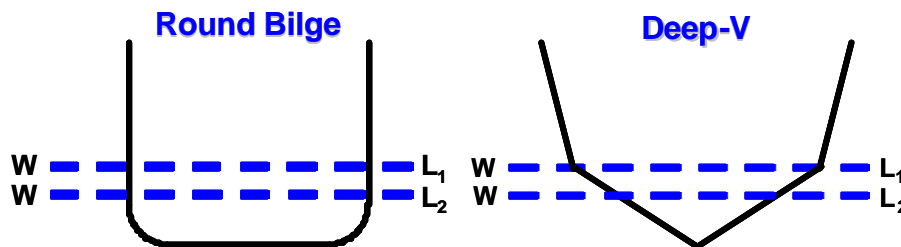


Figure 6 Hull Form Comparison

Other key parameters to consider when selecting a parent hull form include low slamming and low added resistance in waves.

Our search for an appropriate hull form to use as a basis for integrated hybrid ship designs led us to consider the deep-V hull form developed in Europe by Erbil Serter. This hull form series demonstrates all the desired characteristics discussed above, there is a large body of test data available, and there are a number of internationally fielded commercial and military designs in service. Navatek's parent company, Pacific Marine, is the exclusive U.S. licensee for the Serter hull design.



Figure 7 Serter Deep-V Hull Form Model Test

TECHNOLOGY DEMONSTRATORS

Navatek has built a number of vessels over the years that have served as technology demonstrators for its lifting body technology. The first of these was the *MIDFOIL*, a 65-foot, 50 LT boat initially launched in 1998 and then modified and re-launched in 2000. Figure 8 shows the two configurations.



Figure 8 *MIDFOIL* Lifting Body Technology Demonstrator: Original (left) and Modified (right)

The original configuration employed a thick two-dimensional foil fabricated of aluminum, with angled control fins incorporated into the forward floats. The propulsion system consisted of twin 1,000 hp diesel engines driving motor-generators that in turn powered two electric motors located in the foil; fixed-pitch propellers provided thrust.

In the modified configuration a composite three-dimensional lifting body replaced the original foil, the angled fins were replaced with a centerline “T” foil, and the electric drive system was replaced with a conventional mechanical drive train (“V” configured reduction gears in the main hulls and fixed-pitch propellers). The expected advantages of the lifting body over the two-dimensional foil included a) improved drag, b) improved free surface wave characteristics, c) improved stability, and d) higher cavitation speeds, all of which have been amply demonstrated during ongoing trials in Hawaiian waters.

Current lifting body technology demonstration projects in progress at Navatek include the *HYSWAC* and the HDV-100’.

HYSWAC. This is the U.S. Navy’s surface effect ship SES-200 (IX-515) (Figure 9) converted to a small waterplane area configuration using Navatek’s patented lifting body technology (Figure 10); this project is funded through the Navy’s Office of Naval Research (ONR). The principal characteristics of *HYSWAC* are provided in Table 1 (following page).



Figure 9 SES-200 (IX-515)

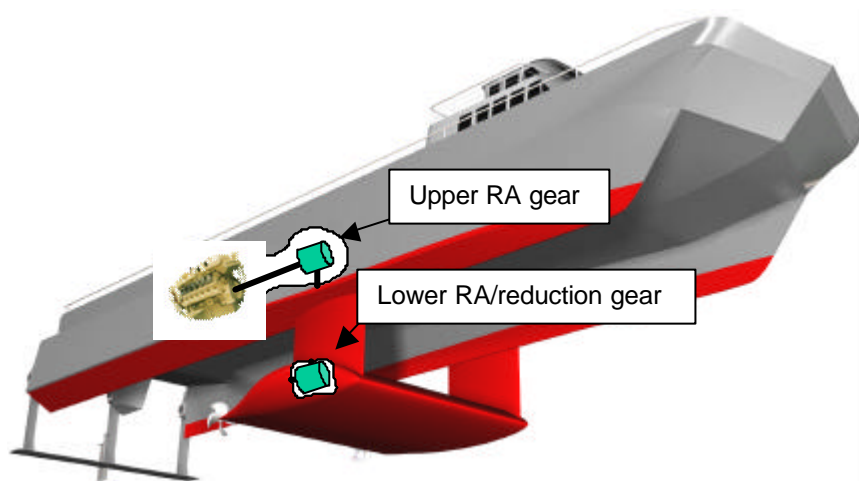


Figure 10 HYSWAC

Length	160 ft (48.8 m)
Beam	43.0 ft (13.1m)
Draft	18.5 ft (5.6m)
$\Delta_{Full\ Load}$	270 LT
Speed	30 knots
Installed horsepower	10,000 hp

Table 1 HYSWAC Principal Characteristics

Conversion of SES-200 into HYSWAC involves, in part, removal of the air cushion forward skirt, aft seal, lift fans and engines, and repowering the vessel. Figure 11 shows SES-200 in dry dock, during which time the waterjet propulsors were also removed. Key features of the HYSWAC configuration include the main lifting body, located roughly at midships and displacing 160 LT; an aft cross-foil, located at the transom; a propulsion system consisting of two 5,000 hp diesel engines, two upper high-speed right angle gears, and two lower right angle/reduction gears; trailing edge flaps on the lifting body and on the aft cross-foil; and an advanced ride control system that will allow the vessel to “fly” in the same fashion as a hydrofoil.



Figure 11 SES-200 in dry dock

The main objectives of the HYSWAC project are as follows:

- Demonstrate the scalability of the lifting body ship concept. With a lifting body displacing 160 LT and a full load displacement of 270 LT, *HYSWAC* represents a significant scale-up from *MIDFOIL*.
- Validate the predictive capability of our design and analysis tools. We expect to gather a wealth of data on the performance of *HYSWAC* that will further validate and help to refine our computational tools.
- Demonstrate the producibility of a large lifting body with large structural loads. The lifting body is being fabricated of marine-grade aluminum using conventional construction techniques.
- Demonstrate the stability and controllability of the lifting body ship concept.
- Demonstrate the superior seakeeping and motions characteristics of the lifting body ship concept. We expect to show excellent zero-speed and low-speed motions due to the lifting body's motion damping characteristics, and also excellent motions at high speeds due to the advanced ride control system.

Completion of the conversion work is expected in late summer of 2003, with sea trials to follow immediately thereafter.

HDV-100'. This 100-foot, 98 LT technology demonstrator will be the first of our new Hybrid Deep-V designs based on the Serter Deep-V hull form. The configuration consists of a deep-V monohull, a twin lifting body and cross foil assembly aft, and a control foil forward. The lifting bodies will be scaled-up versions of the test bodies shown in Figure 5. Outriggers assist with static transverse stability and provide the attachment point for the lifting body struts. Propulsion consists of four diesel engines driving a combination of surfacing

propellers and a controllable pitch propeller. The design speed goal is 50 knots. Objectives for the boat include validation and demonstration of the Serter hull characteristics (reduced slamming, low added resistance), and demonstration of the configuration's stability, controllability, and seakeeping/motions characteristics.

Under construction as of this writing, initially the boat will serve as a research platform, to include demonstration of a polymer ejection friction drag reduction system in the lifting bodies. Ultimately, we expect to outfit the boat as a commercial passenger ferry, as shown in Figure 12, and consequently we are working closely with the American Bureau of Shipping (ABS) on this project to develop classification rules for lifting body ships.

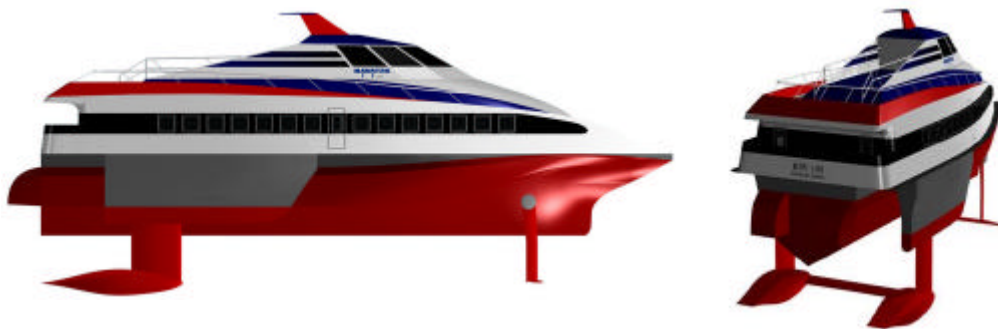
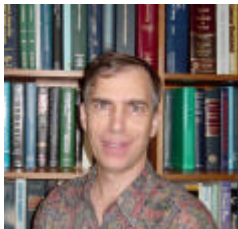


Figure 12 HDV-100' in Passenger Ferry Configuration

CONCLUSION

Lifting bodies and hybrid lifting body ships are an emerging technology with an exciting potential to offer significantly improved performance for a wide range of commercial and military applications.

AUTHOR'S BIOGRAPHY



Todd J. Peltzer joined Navatek in 1999 as a Program Manager supporting a variety of projects including full-scale hydrodynamic measurements on *MIDFOIL* and the AHFID electric drive demonstration. Prior to joining Navatek, he completed twenty years of active duty in the U.S. Navy, attaining the rank of Commander. As an Engineering Duty Officer and Salvage Officer, he gained extensive work experience in ship repair and construction techniques, design and engineering, ship salvage and towing, and deep-sea diving. His assignments included Project Manager for several multi-million dollar ship repair projects on both surface ships and submarines, including the overhaul of a Los Angeles class submarine's nuclear reactor. Mr. Peltzer received a B.S. in Naval Architecture and Marine Engineering from Massachusetts Institute of Technology in 1979, and he received a M.S. in Mechanical Engineering and the advanced degree of Naval Engineer from MIT in 1989. He has been a Licensed Professional Engineer (Mechanical) in the State of Hawaii since 1998. He is an active member of the Society of Naval Architects and Marine Engineers and the American Society of Naval Engineers.