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TESTING ON A LARGE SCALE

Surface effect ship studies demonstrate the value of this naval asset

BY EDWARD LUNQUIST
The Large Cavitation Channel is used to investigate the physical response in the coupled behavior between the SES air cushion, the bow skirts, and the incoming water flow.
New studies are being conducted at the United States Navy's William B. Morgan Large Cavitation Channel (LCC) in Memphis, Tennessee, to test the interaction between surface effect ship (SES) bow seals and the moving water surface. The navy recently invited experts to the facility to observe the LCC being operated in a modified configuration to create a free surface effect.

Although not well known, the LCC is a sizable testing asset in more ways than one. It is a facility of the Naval Surface Warfare Center (NSWC) Carderock Division. While Carderock's David Taylor Model Basin has a world-class reputation as a tow tank for hull testing, the LCC is uniquely capable of performing large scale propulsor evaluation tests—including cavitation—using fully-appended models of surface ships, submarines, torpedoes, and unmanned underwater vehicles. Operational since 1991, the LCC is like a very large wind tunnel, but filled with water and used for high Reynolds number hydrodynamic experimentation. Reynolds numbers are used in fluid mechanics to characterize different types of flow regimes, such as laminar or turbulent flow, and to measure the ratio of inertial forces to viscous forces.

The navy wanted to establish an LCC at Carderock to complement the tow tanks there. Getting such large components into Carderock was a problem. The contractor, Chicago Bridge and Iron (CBI), had a better idea. It fabricated the LCC at its plant in Memphis, Tennessee. This plant, which had as many as 800 employees at one time, manufactured very large pressure vessels for nuclear power plants. These huge structures could then be shipped by barge on the Mississippi.
River. Nuclear power plant construction came to a stop after Three Mile Island, changing the market, and the company has closed their Memphis facility. As a cost-saving alternative, CBI offered to build the LCC in place on-site, and operate it at their now-closed Memphis facility, which had the size to house it.

Dr. Bob Etter, of NSWC Carderock, has been with the LCC since its inception as chief engineer of the project office responsible for design, construction, and initial operation of the facility. "The 40-ft. long test section is 10 feet by 10 feet in cross section," says Etter. "Big enough to mount a 36-ft. long model of a DDG 51 hull—weighing 5 tons fully rigged—suspended from the test section ceiling."

These models are similar in size to those used in the largest tow tank at Carderock. "But whereas you may be able to get data from a 30- or 40-second run in the test tank, the LCC allows you to observe and gather data for hours uninterrupted," adds Etter.

The water flow can operate at a velocity up to 35 knots, thanks to a custom-made 14,000 hp, variable RPM motor, built by GEC of the United Kingdom, with a 100-ft. long, 4-ft. diameter shaft turning an 18-ft. diameter axial flow pump, designed by Allis Chalmers (now Voith Siemens Hydro Power) in York, Pennsylvania. Pressure can be varied from 2 to 60 psia, which covers the range from a high vacuum to a high over pressure.

Changing the pressure is important when examining cavitation at different depths and simulating conditions at much higher speeds up to 100 knots or more, Etter says.

The overhead bridge cranes in the building, inherited from the CBI plant, are each capable of lifting 500 tons and can be ganged to lift 1,000 tons. Out by the waterfront, a large 1,250-ton crane was used by CBI for heavy lifts on and off barges, and enabled the test section fabrication and the big electric motor to be lifted off the barges used to bring them to the site.

The waterfront crane is still one of the largest on the Mississippi. Ownership of the crane was officially transferred to the Memphis and Shelby County Port Commission in August 2000 and is designated as part of the Memphis Heavy Lift Terminal. A contractor, Barnhart Crane, operates the heavy lift capability for the Port Commission. "In exchange for the crane, the Navy acquired a restrictive

NAME RECOGNITION

The Large Cavitation Channel is named for Dr. William B. Morgan, who was the head of the Hydrodynamics Directorate at David Taylor Model Basin for 22 years before retiring in 2001. According to Bob Etter, Morgan worked at the Model Basin for nearly 50 years. He was born in Iowa and educated at the University of Iowa and the University of California, Berkeley.

"His main technical area was propellers and propulsion," says Etter. "He published numerous reports and technical papers, some of which were of lasting significance. He was a leader in the development and use of highly skewed propellers that improved acoustic and vibration performance of naval ships. He received several awards in his career including election to the National Academy of Engineering in 1992."

"Bill Morgan hired me as Chief Engineer of the LCC Project in 1984," says Etter. "He was relentless in pushing for the LCC acquisition and viewed it as essential to the hydrodynamic and hydroacoustic capability of the U.S. Navy. He was a lifelong leader in several engineering societies and continues to participate in those organizations to this day."

There is also a campus road at Carderock named Bill Morgan Road in his honor, Etter says. "This kind of recognition is extremely rare in the Navy, testifying to the high regard the organization and his co-workers held for Bill."

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easement on 70 acres of land around the LCC to guarantee that no development potentially interfering with the quiet environment required for acoustic testing would ever occur," says Etter. "The navy also has guaranteed access to use of the crane if desired."

The channel uses fresh water from the municipal water supply. When installing or changing test objects, some 20% of the 1.4 million gallons of water must be removed and temporarily stored in a large tank so that the test section can be opened. According to Etter, all parts of the channel that come into contact with water are made of welded 304L stainless steel.

The LCC was designed to be able to test both submerged and surface hulls, but until now had never been used to test a platform with a free surface. To test the interaction between SES skirts and the water surface, the LCC was modified using a gate to create a surface within the test section. The experiments are being conducted by a team from the University of Michigan, led by Dr. Steven F. Zalek, under the sponsorship of the Office of Naval Research (ONR).

**Building data to reduce risk**

Kit Ryan is Allon Science and Technology's chief naval architect and was the technical director on the company's T-Craft design effort that occurred over a three-year period ending May 2010. With more than 40 years of professional experience, Ryan previously served at the Naval Sea Systems Command on a number of ship programs and now works with ship design-related projects with Allon's Design, Engineering and Technology Group.

"We are interested in the LCC testing in what it can do to help us improve our powering prediction computer program for SES type ships, so this basic research effort at the LCC can really benefit us. Deciding how much power to install in a high-performance ship like an SES is an important decision and there is much less existing empirical information in the literature about it than for other types of ships, adding to the risk of not getting it right. These tests will help the whole community in this regard."

Ryan adds that the LCC is a unique facility that primarily provides state of the art cavitation testing for propellers at a large scale. And, he says, it's big. "I haven't seen any other water channel that is even in the same ball park as this one. Certainly there are none others in this country. The sheer size of the test capability and the channel itself dwarfs anything else like it."

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OPERATING SPECIFICATIONS

The Large Cavitation Channel is a vertical plane, closed recirculating 1.4 million gallon, variable-speed, variable-pressure channel with the lower half submerged in a 2.5 million gallon water-filled trench, with numerous acoustic treatment features. The facility has a 6:1 contraction ratio, aeration/deaeration system, filter system (5-micron), temperature control, stainless steel shell, and low turbulence (0.1%). The high-speed capability ranges up to 50 ft/s. The large test chamber is 10 ft. by 10 ft. in cross section with a 13.1 m (43 ft.) working length. Pressure in the test section ranges from less than atmospheric to four times atmospheric pressure, the equivalent of water approximately 100 ft. in depth.

The experimentation being conducted at the LCC impressed Ryan. "The tests tackled extremely difficult technical areas with creativity and superb attention to technical and theoretical issues to provide the best possible results. The knowledge brought by the test team, primarily from University of Michigan, precluded major problems and enabled rapid progress toward the test objectives. The team had an excellent mix of skill sets in hydrodynamics, mechanical, computer, electrical, and model testing to solve the design and development challenges quickly and effectively."

The feasibility for the LCC to be able to conduct free surface testing is remarkable, Ryan says. "With the ability to conduct continuous testing plus the direct underwater visual viewing of the test fixture, we could see behavior of the surface effect ship bow seal that has never been revealed before—a big step forward in understanding the hydrodynamics of these complex seal systems. The free surface capability opens up whole new possibilities for continuous testing, meaning that lengthy data sets can be gathered quickly."

The professional community involved in naval architecture and marine engineering benefits from the LCC, Ryan says. "The LCC is truly a national resource. Even if it doesn't get 100% utilization, when it is needed there is no equal. The navy must retain this capability if we are to maintain our leadership in submarines and other critical technologies."

Experimentalists and numerical scientists

"The work put up by the team of University of Michigan along with the staff at the Large Cavitation Channel facility is simply extraordinary," says Pere-Andreu Ubach de Fuentes, assistant director of CIME (International Center for Numerical Methods in Engineering) in Barcelona, Spain. Fuentes attended the ONR-sponsored demonstration of the LCC SES skirt testing. "It is a remarkable effort with experimentalists cooperating with numerical scientists in order to raise the level of understanding of the physical response in the coupled behavior between the SES air cushion, the bow skirts, and the incoming water flow. From a numerical approach standpoint, I am very excited at the prospect of obtaining very high quality experimental results of a problem as complex as this one."

The facility is impressive, capable and well run, says David Lavis, senior vice president and general manager of CDI Marine Company - Band Lavis Division, and an expert in high-speed ship and craft design. Lavis served as chairman of BLA for 21 years before that company's 1998 acquisition by CDI Marine Company. He has held management positions with the Marine Division of Aerojet General, Bell Aerospace Textron, and Saunders Roe in the U.K.

"I know of no comparable facility in capability," Lavis says. "I have seen cavitation tunnels in Hamburg Germany, MARIN Wageningen in Holland, and Marintek in Trondheim, Norway and would guess that they do significant commercial work at much less cost, albeit with smaller/less capable facilities."

"The demonstration of the set up was very impressive and gave unprecedented fish-eye views of the behavior of finger seal elements immersed in water at high speed along with recordings of seal drag," Lavis says.

The LCC is a unique facility—at least within the United States—capable of running large models at high test speeds in scale cavitation conditions, says Robert Moore, an aeronautical engineer with Textron Marine & Land Systems for 33 years, now retired and working for Textron as a consultant on the T-Craft project. "I do not think there is any other facility that can come close to the combination of Froude number, Reynolds number and cavitation number that can be achieved simultaneously in the LCC," Moore says.

"Compared with other free-surface channel or flume facilities, the test speeds are higher, making it usable for research into the hydrodynamics of high speed craft such as Surface Effect Ships," Moore says. "Compares with a towing tank, you can run continuously, and the ability to view the test article for extended periods of time from above or below the water is extremely valuable."

"The planned testing of bow seals made from dramatically different materials could also be very valuable in understanding the physical phenomena at play in the interaction of seal fabric with the water surface," Moore says.

Moore says the facility provides a unique capability to run continuously, and vary parameters such as cushion pressure, cushion height etc., while observing the model at close quarters from above water or under water. "For the test conditions we

To conduct free surface testing, the LCC has been fitted with a gate, designed at the University of Michigan."
were shown, there didn't appear to be a great deal of flagellation of the finger material, but that will certainly not be the case for all test conditions. When flagellation is occurring, a strobe light may prove very useful for observing the phenomenon in slow motion."

According to Moore, the combination of large test section and high-speed flow capability enables testing at higher Reynolds numbers than is possible with any equivalent facility. "Most specifically, the ability to observe flow conditions for extended periods of time is unique, and extremely valuable to practicing naval architects and marine engineers."

Dr. Zalek, the project leader, says "Our program goals are to devise and execute a large-scale, high Reynolds number SES bow seal fluid-structure physical experiment, and obtain a better understanding of the seal-air cushion-water interface fundamental physics through a parameter matrix of experimental conditions."

He adds that the testing will examine bow seal position, deformation and motion; bow seal forces; bow seal local hydrodynamics; and the air cushion free surface. "We're not trying to model an SES in its entirety, but capture the physics of a SES bow seal system. The data will be useful in the development of physics-based numerical models."

The experiments will evaluate two different seal types—the finger seal (5 fingers), and a two-dimensional planing-type seal at two seal-depth immersions (0.6, 6, and 12 in.), at different cushion pressures (3, 6, and 12 in. WC) and stream speeds between 4 through 8 m/s. Two different types of seal material will be evaluated, 63 oz/yd2Nitrile/Nylon and 7 oz/yd2Hypalon/Nylon.

**More science, less art**

Dave Foster is the LCC director. He leads a team of six full-time civil service employees. Because of its size, Foster says the LCC enables testing with more fidelity. "If you test in a smaller scale facility, you take on assumptions. With computational fluid dynamics, we want to minimize the amount of adjustments you make by art. The more science you get, the better."

The LCC has the advantage of being the largest water tunnel in the world, says Dr. Lawrence J. Doctors, a professor in the School of Mechanical and Manufacturing Engineering at the University of New South Wales in Australia. "Its dimensions are sufficiently large so that the Reynolds number of the test models is close to that of the prototype vessel or component of the vessel. In the current case, we are testing a model of a section of a bow seal suitable for an SES or an air-cushion vehicle (ACV). The model would be approximately half or quarter scale. This means that the viscous effects (dependent on the Reynolds number) are close to those on the prototype. A second advantage of its large size is that the instrumentation of the model is more straightforward. Our current seal model is very heavily instrumented with more than 70 channels of data. It would be physically difficult to install so many sensors on a smaller model."

Doctors says the testing will explore resistance of an SES; modeling of bow seals; drag of SES with immersed seals; validation for Allen's "Sea Train" concept; and Umoe Mandal's SES. "Another important advantage of a water tunnel is that one can exerturize the flow to a preset value," says Doctors. "The pressurization is normally negative in that we wish to lower the ambient pressure. The pressurization or depressurization is executed by pumping a small quantity of water into or out of the tunnel. This characteristic does not apply to our current tests with a free surface. However, it is vital for studies of cavitation. Cavitation is a phenomenon that degrades the performance of propellers, foils, and other high-speed marine components."

**Adding a free surface**

The LCC is normally completely filled with water for testing. To conduct free surface testing, the LCC has been fitted with the previously mentioned gate, designed at the University of Michigan. "The carefully shaped two-part flap fits into the top of the facility just after the contraction and just upstream of the test section," says Doctors. "The angle of the gate can be controlled via a hydraulic system to the required angle. In this way, a free surface springs from the lower, sharp edge of the gate. The height of the free surface is altered by the appropriate setting of the gate angle."

According to Doctors, an important requirement is that the free surface must be flat and horizontal in the vicinity of the test apparatus. "This has been found to be the case," he says. "I am involved in the current testing and am very keen to analyze the test results and compare them with my theoretical model of SES and ACV seals," Doctors says. "Dr. Steve Zalek and his doctoral student, Andrew Wiggins, and the rest of the Michigan team, have produced a remarkable piece of test apparatus."

"The fact that the navy is in possession of the LCC places it in the unique and superior position of being able to research and develop the most advanced naval vessels," says Doctors. "The hydrodynamic community is indeed fortunate to have such a facility available for these and many other highly sophisticated experiments."

The research effort, entitled "Surface-Effect-Ship Bow-Seal High-Reynolds Number Experiments," is being funded by ONR to support the development and design of the highly innovative sea-base connector T-Craft prototype demonstrator.

But, says Program Officer Kelly Cooper with the Sea Platforms and Weapons Division at ONR, the project has benefits beyond T-Craft. "The experimentation will help us better understand this critical aspect of surface effect ships and air cushion vehicles, and will vastly improve the computer modeling tools available to ship designers." MT

The LCC facility is available for researchers to conduct testing on a space-available basis. To inquire about testing capabilities and schedule availability, contact the director, Dave Foster at 301-227-1228, or by e-mail at code5100web.nswccd@navy.mil.