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The Harold E. Saunders Maneuvering and Seakeeping (MASK) Facility New Directional Wavemaker

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Abstract— The Naval Surface Warfare Center, Carderock Division has modernized their pneumatic type wavemaker. The original design dates back to the mid 1940's, was constructed in the late 1950's and is located in Building 18 that houses both the Maneuvering and Seakeeping Basin (MASK) and the Rotating Arm Facilities.

In 2007, a contract was awarded to MAR Inc. who led a team consisting of Edinburgh Design Limited, Atlantic Industrial Technologies, INCON and McLaren Associates to design, construct and install the new wavemaker. The project, design, construction and installation was completed in the fall of 2013.

This wavemaker has 216 pivoting paddles along two adjacent sides of the basin. Each paddle is 0.658 m wide, with a hinge depth of 2.5 m. It is dry-back type, driven by electric motors through a timing belt on a curved sector. The hydrostatic force of the water on the wave paddle faces are compensated for with air springs. The waves are generated using an energy algorithm using paddle force as the primary feed-back.

Two additional design features of this wavemaker. First a curved corner, used to minimize the singularity that is created with a square one as was used in the pneumatic design. Second a control algorithm is applied that not only generates the commanded waveform, but also attempts to absorb any unwanted background wave energy such as beach reflections, model wake and most importantly second order self-generated cross board wave.

This wavemaker is capable of producing regular waves at oblique angles to the wave banks as well as long crested and short crested irregular model seas. Using the directional capability, deterministic and focused wave events can be simulated. Multi Directional waves with spreading modeling such things as a local sea and swell can now be modeled.

Another powerful capability of the new system is the ability to preview the commanded waves in 3D virtual space on the computer screen. In this way, the test engineer can, prior to running the wavemaker, view the model sea. The test team is now able to make decisions relative to the placement of the model, course and direction, in order to maximize the interaction with the modeled seaway.

1. Introduction

In 2006, The Naval Surface Warfare Center, Carderock Division (NSWCCD) (Fig. 1) began a study that led to a "White Paper" stating the need for new wavemaking systems for the Maneuvering and Seakeeping Basin (MASK), High Speed and Deep Towing Basins. These original pneumatic wavemakers are designs that date back to the mid 1940's, the newest, MASK, being constructed in the late 1950's and located in Building 18 that houses both the MASK and the Rotating Arm Facilities (Fig. 2).

Figure 1. David Taylor Model Basin

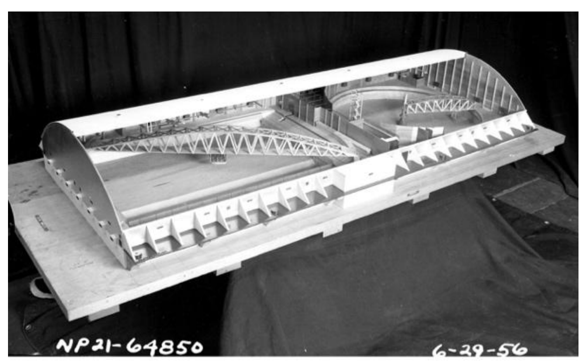

Figure 2. Rotating Arm and Maneuvering and Seakeeping Basin.

The major argument for the need of the Navy to modernize their wavemaking capability was to create the ability to test in short crested seas. The existing pneumatic wavemakers, although simple and easy to maintain, as testified by their length of service, were too difficult to control to produce wave spectra envisioned for future testing - let alone short crested directional seas. Given the age of the three wavemaking systems and the need for refurbishment to reduce down time and restore original wavemaking capability lost due to aged hydraulics, modernization through replacement to new and more easily controllable machines was proposed.

In 2007 a contract was awarded to MAR Inc. to lead a team (Fig. 3) consisting of Edinburgh Design Limited (wavemaker designer), Atlantic Industrial Technologies (Machinery Fabrication and Engineering Design), INCON (Installation of Machine and Structural and Electrical Support Components) and McLaren Associates (Design and Inspection of Concrete Support Structure).

Figure 3. Wavemaker Team

Edinburgh Design Limited (EDL) designed a segmented dryback directional wavemaker for the MASK (Fig. 4). This design promised the same capacity in achievable wave heights and frequency range as well as the ability to skew the wave fronts and with the software under development by EDL, the ability to produce multiple irregular seaways with or without spreading.

For the Deep (Fig. 5) and High Speed Basins (Fig. 6), segmented variable depth wavemakers were proposed. A segmented and dryback design was used to allow interchangeability of parts, and make it possible to use the same control software architecture in all wavemaking systems.

Since the Deep Basin wavemaker divided the wide basin into a shallow and deep end, it needed to be able to “tuck” down under a towing carriage if ever it was required on the other side. This opened the doors for the variable depth capability. Retaining segmentation allows the production of more linear wave fronts in the basins and reduction of the so-called serpentine waves often produced near the tank width resonance.

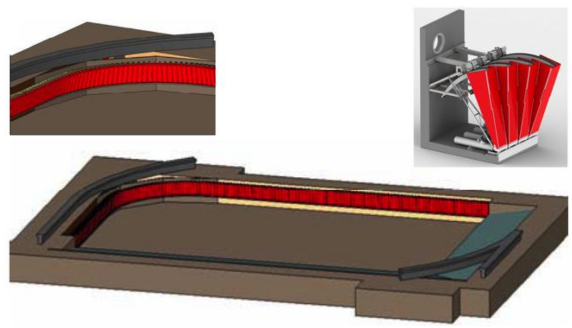

Figure 4. EDL MASK Wavemaker Design.

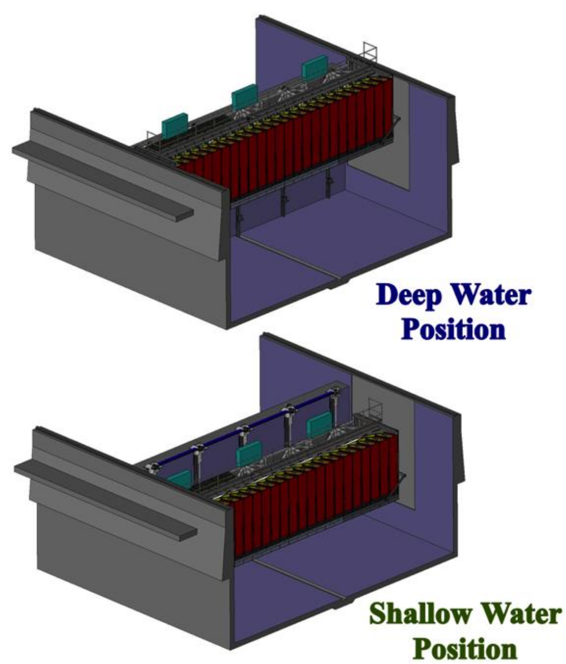

Figure 5. EDL Deep Basin Wavemaker Design.

The Navy decided to fund the design of all wavemakers and the construction of the MASK system. The MASK wavemaker was installed and completed in the fall of 2013 (Figs. 7) and is currently being used to support a future Naval Surface Ship Combatant.

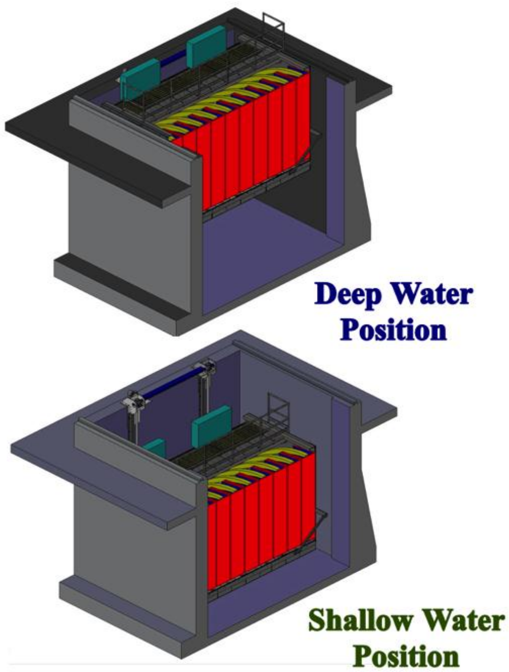

Figure 6. EDL Wavemaker Design

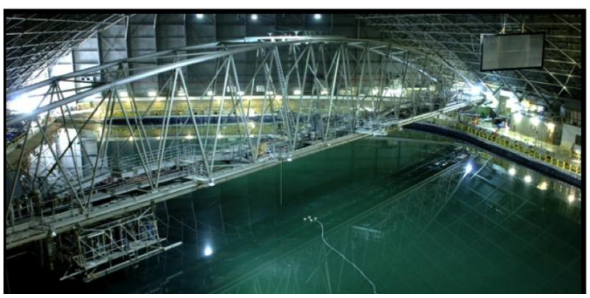

Figure 7. Curved Corner of EDL 216 Paddle Directional Wavemaker

2. History

NCWCCD can trace its own roots to the Experimental Model Basin (EMB) built by then Captain David W. Taylor (Fig. 8) at the Navy Yard in Washington, DC (Fig. 9). This flap type wavemaker was moved into the 140 ft basin in 1940. It was first used as a flap wavemaker and then was cannibalized to provide the drive mechanism for early prototypes of pneumatic type wavemakers in 1950 (Fig. 10).

Pneumatic wavemakers were installed in both the Deep and High Speed Basins in the early 1950's (Fig. 11). Immediately work began on the design of a seakeeping basin that would become the MASK. A 1/10th scale model of the MASK was built and tested at the then David Taylor Model Basin (Fig. 12). This facility was given to the University of Michigan where it was used by the Naval Architecture Department (see http://name.engin.umich.edu/).

RADM David Watson Taylor, *USN Retired (1864 - 1940) was a naval architect and engineer of the United States Navy. He graduated with the highest grade average in U.S. Naval Academy history. He served during World War I as Chief Constructor of the Navy, and Chief of the Bureau of Construction and Repair. Taylor is best known as the man who constructed the first experimental towing tank ever built in the United States. The Navy's Research and Development community honored Taylor by naming its new model basin, constructed at Carderock, Maryland, after him. The Model Basin retains his name as a living memorial to this distinguished naval architect and marine engineer.*

Figure 8. Admiral David W. Taylor.

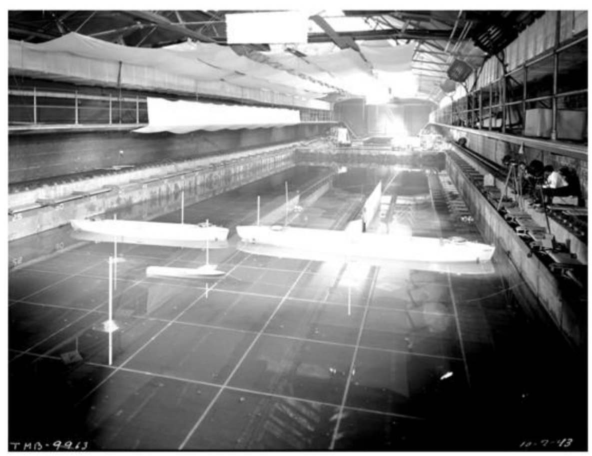

Figure 9. Navy's 1st Flap Wavemaker in the Experimental Model Basin (1913).

Looking at Figure 12 it is interesting to take note of the non-uniformity along the wave fronts. There were 21 total wave domes in the old pneumatic MASK wavemaker. The west bank held 8 domes and the north bank 13. In the far field, each dome is generating a ring wave. Although it appears that the wave front produced by, in this case eight wave domes, has a lack of uniformity caused primarily by the second order cross tank energy as well as the reflections of both the beach and adjacent static wavemaker. The use of force feedback and wave absorption has greatly improved the uniformity in the basin.

Figure 10. Pneumatic Prototypes Developed in the 140ft Basin.

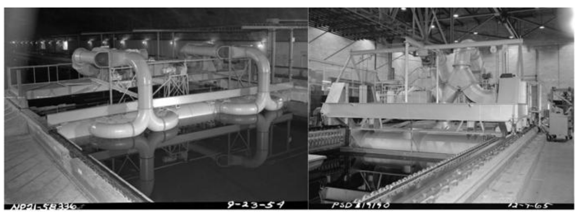

Figure 11. Pneumatic Wavemakers Located in the Deep and High Speed Basins.

Figure 12. 1/10th Scale Model of the MASK Basin.

The Harold E. Saunders Maneuvering and Seakeeping Basin (MASK) was placed into service in 1961, being named for Captain Saunders (Fig. 13). Its wavemaking system comprised of two banks of 21 ft wide pneumatic domes, as previously stated 8 on the west bank and 13 in the north bank (Fig. 14). The pneumatic design was chosen because of its promise of lower maintenance costs. This promise has been made good over the years.

The original MASK wavemaker used a shaft line drive driven by a "Scotch Yoke" arrangement to convert the rotary motion of the hydraulically driven line shafts in to reciprocal motion to move the control flappers that regulated the pressure created in the domes by centrifugal blowers. The west or short bank was changed during construction to independent hydraulic actuator control to permit study into the generation and testing of ship models in irregular waves. It is interesting to note that the original "Scotch Yoke" line drive could be indexed to phase the domes to skew the wave front. However, with a dome width of 21 ft, the angle achievable was limited.

Captain Harold Eugene Saunders, USN Retired (1890–1961) was a distinguished career Naval officer. He graduated with the second highest grade average in U.S. Naval Academy history, second to David W. Taylor. He served at the Portsmouth, New Hampshire Navy yard and was involved in the design and construction of submarines. He received the Navy Distinguished Service Medal for his work in salvaging the USS-4 (SS-109) in 1927. Saunders was a member of the first and second Byrd expeditions to Antarctica, where he served as a geographer. The Saunders Ice Shelf, Saunders Coast, and Saunders Mountain are named for him. He is best known for being the Chief Constructor of the David Taylor Model Basin. He authored the 3-volume book, Hydrodynamics in Ship Design, which was published in 1957 by SNAME. The Maneuvering And Seakeeping Basin retains his name as a living memorial to this distinguished naval architect and marine engineer.

Figure 13. Captain Harold E. Saunders

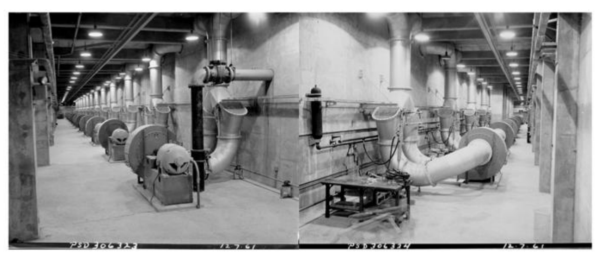

Figure 14. MASK Pneumatic Drive Lines.

This wavemaker was refurbished in the mid 1980's replacing both banks with independent MTS Inc. hydraulic actuation. It has been a good and reliable machine.

3. Design

The MASK wavemaker was reliable; however it had severe limitations on its ability to produce model sea spectra especially at frequencies above 1.4 Hz. The system was essentially a spring mass system that was very under damped with a very soft spring (the air column) making it extremely non-linear.

Wave spectra are produced then and now through an iteration process, i.e, an initial drive history is created, a transfer function assumed and then, through a trial and error procedure, modified until the desired spectral shape is obtained.

This iterative process could take as many as 7 or 9 iterations adding days to the test time and commensurate cost. A single universal transfer was never found due the nonlinear interactions of the machine (Fig. 15). And directional wave were out of the question.

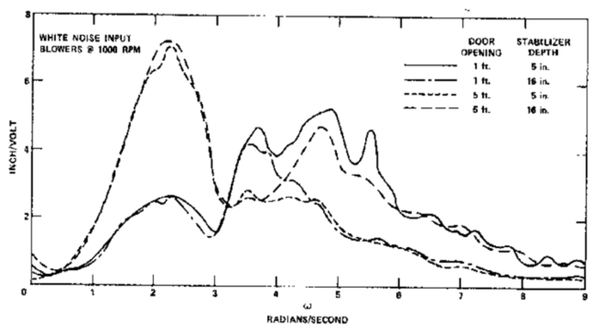

Figure 15. Example MASK Pneumatic Transfer Function.

Although a flap type wavemaker was first used by the Navy and then abandoned, the main advantage of that system is its linearity. The use of the EDL design that utilizes an air spring with its dryback design to reduce power required and using force as the major feedback created a superior alternative to the pneumatic.

The EDL designed directional wavemaker has 216 pivoting GRP paddles located along west and north sides of the MASK basin. The MASK is 98.3 m (322.5 ft) by 61.7 m (202.5 ft) in area and 6.1 m (20 ft) deep. The paddles have a pitch of 0.658 m (25.9 in), with a hinge depth of 2.5 m (8.2 ft) (Fig. 16).

This is a dry-back type wavemaker. It is driven by electric motors through a timing belt along a curved sector (Fig. 17). The hydrostatic force of the standing water on the wave paddle face is compensated for with air springs made from rubber bellows (Fig. 18). The waves are generated by an energy algorithm using paddle force as the primary feedback. A load cell at the top and bottom (Fig.18) measures the force used in the algorithm.

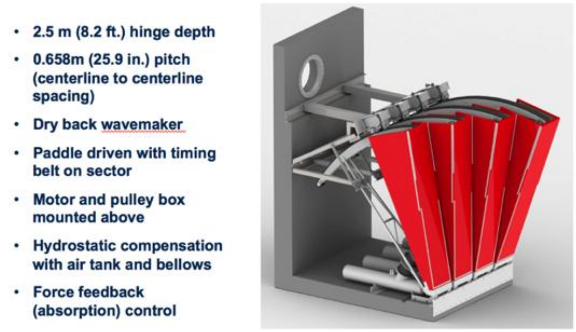

Figure 16. EDL Paddle Design.

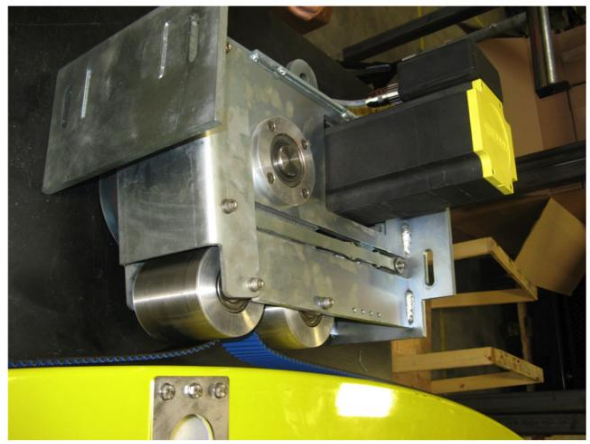
Figure 17. Pulley Box Drive Arrangement.

There are two additional design features of this wavemaker that have proven to improve the wave quality. A curved corner is used to minimize the singularity that is created with a square one as was used in the original pneumatic design. The control algorithm not only generates the commanded waveform, it also attempts to absorb any unwanted background wave energy such as beach reflections, model wake and most importantly the self-generated, second order cross-board waves.

The new wavemaker can produce multi-directional and short crested seas, multiple sea states at various headings, and synthesize wave grouping and episodic events. It is capable of producing regular waves having a 1/10 slope of 98 cm (38.6 in) in height. It can also produce a fully developed seaway (Pierson-Moskowitz spectral distribution) of 35 cm (14.6 in) in significant wave height and high steepness focused waves of 50 cm (19.7 in) in significant height (Fig. 19).

This wavemaker is capable of producing regular waves at oblique angles to the wave banks as well as both long crested and short crested irregular scaled seas. Using the directional capability, deterministic and focused wave events can be simulated.

Figure 18. Bellows and Lower Force Transducer

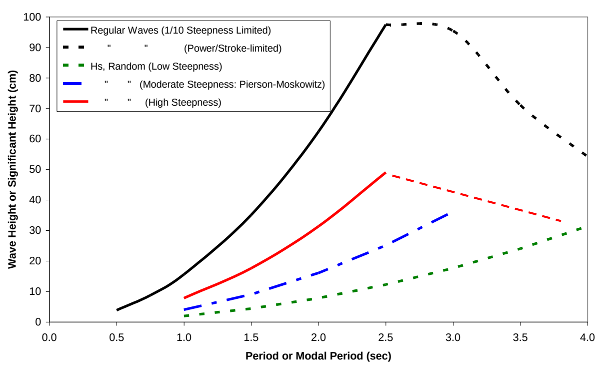

Figure 19. Wave Height Capability

Most any sea spectra can be produced, i.e., Pierson-Moskowitz, Bretschneider, JONSWAP and their varients are available. Other spectral forms and specific time histories can be easily added to the existing library using the Wave Generation software.

Another powerful capability of the new system is the ability to preview the commanded waves in 3D virtual space on the computer screen (Fig. 20). In this way, the test engineer can, prior to running the wavemaker, view the model sea. This allows the tester to make decisions relative to the placement of the model, course and direction, in order to maximize the interaction with the modeled seaway.

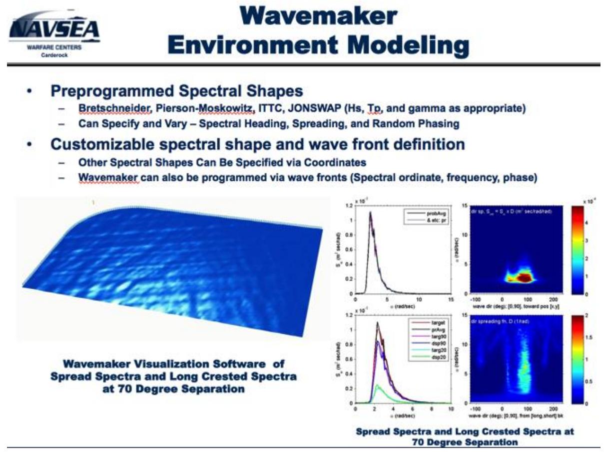

Figure 20. Virtual Wavemaker

4. Construction

The new MASK wavemaker was a sizeable construction project. During this six-year upgrade, MAR, Inc., was the prime contractor, with Edinburgh Designs Ltd., providing the design; Atlantic Industrial Technologies fabricating the major components, and Intelligent Controls and Power Reliability Systems, INCON was the contractor providing demolition of the existing equipment and installation of the new wavemaker and McLaren Engineering provided the concrete structural design. The actual mechanics of removal, construction of the new infrastructure, installation of the machine, tuning and calibration went very well (Fig. 21).

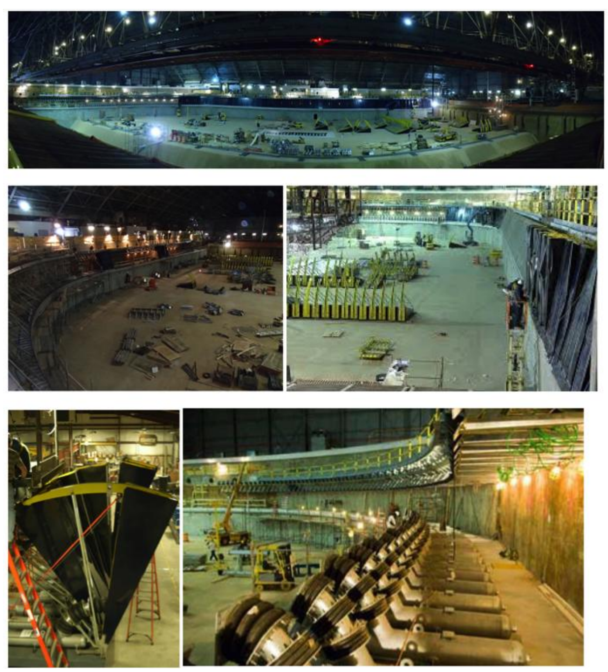

Figure 21. Construction.

"The Wavemaker Modernization team's biggest challenge was funding. The Team have led by example, working around difficult budget times, furloughs, and constantly adjusting work schedules in support of this critical Navy ship and ship systems testing facility upgrade, while maintaining the same high level of service to which their customers are accustomed," said CAPT. Richard Blank, commander, NSWC Carderock Division. "It's that sort of effort and dedication to NAVSEA and the NSWC Carderock team that allows our technical expertise to continually flourish for our Navy, for our nation." The end result is an advanced wavemaking facility, certainly the best processed by the United States Navy (Fig. 22).

Figure 22. New NSWCCD MASK Wavemaker

5. Using The New Machine

At present NSWCCD is in the learning stage: mastering the new capabilities and utilizing innovative test results to push the state-of-the-art in model sea generation and advancing the testing of advanced marine vehicles and ocean systems. A new Naval Combatant design has been evaluated in short crested seas for the first time. Following well planned and executed tests, technical papers will describe in detail both the capabilities and limitations of this new and valuable scientific resource.

Operation, from a manning perspective is little different than the old pneumatic wavemaker. One electrician operates the wavemaker, he is provided wave files by a test engineer, or directions during an iteration calibration, which now takes 2 to 3 iterations. An electrician or machinist is on call and performs periodic inspections while aiding in start up and shut down.

The single most noticeable feature of the new wavemaker is its sound, or lack of it. The old pneumatic wavemaker was very noisy. It was difficult to work in the area any length of time, and the noise generated by the generators and blowers penetrated the whole building and into the office spaces. Now, all that is heard are the breaking of the waves on the beaches.

The Naval Surface Warfare Center's David Taylor Model Basin performs work for Navy, DoD, Federal and State Governments as well as commercial entities. For more information regarding capabilities, scheduling, and availability, please contact:

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Carderock Division

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www.navsea.navy.mil/nswc/carderock/pub/career/student.aspx.

References

[1] Naval Surface Warfare Center, Carderock Division. Available online. URL: www.navsea.navy.mil/nswc/carderock/default.aspx. Accessed on December 19, 2014.