THE 29th AMERICAN TOWING TANK CONFERENCE

ANNAPOLIS, MARYLAND, AUGUST 2010

The History of the Naval Academy Hydromechanics Laboratory (NAHL)

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Figure 1 - High and Low Speed Carriages, 1977

Figure 2 - High Speed Carriage, 2008

ABSTRACT

The history of the U. S. Naval Academy Hydromechanics Laboratories in Isherwood Hall and in Rickover Hall is documented in this paper. The Rickover Hall Hydromechanics Laboratory dedication ceremony took place during the 18th ATTC in Annapolis in 1977. The design/development of the laboratory is discussed and education and research activities are summarized. Further details are recorded in the Appendices that are available as a companion CD to the printed proceedings of this conference.

NOTATION

ATTC	American Towing Tank Conference
s_C	Crest front steepness of a breaking wave
$\mu_{H,}$	Horizontal asymmetry factor of a wave

THE EARLY YEARS - ISHERWOOD HALL

During the 1950s, the Ship Hydromechanics Laboratory in the Engineering Department (now Engineering Division) consisted of an 85' x 6' x 4' towing tank, an 18' x 22' x 4' intact and damaged stability demonstration tank and a small circulating water channel. The towing and stability tanks were originally built of surplus destroyer plating from Norfolk Naval Shipyard shortly after World War II. At that time, because of its location restrictions, the towing tank was only 52 feet in length. The towing mechanism and dynamometer were of the gravity type and were originally obtained as surplus material from the David Taylor Model Basin, along with the original towing models. All of the installation labor and fabrication of the tanks was accomplished by shop personnel of the Engineering Department. In 1951, a new gravity dynamometer was built by the shop personnel and a new and more precise speed measuring mechanics was devised.

In 1955 the towing tank was lengthened to 85' by breaking through the wall at the east side of the building and roofing over the space between this portion of Isherwood Hall and the shop building containing the towing tank and stability tank. A pneumatic wave maker was built and installed in the tank in 1959 and in 1960-61 a powered carriage for towing models, both surface and submerged, was added to the tank. The carriage was suspended from a centerline round rail and powered by a belt drive to drive wheels running on a round rail on the far side of the tank (See photos below and in Appendix 8) All of these improvements were initiated by Professor Thomas Gillmer, the original Director of the Ship Hydromechanics Lab and built by the Engineering Department personnel, the only expenditures being for material, electric motors, and dynamometer instrumentation.

Even so, major changes in the Naval Academy “one size fits all” curriculum made this existing tank rather

inadequate to support these changes. In 1957 the Superintendent introduced the first accelerated courses in the Mathematics Department. Russia's launching of Sputnik in October 1957 contributed to a revolution in the thinking about the existing Naval Academy goal of producing "immediately employable ensigns". In 1959 a major overhaul of the core curriculum was begun by the Folsom Curriculum Review Board, partly because USNA graduates could not enter civilian graduate schools without further study or prerequisite courses. These early changes involved validation of courses previously taken elsewhere, overload courses and electives. (The second Trident Scholar to use the towing tank had two years of college before entering the Naval Academy with the class of 1966). Many of the changes were the result of efforts by Captain William Brinkloe, Secretary of the Academy Board during 1959-60 (previously head of the Engineering Department in 1957-59 who had assigned Lt.JG Bruce Johnson his first engineering design task, a wind tunnel for Isherwood Hall (the yellow wind tunnel was transferred to Rickover Hall and eventually scrapped).

In 1960 it was decided to remove the core courses in Naval Construction and Ship Stability and IC Engines from first class year and replace them with a two year sequence in thermodynamics and fluid mechanics This coincided with the creation of the first majors at USNA which involved taking 15 to 23 semester hours of electives beyond the common core of 160 hours. This could be accomplished by validation and/or overloads.

The first elective in Naval Architecture was offered as part of a new Marine Engineering major for the 1960-61 academic year. For 1961-62, courses in both hydrostatics and hydrodynamics were introduced for the Marine Engineering major and an Aeronautical Engineering major was added. In 1963-64, the Marine Engineering major was absorbed into the new Mechanical Engineering major which had a naval architecture track with two electives, E801-Hydrostatics and E802-Hydrodynamics as well as Reactor Physics and Heat Transfer/Systems Engineering tracks. Also during that period, the majors and minor's programs were being modified away from the restrictions of the core curriculum of 164 semester hours with no electives. The new minors and majors programs required a minimum of 137 to 144 semester hours of credit.

Justification for a new Hydromechanics Lab

These fundamental changes to the academic program during 1963-64 included the appointment of a civilian Academic Dean and the establishment of the Trident Scholar Program. Under this program, midshipmen standing in the top 10 percent of their class at the end of the first semester of their junior year are invited to submit proposed research projects and programs of study for evaluation. Six scholars were selected in both 1963-64 (one towing tank project) and 1964-65 (one towing tank project), eight in 1965-66 (two towing tank projects, see Johnson and Barchi, 1968), twelve in 1966-67 (one towing tank project), and fifteen in 1967-68 (two towing tank projects, both done at DTMB using full scale 8-oared racing shells, see Johnson and Saylor, 1971). The migration to using the DTMB towing tank was necessitated by the limitations imposed by the small size of the USNA towing tank. The lack of ability to achieve speeds required for realistic Reynolds Number testing or to hold speeds of reasonable ranges for adequate steady state periods created a need for a larger and more versatile towing tank facility at the Naval Academy, since numerous scheduling problems at DTMB resulted in very limited testing time for the Trident Scholar projects. It became necessary both in research and instruction to examine isolated and individual portions of the ship resistance problems. Such examination, because of the difficulties of scaling and the limitations of the physical laws of similitude, requires testing of larger models at speeds more closely related to "full scale" speeds.

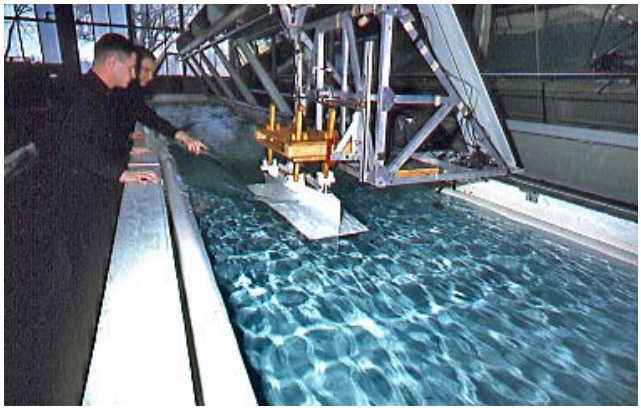

Figure 3 - 1966 Trident Scholar Polymer Additive Study in 85 foot tank

Figure 4 - Midshipmen Barchi and McKenney with 1966 Instrumentation

During this time Professor Gillmer initiated a number of studies concerning increasing the size and scope of the Hydromechanics Laboratory. In an overall USNA study, a new Hydromechanics Laboratory was to be located on the

ground floor of Griffin Hall. This location restricted the length of a towing tank to 175 feet and a width between building columns of 19 feet. It became evident at once that such a length provided but little improvement in capability over the existing tank. A search was therefore instituted to provide a location for a tank with a capability of high carriage speed of approximately 20 knots for a 5 sec. steady state test run. Such a tank requires approximately 300 feet of length. Within the present engineering group of buildings there was no existing space which offers a 300 foot site; however, Melville Hall could be modified to accommodate the 300 foot tank by extending it south to a juncture with Griffin Hall. Working with Lt. Tom Dyer and Professors Johnson and Compton, these early studies of a 175 x 12 x 8 tank suggested by DTMB and a later Master Plan proposal of a 300 x 16 x 12 tank in renovated Griffin and Melville Halls using a cable or tape driven towing carriage whose upper speed capability is approximately 20 knots for a steady state run of near 5 seconds, considered a minimum acceptable facility.

During the summer of 1966, Professor Johnson spent five weeks inspecting hydromechanics laboratories in Europe. He also attended the International Towing Tank conference in Tokyo in October, 1966 with side trips to the major Japanese towing tanks. Almost universally, the contacts made during these visits recommended that the towing tank cross section be larger. Most of the new tanks in the size range of the proposed USNA tank were at least 20 feet wide, and could handle models up to 16 feet long. Therefore the Griffin-Melville Hall proposal was rejected as being too narrow for the model size needed for self propulsion tests. The first iteration in finding a location for a 300 foot long tank involved closing the triangle formed by Isherwood, Griffin and Melville Hall (a hypotenuse with a useful average length of 385 feet) to house both a new 30 foot wide hydromechanics lab with a 300 foot long by 21 foot wide by 16 foot deep towing tank and a new aerodynamics laboratory 60 feet wide.

The master plan architects, Warneke-Ewing, rejected this suggestion and instead, proposed a new building (the Engineering Studies Complex, now named Rickover Hall) to house a 380 x 26 x 16 towing tank, including a 120 ft replacement for the original towing tank plus many other laboratory spaces needed for the new accredited engineering curricula. The longer length raised the possibility of increasing the maximum externally powered carriage speed to 30 knots (50 fps) for a 6 second (300 foot) steady state run assuming acceleration to steady state and deceleration at 1g would not take more that 40 feet at each end (not realistic considering available control systems). This capability was needed for submerged vehicle tests at relatively high Reynolds numbers and to acquire sufficient samples of acoustic data to make analysis of a single run statistically significant (see Compton, Dyer and Johnson, 1968). An 8 second run at 20 knots was also theoretically possible for experiments such as planing boat tests. This change led to referring to the facility as a high performance towing tank. Note that the 380 foot useable tank length also required a 15 foot set aside for the wavemaker at the far end of the tank plus a 17 foot submerged model drydock and a 17 foot fingerdock rigging area for a total length of 429 feet. It has always been officially referred to as a 380 foot tank because Superintendent Kaufman jokingly threatened to cancel the project “if it grew one more foot”.

The approval process beyond the Naval Academy was greatly supported by both Captain Randy King, the head of the Engineering Department, and the Superintendent, RADM Draper Kaufman. They had to fend off the Navy criticism in a 9-18-1968 Memorandum from Commander, NAVFAC to Chief, NAVPERS containing the phrase “As you know, the Military Construction Program is subjected to searching line item review by the Congress, and this towing tank is an apparent duplication of research facilities existing at Carderock.” This comment endangered the whole Engineering Studies Complex proposal, since the Hydromechanics Laboratory dominated the ground floor layout.

To counter the apparent duplication of facilities at DTMB argument, it was decided to acoustically isolate the 380 foot tank by putting it on separate pilings with sound absorbing material between the tank and the supporting structure for the carriage rails, which were to be cantilevered over the tank wall to reduce the span of the carriages for mass and acceleration reasons. The purpose of the acoustic isolation was to enable the study of turbulent flow noise on torpedoes and sonar domes, a capability not supported by the DTMB facilities (see Johnson, 1970). Note that this justification argument preceded the new wavemaker concept proposed by Professor Roger Compton in 1971-72 of using computer controlled hydraulic dual-flap wavemakers in both tanks (See the sketch in Appendix 8). This radical change in wavemaker design would give them a wave generation capability not available anywhere else in the towing tank community. Thus, NAHL would have capabilities not available elsewhere in the US and satisfied the Navy justification to allocate funds for significant engineering design and development costs.

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CONSTRUCTION OF RICKOVER HALL, 1971-1975

Rickover Hall, designed by the Warnecke/Ewing Joint Venture of Washington, DC and managed by the Chesapeake Division of the Naval Facilities Engineering Command, was constructed using two construction contracts, Phase I for the foundations including the 380 foot towing tank situated on refusal piles to insure stability and the Phase II for the building itself. Construction was begun in 1971 by Norair Engineering of Washington DC. The basin construction (below) and necessary pilings were completed in 1972. The Phase II contract went to J. E. Bateson of Baltimore, MD, who began construction in 1973 and completed Phase II in 1975-6. The construction is illustrated by additional photographs in the separate pdf file as Appendix 9.

Design and Construction of the new Hydromechanics Laboratory in Rickover Hall:

Figure 5 - Phase I Refusal Pile, August 1971

Figure 6 - Phase I 380 Ft Towing Tank Construction, May 1972

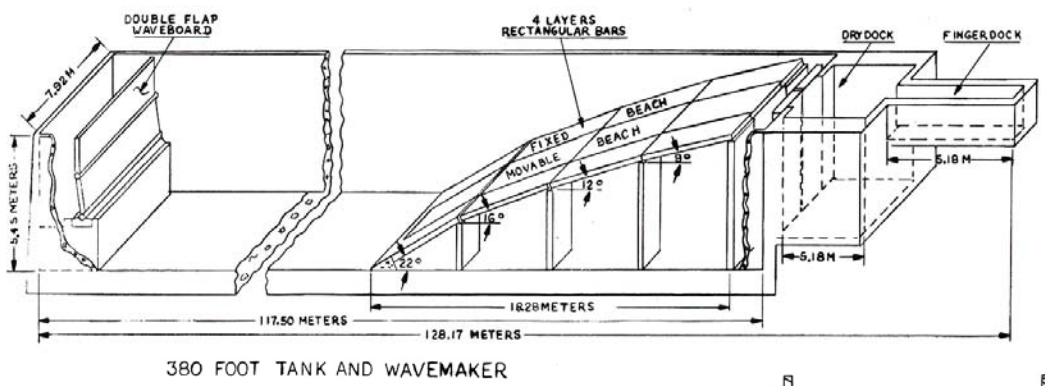
A. The 380 Foot Tank Carriage and Data Transmission System Contract

Once the funding hurdles for the necessary A&E contracts were satisfied in 1969, AAI Corporation of Baltimore, MD was selected to conduct an in depth design and developmental effort under contract to the Chesapeake Division of the Naval Facilities Engineering Command. This study centered on the high and low speed towing carriages and their propulsion, velocity control and data transmission systems, the rail system, the breaking system and the acoustic provisions. These development studies resulted in the preparation of preliminary performance specifications for the aforementioned systems (see Schroder et.al. 1971).

While Rickover Hall was under construction, AAI Corporation of Cockeysville, MD completed the carriage design and data link specifications and ABA/Electromechanical Systems of St. Petersburg constructed the carriages, the rail system, and was contracted to install the optical data transmission system supplied by ITT Gilfillan of Van Nuys, CA. (Schroeder et.al. 1971) These items were placed in storage awaiting completion of the building in 1975. Also during construction, CADCOM of Annapolis, MD prepared the Digital Systems Specification and Integration contract (Gebhardt et.al. 1977) which was won by a joint venture of Computer Sciences Corporation of Fall church, VA for the computers, the data acquisition and software systems with a subcontract for the three wavemakers (380, 120 and coastal tank) to MTS Corporation of Minneapolis, MN and the Dynamometry and Instrumentation systems to Hydronautics of Laurel, MD. AKROEX of Annapolis, MD did the on-site Installation Engineering

The proposed 380 foot tank design had several unique features associated with the acoustic isolation of the basin from the carriage system. In order to provide acoustic isolation of the concrete basin, it was supported on separate refusal piles and the inside of the basin extended from

elevation –11 feet below MLW to +7 feet above MLW with a normal water level of +5 feet giving a operating tank depth of 16 feet (see Figure 3c Schroeder et.al. 1971). The empty basin represents a 4000 MT vessel being held down by the refusal piles. Supporting the rails on separate building piling using a cantilevered continuous reinforced concrete beam 36 inches high by 32 inches wide provided several advantages, including having a stable rail platform whose alignment is not affected by filling and emptying the basin. This method also gives unrestricted tank level viewing with the carriage rails at elevation 9 feet passing overhead of the viewing area surrounding the tank (see Figure 8). (From an educational point of view it is important to view the model as it passes, which is not possible when the rails are mounted on top of the tank walls. This is also why smaller educational towing tanks are frequently supported by an overhead center rail and a side rail on the far wall, as in both the 85 foot and 120 foot towing tanks.) In addition to the tank level viewing platforms, the 380 foot tank has observation platforms on both carriages for close inspection of test model while underway.



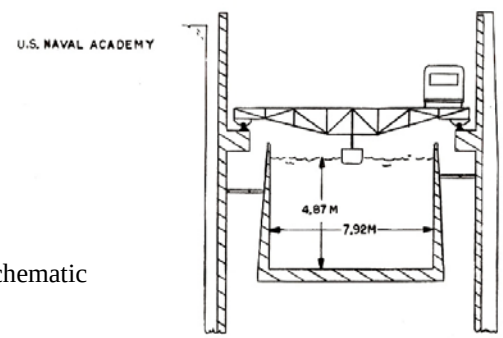


Figure 7 - 380 Foot Towing Tank Schematic

The Unique Carriage Suspension System in the 380 Foot Towing Tank

Since the primary mission of the high speed carriage was to conduct flow noise measurements, quiet operation, stiffness to limit submerged model deflection and sufficient load capacity to carry the large overturning moments and lift forces for hydrofoil testing were the principal requirements of its suspension system. A “Rulon” slipper suspension system was therefore selected for the high speed carriage, backed up by Roundway bearings for towing the low speed carriage. Photos of the Rulon and Roundway bearings are shown in Appendix 2. Suspensions could be quickly changed by means of four gear boxes which raise and lower the upper bearing surfaces of each slipper. Both suspensions are self-aligning in pitch, roll and yaw. All lateral loads are reacted by the suspensions on the right hand side of the carriage while the suspensions on the left side are articulated to accommodate variations in rail spacing (see figure 8 from Schroeder et.al. 1971). The link chains on the Roundway bearings stretched with use from many cycles up and down the towing tank at speeds up to 32 fps (10 mps) and required replacement about twice each year. This plus losing the spare sets in the Hurricane Isabel flood, resulted in the bearings being replaced in 2005 by single wheels (see photographs in Appendix 2). The lab is currently studying sets of two bogie wheels on a rocker arm (used by the majority of large towing tanks and railroad cars) which span the rail gaps as did the Roundway bearings.

The two 380 foot tank carriages

The high speed carriage is shown in Figures 1 and 2. It is an open truss construction based on model tests in a wind tunnel at the Naval Academy. The original concept had a wedge or streamlined fairing along the front of the foremost transverse box beam. However, the aerodynamic tests indicated that an overpressure field is induced upstream of the leading carriage which tends to become an

underpressure function beneath and downstream of the carriage. This was considered to be a critical condition for the low speed carriage operation since a wave system produced by the induced pressure fields distorts the water surface. (Professor Johnson had been warned about this problem when he visited high speed tanks with streamlined carriages in 1966.)

The high speed carriage was designed to be unmanned at the highest speeds and required the use of the rulon slippers. (See Appendix 2 for details.) However, during the initial acceptance tests of the carriage running at 50 fps (30 knots) demonstrated that the regenerative primary breaking system caused a commutation fault clearing the drive decoupling fuse and causing the system to coast into the arresting cable. The first time this happened, the arresting cable failed at the cable end causing the cable to loop over the wavemaker and successfully test the secondary (emergency) braking system, which stopped the carriage in about 1 meter of travel (see photo of emergency stopping systems in Appendix 9). It was determined that the carriage cannot attempt to exceed 45 fps while on the slippers without tripping the protection fuse. The use of the slippers was eventually abandoned because of operational issues and the complications of attempting acoustic flow noise testing. It was decided to allow speeds up to 10 meters per second using the Roundway Bearings on the high speed carriage and that continues to be the speed limit for which useful steady state runs can be made. Increasing the mass of the carriage with instrumentation packages and viewing modules limits the carriage acceleration to 0.5g and this reduces the steady state run time to about 3.5 seconds. The original laser data transmission system for both data and video has been replaced by on-board laptops and a wireless connection to a shore PC. Video signals can be transmitted to shore by both wireless and high fidelity optic fiber trailing cables.

Figure 8 - The open structure of the High Speed Carriage

The towed low speed carriage can be fitted with a vertical rail module for mounting a variety of resistance and seakeeping towing gear, or a Hydronautics planar motion mechanism for maneuvering studies. The original Airstream trailer has been replaced with a smaller instrumentation cab. The two carriages have identical transverse guide rail center modules so various dynamometers such as the open water propeller dynamometer (also shared by the circulating water channel) can be interchanged between carriages. Side-by-side tests can also be conducted by mounting two modules abreast on the same carriage.

The carriage propulsion system, rail system, braking systems, interlocks, and control systems are discussed in Appendix 2.

B. The Wavemaker and Computer Systems Contracts

The standard NAVFAC procedure of a separate A&E contract followed by a supply contract resulted in doubling the cost of the carriage and control systems contract because of the numerous change orders required to make the control system meet the design requirements. As a result, the Naval Academy convinced NAVFAC to go to a two step RFP designer-builder approach since the system performance requirements involved engineering challenges never before attempted.

A local firm, CADCOM of Annapolis, was hired to prepare the performance specifications for the various wavemakers for the three tanks and the computer and software systems for the Hydromechanics Laboratory (called the Wavemaker Systems Contract). The CADCOM team, (led by Dr. John Gebhardt, formerly of the Naval Academy faculty) worked closely with the Hydrolab development team whose project director since 1968 was Professor Johnson and membership including Professor Roger Compton, LCDR Dennis McCahill and Lt. R. E. Ryberg (who replaced Lt. Tom Dyer who left the Navy in 1969). Step 1 of the RFP was finished in December 1972 and was advertised in the commerce business daily on 1 Feb 1973. A number of companies who attended the bidder's conference in December 1972 submitted proposals by 15 May which included MTS building a miniature model of the double flap wavemaker at St. Anthony Falls Hydraulic Laboratory and discovering that operating the upper flap within 10 degrees of vertical greatly reduced the creation of higher harmonics when generating large waves. Single flap wavemakers can produce camelback shaped sine waves when extended beyond their linear transfer function angles, i.e., approximately 10 degrees from the vertical.

The evaluations were completed in September 1973 and two teams were invited to submit Phase 2 bids:

1) ABA Industries which had built the carriage/rail systems was teamed with Kempf and Remmers of Hamburg Germany for the wavemaker design and construction and Hydronautics for the instrumentation portion.

2) Computer Sciences Corporation was teamed with MTS for the wavemaker design and construction and

Hydronautics for the instrumentation portion. Since the 380 foot basin and the space for the side wall wiper plates had been constructed around the design of the Kempf and Remmers wavemaker, the MTS proposal had to fit into the same space, requiring a compromise in the hydraulic ram for the lower flap having hydraulic fluid on one side and the nitrogen static support on the other side.

The CSC/MTS consortium won the bidding by a small total price differential and the contract was let in November 1973. Thus NAHL ended up with an untried lower flap hydraulic system (see Clark and Menken, 1977, Anderson and Johnson, 1977).

C. Control Room Instrumentation

The Control Room between the two towing tanks was laid out and supplied by CSC Corporation. The original Autotank software system which supported both the 380 and 120 foot towing tanks was built around a 128KB PDP-11/50D computer with the RSX-11D operating system and a 20MB Hard drive, backed up by a DEC TU10 9-track tape transport (Gebhardt, Williams and Compton, 1977). This system was state of the art at the time of installation and now seems primitive. It has been upgraded several times since 1977, was replaced in the 1980's by a DEC VAX system and eventually replaced altogether with laptops which could operate on the moving carriages and a wireless network to standard PC's on shore. The original hardware and software systems have been replaced as described below in the Laboratory Staff section.

D. 120 foot tank

The 120 foot tank carriage, rail system and contol system were designed and supplied by AeroLab Supply Company of Savage, MD using a designer/builder contract. The dual-flap wavemaker was designed and built by MTS Corporation.

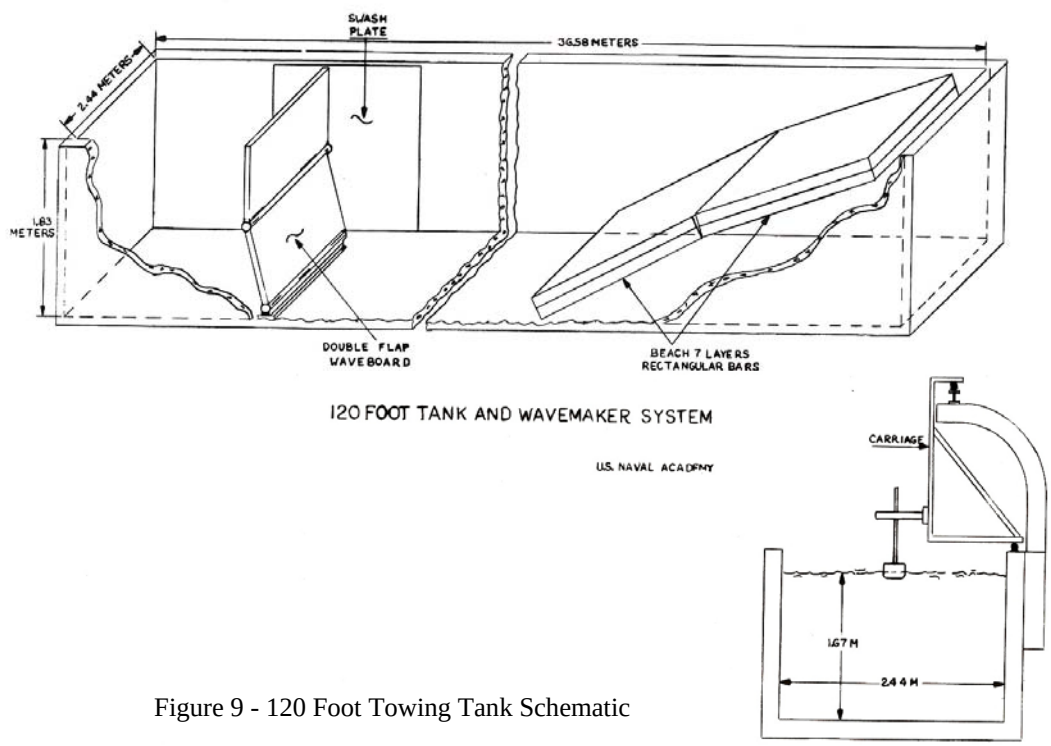


Figure 9 - 120 Foot Towing Tank Schematic

E. Circulating Water Channel

The Circulating Water Channel was designed by Tetra Tech of Pasadena CA and built by Aerolab Supply Company of Savage MD. It features a free surface skimmer to create a smooth free surface for testing small surface piercing models. It also has a propeller dynamometer module that is compatible with open water propeller tests in the 380 foot towing tank.

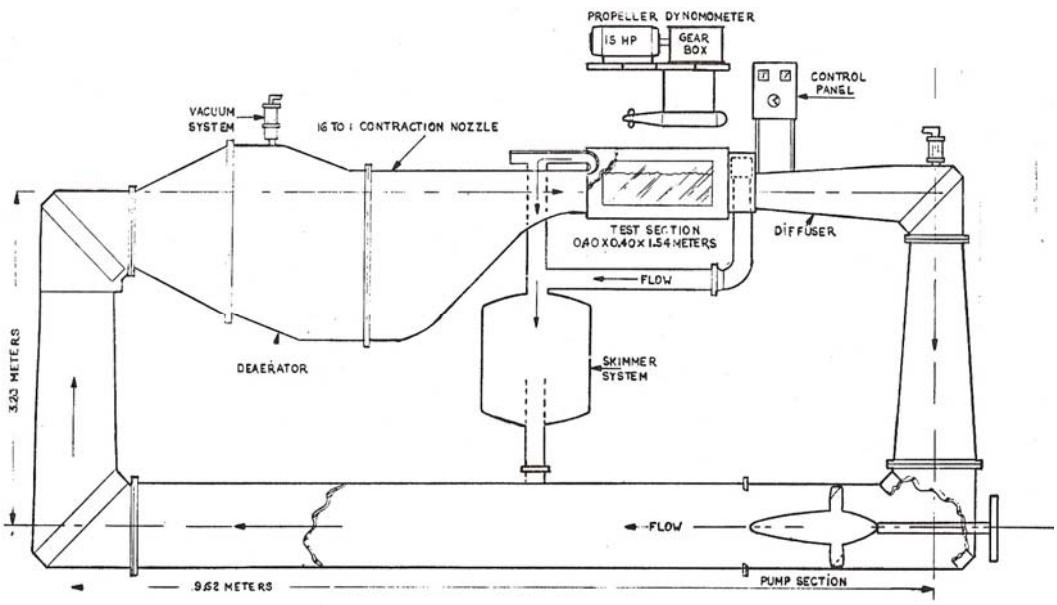


Figure 10 – Circulating Water Channel Schematic

F. Coastal Engineering Lab

The Coastal Engineering Lab was laid out as part of the Warneke/Ewing final design. The hydraulic piston wavemaker was designed and constructed by MTS Systems Corp. Numerous photographs are available in Appendix 5.

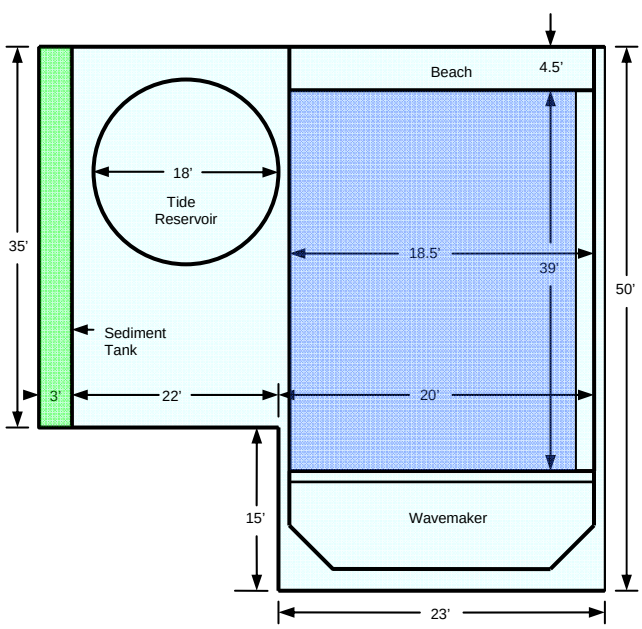


Figure 11 - Coastal Engineering Tank schematic

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EDUCATION AND RESEARCH IN RICKOVER HALL: 1975-2010

Development of the Laboratory Staff

A major difference between the Naval Academy and other engineering universities was the lack of graduate students on site at the Academy. In most academic laboratories, grad students serve as the core workforce and pass along corporate knowledge of lab operation and test techniques over the years. The lack of grad students at USNA made it necessary to cultivate a full-time lab staff.

The composition of the lab staff at the Naval Academy was intended to fall somewhere between that in an engineering university and in a government research lab. In the early days the staff consisted of a director who was a faculty member (Prof. Johnson), a laboratory Branch Head (initially Ronald (Max) Altmann, formerly of Hydronautics, who got the tank up and running and left in March 1979), a Research Head (John Hill, who replaced Max Altmann as Branch Head until he retired in 2007), a staff Naval Architect (Randy Watkins who left in April of 1980) up to four naval architect/engineers, an electrical engineer, two engineering technicians, one electronics technician and an administrative professional. In 1981 Howard Chatterton joined the staff as Director of Research until 1986. Over the years the lab has also supported a variety of temporary and visiting NAVSEA EIT engineers, professors, ensigns and midshipmen.

The waterfront venue of Annapolis has always helped to attract talented engineers and technicians, and the lab staff has evolved into a team that is cross-trained to cover the many more roles that would be found at a larger government research lab. All of the engineers can machine a part on a lathe or solder electronics components and all of the technicians can plot and review data on a computer. The current lab staff consists of a faculty director, branch head/engineer, three naval architect/ocean engineers, two technicians and an administrator. With this pared down staff, the philosophy has been to keep electronics, data acquisition and major systems as standard as possible. For example, a one-page Matlab program is the basis for the eight data acquisition systems in the lab. Student, faculty and staff typically use Excel and Matlab programs to conduct their data analysis as needed. Similar "off-the-shelf" approaches are taken for sensors and electronics which has allowed the lab to get by without a dedicated electronics expert.

In meeting the Naval Academy mission to educate midshipmen, it is also important to support faculty research projects. A capable lab and staff has made it possible to attract bright faculty members and allow current faculty to move forward in their fields of study. When classes are not in session, most notably during the summer academic break, the staff supports a wide variety of funded and developmental research projects. Highlights of these projects are presented below and a full list of references from work that was formerly reported is presented in Appendices 3-7.

Summary of NAHL Utilization 1975-2010

The first facilities to be operational were the 120 foot towing tank and the static stability basin in 1975, when Rickover Hall was opened for classes. The 120 foot tank was used to support the Experimental Naval Architecture Course (Compton 1977), and the Ocean Wave Mechanics Course. The use of 5 foot long models, constructed in the new model support shop enabled midshipman research projects to get underway including studies of stern wedges for naval vessels and comparative studies of US versus USSR frigates. The desire to replace the old wooden yard patrol craft resulted in several studies in both the tank and the stability basin.

Since the 120 foot tank contained one of the first computer controlled double flap wavemakers, it proved very useful in developing the ability to generate deterministic extreme waves (Anderson and Johnson, 1977). The first large plunging breaking waves were produced using a manually controlled sweep frequency generator, but the breaking waves produced were not be reproducible. Carvel Holton, the staff Electronic Engineer, wrote software to consistently break the wave at the location of the windows in the 120 foot towing tank. "This technique consists of generating a drive signal which combines decreasing frequency with an exponentially increasing amplitude of specified form. The resulting wave energy which is focused at some point downstream of the wavemaker can result in some nonlinear, asymmetric, and/or breaking waves occurring repeatedly at the same location in the tank." (Salsich, Johnson and Holton, 1983).

This capability resulted in the Hydro Lab being tasked to investigate the dynamic stability characteristics of yachts that were in the wrong place at the wrong time during the Fastnet Race disaster of 1979. A previously unrecognized capsize mode was observed when capsizes were produced by being precisely located in the curl of the wave, but also in the secondary upwelling wave generated by the curl of the wave striking the surface of the water. This phenomenon is the cause of nearly all videotaped capsizes in the ocean and is observed in the froth when surfing waves collapse. The US Coast Guard was also interested in the characteristics of their surf rescue vessels and studies were done of the existing 41 and 44 foot motor life boats and in the proposed 47 foot motor lifeboat (Zseleczky, 1989). These capsize tests showed that the proposed new 47 foot motor life boat should have superior self-righting capabilities and that was proven once the boat was put into service (Johnson, 2000).

To further understand extreme waves, a systematic study (Duncan, Wallendorf, and Johnson, 1987) was done based on measuring the changes in the wave characterizations of Peter Kjeldsen (IAHR 1986). The analysis of various wave profile parameters measured with single wave height probes indicates that the horizontal asymmetry factor, $\mu_{H,}$ may be the best indicator of the occurrence of a breaking wave. It increased steadily to about 0.75 at the point of incipient breaking for the six waves investigated. The crest front steepness, s_C , also increased as the wave approached the point of incipient breaking. It then decreased during the beginning of the breaking process. Its value at the break point was 0.50 for the spilling breakers and 0.70 for the plunging breakers. Thus, the value of s_C at the instant when $\mu_H = 0.75$ may be a good indicator of breaker type"

Research could not be done in the 380 foot tank until several years later. Although the 380 foot towing tank was dedicated at the 18th ATTC in 1977 (Appendix 1 and 1a), the facility required considerable debugging of the carriage speed control and wavemaker. Also, the wave absorbing beach had to be refurbished because of deterioration from different grades of stainless steel used in its construction.

One of the first major projects investigated in the 380 foot tank was the proposed single pass seakeeping test technique (Johnson, et.al. 1980). The method did not produce the desired periodic irregular encountered waves, evidently because of non-linear wave-wave interactions and the technique was abandoned when these results were confirmed by a Japanese tank.

Some of the research projects initially performed in the large tank included a HYSWAS midshipman research project and model tests of a proposed USCG DDI Icebreaker. The first large scale Trident Scholar Project performed in the 380 foot tank was that done by Mark Rolfes "Wave Force and Structure Response: A Comparison of Theory and Experiment Using Regular and Irregular Sea States" (Rolfes and Dawson, 1980). This was followed by five more Trident Scholar projects between 1982 and 1987. Jeff Hoyle was the first Trident Scholar to publish the results of his Trident Scholar Project as a SNAME Transactions paper (Hoyle, et.al. 1986). This project was a joint effort with the CFD group at the David Taylor Model Basin.

Most of the experimental projects completed in the lab were documented in internal USNA Division of Engineering and Weapons (EW) reports. The full titles and references for these reports are listed in Appendix 7. Previous work on the effects of Bow Bulbs and various stern wedges done in the 120 foot tank were extended to the FFG-7 class frigates tested with larger models in the 380 foot tank (see reports EW-06-84, EW-28-84) as was the considerable amount of work for the USCG Experimental Station (see EW reports from 1982-1986). The small tank/large tank capability was used more recently to evaluate High Speed Sealift ship concepts such as catamaran, trimaran, swath, etc using 5 foot models for preliminary tests in the 120 foot towing tank, then larger models in the 380 foot tank to refine the predictions (EW-01-07). A final version of this hull was tested at an even larger scale at NSWC Carderock.

Visiting NAVSEA Research Professor Adrian Lloyd pushed the envelope of testing in the 380 foot tank with his studies of "The Effect of Bow Shape on Deck Wetness in Head Seas" (Lloyd 1983, 1986). At about the same time, five foot models were being tested in the 120 foot tank to evaluate hull options for the Academy's Yard Patrol boat replacement. This project started out as a series of student projects and was expanded by Professor Roger Compton into a carefully tested and rigorously reported model test series that provided one of the richest sources data for semi-planing transom stern hulls (Compton 1986).

From the mid 1980's through the early 1990's the Hydromechanics Lab worked closely with the U.S. Coast Guard on a large number of projects. Howard Chatterton, the lab's Director of Research from 1981-1986 brought in all kinds of work from the USCG Ship Engineering branch on their cutters and icebreakers (EW Reports 1981-1986). This connection lead to more work with the USCG Boat Engineering branch, which funded resistance and seakeeping tests for its 110' and 120' WPB's, the 30' SRB and 44' and 47' MLB (EW Reports 1984-1990). The Coast Guard recognized the advantages of the lab's ability to take on short term, unique projects and turn out a final report in a short timeframe. For example, tests were conducted on the 47 MLB model during the final phases of design and prototype construction to check underway roll stability and dynamic pitch/yaw stability.

In working with the Coast Guard on their planing boat projects the lab encountered many of the pitfalls and challenges involved in high speed vehicle testing and developed expertise in dealing with them. A joint project with the Davidson Lab launched an investigation into how to adequately measure and analyze planing boat acceleration measurements (Zseleczky and McKee, 1989), this is still a hotly debated topic today. During this period an interesting set of side-by-side tests were conducted to evaluate the seakeeping behavior of hard chine vs. round bilge hulls in irregular waves (Zseleczky, et.al, 1992) and a student planing boat project evolved into a SNAME Transactions paper on porpoising prediction (Celano, 1998). In 1999 the lab was invited to participate with the ITTC Specialist Committee for High Speed Marine Vehicles (22nd ITTC) in setting guidelines for HSMV testing.

The extensive work in the coastal tank for NFESC is covered in Appendix 5 and the three Kriebel et.al. references below. Some interesting new capabilities were developed for these tests such as a portable towing carriage

for modeling ship mooring forces from passing ship wakes and devices for measuring berthing forces while docking. Another study by Professor Kriebel modeled tidal scouring in a harbor using computer controlled pumps and cameras in the coastal tank to record dye movement over repeated tide cycles.

Extensive investigations of turbulent boundary layers have been done in the water channel facilities covered in Appendix 6 and the Schultz et.al and Flack et.al. references below. These studies were the motivation for developing the low-turbulence water channel which was designed by Professor Schultz and built completely in-house out of composite materials. Laser PIV and/or LDV velocity measurements were used in most of these studies.

In the 1990's the lab developed the capability to create a wind field over the 380 foot tank using a bank of centrifugal blowers (Nehrling et.al., 1995. Several interesting studies were conducted in wind and waves including an investigation of intact stability (Reports EW-19-93 and EW-7:11-94) and a study on safety considerations for sailing the Navy ship Constitution (Chatterton, 1999).

A variety of submarine-related tests have been conducted including forces and moments on subs with low L/B, submarine fin variations, torpedoes, UUV's, ASDS, diver propulsion vehicles, SUBOFF, torpedo countermeasures, strut vs. sting testing, underwater vehicle docking, optic fiber deployment, and breaking wave forces on a periscope.

Unusual test subjects include: sailboats (Miller, 2003, 2007, 2009), rowing shells, human divers, oyster nets, full scale wave buoys, anti-terrorist ship barriers, Bradley tank skirts, crew team oars, and a mobile offshore base. These projects are fully referenced in the USNA Division of Engineering and Weapons (EW) Reports in Appendix 7.

In 2003 the Annapolis flood following Hurricane Isabel swamped the lab with three feet of mud, grass and salt water, wiping out a large part of the equipment and many of the hardcopy and digital archives. The rebuild of the lab after the flood was documented by Zseleczky, 2007. As in the early days of USNA, NSWC Carderock came to the rescue by allowing a two-semester student project on sailboat rudder forces to be completed in their large tank (Patton, 2004).

Summary of Academic Classes in the Lab

Since the mission of the Naval Academy is to educate midshipmen, serious efforts are made to fold advances from research projects back into engineering laboratory classes. Given the excellent facilities and the benefits of ongoing research, the third and forth year Naval Architecture and Ocean Engineering students participate in lab classes that are unthinkable at the undergraduate level in any other university. A sample of lab classes that are conducted every year follows:

- *Resistance and Propulsion*: flat plate friction resistance measurements, geosim models tested in the small and large tanks during the same lab class (Series 60, AOE, DDG), standard EHP, SHP, propeller open water and cavitation experiments, shallow water resistance measurements
- *Seakeeping and Maneuvering*: regular and irregular wave properties, seakeeping in head seas and zero-speed beam seas, rudder forces, added mass of Lewis forms, determination of hydrodynamic coefficients from Planar Motion Mechanism tests
- *Advanced Marine Vehicles*: catamaran and trimaran resistance, hydrofoil lift and drag, foil/cat, ACV, SES, SWATH, HYSWAS
- *Ocean Engineering Mechanics*: velocity and pressure beneath waves, shallow water wave breaking, wave diffraction, standing waves, forces on a cylinder (See also Appendix 5)
- *Coastal Engineering*: Shallow water waves, beach profile changes in surf, seawalls and revetments, breakwater performance, wave screen breakwaters

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List of Appendices in the Separate Files Included in the ATTC Conference CD

Selected References Available from the USNA Hydromechanics Laboratory Website

Appendix 1: Press Release from Public Affairs Office and Dedication Ceremony Photographs, August 1977

Appendix 1a:-Program for the 1977 ATTC Hydromechanics Lab Dedication Ceremony

Appendix 2: Details of the Hydromechanics Laboratory Carriage Propulsion and Rail Systems

1. Carriage Propulsion System
2. The Rail System
3. The 2007 Rail Survey and Leveling

Appendix 3: List of Trident Scholars who used the Naval Academy Hydromechanics Laboratories

Appendix 4: Abstracts of Recent Midshipman Research Projects

Appendix 5:-Example Research Projects in the Coastal Tank:

Appendix 6: Additional References to Research associated with the Naval Academy Hydromechanics Laboratory

Appendix 7: List of HydroLab Reports Catalogued by Pam Majors

Appendix 8: Photos of Isherwood Hall Ship Hydromechanics Laboratory and Professor Compton’s double flap wavemaker concept sketch

Appendix 9: Photos of Rickover Hall Construction and NAHL Operations

Appendix 10: List of Hydromechanics Laboratory Staff Members

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