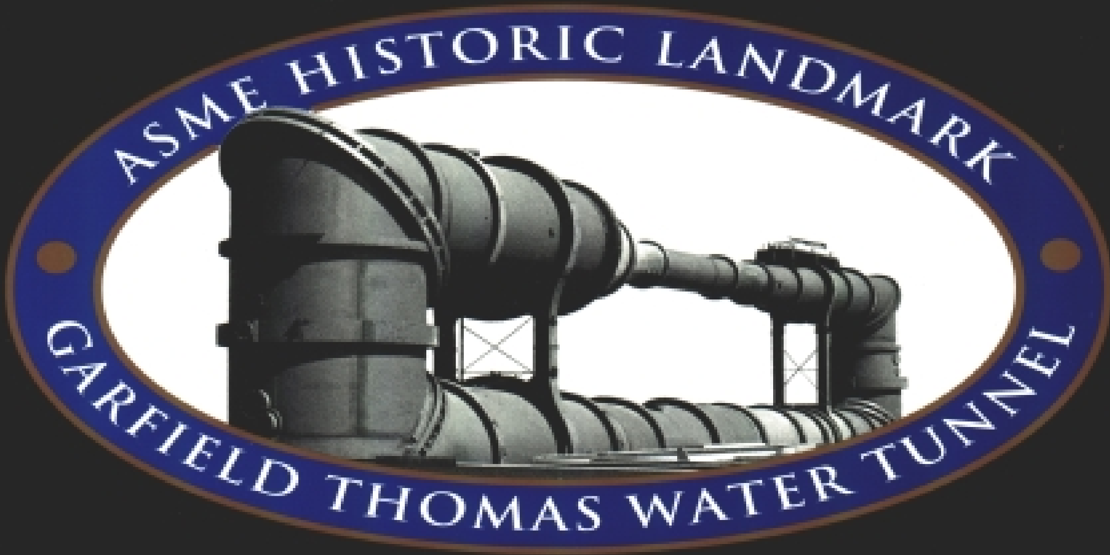
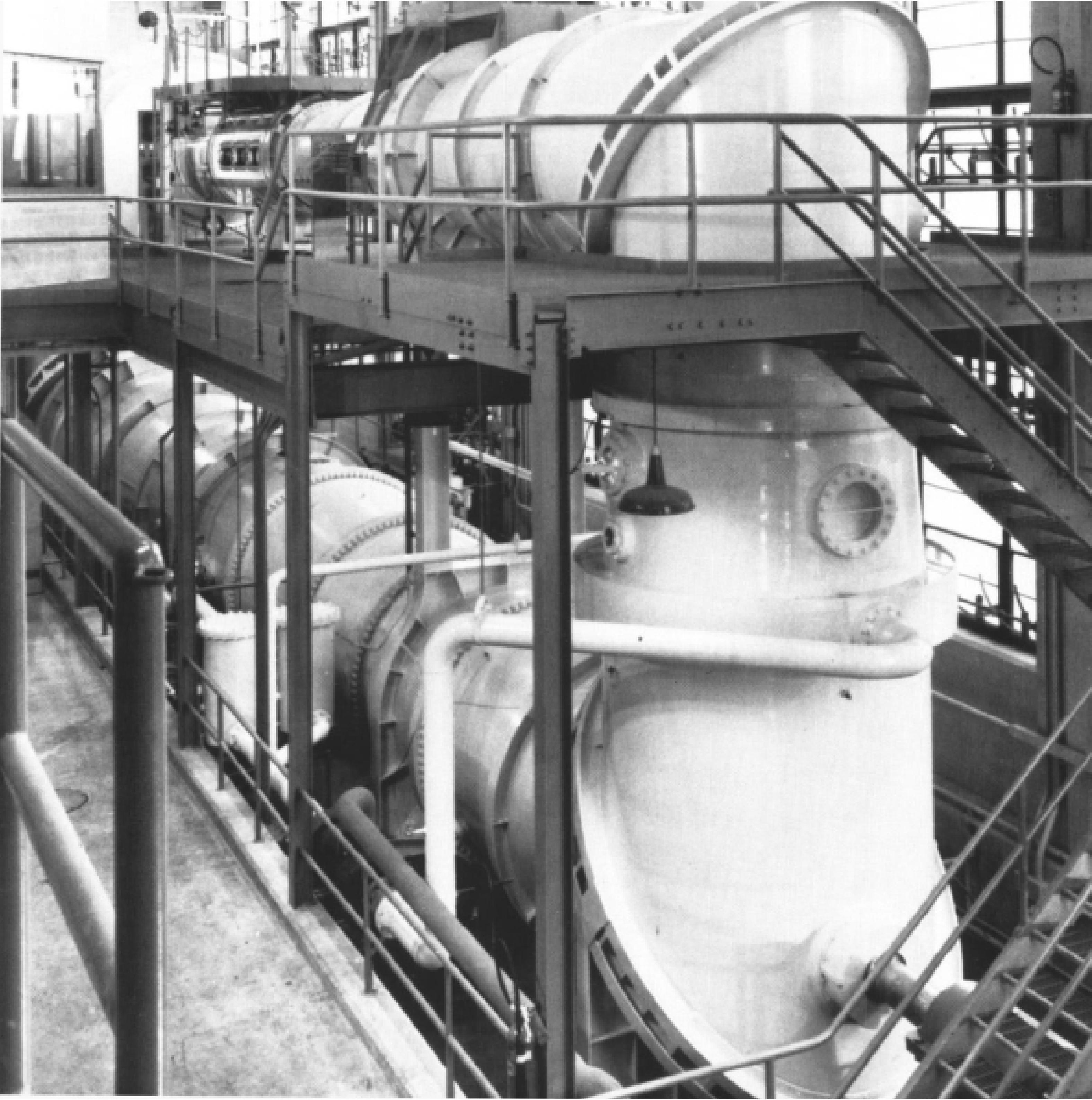


A Closed Circuit, Closed Jet, High-speed, Water Tunnel

A Historic Mechanical Engineering Landmark Dedication
May 6, 1996
State College, Pennsylvania

The American Society of
Mechanical Engineers



THE GARFIELD THOMAS WATER TUNNEL

In the world's largest water tunnel at Pennsylvania State College, the 31-knot stream rushing past a torpedo model forms a pattern of turbulent bubbles. Scientists watching know that the more bubbles they see the less efficient the torpedo is. A perfectly shaped torpedo would leave no turbulent wake at all, for water would flow around it smoothly. As in aircraft, turbulence produces drag, slowing the missile. More important, in torpedoes, it also produces noise.

– excerpted from "Torpedo Turbulence," an article about the Water Tunnel that appeared in the January 14, 1952, issue of Life

Fifty years ago, representatives from the Ordnance Research Laboratory, The Pennsylvania State College, and the Navy initiated a proposal to create the Garfield Thomas Water Tunnel, a 48-inch-diameter water tunnel that would soon be recognized as the largest high-speed water tunnel in the world. Built on the College's main campus, the Water Tunnel was dedicated on October 7, 1949, and began operating six months later. This new facility was named in honor of Lt. (jg) W. Garfield Thomas, Jr., one of the first Penn State graduates to give his life in service to his country in World War II.

BACKGROUND

Total capacity of the tunnel, which is nearly 100 feet long and about 32 feet high, is 100,000 gallons. When operating at top speed, more than a million gallons of water will pass through the test section every three minutes.

– Philadelphia Inquirer, April 24, 1949

The Garfield Thomas Water Tunnel refers to the 48-inch-diameter water tunnel built between 1948 and 1949 at the Ordnance Research Laboratory (ORL), a Navy-sponsored facility at The Pennsylvania State College. A 1946 Laboratory report, titled *Water Tunnel Proposal,* stated that the new tunnel was expected to

- Establish a firm scientific basis for the design of marine propellers
- Increase the overall efficiency of a given hull-and-propeller combination
- Shed new light on the possibilities of obtaining propellers with high speeds of advance
- Secure quiet (cavitation-free) propeller operation for guided weapons at speeds in excess of the maximum then considered possible

For the Laboratory to accomplish these goals, it needed a high-speed water tunnel larger than any yet constructed. The diameter of the test section would have to be at least 48 inches, while the velocity of the water flowing through this section would have to be 30 to 35 knots (48 to 56 feet per second). Moreover, the cost of the tunnel, including the instrumentation and photographic equipment, was estimated at $1 million, with a final cost nearing $2 million.

Why build such a tunnel at Penn State, a land-locked university 200 miles away from the ocean? When World War II ended in 1945, the Navy continued to sponsor research facilities such as the Harvard Underwater Sound Laboratory (HUSL), which designed the first acoustical homing torpedo (FIDO). After Harvard decided to stop working on classified research, HUSL split. The underwater sound laboratory section moved to New London, CT and the torpedo section was moved to Penn State and renamed the Ordnance Research Laboratory (ORL), which later became the Applied Research Laboratory (ARL) in 1973.

By the time the German war ended, the American Navy had gotten religion and now believed that the scientists and engineers really could produce things that were useful. Hadn't we produced FIDO, guided air missiles, and the proximity fuse? This was quite a turnabout from the beginning of the war when on many occasions, civilian scientists and engineers, working on Navy problems, were literally told to get out of the way: "Don't you see we're trying to fight a war--I've got no time for your egg-headed schemes!"

As the war began to wind down, there was a change in the attitude of the civilians working on Navy problems: "You no longer need me, so I had better go back to my previous job or find a postwar position." General Electric and Westinghouse, both involved in the FIDO project, wanted to get back to producing civilian goods that the people needed and wanted to buy. So suddenly the Navy was about to lose the help of people and the know-how which had produced the acoustic homing torpedo. The one island that was left intact was the so-called "fourth floor" at the Harvard Underwater Sound Laboratory. But Harvard, when approached to continue the Laboratory, said "No more classified research; we're going back to teaching students," and that was that.

– excerpted from "How we got here and our *early achievements"*

Dr. Eric A. Walker addressing the 50-year anniversary of ARL

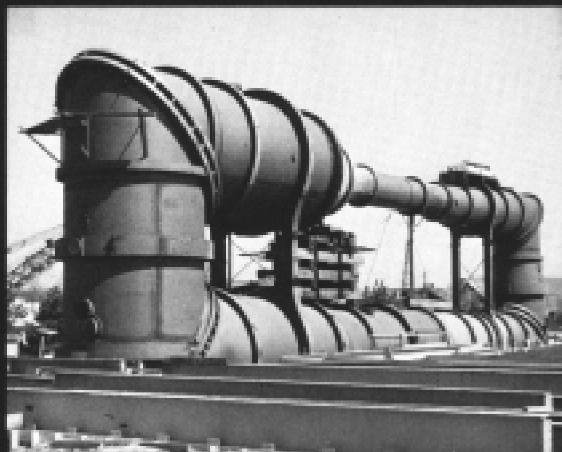
At the Laboratory, a group of competent scientists -- interested in research for the defense of the nation and having cognizance of all phases of the problems encountered in designing underwater ordnance--could be brought together, provided with adequate facilities, and allowed complete freedom of action to do their best work in an academic environment. Since it was not possible to design the torpedo controls without knowing the body shape or to design the propeller without knowing the limitations of the power plant, the Navy hoped that sufficient facilities could be provided in one location to study all phases of the torpedo problem. Toward this end, then, they considered it essential to have facilities for testing underwater vehicles equipped with their propellers.

At this time, the design of marine propellers was more of an art than a science, and torpedo designers relied on data obtained from open water testing. But ORL recognized the importance of knowing the exact character of flow disturbances, or wakes, generated by flow over the body. To make torpedoes quieter and more efficient, the researchers needed a controlled testing facility to actually measure the wake field caused by the torpedo. Then, designers could adjust their specifications.

Previous Navy research had clearly established that in order to determine a propeller's actual performance, it could not be tested by itself in a uniform flow. By placing the propeller on a test vehicle, researchers could evaluate the effects of the flow over the hull and the interaction of the propeller with this flow. Furthermore, in order to measure the dynamics of torpedo models, researchers needed to explore cavitation, which is the formation of gas-filled bubbles in water caused by localized areas of increased vapor pressure exceeding the local static pressure. This fundamental area plays a crucial role in torpedo design because it is a primary cause of underwater noise.

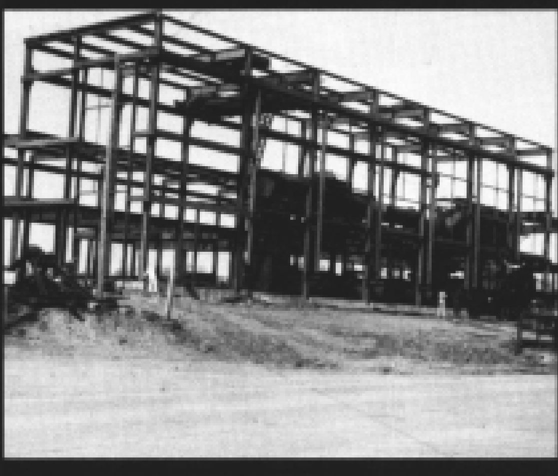
From left to right:
Excavation is underway for the Garfield Thomas Water Tunnel - 1948

The casing is in place for the circulation pump. A workman checks one of the vaned turns.



The water tunnel circuit nears completion

The water tunnel is complete



Construction begins on the building that houses the water tunnel

The Garfield Thomas Water Tunnel Building completed - 1949

TUNNEL DESIGN

"The design team's efforts for the water tunnel is truly amazing when you consider that so Little was known about high Reynolds number flows and that the tunnel design period was very short. The tunnel is hydraulically efficient, acoustically quiet, and mechanically robust, even by today's standards."

– Dr. Michael L. Billet, Director of the Garfield Thomas Water Tunnel

The idea for the Water Tunnel did not originate with ORL's 1946 proposal. Three years earlier, the Navy was already considering proposals for a water tunnel to be constructed at the Harvard Underwater Sound Laboratory (HUSL). Then in 1945, when the branch of HUSL that worked on torpedoes moved to Penn State, a need for such a facility quickly became apparent. The Navy placed a high priority on the construction of a facility for the hydrodynamic testing of underwater vehicles equipped with their propellers.

So in July 1945, Penn State began formal studies of the tunnel design that would enable researchers to study propellers behind torpedo-like bodies. This preliminary activity included literature searches; consultations with the David Taylor Model Basin (a Navy research facility), the Massachusetts Institute of Technology, the California Institute of Technology, the University of Iowa, and other institutions with hydrodynamic facilities; and studies with modern tunnels. In the process, the participants compiled an extensive bibliography on tunnels and tunnel components.

In October 1946, the Navy authorized $1.5 million for construction. The consulting firm of Jackson and Moreland was engaged for the engineering design. Although Dr. Ralph D. Hetzel, then President of The Pennsylvania State College, issued a news release in February 1947 announcing the imminent construction of the tunnel, the work did not begin until more than a year later, when the contract was finalized.

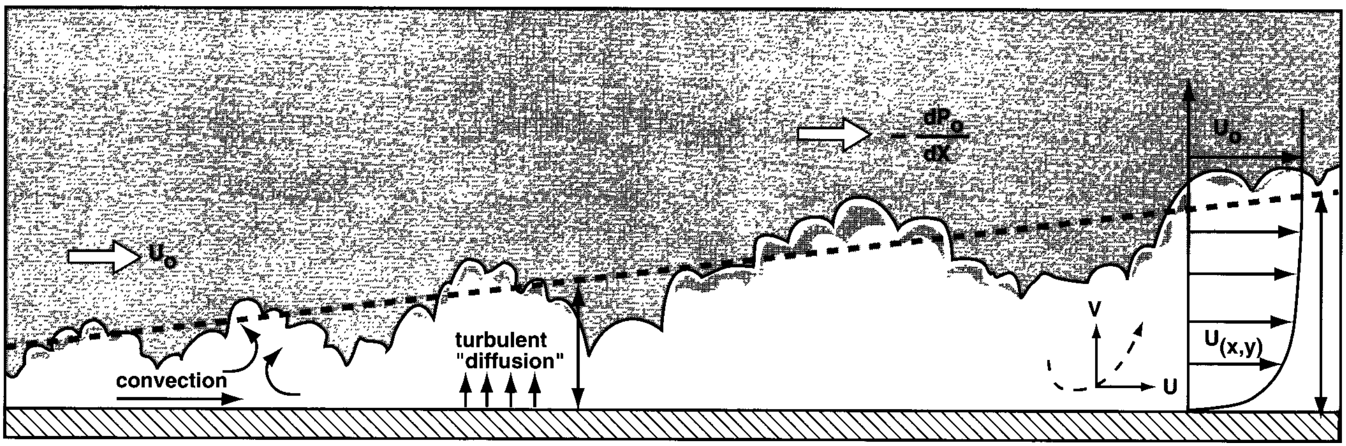
During this time, a group from ORL developed specifications for the tunnel shell construction. They had two primary objectives for their design: *efficiency* and massive *structure* for vibration damping.

EFFICIENCY

The engineers realized that the water in the tunnel had to move as fast as possible based on the amount of input power. The electric motor used to drive the main pump was specified at 2,000-hp with variable speed range between 0 and 180 rpm. This was coupled to an impeller of 95-inches in diameter with an adjustable pitch. Larger motors were considered, but the cost of operating them was deemed prohibitive. To address this concern, the engineers wanted to design the tunnel's components so that flow losses would be minimized, and much of the energy could be recovered in the diffuser section.

Before beginning the water tunnel's construction, the design team studied existing tunnels. They also reviewed information on flow in tunnel components and analyzed such flows. In order to refine their technical design competence, they studied a water tunnel model in the Penn State Hydraulics Laboratory. This experimental water tunnel supported the development of a rational method for analyzing flow in the tunnel components. The study of the interrelationships of the tunnel's components could be experimentally quantified using this model. In a parallel research effort, another team was doing analytical research.

These studies focused on such hydrodynamically critical sections as the tunnel's circuit nozzle, test section, transition section, diffuser, and turns. The team experimented extensively on the diffuser and turns, but their work on the nozzle and transition sections were more analytical. The sections with curved contours immediately



Above: Growth of a fluid boundary layer proceeding and following the test section were the most susceptible to cavitation or flow separation.

The researchers conducted studies that examined the physics of how the water flows through the nozzle, and is diffused back into the circuit to recover some of the energy. They did not want a completely uniform area throughout the tunnel because of the resulting energy losses. The largest loss of energy in the Water Tunnel is in the test section, where the highest velocity is located. {See page 16 for a diagram of the tunnel.}

One particularly important issue was how boundary layers develop along the wall at high Reynolds numbers. As the water flows along a wall, friction retards the flow close to the surface and creates a boundary layer. This highly turbulent region of the flow field displaces water away from the wall and causes energy loss. Also, if the cross-sectional area increased too rapidly in the diffuser, the boundary layers could not follow the wall. Thus, the boundary layers would separate from the wall and cause a larger energy loss {see figure on page 8}.

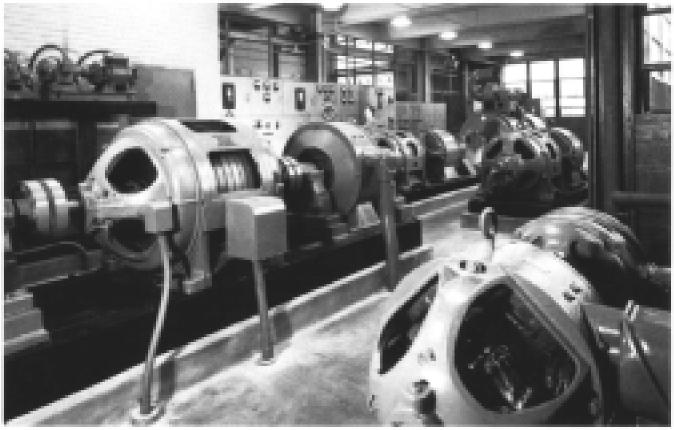
In March 1946, team members James M. Robertson and Donald Ross completed the first analysis of this flow field, and they based their work on established turbulent velocity profile relationships. Their analysis included several novel extensions of conventional theory and led to predictions of velocity profiles. Though their analysis lacked many of the tools available today, Robertson's and Ross' work resulted in the Water Tunnel's successful design.

STRUCTURE

When the researchers collaborated on the tunnel, the team decided that it should be massive in order to minimize vibration. Materials were considered for the tunnel sections based on design and construction techniques, as well as the cost of producing highly accurate flow contours. Fabricated steel cylindrical and contoured sections were chosen for the main tunnel components. The test section and the downstream diffuser section were made from bronze castings, with the work being done by Baldwin Locomotive Works of Philadelphia. This massive size accounts for the vibration damping and explains why this Laboratory facility is one of the quietest testing tunnels in the world.

By November 1947, the design team completed their final specifications, and by the summer of the following year, excavation began.

TUNNEL CONTROL

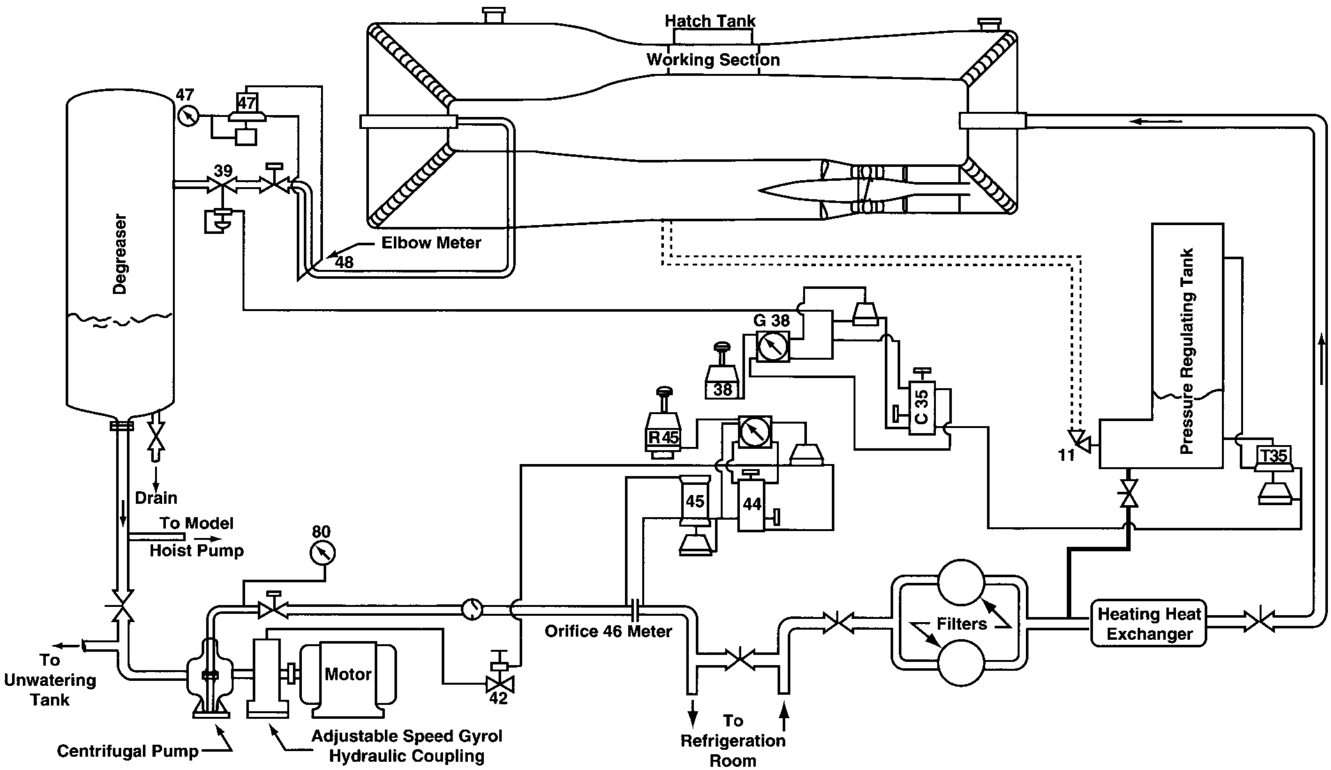


A portion of the equipment that controls the speed and pressure in the Water Tunnel

Auxiliary systems enable the operators of the Water Tunnel to control the properties of the water as it flows through the tunnel. Velocity control is achieved through an axial-flow, propeller-type pump by varying the drive impeller rotational speed and the pitch of the four impeller blades. The impeller is driven at speeds varying from zero to 180 rpm by a 2,000-hp variable-speed induction motor, while the blade pitch can be varied over 28 degrees by means of a hydraulic servomechanism that operates remotely from the tunnel control room. This wide range of speed operation, with accurate and automatic speed control to within one-half percent of the set value over design loading conditions, is accomplished by the modified Kraemer Drive System. Its method of operation eliminates the need for large-scale starting equipment, thus reducing initial and operating costs.

One of the requirements of a tunnel designed to permit the study of cavitation is control of the static pressure within the test section. Pressure control is achieved by varying the air pressure on top of a large pressure-regulating tank connected to the bottom leg of the tunnel. This tank includes a redwood float that prevents air from coming in contact with a large surface area of water; this float is a necessary feature to minimize gas content. The uniqueness of the pressure-regulating system lies in the fact that the operation of the values to bring about the desired pressure changes in the test section (3 psia to 60 psia) is completely automatic once a pressure is set.

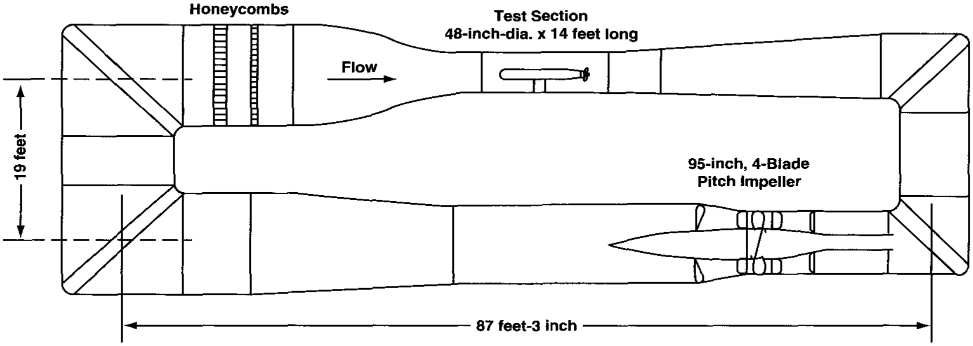
The Water Tunnel includes a water-conditioning, or bypass, system to filter, degas, and control the temperature of the water. The accompanying diagram shows this bypass system, along with the pressure-regulating tank, and the appropriate mechanical devices. A unique attribute of the Water Tunnel is that the condition of the water can be controlled during operation. Control of the gas content is particularly important because the gas content affects cavitation nuclei and subsequent cavitation growth.



Above: Tunnel bypass system and controls

The dedication of the Garfield Thomas Water Tunnel- October 7, 1949.

THE GARFIELD THOMAS WATER TUNNEL SPECIFICATIONS

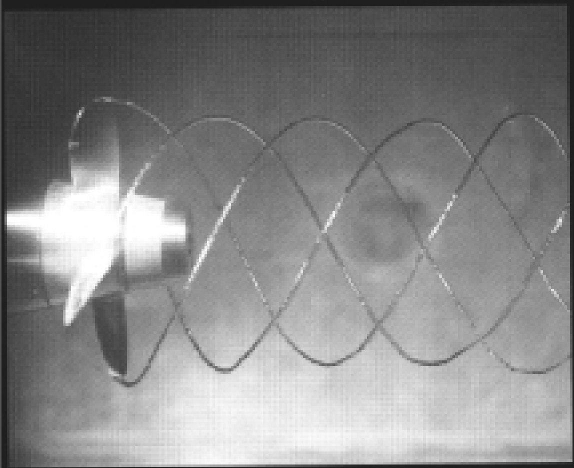


Description of Facility:	Closed Circuit, Closed Jet
Type of Drive System:	4-Blade Adjustable Pitch Impeller
Total Motor Power:	2,000 hp Variable Speed
Working Section Max. Velocity:	60 ft/s
Max. & Min. Abs. Pressure:	60 psia to 3 psia

Measurement Capabilities: Propulsion -- steady thrust and torque, dependency on Reynolds number and advance ratios; Acoustics -- shaft and afterbody unsteady thrust, side forces, flush-mounted unsteady pressures, accelerations, laser vibrometry, radiated noise to downstream array, window hydrophones, and hatch tank focusing hydrophone; Cavitation -- inception, desinence, form, model angle of attack, nuclei content, dependency on Reynolds number and advance ratios, crashback powering and side forces, cavitation breakdown, and air content; Flow Field Characteristics -- linear and circumferential surveys with five-hole pressure probes, laser Doppler velocimetry, static pressure distributions; Flow Visualization -- oil paint, laser light sheet, bubbles, mini-tufts, particle image velocimetry; Maneuvering -- control fin forces; Tests Performed On -- powered models, bodies of revolution, hydrofoils, propellers, etc.

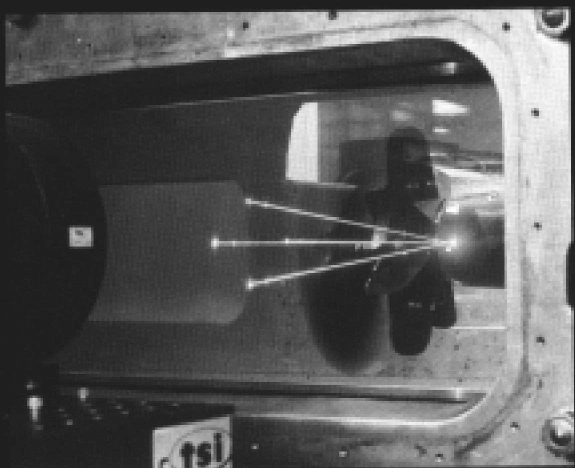
Instrumentation: Propeller dynamometers, 5-hole pressure probes, Pitot probes, lasers, pressure sensors, hydrophones, planar motion mechanism, force balances.
Type and Location of Torque & Thrust Dynamometers: Model internally mounted, 150 hp limit.
Propeller or Model Size Range: Model size from 3.0 inch to 25.0 inch diameter.
Other Remarks: Tunnel turbulence level is 0.1 percent in the test section. Air content can be controlled as low as 1 ppm per mole. Measurement can be made of hydrodynamic functions for stability and control of submerged vehicles. Directional hydrophone system for relative acoustic measurements.

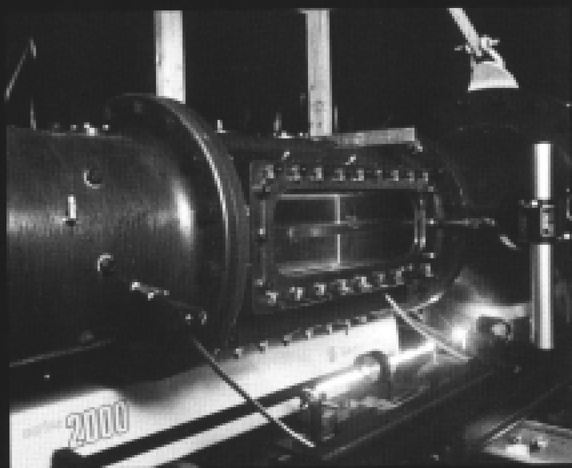
from left to right:



Cavitation visualization of the tip vortex emanating from a marine propeller

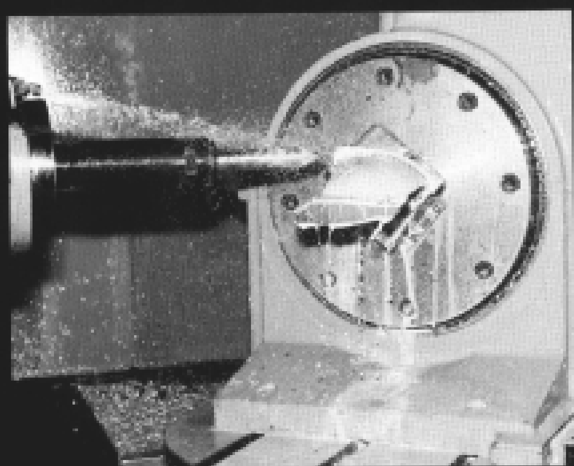
Surface flow visualization of boundary layer transition using dye injected from the nose of a heated body





Velocity measurements of a propeller flow field using laser Doppler velocimetry

Polymer concentration measurements in a drag reduction experiment using laser-induced fluorescence within the 12-inch-diameter water tunnel



Solid modeling of a propulsor blade using computer-aided design

Fabrication of a propulsor blade using a five-axis, numerically-controlled milling machine

OPERATION

The Garfield Thomas Water Tunnel is just a piece of metal, but the real value lies in the scientists who use it. They've produced theories, ideas, and theses that embody a significant contribution to the field of fluid mechanics and acoustics, and their work is well recognized throughout the world.

– Dr. Michael Billet, Director of the Garfield Thomas Water Tunnel

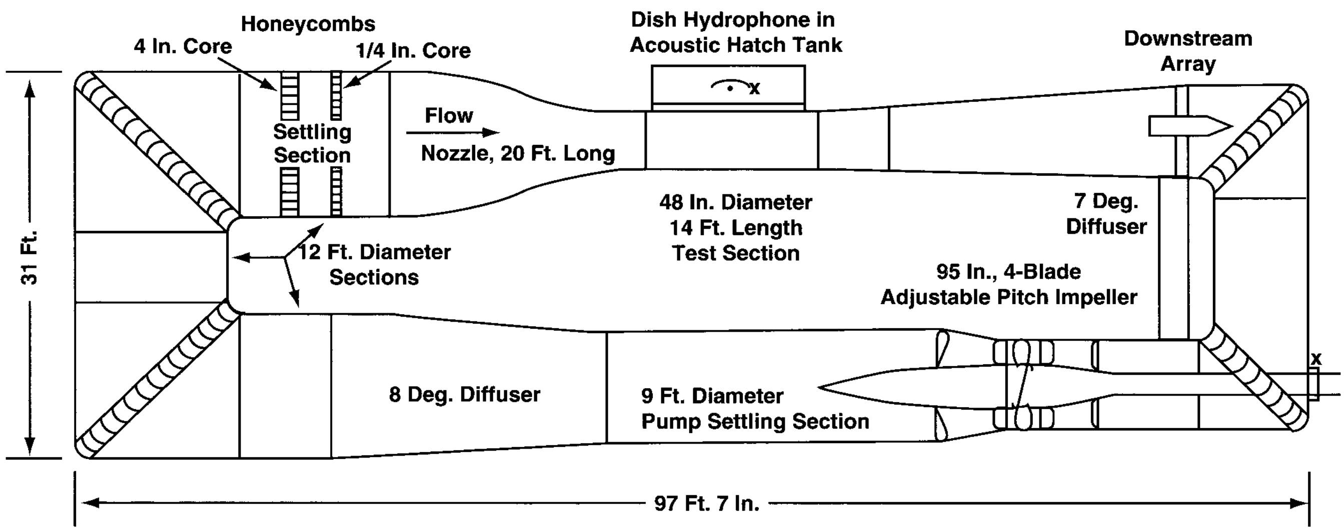
In 1950, James M. Robertson became the first director of the Garfield Thomas Water Tunnel. He and the subsequent five directors have led research and development programs that emphasized an increased understanding of fluid dynamic and acoustic phenomena. Such knowledge can lead to a more efficient, quieter, and cavitation-free operation of propulsors and low-speed turbomachinery.

Water Tunnel Directors	
Dr. James M. Robertson	1950–1954
Dr. George F. Wislicenus	1954–1969
Dr. Maurice M. Sevik	1969–1972
Dr. Blaine R. Parkin	1972–1987
Dr. Robert E. Henderson	1987–1991
Dr. Michael L. Billet	199l–present

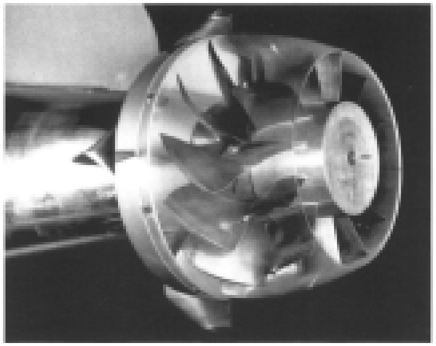
During the tunnel's 50 years of operation, ARL researchers have studied turbulence, drag reduction, flow and structural acoustics, active noise control, and cavitation inception. Over the years, their work has contributed to the advancement of instrumentation and experimental techniques, as well as the coupling between propulsor design and both experimental and computational fluid dynamics and acoustics.

The fact that the Water Tunnel operated almost continuously for 38 years without a major overhaul was a tribute to the many people involved in its design and construction. But in 1988, the Laboratory undertook a major renovation project to eliminate tunnel leaks, refurbish the main impeller drive shaft, and modify the impeller and turning vanes to improve the hydrodynamic and hydroacoustic characteristics. This project also upgraded the primary drive power and speed control system, the tunnel pressure control system, the control room instrumentation, and the model-powering system. With Fred E. Smith and Michael J. Pierzga as the lead project engineers, these renovations and upgrades improved the tunnel's operation.

Current measurement capabilities in the 48-inch-diameter water tunnel provide data for propulsion, acoustics, cavitation, flow field characteristics, flow visualization, and maneuvering. Tests and experiments use time-average, time-dependent, and optical measurement techniques. The instrumentation for the time-dependent measurements include a radiated-noise-to-downstream array of hydrophones, window hydrophones, and a hatch-tank focusing hydrophone. Several optical techniques have been used in the GTWT, as well as in other experimental facilities. These techniques include laser Doppler velocimetry, laser vibrometry, and particle image velocimetry.



THE WATER TUNNEL AND THE U.S. NAVY



As the reputation of the new devices grew, so did the reputation of the Ordnance Research Laboratory. Its personnel has been called upon by many parts of the Navy to help them solve problems.

– Eric Walker, in his speech commemorating ARL's 50th anniversary

The Water Tunnel has proved to be a unique hydrodynamic facility, and it has enabled the Laboratory to conduct research and develop technology leading to applications in the Navy's fleet. Many of these applications began as marine propulsor designs that resulted from the core turbomachinery R&D program initiated during George Wislicenus' tenure as Director. The Water Tunnel's biggest contribution was that it gave the Laboratory the means to design wake-adapted propellers. By measuring the wakes, the faculty could develop theories of how to design propellers for wake-adapted situations. This capability has led to quieter propulsors for the Navy.

In addition to propeller testing, ARL's staff has also conducted the first submarine model testing (the *Albacore* and the *Skipjack)* in this facility Such work also led to increasingly successful submarine designs. Other programs have depended on propulsor design and testing performed at the Water Tunnel, and they include: Torpedo MK-48, Torpedo MK-50, SSBN 616, SSN 637, SSN 688, SSN 21, DE 963, CG 16, and DE 1052.

The Water Tunnel has contributed to many Navy programs by providing sets of experimental data that usually describe cavitation performance. This work has supported such crucial defense systems as the Polaris missile, SUBROC missile, Torpedo MK-46, and Torpedo MK-44.

THE WATER TUNNEL AND PENN STATE

Through the Applied Research Laboratory, the Navy has provided an opportunity for the advancement of academic and applied research in a truly interdisciplinary fashion. Theses produced by graduate students at the Garfield Thomas Water Tunnel have significantly contributed to science and technology. The Water Tunnel is unique because its faculty and students study basic science and physics, and then they put their findings to work to advance technology and application. In this way, this facility has created an invaluable legacy to the nation and the University.

– Dr. Graham B. Spanier, President of The Pennsylvania State University

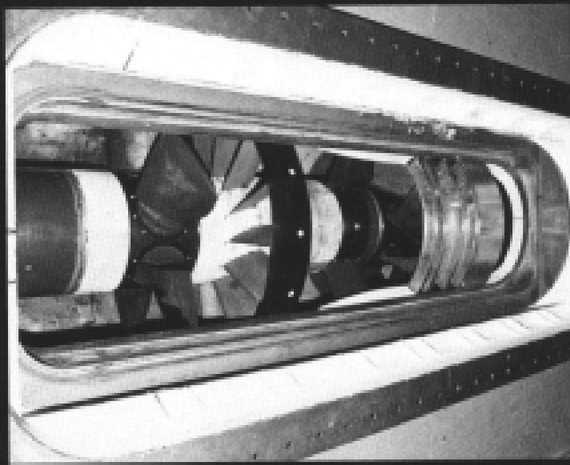
Today, the Laboratory, which was renamed ARL in 1973, is administratively aligned with Penn State under the Senior Vice President for Research and Graduate Education. As such, the Garfield Thomas Water Tunnel actively participates in both research and instructional activities that are so vital to the University, while continuing to supply the Navy with solutions to hydrodynamic and hydroacoustic problems. Many ARL faculty teach and provide educational guidance for students, thus passing on their research knowledge to graduate engineers working in this field.

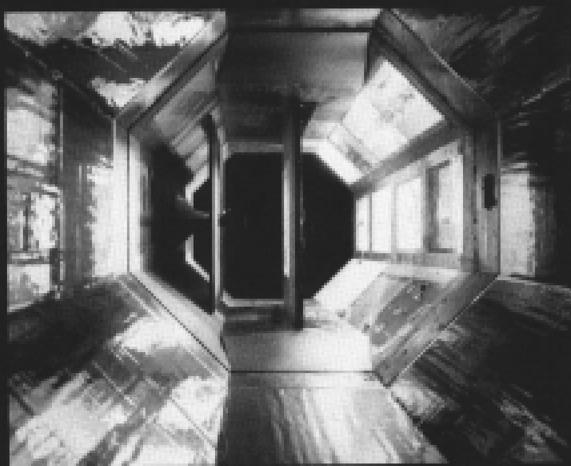
Faculty at the Water Tunnel have a close connection with the College of Engineering. A number of these researchers have held joint appointments so that they could share their expertise in cavitation, turbomachinery, acoustics, and instrumentation.

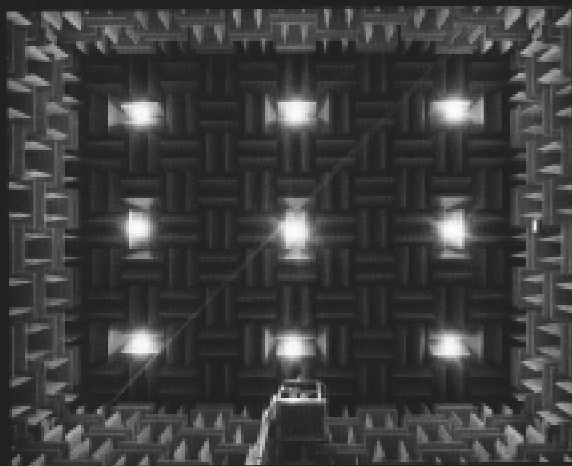
Over the years, this research connection has expanded. Many graduate students rely heavily on the facilities and resident knowledge at the Garfield Thomas Water Tunnel. Dr. Donald Ross wrote the first doctoral dissertation in connection with the design of the conical diffuser, which is located downstream of the test section. In 1954, Dr. Barnes McCormick completed the second doctoral thesis on the tip vortex cavitation of marine propellers. His work was followed by a third investigation, completed by Dr. J. William Holl in 1958, on cavitation inception, which remains one of the most important GTWT contributions to the basic knowledge of hydrodynamics. Since these initial research efforts, many other doctoral and master's degrees have been completed, with a focus on fluid dynamics, acoustics, and turbomachinery.

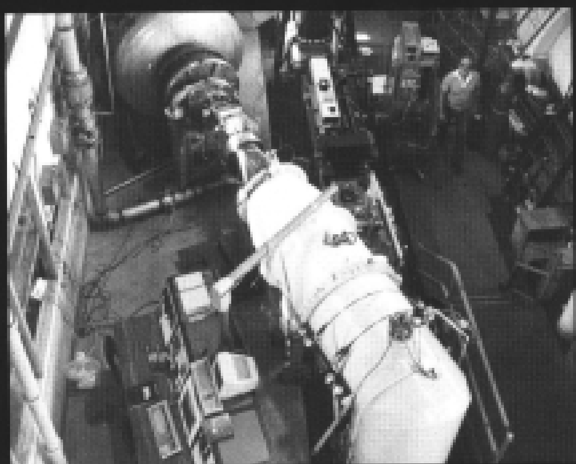
In 1965, ARL began the Graduate Program in Acoustics, which became a part of the College of Engineering. As the preeminent acoustics graduate program in the United States, it is a pioneer in satellite-distance education for government and industry. In supporting this program, the Laboratory provides research topics and assistantships, as well as enabling student participation in several Water Tunnel projects.

Besides these graduate programs, the Water Tunnel also furthers undergraduate education. In 1973, ARL initiated the George F. Wislicenus Engineering Honors Program-named in honor of the former GTWT director-at the Water Tunnel. Ten years later, this program expanded to include all of ARL. The Laboratory also encourages undergraduate student research in both the Computer Science and Engineering Honors Program and the Mathematics Honors Program. Such programs provide opportunities for outstanding students to apply their training to the solution of applied research problems in engineering and science. These students complete an honors program's thesis, which is quite similar to a master's thesis. Furthermore, many other undergraduate students work at the Water Tunnel, either as wage payroll employees or within the Engineering Cooperative Program.









From left to right:
Control room for the 48-inch-diameter water tunnel

High Reynolds number pump facility installed in the hatch of the 48-inch-diameter water tunnel

Ground vortex experiment installed in the subsonic wind tunnel

Flow-through anechoic chamber

Centrifugal pump test facility

Reverberant tank

CURRENT FACILITIES

Today, we celebrate the Garfield Thomas Water Tunnel as a world-class facility for hydrodynamic and hydroacoustic research. With its dedicated and highly innovative faculty and staff, I am confident that it will retain its status well into the twenty-first century.

– Dr. L. Raymond Hettche, Director of the Applied Research Laboratory

Today, the Garfield Thomas Water Tunnel is a complex of hydrodynamic and hydroacoustic test facilities that are registered with the International Towing Tank Conference (ITTC), an organization of member countries that design and test ships and other marine structures in tanks and tunnels. Since beginning operations, the Water Tunnel has expanded to increase its capabilities. This change has included the addition of several smaller tunnels installed in the building housing the Water Tunnel. With a smaller water tunnel, researchers can localize specific physics problems, so it is especially appropriate for graduate student work.

This expansion effort began in 1951, when the Laboratory constructed a 12-inch-diameter water tunnel to supplement the 48-inch-diameter tunnel. This smaller tunnel can be used with either a 12-inch-diameter circular or a 20-inch x 4.5inch rectangular test section, and can achieve a water velocity of 80 feet per second. The tunnel has supported many basic research experiments in hydrodynamics and has aided in the development of advanced instrumentation such as laser measurement systems, the first Schlieren photography systems, and five-hole pressure probes.

In 1960, a third water tunnel was installed at the Laboratory. Originally constructed by NASA, this high-speed tunnel was enhanced to study cavitation in liquid oxygen and nitrogen pumps used in the space industry. Inside the facility, the flow can reach velocities up to 290 feet per second through its 1.5-inch-diameter test section. Research can be done using either water or other liquids such as Freon 113. This tunnel has been used for cavitation damage studies on surfaces of many types of materials including bronzes, stainless steels, and composites.

A fourth water tunnel with a six-inch-diameter test section, was added in 1969. This tunnel was assembled from the original model for the Garfield Thomas Water Tunnel used to study the tunnel sections and flow parameters in the late-1940s. It was first located in the Hydraulics Laboratory in the Civil Engineering Department and was later moved to the Aerospace Engineering Department in the mid-1960s. In 1972, the tunnel was upgraded by the Laboratory, including the addition of a double-suction pump. With this six-inch-diameter test section and a water velocity up to 90 feet per second, researchers can conduct basic flow studies and perform pressure probe calibrations.

In addition to these water tunnels, ARL has built several wind tunnels. In 1953, the Laboratory designed and built a subsonic wind tunnel to study the flow around various body shapes and propulsors. With its simpler instrumentation, this particular tunnel did away with researchers' concerns of structural problems and leakage. This octagon-shaped test section has essentially the same wetted diameter as the 48-inch-diameter water tunnel.

In 1968, in order to test blade shapes for future propulsor designs, the Laboratory built an open-return wind tunnel that included a rectilinear cascade test section. The construction of this tunnel enabled the faculty to study other types of low-speed turbomachines. The importance of this type of research led to the construction of an axial-flow research fan in 1971. This facility was primarily used for unsteady flow experiments.

By 1988, the Laboratory needed to build an additional facility to support these tests and other types of acoustic experiments. A large flow-through anechoic chamber was constructed in the main building that housed the Water Tunnel. With a working volume that is 18-feet wide x 22-feet deep x 30-feet high, this chamber has a low frequency cutoff of 90 Hz. This versatile facility can be used as a normal anechoic chamber or as a flow-through chamber, with either the axial-flow research fan or a quiet open-jet facility.

As the only type of its kind in the world, the boundary layer research facility, built in 1961, has an 11.5-inch-diameter test section. Glycerine, with a viscosity 200 times greater than water, is used as the working fluid in this closed-loop tunnel. This large viscosity greatly magnifies boundary layer effects of flow over objects in the tunnel. Researchers have used this facility to conduct significant studies of turbulence characteristics in a fully-developed pipe flow with fluid velocity of 20 feet per second.

Besides constructing new tunnels, ARL has also modified the test sections of existing tunnels to increase their potential capabilities. In 1985, Laboratory engineers designed and built the high Reynolds number pump

(HIREP) facility, which is placed in the test section of the 48-inch-diameter water tunnel. HIREP consists of a 42-inch-diameter pump stage driven by a 48-inch-diameter downstream turbine coupled through a drive shaft. This large size allows for the testing of propulsor blades with a much larger Reynolds number than can usually be achieved for model propulsor blades installed behind underwater vehicles. HIREP's size means that it can accommodate a variety of instrumentation in both the stationary and rotating frames of reference. Furthermore, ARL researchers can study very high Reynolds number boundary layers by installing a large flat plate facility into the 48-inch-diameter water tunnel.

Whereas HIREP allowed ARL to perform new types of experiments in axial-flow pumps, the centrifugal pump test facility, which was constructed in 1988, allowed its researchers to focus on radial-flow machines. As an alternate test section for the 12-inch-diameter water tunnel, this facility supports the testing of a range of pump geometries. Experiments include the testing of cavitation performance, acoustic and vibration levels, overall operating performance, and detailed velocities and pressures.

For their work in structural acoustics, Water Tunnel engineers can access the Structural Acoustics Laboratory (SAL), which was built in 1968, and the Reverberant Tank, which was installed in 1994. The capabilities of the 8-feet wide x 8-feet deep x 25-feet high SAL include:

- Calibrating model-installed acoustic pressure and unsteady force transducers
- Measuring admittance and damping of large-scale structures
- Measuring structural radiation efficiency within a reverberant nonsymmetric tank insert

The Reverberant Tank, with dimensions of 28.7-feet wide x 22.7-feet deep x 18-feet high feet, is used to measure admittance, loss factor, and the radiation efficiency of large- and small-scale structures.

Students, State College residents, and visitors may wonder why the Garfield Thomas Water Tunnel building, the site of classified research, has such large window panes. The original designers wanted removable windows so that they could easily repair or change tunnel sections. But as it proved too costly, the staff ended up knocking out part of the facility's side wall to remove different components.

Besides engineers, students, and experimental facilities, the GTWT building also houses a drafting group, a machine shop (with four numerically controlled milling machines and a numerically controlled measuring machine), an instrumentation and electronics shop, and a tunnel crew to support the large number of tunnel tests. Two separate computer networks within the building support the design of propulsors and low-speed machinery, computational fluid dynamics, dynamic finite-element analysis, and data acquisition and reduction.

LT. (jg) W. GARFIELD THOMAS, JR.

Born in 1916, the Lieutenant was the son of W. Garfield Thomas, Sr., then the Pennsylvania Deputy Secretary of Mines, and Emeline Thomas. After growing up in Colver, Pennsylvania, the young Thomas studied journalism at Penn State. His achievements at the University included serving as the manager of the soccer team as well as becoming the class historian and secretary. After graduating in 1938, he began working for the Ebensburg Coal Company and then the Atlantic Refining Company.

When the threat of war appeared on the horizon, Thomas felt compelled to serve his nation. During the summer of 1940, after joining the Naval Reserve, he sailed to Cuba on the USS *Wyoming.* Later that fall, he completed an intensive three-month officers' training course and was among the first class of volunteer ensigns graduated outside of Annapolis in peacetime.

By the end of the year, Lt. Thomas reported for duty on the USS *Boise,* a 10,000-ton light cruiser, and in early 1941, he traveled to Pearl Harbor. For more than a year, Lt. Thomas and his shipmates on the *Boise* sailed the treacherous Pacific. But they did not encounter battle until the late evening of October 11, 1942, when they entered Cape Esperance on the northwest tip of Guadalcanal. In this grim struggle, which continued the next day, the *Boise* sank six Japanese ships, but was herself hit by enemy fire.

Thomas, the officer in charge of the number one turret, was mortally wounded when an eight-inch shell abruptly pierced this armored steel structure. Despite his injuries, the 27-year-old man bravely stayed behind in his blazing station and ordered his men to abandon ship. But as the eleventh man stepped outside, the flames that engulfed the turret prevented the Lieutenant from escaping. He died aboard the embattled *Boise* and was later buried at sea.

For his courageousness, Lt. Thomas was posthumously awarded the Navy Cross and the Purple Heart. A year after his death, the Navy named a destroyer escort in his honor. At the launching ceremony, his sister, Lt. Betty K. Thomas, (now Mrs. Sauer), a dietitian in the Army Medical Corps, christened the ship.

In May 1949, Penn State's Board of Trustees notified Thomas' parents that the new Water Tunnel building would be named after their son. In his reply, Mr. Thomas wrote:

"The dedication of the new Water Tunnel building in memory of my son is indeed a great honor to me and his mother as it will be a memorial to him that will last through the years."

The American Society of Mechanical Engineers

THE HISTORY AND HERITAGE PROGRAM OF ASME

The ASME History and Heritage Recognition Program began in September 1971. To implement and achieve its goals, ASME formed a History and Heritage Committee, composed of mechanical engineers, historians of technology, and the Curator Emeritus of Mechanical and Civil Engineering at the Smithsonian Institution. The Committee provides a public service by examining, noting, recording, and acknowledging mechanical engineering achievements of particular significance. The History and Heritage Committee is part of the ASME Council on Public Affairs and Board on Public Information. For further information, please contact Public Information, the American Society for Mechanical Engineers, 345 East 47 Street, New York, NY 10017-2392, 212-705-7740; fax 212-701-8676.

The Garfield Thomas Water Tunnel is the 189th designation as a Historic Mechanical Engineering Landmark. Each reflects its influence on society, either in its immediate locale, nationwide, or throughout the world.

An ASME landmark represents a progressive step in the evolution of mechanical engineering. Site designations note an event or development of clear historical importance to mechanical engineers. Collections mark the contributions of several objects with special significance to the historical development of mechanical engineering.

The ASME Historic Mechanical Engineering Recognition Program illuminates our technological heritage and serves to encourage the preservation of the physical remains of historically important works. It provides an annotated roster for engineers, students, educators, historians, and travelers, and helps establish persistent reminders of where we have been and where we are going along the divergent paths of discovery.

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The Garfield Thomas Water Tunnel

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ACKNOWLEDGEMENTS

The Central Pennsylvania Section of the American Society of Mechanical Engineers gratefully acknowledges the efforts and support of the Applied Research Laboratory in the design and production of this document.

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Historical research was provided by:
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Special acknowledgment to:
L. Raymond Hettche, Director of ARL for his total support of this historical documentation and to Robert A. Martin and Eric C. Granlund of ASME for their work on the dedication.

References for further reading may be obtained at the Penn State Room of The Pennsylvania State University's Pattee Library and at the Library of the Applied Research Laboratory.

U.Ed. ARL 96-15

NATIONAL HISTORIC MECHANICAL ENGINEERING LANDMARK
THE GARFIELD THOMAS WATER TUNNEL
1949

THE TUNNEL WAS BUILT IN COOPERATION WITH THE U.S. NAVY. AT 48 INCHES (1.2 METERS) IN DIAMETER, IT WAS THE LARGEST, HIGH-SPEED TUNNEL THEN IN EXISTENCE. IT WAS FIRST USED TO EVALUATE THE BEST HYDRODYNAMIC DESIGN OF TORPEDO SHAPES AND PROPELLERS, AND LATER, SUBMARINE HULLS AND PROPULSION SYSTEMS. THESE STUDIES LED TO ADVANCED RESEARCH ON BASIC FLOW PROBLEMS IN CAVITATION, TURBULENCE, HYDROACOUSTICS, TRANSITION, HYDRODYNAMIC DRAG, AND HYDRAULIC AND SUBSONIC TURBOMACHINERY. THE FACILITY CONTINUES TO BE AN INVALUABLE TOOL FOR SUCH RESEARCH.

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1996 NL 116