Pump Lab Reminiscences

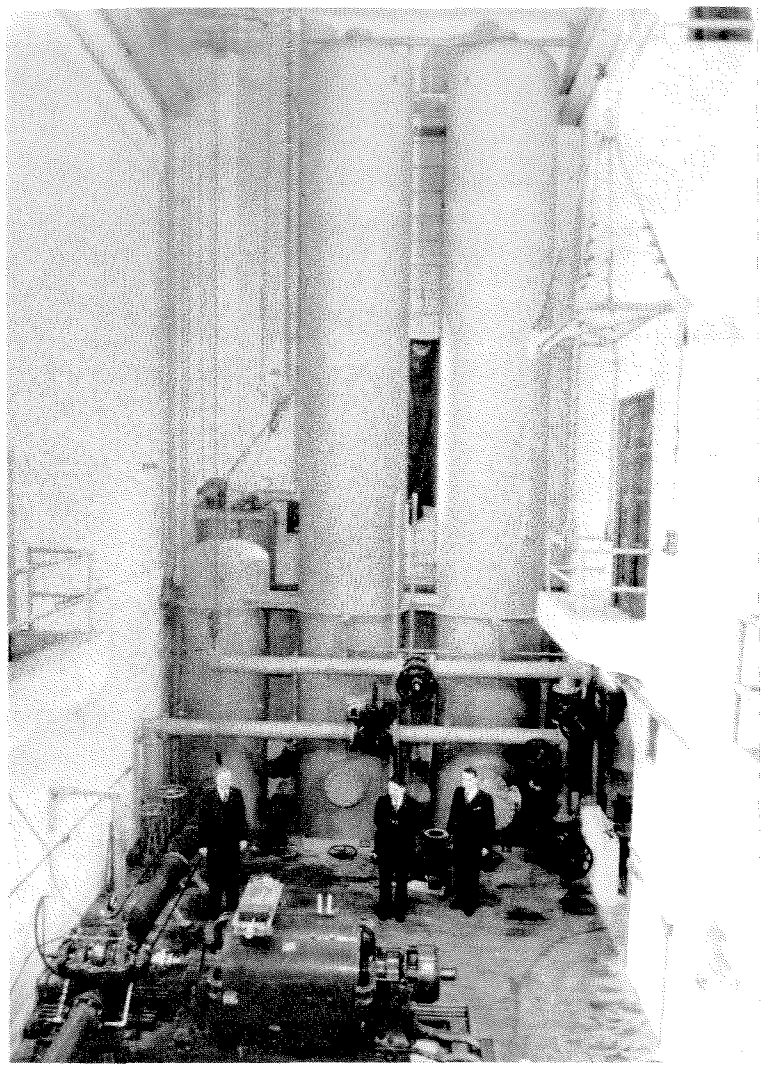
Many who have been around Caltech since the 1930s remember the old Hydraulic Machinery Laboratory, better known as the pump lab. Last year George Housner, now the Carl F Braun Professor of Engineering, Emeritus, who has been here since 1934, and others (including pump lab veterans Rolf Sabersky and Allan Acosta, both professors of mechanical engineering, and Vito Vanoni, professor of hydraulics, emeritus) were reminiscing about the pump lab and realized that no one had a clear picture of how it had come into existence.

Housner set about clarifying that picture, soliciting the recollections of some of the "old timers" who were still around. The picture still isn't clear, though, since these old timers were too young at the time to have been in on the arrangements that were originally struck between Caltech, the Metropolitan Water District of Southern California (which was about to embark on a mammoth pumping project), and the city of Pasadena, which had more than a passing interest in independence from the water supply of Los Angeles.

The Caltech Archives contributed some background, including a letter from F. E. Weymouth, general manager and chief engineer of the MWD, outlining what the MWD stood to gain from the proposed research at Caltech: The power and pumping system of the aqueduct would call for a long-term involvement of more than $33 million; each percent gained in pumping efficiency would mean savings of about $49,000 a year (in 1930 dollars) in power cost.

A letter from Theodore von Kármán to the Executive Council made the case for Caltech's involvement. It said in part: "If the research work would be chiefly directed to the improvement of hydraulic machinery on the empirical basis, then objections against the permanent value for the Institute might be raised. But if the research program is founded on a broader conception, I believe that a laboratory of this kind will have a unique position in this country and almost in the whole world.

"Considering the recent development of aeronautics as a science and as a technical art, the great achievements are due to the fact that the technical development was connected simultaneously with the development of the scientific fluid mechanics, and that the aeronautical engineers departed from the method of purely empirical computation and adopted the methods used in natural science



The pump lab tanks, which were built to withstand a pressure of 600 psi and were used to control the pressure for cavitation tests, tower over von Kármán (right), Knapp (center), and an unidentified man, probably from the MWD.

and applied mathematics. The same development is starting now in hydraulic engineering. I believe that the substitution of the results of systematic theoretical and experimental research for empirical methods will bring great benefits in the near future to several very different branches of engineering dealing with problems of fluid motion."

Clearly there was good reason to get together.

Perhaps the most knowledgable of the old hands is Jim Daily, who came to the pump lab as a graduate student in 1935 and became the lab's "curator" for several years before finishing his PhD in 1945. (Sally Atwood Daily, Jim's wife, helped publish the first issues of the Caltech Alumni Review *in 1937-38 with her brother Bill Atwood, its first editor. Atwood was a Caltech alumnus and part of the MWD staff; the* Alumni Review *was renamed* Engineering & Science *in 1943.) Daily left in 1946 to join the faculty of MIT for 18 years and is now professor of fluid mechanics and hydraulic engineering, emeritus, from the University of Michigan. He recently returned to Pasadena to live and contributed the following reminiscences to Housner's history project.*

by James W. Daily

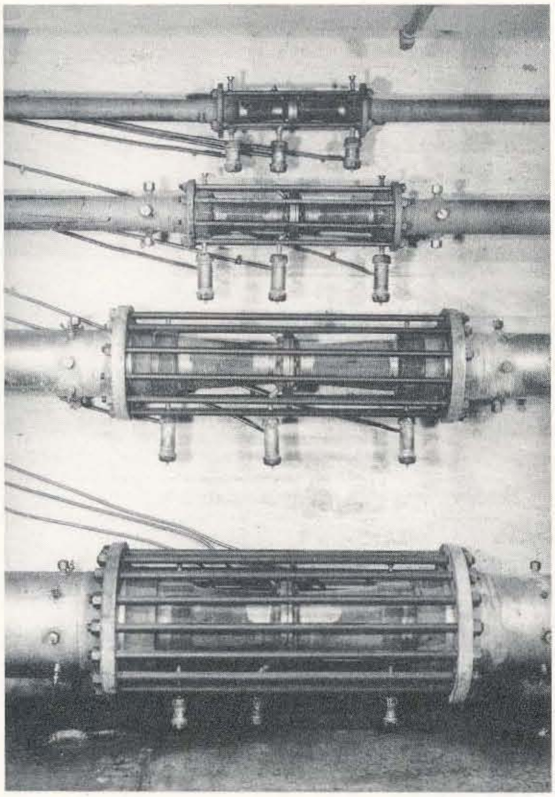
THE HYDRAULIC MACHINERY Laboratory at Caltech had its genesis with some graduate student thesis projects in the early 1930s under Robert T. Knapp, assistant professor of mechanical engineering. Bob Knapp had spent 1929-30 as a Freeman Fellow in Europe, visiting hydraulic laboratories and other hydraulic facilities and factories with a special interest in hydraulic machinery. He came back with much enthusiasm and many ideas. The sharpest was his conviction that there was a need in this country for more definitive research into the hydraulics of centrifugal pumps, that it should be done in a laboratory independent of all manufacturers, and it should be located at Caltech.

The time was ripe for many reasons. First, the Europeans, and especially the Germans, had a lead in pump research and technology. Second, southern California needed water, and there was a project underway to build a great aqueduct from the Colorado River to Los Angeles and adjacent cities and districts. It was to be 300 miles long, and a series of five pumping plants were necessary to lift the water some 1600 feet over the mountains. The pumps were to be among the largest and most powerful installed anywhere in the world. There was a fledgling organization, the Metropolitan Water District of Southern California (MWD), which had designed the project and was busy initiating the construction.

The pump research program began in an "initial" pump lab, as George Wislicenus, one of Knapp's early students, has called it. This was in the north end of the Caltech boiler building (or at the west end of what is now Spaulding Laboratory) where there was some space for experiments. "Wis" was a young pump designer from Worthington Pump Company in Harrison, New Jersey, who had come to Caltech for graduate study. In 1931 or 1932 he carried out various pump tests which figured importantly in the efforts under way to induce the MWD to support a more sophisticated laboratory effort aimed, of course, at the problems that might arise with the exceptional pumps that were required for the new aqueduct. This eventually became the "final" pump lab.

The exact steps leading to the contract with the MWD are not clear, but the agreement seems to have been the result of an orchestrated effort that began in 1930. In addition to Knapp, Professors Robert L. Daugherty (mechanical and hydraulic engineering), Franklin Thomas (civil engineering and chairman of the division), and Theodore von Kármán (aeronautics and director of GALCIT) were involved, as well as Robert A. Millikan. Daugherty and Thomas were active in Pasadena affairs; they were or had been city directors. At some time in that era Daugherty was mayor. Thomas was also Pasadena's representative on the MWD Board of Directors. Von Kármán, who was a new and widely respected professor from Aachen, Germany, became interested in seeing the development of a program in hydraulics. Moreover, Millikan was showing interest.

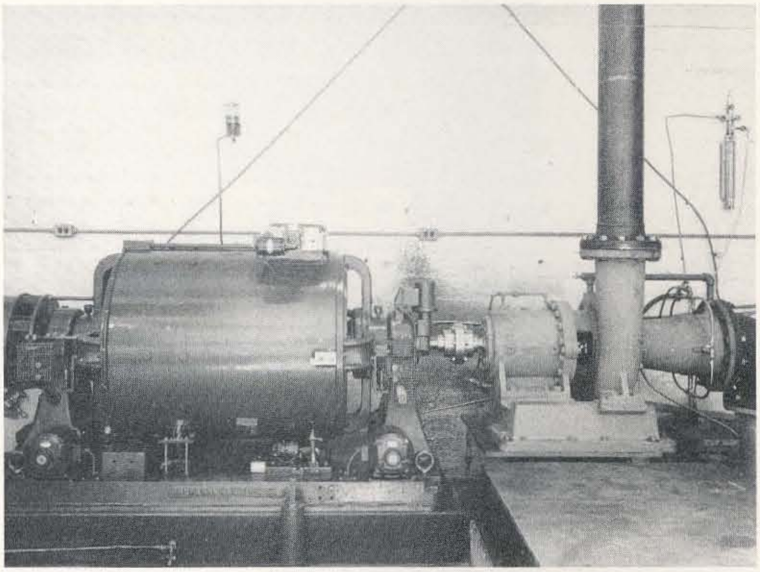
As early as December 1930, a conference with MWD officials that was attended by Knapp, von Kármán, Daugherty, and Millikan disclosed MWD's interest in a pump testing facility because MWD foresaw many

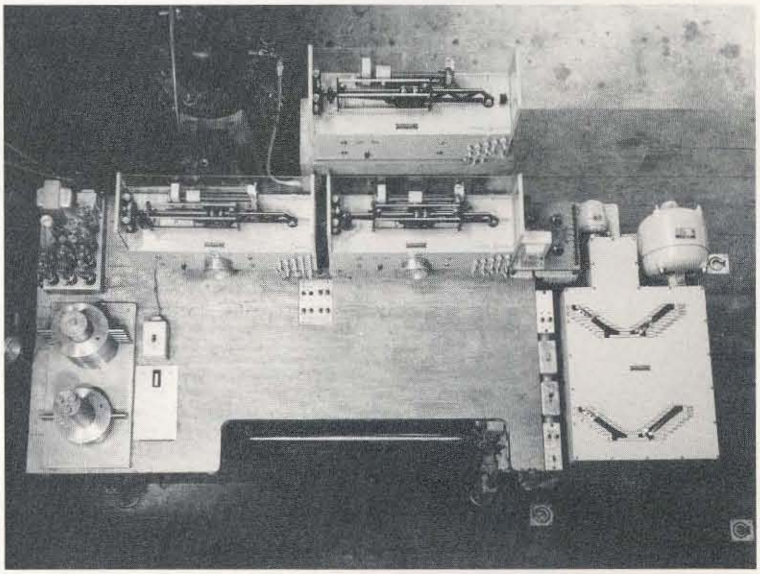


hydraulic problems of scientific importance. It was concluded that Caltech should make a careful study of the possibilities. In brief, the studies were made, there was some iteration, and, following the inevitable delays, the contract was finally signed on November 14, 1933.

The laboratory was planned to occupy the tall three-story bay and subbasement at the west end of Guggenheim Laboratory and part of an east-west channel along the northern face of the Guggenheim basement and subbasement. The three-story bay was intended originally to house a large universal testing machine. The channel was to have been a towing tank.

Design of both the instruments and the equipment began immediately after the contract was signed. Wislicenus designed much of the main system and instrumentation under Knapp's supervision. The lab and its instrumentation were designed to provide accuracy (0.1 percent to an individual test point), to eliminate the personal equation in taking data, to use primary standard type of instruments and to have the utmost flexibility. Special features included weighing-type pressure gauges and venturi manometers, a quartz crystal time standard, a feedback device for comparing the dynamometer speed with a standard speed and automatically providing corrections to overcome instantaneous differences, and a system for "freezing" the instrument readings when conditions were stable. This last was accomplished by both of two operators simultaneously exercising their individual controls to interrupt the current flow to the instrument readout bank.





Pump lab fixtures (1936) included venturi meters (far left) to measure the rate of flow, a dynamometer and one of the test pumps (top), and the test bank (below) with its beam balance-type gauges to measure pressure.

The laboratory was calibrated and in full operation by September 1934. Today Wis assumes a modest attitude about his role. Actually, his instruments used in this laboratory and in the later Caltech water tunnels constructed during and after World War II were excellent and exceptional and later were copied extensively.

Knapp's vision in the whole project, including the laboratory plan and most of its details, led to an accurate and efficient data collection system, which was the forerunner of the systems now used worldwide in modern laboratories. The latter make use of solid state devices and computers, neither of which existed in the 1930s. The pump lab instrumentation was a combination of mechanical and electrical devices and vacuum tube electronics; it made up an advanced and sophisticated system for its day. The laboratory instruments (as well as many later precision machined devices for the lab) were made by Fred C. Henson's shop on East Colorado.

Among those who took a deep interest in the pump lab development was Aladar Hollander, known affectionately as A. H. He had been a student at the Technische Hochschule in Budapest during von Kármán's time and after World War II became professor of mechanical engineering at Caltech. In the early 1930s, however, he was chief engineer for the Byron Jackson Co. Pump Division and in one sense a bystander. But he was well known for his expertise and his sage advice, and his support of the project was invaluable.

In the beginning of the MWD program the pump lab experiments looked into a variety of phenomena as well as the basic behavior of centrifugal pumps. The effects of cavitation on the performance of pumps were examined in a detail not done before. The suitability of single-stage, single-suction, volute pumps for the MWD application was investigated. In addition, radial thrust measurements were made with the results leading to specifications for heavier shafting than normally used by the manufacturers. The basic impeller flows and volute effects were studied by measuring the impeller outflow velocities and directions versus vane tip position. Ray Binder conducted these impeller studies as his PhD dissertation under Knapp. A. L. (Maj) Klein, assistant professor of aeronautics, suggested a special sampling valve, which was constructed for these measurements.

This first phase of the MWD program also included determination of *Complete Characteristics,* that is, a four- quadrant performance plot of lines of constant head and power on a chart of discharge-versus-speed giving alternate modes of pumping and turbining. Such data were used in calculations of pressure surges (water hammer) during startups and shutdowns.

The result of this preliminary work was to "tighten up" the final specifications for the pump purchases in various ways from what MWD might have used if the prevailing "wisdom" of many pump engineers' recommendations had been followed.

When I arrived at Caltech, Ralph M. Watson was in charge of the Hydraulic Machinery Laboratory under the triumvirate of von Kármán, Daugherty, and Knapp. Wislicenus, who had finished his PhD program in 1934, had gone back to his firm in the summer of 1935. On arrival I learned that a man named Frank Wattendorf had preceded Watson. Frank was from Aeronautics, and von Kármán had arranged that he go to Peking to build a wind tunnel at Tsing Hua University. This, I was told (by the boys), created a vacancy, at the lowest level, of course, which I filled. This job allowed me to continue graduate studies on a part-time basis. Later such positions came to be called research assistantships.

By December 1935 four pump manufacturers had submitted bidders' models for testing to decide which ones, if any, were to be awarded contracts. The awards were to Byron Jackson (Intake and Gene plants), Worthington (Eagle Mountain and Hayfield), and Allis Chalmers (Iron Mountain). These contracts covered three pumps of the total of nine planned for the ultimate installation in each of the five pumping plants.

At this stage the active lab staff was small and included some on temporary duty from MWD as well as the Caltech employees. The people from the MWD office were A. W. (Bill) Atwood, an electrical engineering graduate of Caltech doing hydraulics temporarily (who in due course became my brother-in-law), Paul Winn, and Harold Levinton. The Caltech group included, as I remember, Ralph (Pop) Baker (older, of course — maybe 35!), an aeronautics graduate student; John Knecnik, an M.E. undergraduate; Ray Binder, an M.E. graduate student; Ed Simmons, an E.E. and of strain gauge fame; and Rudi von Huene, an M.E. and specialist in making thin sections. Mechanic Ray Kingan was a mainstay of the lab. Ray is now deceased, but his son Jack is employed at Caltech.

Soon after my arrival at Caltech, I met Bert Fenner who was both purchasing agent for the Institute and in charge of the "wiring shop," which handled all the electrical maintenance for the Institute and all its labs. I had many pleasant dealings with him throughout my stay at Caltech. Later I had similarly satisfying contacts with Wesley (Herky) Hertenstein, who was in charge of buildings and grounds.

The crew of the pump lab included (back row, from left) Harold Levinton (MWD), Ralph Baker, Bill Atwood (MWD), John Knecnik, Jim Daily, Art Ippen; (front row) Ralph Watson, Ray Kingan, Rudi von Huene, and Ed Simmons.

All of the bidders' models submitted for the MWD tests of December 1935 were designed to operate at speeds which would give the full prototype head. This gave water velocities inside the pump equal to those in the prototype machine. There was some disagreement among engineers at the time, as this differed from the practice with turbines of using straight Froude number modeling and hence very low speeds and internal velocities. The Caltech method, however, gave a high model Reynolds number, a compromise with the even higher and unattainable Reynolds number inherent in the prototype.

One fact that helped both the initial bidders and the awardees was that the requirements for Intake and Gene plants were nearly the same. Consequently, one model was required for the pair. The same held for Eagle Mountain and Hayfield.

As the next step each successful bidder submitted a contractor's model, which was to a larger scale than the bidder's model but also designed to operate at a speed giving the prototype head. These were thoroughly tested to verify that any changes from the bidders' models did indeed satisfy the specifications.

Simultaneously with the testing of the contractors' models, some other investigations were made for MWD. One of particular interest at that date was measurement of valve pressure drop versus opening. Such data were especially useful for combining with the previously mentioned *Complete Characteristics* of pumps when calculating hydraulic transients. To make a comparison of gate valve and plug valve behavior, Arthur T. Ippen (PhD 1936) joined the project in the spring and early summer of 1936. This resulted in plug valves being specified for the discharge cutoff valves which followed each pump in each plant.

The project ended in the summer of 1936. The MWD personnel returned to their Los Angeles office, and the Caltech students either graduated or went back to school full time. Art Ippen, who was from Germany, went to Lehigh as a faculty member in 1938. Following World War II he went to MIT, where he became head of the Hydrodynamics Laboratory. After a very successful career he died suddenly in 1974. Watson went to New Jersey to employment with Worthington until the mid-1950s, when he went to Syracuse University as professor and associate dean of engineering until his retirement.

Wattendorf remained close to von Kármán after returning from China and was his right-hand man until von Kármán's death in 1963. Wislicenus did defense work with Packard Motor Car Company during World War II. After teaching at Johns Hopkins until the early 1950s, Wis went to Pennsylvania State University, where he headed the Naval Ordinance Research Laboratory and the Garfield Thomas water tunnel and was head of the Aeronautics Department until his retirement. Kingan became the mechanic in the old M.E. shop and laboratory. I became the "curator" of the suddenly quiet pump lab as it awaited its next challenge. I believe it was at this time that MWD passed title to its interest in the laboratory to Caltech.

As curator my duties were to look after the equipment and the instruments. This included operating it every now and then, oiling all parts and instruments and so on. One day when entering the laboratory, there was a strong odor of gases such as rocket exhausts. There were also the remains of a pendulum supported from the ceiling two floors above. It seems that Frank Malina's crew had used the dormant lab for their rocket experiments. Objections were raised, and they were banished to an outside site at the east end of Guggenheim (where Firestone now stands). I didn't know (nor did they, for that matter) that this early experiment was one of the first steps leading to today's giant Aerojet General Corporation and the Jet Propulsion Laboratory.

The MWD tests did result in large overall savings and avoidance of future problems, such as deflections due to radial thrust as well as avoiding excess vibration and materials damage that cavitation would have caused. Moreover, many of the questions investigated affected the first cost of the pumping plants as a whole, in addition to affecting the costs of the pumps themselves. The field tests of the completed initial three prototype units, which took place in 1939, proceeded smoothly, and the results followed the predictions based on the laboratory tests.

There was one perturbation to interrupt the smoothness of the field test procedures. These tests used the salt velocity method to measure the water flow rates in the 10-foot diameter penstock following each pair of pumps. In this method a salt solution is injected to be entrained by the flow, and the water velocity is then measured by timing the salt's passage between two downstream sets of electrodes. The method depends on thorough mixing of the salt solution with the water flow. The first determinations gave too low a value, as everyone agreed. It was surmised that better radial mixing of the salt cloud was necessary. Baffle turbulators were added, and the measured flow rate increased! Agreement was reached on the acceptable amount of baffling to use, and the tests proceeded. These tests were supervised by Professor L. J. Hooper of Worcester Polytechnic Institute.

Bill Atwood tells the following anecdote about the field tests. "The tests on the model pumps proved that a single-stage centrifugal pump would meet the requirements and an efficiency of 88 percent or better could be achieved. Therefore the final specifications for the prototype units (MWD 116) required a guarantee of 88 percent efficiency and provided a bonus for each percent achieved above that. Failure to meet the guarantee required the manufacturer to modify or replace the pump.

"Paul Winn and I, having spent several years as MWD representatives at the Caltech pump lab, were both deeply involved in the final field tests. The tests at Intake and Gene were witnessed by A. H. Hollander. He would look over our shoulders at the readings as we recorded them and retire to a corner of the pump house and work his little slide rule. We would glance over, and if he was smiling all was going well, but if he was frowning we would check our instruments. After the run was over, Paul and I would retire to the conference room and with the calculator apply the various corrections and grind out the results. However, from Hollander's smiles we already knew they would be good. The final results showed an excellent 90.9 percent for the five pumps that were tested. That evening A. H. treated the entire test crew to a case of special German wine he had brought along in anticipation of such excellent results."

The machinery for the Colorado River Aqueduct started pumping in 1939, transporting (as efficiently as science had deemed possible) water to thirsty southern California. The knowledge gained from the extensive testing resulted in considerably higher efficiencies than would otherwise have been obtained, according to the MWD. The contractors got their bonuses, MWD got lower operating costs, and the Caltech pump lab got a rest before going on to one more major project — investigating hydraulic problems for the Grand Coulee Dam irrigation project for the U. S. Bureau of Reclamation from 1938 to 1940. □