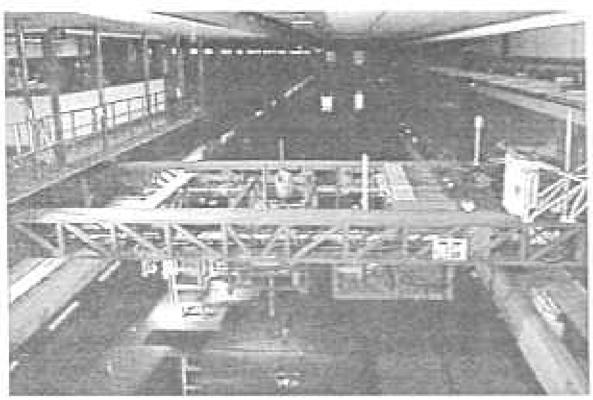
pressure effects from the tank walls. The tank has a specially designed "wave beach" at the northern end, which dissipates waves created by the double-flap MTS wavemaker located at the southern end. Since porpoising is a calm-water phenomena, the wavemaker was not used, but the wave beach and the swimming pool type lane marker, which runs the length of the tank on the right side, were critical to the experiments in that they absorbed the model's wake after each run. For the heavier displacement runs, approximately 15 minutes were required for the wave disturbance to die down, even with the lane marker and wave beach in place. The normal testing arrangement consists of a high-speed and a low-speed module connected together in the form of a tractor-trailer configuration. This arrangement has a top speed of 25 feet per second and weighs approximately 40,000 lb. The high-speed carriage can run at speeds up to 32 feet per second and weighs approximately 8000 lb. It is supported by four roller-chain bearings riding on 3 inch diameter, case hardened steel rails that run the entire length of the tank.

The propulsive force is provided by two AC motors located at the southern end of the tank behind the wavemaker assembly. These motors are rated at 400 hp each, with a 1600 hp total peak rating. They are geared to a continuous cable drive that is always attached to the high-speed carriage. The carriage speed is controlled from a room located near the northern end. Because of the danger and potential for serious injury to anyone riding the carriage near maximum speed, special attention has been given to the carriage stopping system. When the carriage operator sets the desired speed, he also dials in a stopping point, in feet from the end of the tank. The optimum points have been determined by the lab staff empirically, with the goal being to gain the longest possible run time and still stop safely. The normal stopping mode decelerates the carriage at approximately 0.25g. Should the operator miscalculate the stopping point, or the normal system fail, a separate emergency stopping circuit is provided which arrests the carriage at approximately 1G. In the extremely unlikely case that the stopping circuit should fail, an arresting wire



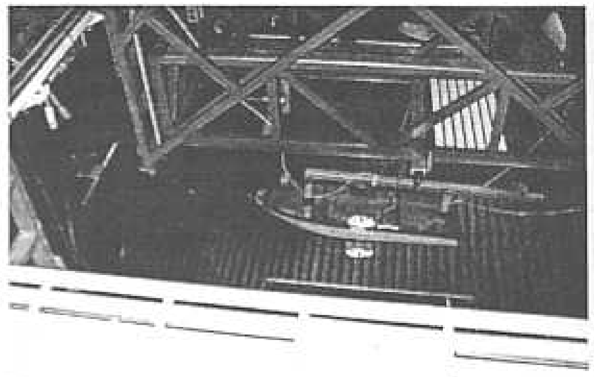


Figure 3 – Vertical Rail Module with model (top) and High-Speed Towing Carriage

has been provided which physically arrests the carriage. The last line of defense consists of a pair of hydraulic damper pistons, which, if hit, would provide a deceleration just shy of impacting a brick wall. Figure 3 shows the high-speed carriage, with a model attached beneath the vertical rail module.

The small prismatic models used by Day & Haag were tested in the 94' x 10' x 5' towing tank at Webb Institute. Their work represents the current industry benchmark for predicting the inception of porpoising of planing boats. Day & Haag towed their models using two light cables. The goal for such a setup was to eliminate all unwanted damping forces on the light models, which might have prevented porpoising inception. Their towing point was determined by using Equation (6), which determines the towing height above the baseline, H_V as a function of H_C, the height of the chines above the baseline, and b_{PX}, the chine beam. The linear scale ratio, λ_{DH} was introduced into Day & Haag's equation to account for the size difference between the two sets of models.

$$H_V = .4 * H_C + 2.10 * \lambda_{DH} \qquad (6)$$

This towing height was empirically selected with the intention of keeping the towing lines above the spray coming from the boat. Day & Haag pointed out that since planing boats could be propelled by any means of propulsion, any propulsion point could be assumed. This is reasonable for a general case. The second portion of this testing program investigates the effects of geometrically scaled application of the towing force. The towing rig pictured in Figures 3 and 4 was designed to be geometrically similar to Day & Haag's.

For a planing hull, the beam, b, is used as the characteristic length when making nearly all dimensionless calculations required for scaling. This is logical because planing is a dynamic condition, and usually a large fraction of the hull is out of the water at speed. Therefore, the only parameter that does not vary with speed is beam, at least at moderate to heavy loading. This technique is used not only for linear measurements, but also for determination of lifting, speed, and displacement nondimensional coefficients. The scale ratio between Day & Haag's models and those used for this test was λ_{DH}=4.73, based on beams. The longitudinal position of the towing point was scaled linearly as well and was set to 27.1 inches forward of the transom for the present NAHL tests.

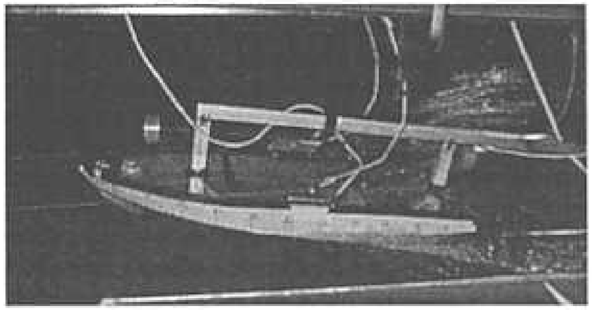


Figure 4 – 20 Degree Deadrise Model

The towing rig was completed by clamping a sturdy vertical steel post to the forward end of the high-speed carriage. A 500lb capacity force block, used to measure the resistance of the boat, was mounted at the bottom of the vertical post. Given that the experimenter knew beforehand the approximate range of resistance values, using the 500lb unit to measure force magnitudes of 15 to 30lb does not seem like a prudent choice, because the resolution of the 500lb unit is on the order of 1 lb. The next smaller unit available had a maximum rating of 100 lb., which would have worked very well for measuring the steady state resistance force, and would have easily tolerated the forces due to the normal carriage acceleration rate of 8.3 ft/sec^2. The 100lb block was not used for fear of damaging it should an accident occur. The towing arrangement was such that the potential existed for the model to broach or to submarine, either of which could produce very large forces.

A spreader bar consisting of aluminum channel was bolted to the bottom of the force block, visible at the extreme left of Figure 3. The two towing cables had thimbles installed at either end, and were within $^1/_{32}$" of being identical in length. The towing length was arbitrarily set at 84" to place the model beneath the vertical rail module of the high-speed carriage, as the towing length in fact had little significance on the inception of porpoising. Day & Haag did not give any justification for setting their towing cable length. More important was to ensure that the cables were as near to horizontal as possible, that they were the same length, and that they were parallel. The steel post was adjusted to bring the towing point to 8 ½" above the water's surface, which brought the cables parallel to the water when the model was operating at planing speed. Two $^1/_8$" aluminum plates were bolted through the hull sides, and braced by horizontal aluminum strips that rode on the gunwale of the boat, helping to distribute the potentially large towing forces. The hullsides of this model were never intended to be a towing point. This setup proved effective, and caused no problems. Figures 3 and 4 show the cable attachment to the force block and to the model for the Day & Haag validation test.

A major requirement for the testing was the ability to make significant changes to the longitudinal position of the center of gravity quickly and accurately. This was accomplished by fabricating two vertical posts from 2" x 2" hollow rectangular aluminum tubing. Large bases were constructed to help distribute the load, and each post was attached "truss style" to its base. A hole was drilled near the top of each post for the 50" weight-carrying rod made of ½" threaded rod to pass through. The rod was 15" above and parallel to the keel. Because of the mechanical data measurement rig used by Day & Haag, a very large radius of gyration, k_{yy}, was produced. Although the argument had already been made (that longitudinal moment of inertia would not have any significant effect upon the inception of porpoising), an attempt to scale the radius of gyration was made on the intuitive expectation that porpoising frequency would be affected by longitudinal moment of inertia. The resulting model configuration can be seen in Figure 4. The longitudinal 2" x 2" tube bolted to the top of the weight posts allowed for not only the vertical center of gravity to be scaled properly, but also for weights to be placed aft of the transom. The longitudinal position of CG could not be driven far enough aft while maintaining the necessary radius of gyration without moving the rear weight aft of the transom.

Since the model was expected to become partially submerged during stopping at heavier loading conditions, a ¼" sheet of Plexiglas was cut to serve as a deck for the model. Holes for the vertical weight posts and towing brackets were sealed with vinyl tape. During stopping, the model's wake would consistently wash up on the deck, while at the same time, the model would swing back on its stopping mechanism, forcing the stern even further under the water. The model would have been swamped after every run without the deck. Special attention had to be paid to designing an arresting mechanism that would safely absorb the stopping forces. Day & Haag developed a stopping mechanism that lifted progressively more chain as the model traveled past the desired end of the test run. A similar mechanism was not practical for the NAHL carriage, so an arresting mechanism was designed using four pieces of nylon line, chosen for its relative elasticity. The criteria for designing such a system were that it must not interfere with the porpoising motions of the boat, nor apply any significant extra weight to the model while running. The two towing points, as well as the rear post of the weight-carrying bar were used as attachment points. The end of each line was shackled to selected points on the carriage. Shackles were used so that the model could be removed from the rig easily, and yet be identical for each day's testing. The lengths of the lines were adjusted so that they all came under tension evenly when the boat surged forward. This rig provided controlled stops, and even kept the model safe during an unexpected 1G stop.

The model selected for towing in this manner was the 20 degree deadrise prismatic hull because it was the only available model that matched one of Day & Haag's models in terms of deadrise angle. The NAHL model was run at Δ=76.06 lb., and Δ=101.2 lb. The speeds for each run were determined by Froude Scaling Day & Haag's test conditions. The original intention was to replicate Day & Haag's tests exactly, but only after the whole initial series of tests were complete was it realized that the actual chine beam of the prismatic model series was only 17.5", and not the 18.0" originally assumed. Although prismatic in form, the hullsides of the NAHL model have a slight flare, which reduces the chine beam by ½" from the maximum beam at the gunwhale. Since load coefficient is a function of the chine beam of the boat cubed, the ½" did make a substantial difference in the results. In retrospect, however, this mistake was fortunate because, after the appropriate corrections were made, the results followed the Day & Haag trend closely.

Given what has been established so far, it is possible to determine the critical running trim angle of a boat below which it must stay in order to avoid the inception of the porpoising. From a purely operational standpoint, the experienced operator might be able to make underway adjustments to the control surfaces and outdrives to keep the boat trimmed below the critical trim angle by feel, without working equations or looking at an inclinometer. What the operator cannot do underway, however, is what the designers and outfitters should do in the early stages of design and construction. The ability to ensure that the trim tab size, range of deflection and range of motion of the drive unit are sufficient to stabilize the boat across the speed envelope is the logical application of a predictive method.

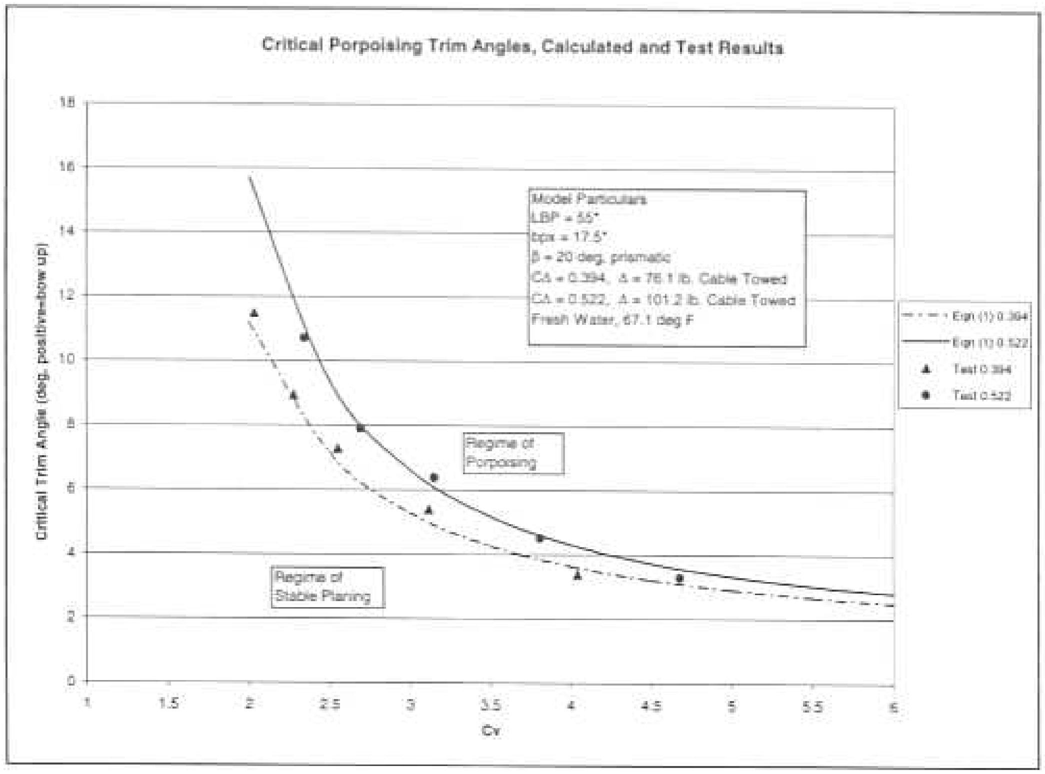


Figure 5 – Results of Cable Towed Experiments vs. Predictions